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Hybrid energy renovation of existing buildings: A case study of collective housing in Skikda

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ABSTRACT

The actual worldwide alarming energy and environmental situation has led to a call for action and the search for strategies to achieve energy savings, to end the dependence on fossil fuels and to opt for a clean environment, adapted to human and non-human life in the best possible conditions. One of the sectors targeted is the building industry sector, because of its significant contribution in this vulnerable situation. This present research is a comparative study that analysed and evaluated the initial state of four (4) existing collective housing structures in Skikda, a Mediterranean town in north-eastern Algeria, before proposing and testing the effect of nine (9) energy renovation scenarios. The study used several tools, including ArcMap, Autodesk's Revit via Insight 360, and the CEA software. The models of the latter were calibrated and validated against real electricity and gas consumption data obtained from SONELGAZ local agencies of Skikda. The study's first phase focused on the initial state and examined the solar, topographical, and urban factors and their impact on energy consumption and ecological footprint. A multi-spatial scale analysis was used, including the exploitation of topographic sections, various data collected on buildings and their urban environments, and also a reduced-order UBEM approach as well as solar estimation approach based on a 3D model. The second phase of this study interested on the effects of ameliorative interventions that was by single measures (passive or active), or through hybrid improvements. The passive measures were by changing the existing single glazing with double or triple glazing. Hybrid PVT panels as active measures were also used by changing their quantities and locations between fixings on roofs or south facades, according to different scenarios. Another scenario proposed the use of electric boilers to cover domestic hot water needs. The results reveal that overall energy consumption in the four archetypes was primarily influenced by the thermal transmittance of the envelope and its age throughout the year, except during the coldest period when the altitude of the building and its exposure to prevailing winds had the greatest impact. On the other hand, the building's shape and urban surroundings did not significantly affect energy consumption, but did impact the reception of solar rays, which influenced the choice of placement of hybrid PVT panels. At apartment-scale, the height and orientation can significantly impact its energy consumption, where lower floors apartments and north-facing ones, tend to consume more energy. The energy and ecological assessment of the initial state of the various archetypes, and of the most of the apartments, in relation to European benchmarks showed that they were of medium performance. The various energy renovation scenarios have offered varying degrees of energy and environmental improvements and optimization. Synergies in hybrid energy renovations have yielded very high performance levels, especially by combining the use of triple-glazed windows with the integration of PVT hybrid panels over the entire roof together with seasonal thermal energy storage system, making the buildings highly energy-efficient and environmentally friendly, despite their different reactivity in the four (4) cases, due to differences in the morphologies of the archetypes, their urban and topographical context, and their exposure to external weather fluctuations. The results also showed the interaction and interdependence that exist between architectural, urban, topographical, solar and human behavioural aspects, whether at a single scale or at several spatial scales, and their effect on energy consumption, on the carbonic emission rates, and also on the performance of renovation methods and technics.

Keywords: Building hybrid renovation, UBEM approach, Multiscale analysis, Ecological improvement, Solar energy, collective housing, Skikda.

ملخص

أدى الوضع الحالي المثير للقلق في مجال الطاقة والبيئة في جميع أنحاء العالم إلى الدعوة إلى العمل والبحث عن استراتيجيات لتحقيق وفورات في الاستهلاك الطاقوي، وإنهاء الاعتماد على الوقود الأحفوري، مع توفير بيئة نظيفة تتكيف مع حياة البشر وجميع الكائنات الحية في أفضل الظروف الممكنة. أحد القطاعات المستهدفة هو قطاع المباني، بسبب مساهمته الكبيرة في الوصول الى هذه الحالة الطارئة. هذا البحث الذي أمامنا هو عبارة عن دراسة مقارنة قامت بتحليل وتقييم الحالة الأولية لأربعة (4) هياكل سكنية جماعية موجودة في مدينة سكيكدة المتوسطية الواقعة في شمال شرق الجزائر، قبل اقتراح واختبار تأثير تسع (9) سيناريوهات لتجديد الطاقة. واستخدمت الدراسة عدة أدوات منها ArcMap وAutodesk Revit عبر Insight 360 وبرنامج City Energy Analyst. تمت معايرة نماذج هذا الأخير والتحقق من صحتها عن طريق بيانات استهلاك الكهرباء والغاز الواقعية التي تم الحصول عليها من وكالات سونلغاز المحلية. ركزت المرحلة الأولى من الدراسة على الحالة الأولية وفحصت الجوانب الشمسية والطوبوغرافية والحضرية وتأثيرها على استهلاك الطاقة وقيمة البصمة البيئية. تم استخدام التحليل المتعدد النطاقات المكانية، بما في ذلك استغلال المقاطع الطبوغرافية، والبيانات المختلفة التي تم جمعها عن المباني وبيئاتها الحضرية، بالإضافة إلى إستعمال نهج نمذجة الطاقة في المباني الحضرية مخفض الطلب وأيضا نهج تقدير الطاقة الشمسية على أساس نموذج ثلاثي الأبعاد. ركزت المرحلة الثانية من هذه الدراسة على تأثيرات التدخلات التحسينية سواء السلبية أو النشطة منفردة، او درجة تأثير التحسينات الطاقوية و البيئية الهجينة. كانت التدابير السلبية عن طريق تغيير الزجاج الفردي الحالي بزجاج مزدوج أو ثلاثي. تم استخدام الألواح الكهروضوئية الحرارية الهجينة كإجراء نشط من خلال تثبيتها إما على الأسطح أو على الواجهات العمودية الجنوبية، مع تغيير عدد هذه الألواح وفق سيناريوهات مختلفة. كما تم اقترح سيناريو آخر استخدمت فيه الغلايات الكهربائية لتغطية الاحتياجات المنزلية من المياه الساخنة. وتكشف النتائج عن تأثر استهلاك الطاقة الاجمالي في النماذج الأربعة, على مدار العام ,في المقام الأول بالخاصية الحرارية للغلاف الخارجي للمبنى وعمره ، باستثناء الفترة الأكثر برودة التي كان فيها الإرتفاع الطبوغرافي للمبنى ودرجة تعرضه للرياح السائدة أكثر تأثيرا. لم يكن لشكل المبنى وبيئته الحضرية تأثير كبير على استهلاك الطاقة، ولكن كان لهما تأثير على استقبال الأشعة الشمسية، مما أثر على اختيار موقع تثبيت الألواح الشمسية الهجينة. على نطاق الشقق، كان لارتفاع الشقة و اتجاه واجهتها مقارنة بباقي الشقق في نفس المبنى تأثير كبير على استهلاك الطاقة, حيث تميل شقق الطوابق السفلية والشقق المواجهة للشمال إلى استهلاك قدر اكبر من الطاقة. أظهر التقييم الطاقي والإيكولوجي للحالة الأولية للمباني الأربعة ككل و أغلب الشقق السكنية, مقارنة بالمراجع الأوروبية أنها كانت متوسطة الكفاءة بشكل عام. وقد أتاحت مختلف تدابير تجديد المباني درجات متفاوتة من التحسين الطاقوي والبيئي. أدت أوجه التآزر في التعديلات التحديثية الهجينة للطاقة إلى كفاءة جد عالية، ولا سيما عن طريق الجمع بين استخدام النوافذ الثلاثية الزجاج ودمج الألواح الكهروضوئية الحرارية الهجينة على السطح بأكمله مصحوبة بنظام موسمي لتخزين الطاقة الحرارية، مما ادى الى جعل المباني شديدة الكفاءة طاقويا وبيئيا ,على الرغم من اختلاف تفاعلها في حالات الدراسة الاربع (4) مع مختلف التدخلات التحسينية على المبنى، بسبب الاختلافات في شكل النماذج وكذلك محيطها الحضري والطوبوغرافي، ودرجة تعرضها لتقلبات الطقس الخارجية . أظهرت النتائج أيضًا التداخل و الترابط الذي كان موجودًا بين الجوانب المعمارية والحضرية والطوبوغرافية والشمسية والسلوكية البشرية, سواءا على نطاق واحد، أو على عدة نطاقات مكانية و تأثيرها على استهلاك الطاقة، و على الكفاءة الإيكولوجية للمباني، فضلا عن درجة أداء و نجاح مختلف تقنيات و طرق التجديد المنتهجة.

الكلمات المفتاحية : التجديد الهجين للمباني، نهج نمذجة الطاقة للمباني الحضرية، التحليل متعدد النطاقات، التحسين البيئي، الطاقة الشمسية، السكن الجماعي، سكيكدة.

RESUME

La situation énergétique et environnementale mondiale actuelle alarmante a conduit à un appel à l'action et à la recherche de stratégies pour réaliser des économies d'énergie, pour mettre fin à la dépendance aux combustibles fossiles et pour opter pour un environnement propre, adapté à l'homme et aux différents êtres vivants dans les meilleures conditions possibles. L'un des secteurs visés est le secteur de la construction, en raison de sa contribution significative dans cette situation vulnérable. Cette présente recherche est une étude comparative qui a analysé et évalué l'état initial de (4) structures de logement collectif existantes à Skikda, une ville méditerranéenne du nord-est de l'Algérie, avant de proposer et de tester l'effet de (9) scénarios de rénovation énergétique. L'étude a utilisé plusieurs outils, dont ArcMap, Revit d'Autodesk via Insight 360, et le logiciel CEA. Les modèles de ce dernier ont été calibrés et validés par rapport aux données réelles de consommation d'électricité et de gaz obtenues auprès des agences locales de SONELGAZ. La première phase de l'étude s'est concentrée sur l'état initial et a examiné les aspects solaires, topographiques et urbains et leur impact sur la consommation d'énergie et l'empreinte écologique. Une réflexion d'analyse à multi échelle spatiale a été utilisée, incluant l'exploitation de coupes topographiques, de diverses données collectées sur les bâtiments et leurs environnements urbains, ainsi qu'une approche UBEM d'ordre réduit et une approche d'estimation solaire basée sur un modèle 3D. La deuxième phase de cette étude s'est intéressée sur les effets d'interventions d'amélioration simples (passives ou actives), ou via des améliorations hybrides. Les mesures passives consistaient à remplacer le simple vitrage existant par du double ou du triple vitrage. Les panneaux PVT hybrides en tant que mesures actives ont également été utilisés par changement de leurs quantités et leurs emplacements entre fixations sur les toitures ou sur les façades sud, selon différents scénarios. Un autre scénario proposait l'utilisation de chaudières électriques pour couvrir les besoins en eau chaude sanitaire. Les résultats révèlent que la consommation globale d'énergie dans les quatre archétypes a été principalement influencée par la transmittance thermique de l'enveloppe et son âge tout au long de l'année, sauf pendant la période la plus froide où l'altitude du bâtiment et son exposition aux vents dominants ont eu le plus grand impact. Par contre, la forme du bâtiment et son environnement urbain n'ont pas eu d'incidence significative sur la consommation d'énergie, mais ont eu un impact sur la réception des rayons solaires, ce qui a influencé le choix d'emplacement des panneaux solaires hybrides. À l'échelle d'appartement, la hauteur et l'orientation peuvent avoir un impact significatif sur la consommation d'énergie, où les appartements d'étages inférieurs et ceux qui sont orientés au nord ont tendance à consommer plus d'énergie. L'évaluation énergétique et écologique de l'état initial des différents archétypes, et la plupart des appartements, par rapport aux références européennes a montré qu'ils étaient moyennement performants. Les différentes mesures de rénovation énergétique ont offert divers degrés d'amélioration et d'optimisation sur le plan énergétique et environnemental. Les synergies entre différents types de mesures de rénovations énergétiques ont donné très hauts niveaux de performance , notamment en combinant l'utilisation de fenêtres à triple vitrage avec l'intégration de panneaux hybrides PVT sur l'ensemble de la toiture accompagnés d'un système de stockage saisonnier de l'énergie thermique, rendant les bâtiments très efficaces sur le plan énergétique et écologique, malgré leur réactivité différente dans les (4) cas, en raison des différences dans les morphologies des archétypes, ainsi que de leur contexte urbain et topographique, et de leur exposition aux fluctuations météorologiques externes. Les résultats ont également montré l'interaction et l'interdépendance qui existent entre les aspects architecturaux, urbains, topographiques, solaires et comportementaux humains, que ce soit à une seule échelle ou à plusieurs échelles spatiales, et leur effet sur la consommation d'énergie, sur les taux des émissions carboniques et même sur le degré de réussite et de performance des différentes méthodes et techniques d'améliorations rénovatives.

Mots-clés : Rénovation hybride des bâtiments, approche UBEM, analyse multi-échelle, amélioration écologique, énergie solaire, habitats collectifs, Skikda.

Acronyms

APRUE	Agence Nationale pour la Promotion et la Rationalisation de l'Utilisation de l'Énergie (National Agency for the Promotion and Rationalization of the Use of Energy.)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
BAPV	Building applied photovoltaics.
BEM	Building Energy Modelling.
BEMS	Building energy management system
BEPOS	Positive energy building.
BIPV	Building integrated photovoltaics.
BREEAM	Building research establishment environmental assessment method.
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CDER	Centre for the Development of Renewable Energies.
CEA	City Energy Analyst tool.
CEN	European Committee for Standardization
CEREFE	Algerian Renewable Energy and Energy Efficiency Commission.
CFC	Chlorofluorocarbure
CNERIB	National Centre for Integrated Building Studies and Research.
COVID-19	Corona virus disease 2019.
CREG	Commission for energy and gas regulation.
CSP	Concentrated solar power.
CVRMSE	Coefficient of the Variation of the Root Mean Square Error.
DTR	Regulatory technical document.
EPFL	École Polytechnique Fédérale de Lausanne.
FAR	Floor area ratio.
FSI	Floor space index.
GHG	Greenhouse gas.
GRTE	Algerian Electricity Transmission System Management Company
HBM	Habitation à loyer modéré (Low-cost housing).
HLM	Housing moderate rents for linear planning.
HQE	High Environmental Quality
HVAC	Heating, ventilation and air conditioning.
Hybrid PVT	Hybrid Photovoltaic- thermal system.
IABHER	Integrated Analysis of Built and Human Environment Renovation
IEA	International Energy Agency.

IPCC	Intergovernmental panel on climate change.
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
LEED	Leadership in Energy and Environmental Design.
LEC	Low energy case
LPG	Liquefied petroleum gas.
MTEER	Ministry of Energy Transition and Renewable Energies.
MXI	Mixed use index.
NMBE	Normalized Mean Bias Error
NVE	Norges Vassdrags- og Energidirektorat (Norwegian Water Resources and Energy Directorate)
NZEB	Net Zero energy buildings.
ONS	Algerian National statistics office.
OSV	Obstruction sky view.
OPEC	Organization of petroleum exporting countries.
OSR	Open space ratio.
PE	Percentage of error
PV	Photovoltaic.
RE	Renewable energy.
RETA	Réglementation Thermique Algérienne (Algerian Thermal Regulation).
SKTM	Society of Electricity and Renewable Energy.
SONATRACH	(The National Company for Research, Production, Transportation, Transformation, and Marketing of Hydrocarbons).
SONELGAZ	National Company for Electricity and Gas (Société Nationale de l'Electricité et du Gaz)
SVF	Sky view factor.
TEASER	Tool for Energy Analysis and Simulation for Efficient Retrofit
UBEM	Urban building energy modelling
UHA	Urban horizon angle.
UHI	Urban heat island.
UNFCCC	United Nations Framework Convention on Climate Change.
WWR	Window to wall ratio
ZHUN	New urban housing zones.

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GENERAL INTRODUCTION

1- Introduction

Energy is considered as a vital source, which is playing an important role in the development and existence of human society, and indeed all living creatures (Ministère de l'Education Nationale Francaise, 2008). Machines and new technologies also require energy potential to function, where it turns out since the industrial revolution that the modern way of life is absolutely dependent on energy, especially that of fossil origin (Yang et al., 2021), and the need for energy continues to grow for all the requirements of daily life (Bayraktar, 2016).

The new era lifestyle is known by massive industrialization based in particular on the extraction or exploitation of fossil hydrocarbons (oil, natural gas and coal combustion), along with high and rapid urbanization (Thiébault & Moatti, 2016), seeing that more than two-thirds of the world's population is expected to live in cities by 2050, with different levels of urbanization in different parts of the world. The most urbanized regions in 2018 were North America (82% of people living in cities), Latin America and the Caribbean (81%), Europe (74%) and Oceania (68%). Asia's urbanization rate is currently approaching 50%. By comparison, 43% of Africa's population lives in urban areas (United Nations, 2018).

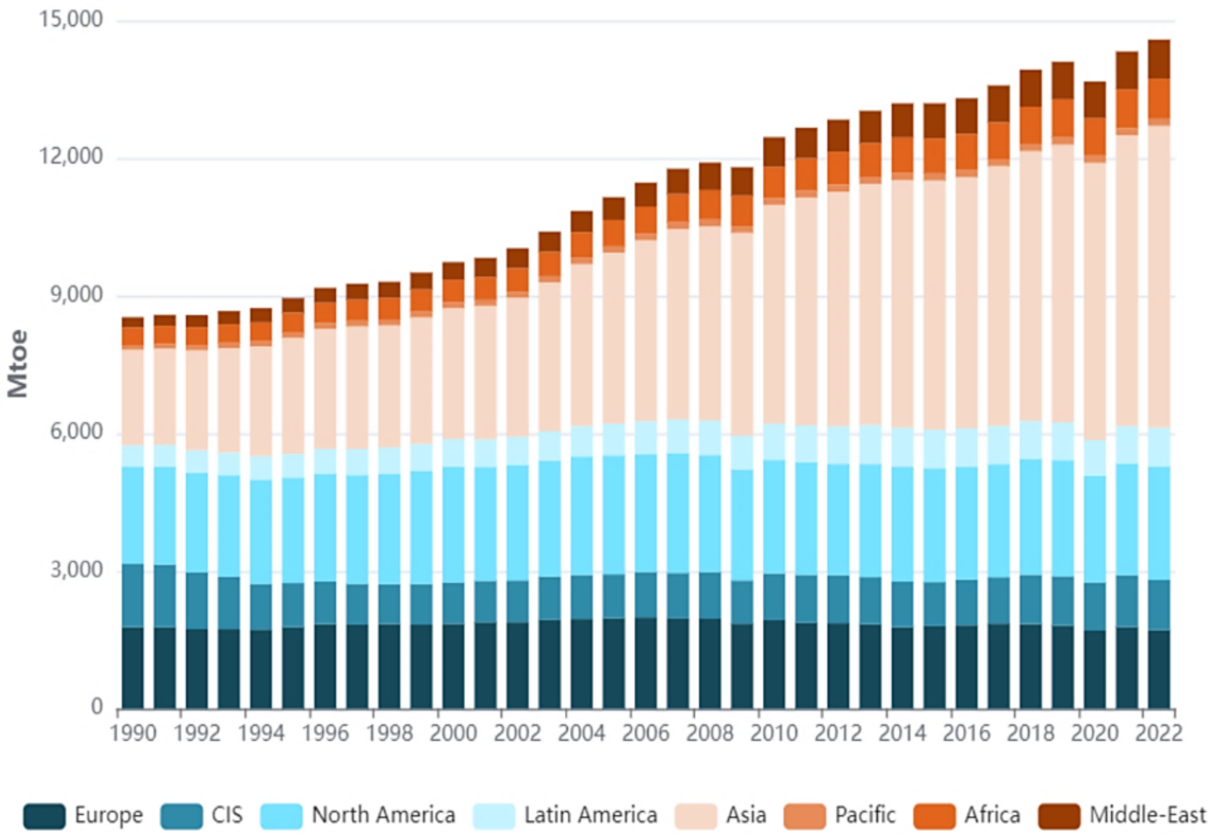


Figure 1. Worldwide energy consumption evolution over 1990 - 2022 (Mtoe).

Source: (Enerdata website, 2023).

This has led to a continuous increasing in energy demand, and an annual worldwide consumption of almost 15000 Mtoe, in 2022 (Enerdata website, 2023), as shown in (Figure 1). According to (IEA, 2021) statistics, the residential sector alone accounting for 26.6% of electricity usage and 29.7% of the natural gas use in 2019. Consequently, annual global greenhouse gas emissions totalled 37 Gt, with a significant contribution from the buildings sector, as illustrated in (Figure 2).
Operational use of buildings was responsible for 27% (9.9 Gt) of global greenhouse gas emissions, while the building construction industry contributed 6% (2.3 Gt), alongside other construction industries contributing 7% (2.4 Gt).
The observed global environmental problems such as climate change, acid rains, remarkable rise in average temperature, depletion of certain natural resources (Nahal, 2019); in addition to mortalities, respiratory diseases, were linked especially to the emission of greenhouse gases and its causes (Thiébault & Moatti, 2016).

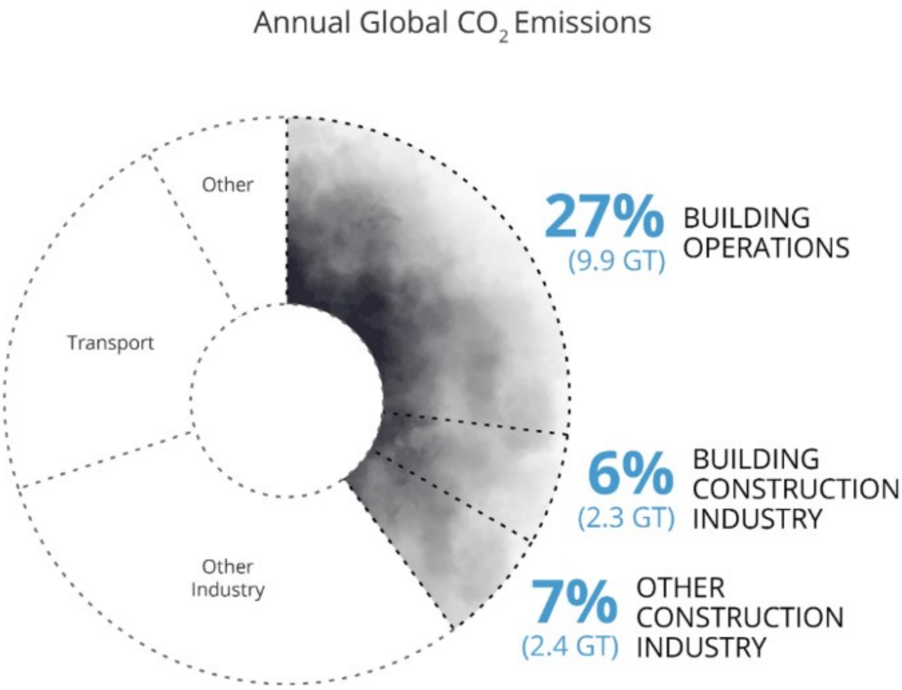


Figure 2. the percentage of contribution of buildings operations and construction industries in the annual worldwide CO2 emissions (2022).
Source: (architecture2030 website, 2022).

These statistics also demonstrate compelling opportunities to decrease energy consumption and the associated greenhouse gas emissions. These improvements can be achieved through the deployment of energy efficiency legislation and public awareness programs. A series of actions, research and international agreements and conferences were then planned and held over the last decades, such as the Kyoto Protocol, the COP's and the Earth Summits, especially the one in Rio de Janeiro where Agenda 21 emerged (Unies, 2002), with the aim of overcoming and setting aside these multidimensional complications.

The scientific evidence and global reports are clear about the question that to minimize the worst effects of climate change, greenhouse gas emissions must be reduced by around 50% by 2030 and carbon neutrality achieved by 2050. To achieve this goal, it is essential to move away from reliance on fossil fuels and instead invest in clean, accessible, affordable, durable as well as reliable alternative energy sources. Renewable energy sources are available all over the world, but their full potential remains unexploited. According to IRENA, it is both feasible and desirable for renewable energy to provide 90% of the world's electricity by 2050. Renewable energy helps countries to reduce their reliance on imports, diversify their economy, and insulate themselves from volatile swings in fossil fuel costs. Furthermore, by providing new employment possibilities and eliminating poverty, they encourage inclusive economic growth (United Nations, 2023).

The policy of energy transition can be embodied in the residential sector by an energy renovation, which must be delicate, by first passing through the understanding of the correlation between solar potential, urban form, and energy consumption; the latter is also linked to numerous factors classified under: meteorological factors, architectural, psycho-physiological, behavioural, and factors related to the equipment used (L. Li et al., 2021).

In this context, energy renovation of buildings can be achieved through passive interventions on the building envelope, reducing energy demand, or through active measures by integrating renewable energy installations. Hybrid interventions, combining both methods, are also possible. Previous research has explored the impact of these different measures on energy efficiency and ecological footprint. As an illustration of the first type, (Stovall et al., 2007) conducted an experimental study on common houses in various locations in the United States to undergo wall renovations. These included cladding replacement, installation of insulation underneath the cladding, and airtightness methods for new windows. Furthermore, (Santamouris, 2014) investigated the use of vegetation layers on the roof in Athens, Greece. Several other studies focused on the second type of interventions. For instance, according to the research of (Mauri, 2016), the renovation procedure at the Province of Agrigento's headquarters in Italy included the installation of photovoltaic panels and a geothermal heat pump.

The third category has undergone comprehensive investigation, including the research carried out by (Corrado et al., 2014) on a block of flats in Italy. The study centred on the insulation of walls, upper and lower floors, and the incorporation of low-emissivity windows and solar shading devices, in addition to the implementation of thermal and photovoltaic solar systems. Additionally, (Akande et al., 2014) conducted a study on a public heritage building situated in the Belgian city of Brussels. They examined the implementation of passive retrofit techniques, such as wall insulation and double-glazed windows, as well as the combination of photovoltaic panels, biomass fuelled geothermal heat pumps, and heat recovery ventilation. These studies, in addition to others investigating various technological methods for passive and active improvement on an architectural scale, like (Ferrara et al., 2014) who have analysed their impact on reducing energy consumption and greenhouse gas emissions. Also, (Civiero et al., 2021; Jepsen et al., 2022; Nabinger & Persily, 2011) studied these two aspects on an urban scale, while other studies have examined the economic and social aspects of refurbishment (Mikulić et al., 2020; Stenberg, 2018).

In fact, the success of a renovation intervention also depends on understanding the various characteristics of the building and its surroundings, as well as their impact on energy consumption. In this framework, several researches were on the effect of urban form on energy consumption (Chen & Hong, 2018; Martins et al., 2019; Ahmadian, 2021), others like (Pathirana et al., 2019) took a smaller scale and investigated the effect of building form, orientation, window/wall ratio and interior zones on the energy efficiency and thermal comfort of naturally ventilated houses; alongside additional researchers who sought the effect of facade and roof complexity on incident solar energy reception and energy demand (Hachem et al., 2011; Hemsath & Alagheband Bandhosseini, 2015), in divergence with other researches that have investigated the impact of the thermal properties of building envelope component materials on energy consumption, and indoor thermal comfort too (Zhu et al., 2009 ; Jannat et al., 2020 ; Landuyt et al., 2021 ; Uribe & Vera, 2021).

Several studies have investigated the impact of building height on energy demand and thermal comfort. For example, Shareef (2018) conducted a parametric study on the effect of building height diversity and configuration on thermal performance and cooling load at the urban scale. Guo et al. (2016) considered the impact of heterogeneity in building height and density on land surface temperature. Meanwhile, Godoy-Shimizu et al. (2018) conducted a statistical study that revealed differences in energy demands and greenhouse gas emissions among low-, medium-, and high-rise buildings. However, Xi et al. (2021), Wang and Xu (2021), and Nugroho et al. (2022) investigated the effect of high-rise buildings on the surrounding thermal environment. In contrast, Golkarfard et al. (2011) and Ghafari et al. (2018) examined the influence of ceiling height on energy consumption.

In addition to anthropogenic factors which effect solar radiation and energy needs, there are also natural factors that can affect indoor comfort and energy efficiency, where the study of (Yaşar et al., 2018), for example, was about the effect of the natural topography of the site on building energy consumption.

To guarantee the successful implementation of solar photovoltaic and thermal systems in urban areas with high energy demand, it is crucial to evaluate the solar potential within the location (Abu Qadourah et al., 2022). This potential is closely linked to the local solar radiation, which can vary significantly in urban environments. The level of radiation that reaches a particular area varies over time and is influenced by a range of global, local, geographical, temporal, and climatic factors (D. Li, 2013). Several studies have investigated solar energy production in the building sector. For example, (Ghazali et al., 2017) assessed the financial and functional efficiency of integrating photovoltaic panels on various vertical facades of high-rise buildings in Malaysia. Díez-Mediavilla et al. (2019) calculated the potential photovoltaic productivity of vertical facades facing the four cardinal points in Burgos, Spain, based on the average daily global vertical insolation. Ten-minute datasets were collected over a period of forty-five months, from January 2014 to September 2017, as part of an experimental campaign to estimate the average daily insolation levels, where the photovoltaic potential of vertical surfaces was subsequently calculated using these estimates. Another case study by (Almutairi et al., 2022) was conducted on the prevalent construction style used for houses in Kuwait to analyse the suggested PV placement on the facade of the house facing east, west, and south. The study reviewed literature made by (Samykano, 2023) on experimenting with hybrid PVT (hybrid photovoltaic thermal) systems with and without PCMs (phase change materials) for industrial and building applications. The research covered water heating, water desalination, building thermal management, food processing, HVAC, agricultural processes, and thermal power plants.

The University of Rome 'La Sapienza' conducted an energy and environmental assessment of the PV and PV/T systems under test. They used the SimaPro 51 software in line with the life-cycle assessment (LCA) methodology. The analysis presents the findings of electrical alongside thermal energy generation by the PV as well as PV/T systems, concentrating on their enhanced efficiency and ecological footprint, while factoring in their building and operating necessities (Tripanagnostopoulos et al., 2006).

The study of (Braun et al., 2020) explores the capability of a PVT system to regulate the temperature of office buildings across three varied climate zones. In the system under scrutiny, PVT panels act as a heat source and as heat sink to feed a reversible heat pump. By diminishing the demand for electricity from the grid to dispose of heat, the entire effectiveness and financial feasibility strengthen in comparison to a standard solar cooling system employing a reversible air-to-water heat pump as a source of heat and cold. In their 2011 study, Eicker and Dalibard objectively examined the supply of electricity and cooling for buildings. They discovered that cooling can be directly applied through activated floors or ceilings. To simulate this, they conducted experiments using uncovered prototypes of PVT collectors. The model then computed the nightly radiative heat exchange with the sky. They developed PVT modules without frames and integrated them into a zero-energy residential building, and the efficacy was evaluated in a logical sequence.

(Chow et al., 2007) conducted an experimental building integrated photovoltaic-thermal/water heating system, which was constructed on a rooftop environmental chamber. The researchers evaluated the energy efficiency of thermosyphon and pump circulation modes during the subtropical summer and winter seasons.

All the above highlights the precarious state of the world's energy and environment, emphasising the need for an energy transition. This transition can be applied to the building sector, which contributes significantly to energy consumption and carbon emissions. It also demonstrates the complexity and detail involved in energy renovation work, emphasising the need for careful and well-studied approaches, including passive and active strategies.

2- Problematic

Algeria, as a rentier country, is always confronted with a range of socio-economic, or technological problems that may be of national or international magnitude; it has also undergone climate change that may threaten human survival on earth (Nouaceur et al., 2013; Remini, 2020) and that of the certain exhaustion of fossil fuels, given that, according to forecasts by the International Energy Agency, final energy consumption is expected to be close to 100 million toe for a population of 50 million, so total energy production is likely to be equal to internal energy consumption by 2030. This indicates that the quantities of energy to be exported will be nil, and Algeria's position on the world energy market will change, from an energy-exporting country to one that may become an energy importer (Hamaz & Ait taleb, 2020). These problems are associated with rapid population growth, high unemployment rates according to the national statistics office (ONS, 2021), a slowdown in economic growth and major financial difficulties (Bekhtache, 2012).

According to data concerning Algeria's total final energy consumption for 2019, the energy mix was dominated by fossil fuels (IEA, 2022), with natural gas accounting for 63.7%, oil 35.68% and coal 0.5%, while renewable energies accounted for a negligible 0, 1%, despite the fact that the country also boasts enormous solar potential, with over 3000 hours of sunshine a year and the largest land surface on the African continent, meaning that Algeria has the potential and capacity to become a major player in the renewable energy sector (Hochberg, 2020); which has prompted the state in recent years to take the trouble to adopt the energy transition (Hamaz & Ait Taleb, 2020), through the creation of the Ministry of Energy Transition and Renewable Energies in June 2020 (MTEER, 2021), and the programming of several ambitious large-scale projects (CEREFE, 2020), to better exploit the immense potential of solar energy, which is considered among the highest in the world with an average daily irradiation of 6.57 kWh/m2, representing an annual total of between 2000 kWh per m2 and 2650 kWh per m2 (DENA, 2014). The urban fact of Algerian cities is characterized by hyper-accelerated urban growth that is at odds with the pre-existing spatial structure and out of step with social evolution, creating dysfunction and a falsely practiced city (Chorfi, 2019), in which rapid, large-scale construction without considering passive solutions to cover the excessive population growth and growing demand for housing - which Algeria has experienced in recent decades - has created a rupture between the building and its environment that has appeared in the production of an interior space devoid of minimum conditions of comfort, and the attempt to resolve this situation through recourse to artificial air conditioning, heating and lighting has required an abusive and irrational exploitation of energy resources (Latreche & Sriti, 2018). This has led to the residential sector being the most energy-intensive, and responsible for 43% of total electricity consumption at national level according to the 2017 energy balance made by the National Agency for the Promotion and Rationalization of Energy Use (APRUE, 2019).

Skikda, an Algerian town, faces numerous challenges in all aspects of life. Previous research indicates that buildings, especially collective housing structures, are vulnerable due to their old age and outdated design, which lacks bioclimatic principles. This makes them unsuitable to withstand meteorological factors and disconnected from their natural environment and climate. The situation has worsened due to rapid urbanization (Brighet, 2018), leading to buildings that fail to meet current energy-saving standards and do not provide sufficient comfort for their occupants (Kassis, 2012). Furthermore, these extensive housing complexes were restricted in their construction techniques and materials to meet the requirements and expectations of the residents. Any involvement by the occupants in sporadic transformations of the built environment consequently led to disturbances, disorder, and excessive energy consumption (Boulkenafet, 2014).

The town of Skikda is part of the North/North-East region of Algeria, with a moderate Mediterranean climate and a wide range of altitudes (from zero to one hundred and fifty metres above sea level). This study examines the location of the city in northeastern Algeria, positioned at 36° 86′ N and 6° 92′ E. The region experiences hot summers but moderate winters, with February being the coldest month and recording a mean monthly temperature of 12.9°C.

Meteorological data from 1991-2020 also show that August is the hottest month, with a monthly average temperature of 26.3°C (Site Climats et voyages, 2020). As a result of the large variety in yearly temperatures, particular measures must be implemented to maintain both energy efficiency as well as a pleasant indoor temperature.

Overall, the above-mentioned literature indicates that previous studies on energy consumption, carbon emissions and access to solar energy have only focused on a limited number of factors and on a single scale. They have not studied the interactions between the various factors at different spatial scales. The effect of site topography on energy consumption in buildings and access to solar energy has only been explored in a very small number of studies. What is lacking is a comprehensive study that takes account of the interaction between the building envelope, its urban environment and its topographical situation, at several spatial scales.

Numerous studies have explored the integration of solar panels into buildings, with a specific emphasis on hybrid PVT systems, analysing their technical, economic, energy, and environmental aspects. However, there has been no parametric study examining the energy and environmental performance of these hybrid PVT systems, where panels are integrated at different locations on roofs and vertical surfaces, altering the quantities of panels. Prior research also has not explored the relationship between the performance of PVT hybrid systems and the morphology and context of the building. It is important to investigate this relationship to better understand the potential benefits of PVT hybrid systems in different building types and contexts.

Several studies have analysed the energy consumption of multi-storey buildings and those with several residences per floor. However, none have directly compared the influence of apartment floor's height, and orientation, on the real annual consumption of this apartments as parts of the whole of collective housing buildings, while taking into account the specificities of the surrounding context.

In order to address the gaps highlighted in the literature, this study explores energy consumption, local solar energy generation, and the influence of various factors associated with building structures, urban landscapes, and natural topographical conditions on heating and cooling needs, and overall energy consumption, as well as solar energy access, by investigating the interactions between these different factors at different scales and classifying them according to their energy and environmental impact. This research project also examines the impact of energy renovation through different passive or active or hybrid improvement measures. The study focuses on four (04) collective housing buildings in Algeria, specifically in the city of Skikda. The aim is to analyse solar access, energy consumption, ecological status and the effectiveness of various energy renovation interventions, taking into account the specificities of the archetypes and their natural and urban contexts. Now that the scientific position has been determined, specific research questions can be formulated as follows:

- **How do multiscale factors related to the four collective housing buildings in Skikda selected as case studies impact their exposure to solar radiation, energy consumption, and carbon emissions?**
- **How does the orientation and height of an apartment affect its energy consumption when compared to the whole building, in the four case studies in the city of Skikda?**
- **How do the different passive, active and hybrid renovation interventions affect energy consumption, ecological footprint as well as the classification of existing archetypes in Skikda, in terms of performance in both aspects, compared to European references?**
- **Considering the specific morphologies of the studied archetypes and their surroundings, and the changing of the location and quantity of hybrid PVT solar panels integrated on the external surfaces of the buildings, what are the best scenarios associated with each case study in terms of energy demand and carbon emissions?**

3- Objectives

The energy consumption and environmental condition of buildings are linked to factors at different scales and in different contexts. The degree of success of renovation work depends on certain constraints, variables and circumstances, which can also influence its effectiveness. This research work aims principally to highlight the interaction and correlation between the different spatial aspects linked to the morphology of the building alongside the whole context, and its impact on energy and ecological behaviour, and on the right choice of renovation measures to take in relation to the characteristics of the collective buildings studied. So, the objectives are organised and formulated as this way:

- Evaluate the impact of multi-scale spatial factors on the availability of solar energy and the cumulative insulation on both the external surfaces of buildings and the entire site of the four study cases, identifying the optimal locations for incorporating solar panels in the basis of this evaluation.
- Assess the initial state of all the selected archetype as whole, and the apartments they imply, on the basis of different European benchmarks, both in terms of energy and ecology, and to define the different types of multi-scale factors that influence their performance.
- Evaluate the energy and ecological state of selected archetypes after energy renovation, achieved by formulating scenarios with only single passive or active interventions, or a combination of several different interventions of both types, and deriving the effect of each

intervention separately and synergistically on the performance of the buildings, and selecting the best scenario in relation to the specificities of each case study, also using the different European energy and environmental benchmarks.

- Analyse the impact of altering the quantity and positioning of hybrid PVT solar panels between the roof and vertical facades on their energy efficiency and ability to meet the requirements of the four selected collective housing structures. Taking into account the heights and volumes of the buildings, as well as the complexity of their facades, in addition to the specifics of the surrounding context.

4- Hypothesis

As preliminary responses to the various research questions raised, the distinct hypotheses are presented below:

- The envelope thermal properties, buildings' shape, in addition to their urban and topographical context, has a direct impact on solar access inside and outside buildings, and consequently on energy consumption and solar energy production, and carbonic emissions.
- The apartments located on intermediate floors and also the ones that face south are less energy consumers.
- Various passive and active measures can considerably improve the energy and environmental performance of residential buildings to varying degrees, depending on the shape of the urban space and the intervention measure.
- The integration of PVT hybrid panels, in particular, into the roofs of collective housing makes it possible to achieve much higher levels of energy production and environmental performance than their integration into other external surfaces of the building.

5- Methodology

The research process was developed through a thorough analysis of prior research on the energy retrofitting of buildings and renewable energy systems, specifically in regards to solar resources, as well as the methods and approaches related to their integration within the building industry, in addition to studies related to worldwide, and also Algerian national ecological issues and concerns. Then, a study of the various collective housing typologies presents and lived in Skikda was conducted, which allowed for the selection of four specific research study cases.

To further understand the geometry of the existing archetypes, visits were made to departments specialising in town planning, construction and housing, and affiliated to Skikda, such as OPGI, DUC, DLEP and AADL, alongside the town hall, especially the archives service. Field trips were also undertaken to capture photographic images of the archetypes and the overall neighbourhood. To gather further data, Google earth software as well as websites such as (Topographic-map.com) were employed to extract the ground-level building footprint and site topography. As a result, the complete urban and topographical context could be modelled. After this, in order to begin a quantitative method for analysing the energy and ecological aspects of collective housing, data was collected for the archetypes studied, through visits to the SONELGAZ commercial agencies in Skikda. These visits made it possible to obtain samples of quarterly energy consumption of gas and electricity over two years, for 21 apartments which form part of the four archetypes. These samples were chosen on the basis of the height and orientation of the apartments in relation to the overall envelope. Through all the data obtained and the literature constructed, analyses touching on several aspects, in particular the solar, urban, topographical, behavioural aspect and their interactions with the ecological dimension, as well as energy consumption and production in the context of the study cases. These pre- and post-renovation analyses have been carried out through a collaboration between several IT tools, such as ARCGIS, Revit Autodesk and its Insight 360 plug-in, and the CEA tool. In addition, some energy analyses were carried out by comparing real measurements without use of this kind of tools. Finally, the energy and environmental assessment was carried out according to European standards.

6- Structure of the thesis

This dissertation which begun with a general introduction, is then divided into seven chapters, with the first four covering theoretical aspects that focus on the primary level of knowledge: the conceptual framework. The fifth chapter presents detailed information regarding the study's environment, while the sixth chapter outlines the methodological process executed to examine the research hypotheses.

The final chapter presents the experimental research outcomes and their interpretations. Finally, a general conclusion, which was written with the aim of answering the initial question as constructively, substantively, explicitly, clearly and precisely as possible.

CHAPTER I: outlines the concept of energy and the multiple spatial factors that influence its needs in urban areas, with a focus on households. The identification of these factors begins by defining urban form and other critical aspects related to the built environment and their links to energy consumption and solar exposure. In addition to defining multiscale anthropogenic factors, this chapter presents an overview of diverse natural factors that may affect the energy requirement for indoor comfort and activities.

CHAPTER II: offers an overview of climate change, relevant international institutions and conferences, highlighting the link between climate change and cities. It examines the main industries that generate greenhouse gas emissions as a result of energy consumption modes and their consequences. Furthermore, it provides an understanding of highly efficient and sustainable labels and buildings.

CHAPTER III: focuses on the renewable and fossil energy potential of Algeria, as well as the efforts of the Algerian government and private institutions and individuals towards energy transition. Additionally, it shows various laws and legislation aimed at improving energy and environmental objectives in all sectors, including thermal improvement and reduction of energy consumption and ecological footprint in building and residential sector.

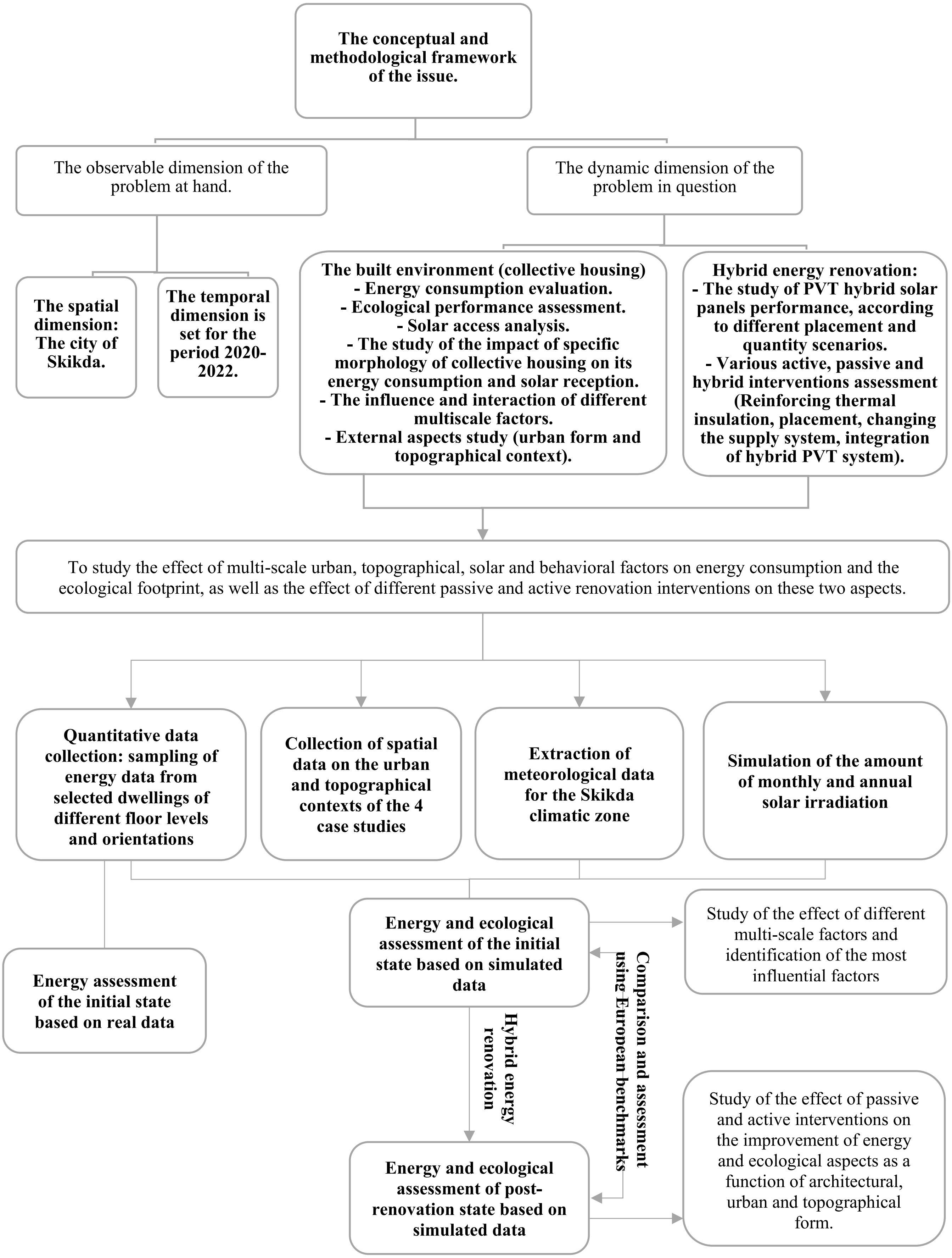
CHAPTER IV: defines what energy renovation involves and what goals it aims to achieve. It highlights different ways to make changes and goes through each stage of the process while taking into account the environment, both built and human. Also, it offers an overview on prior research looked at how different actions to improve energy use and the environment impacted energy efficiency and ecology. It also reviewed various approaches and simulation tools used in this field.

CHAPTER V: provides an overview of the setting of the study, the city of Skikda. The city is discussed across various sections, commencing with a historical overview, succeeded by a climatic study. Furthermore, an epistemological study and classification on the housing present in the city were analysed study aims to demonstrate the four selected sites, which centre on precise archetypes.

CHAPTER VI: presents a comprehensive examination of the methods and tools used to carry out the study. It discusses how the case studies were chosen by identifying their typo-morphological features at different levels. In addition, this chapter illustrates the process of carrying out the solar, topographical, energy and environmental analyses, as well as the various improvement measures used. Lastly, the process used to analyse and evaluate the selected archetypes in terms of energy and ecology is also described.

CHAPTER VII: comprises two main sections. The first section analyses the initial state of the study cases, proceeding from the largest to the smallest scale, encompassing topographical, solar, energetic, and environmental aspects. The second section of this chapter focuses on introducing the outcomes of diverse energy renovation simulations, followed by an energy and environmental appraisal of the four archetypes' conditions. European standards were used to assess their conditions after each scenario.

7- Schematic presentation of the issue



CHAPTER I

Relationship between multiscale spatial factors and energy consumption

I.1. Introduction

Today, urban regions are the most critical areas of the energy crisis. Tackling these problems is therefore essential if the urgent need for an energy transition is to be met. Buildings are essential to the energy transition because of their ability to produce and conserve energy, and also because they are particularly affected by this problem.

To reduce the energy consumption of buildings, increase the use of renewable energy sources and mitigate the urban heat island effect, it is essential to consider energy and environmental quality issues from the earliest stages of urban planning. However, a better understanding of the impact of design choices is needed to effectively integrate energy performance and local climate factors into urban design methods.

Energy, irrespective of its source, is a crucial component for progress. It is necessary for transportation, business and industrial operations, construction and infrastructure, the provision of water, and food production. The majority of these operations take place in or near cities, which are in need of a steady stream of energy to perform their operations. They use over 75% of the world's primary energy and produce between 50% and 60% of its greenhouse gas emissions (UN-Habitat Website, n.d.). According to studies by (Vivan et al., 2012; Masson-Delmotte et al., 2018), this is the primary cause of the rise in global temperatures that is causing severe weather conditions (such as flooding, soaring temperatures, excessive precipitation, and wildfires), acid rains, the loss of liveable lands (Mann, 2009), food shortages, and the plight of over one hundred million individuals.

Therefore, steps must be taken to reduce the negative effects of this enormous amount of energy use. Essential daily human needs, services and business operations are only a few of the things that contribute to the use of energy in cities. Their varying energy needs are mostly influenced by the environment, energy technologies, and urban design. As a result, a city's form influences how much energy it uses (Steemers, 2003; Rickwood et al., 2008; Delmastro et al., 2015).

This chapter introduces the concept of energy and the various spatial factors that affect its requirements in urban areas and particularly residences. The identification of these factors began with defining urban form and other vital aspects related to the constructed environment, as well as their connections with energy usage and solar exposure.

In addition to defining multiscale man-made factors, this chapter provides an overview of various natural factors that may impact the energy demand for indoor comfort and activities.

I.2. Energy

I.2.1. Definition of the concept

Energy is a universally accepted unit of measurement for the advancements in living conditions that have been made by humans throughout history. Dubbed the "universal currency" by (Smil, 1994), energy has played a pivotal role in shaping social structures across different eras, ranging from hunter-gatherer communities and agrarian civilizations to modernized industrial societies. Just like soil and water, energy is an indispensable resource for sustaining life and cannot be substituted (Steger et al., 2013). Leslie A. White regards civilizations as a form of energy organization (White, 1943). Various scholars have divided human history into primary energy epochs, each with specific social and physiological regimes resulting from its distinctive energy foundation (Burke, 2019).

Energy is the force that propels movement or the available power. In physics, energy refers to the power or heat generated when something moves, burns, or exerts itself. It is commonly represented in two forms: kinetic energy or also potential energy. Potential energy is the power something possesses while motionless or unburned. For example, when coal undergoes combustion, a substantial amount of potential energy is released. This potential energy is subsequently converted into kinetic energy, which refers to energy associated with the particles of the system, during the combustion process. The term "energy" is frequently utilized in various contexts (Dictionary.com, 2023).

I.2.2. The evolution of energy-efficient construction techniques throughout history

Since antiquity, man has been finding ways to harness and transform natural processes in order to enhance the quality of life, including houses and their building techniques.

Though the term "energy efficiency" was not as prevalent a concept as it is today, people have developed and passed down codes of best practices through generations prior to the 20th century.

Thus, the construction techniques employed were rooted in past experimentation. At that point in time, this was a perfectly adequate way of improving and preserving certain building techniques.

Each era brought about new advancements or improvements to existing techniques, but an interesting observation is that current systems which utilize renewable resources have ancient ancestors.

People in the Carpathians, according to (Patrascu, 1984) used the technique of partially underground constructing dwellings to get a steadier interior temperature 5500 years ago. Later, the thermal properties of the ground were used in the homes of Cappadocians, Essene communities in the Middle East, and Native Americans. Concerning Persian "Badghir" (or wind tower), (A'zami, 2005) shows a progression of these forms, with wind and earth energy used in specialized channels to offer internal comfort. A comparable technology that uses only wind energy may be seen in Egyptian "malqaf" (or wind catchers) (Sayigh & Marafia, 1998). The Egyptians employed thick brick walls or tiles (The Ceramic Society of Japan, 2012), which also possess particular acoustic properties, to enhance thermal comfort. In contrast, the Greeks and Romans later used hollow walls (Masonry Advisory Council, 2002). Additionally, heating using burning gases that pass-through cavities in the floor or walls was used by Romans (Sear, 1998). These elements, with high thermal mass, effectively sustain a comfortable indoor temperature for an extended period. Mica-covered windows were used to maintain a comfortable indoor temperature by harnessing solar power. This led to the development of a distinctive room style in the Roman Empire called "Heliocaminus" (Oxlade, 2011). Significant advances were made in the construction industry during ancient times, where they were viewed as a traditional means of expressing national identity and were preserved for centuries, including the Middle Ages. The Renaissance highlighted the values of this era and influenced industries such as culture, science, architecture, as well as technology.

The nineteenth century witnessed the development of classicism in science and progressions in the field of architecture. This era stands out as an important period of scientific discovery by conventional standards. Scientists not only demonstrated technological innovation but also established a firm scientific foundation through numerous treatises, publications, dissertations.

In the late 1800s, scientific research in the construction industry involved studying the effects of thermal insulation on heat transfer, moisture generation and movement within walls, the design of multi-layered windows, and other related areas. Pre-heating the air in the basement service room became a common practice at this time. This initiated the ventilation process, which involved the convective circulation of air to the upper floors. At the turn of the twentieth century, researchers had the theoretical and technological foundations necessary to achieve energy-efficient homes. Carrier later invented electric air conditioning technology and published a psychometric chart (Ionescu et al., 2015). "The House of Tomorrow" by George F. Keck and "MIT Solar House 1" by Hoyt C. Hottel in the 1930s demonstrated substantial solar heat gains (Duffie & Beckman, 2013; Jones & Bouamane, 2012). Their innovative approaches to building design and construction marked the beginning of the push for energy efficiency. The success of these buildings was highly dependent on the thermal design of their components and equipment, including solar collectors. Subsequently, numerous technical solutions were developed, and thermal insulation improvement soon became integral. The 1940s were dominated by World War II and its aftermath, leading to a decline in domestic technological progress. Notably, there were few noteworthy advancements in the field of energy in buildings during this period. However, by the end of the 1950s, the seasonal energy storage system became a significant subject in the building industry. In fact, in 1984, Germany completed the first long-term thermal energy storage facility, representing a major breakthrough in the field (Hahne, 2000). Processing thermal load data by computer in the 1960s became an essential practice when assessing the energy performance of buildings (Hensen & Lamberts, 2011). This is when researchers validated methodologies for estimating the energy load of buildings. They subsequently developed the Degree Day Method, Bin-Method, as well as the Modified Bin-Method. P.O. Fanger (1934–2006) made important contributions to the quantification of thermal comfort, which governs the required thermal load. Outdoor conditions also significantly influence his concept. Fanger's model remains one of the most popular comfort models today (Van Hoof, 2008). The oil crisis of 1973 precipitated a growing interest in ensuring greater energy efficiency in building design. This led to a heightened focus on improved levels of air tightness, more effective super-insulation techniques, and the implementation of heat recovery mechanisms in ventilation systems. Additionally, there was an increased adoption of triple pane windows, as well as passive technologies that prioritized the usage of solar thermal energy. At this stage, traditional designs are being replaced by new ones, as Brenda and Robert Vale explain: self-sufficient housing, autonomous residences and green buildings (Vale & Vale, 1975). They revitalized building sustainability by later using their "Green House" in addition to "Autonomous House" theories in a property situated in Nottinghamshire, England. Broken bricks, alongside concrete blocks made from waste ash gathered from a neighbouring power plant, and bricks for the outer walls heated by landfill gasses from decomposing trash were among the locally recycled materials utilized to construct the house. In terms of energy and water supply, the house was regarded as near to self-sufficient. Following the energy crisis, various scientists gradually completed the description of the idea of sustainable development (Ionescu et al., 2015). The building industry has embraced sustainability concepts that have been instrumental in establishing new design techniques. Subsequently, buildings that integrate these ideas have been fittingly named "sustainable buildings," with design considerations cantered on landscape integration and communal acceptance. The term "sustainable building" later developed as a subset of the broader "sustainable development" concept (Chen et al., 2009; Furr, 2009). In 1974, funding for research was granted to Princeton University's Centre for Energy and Environmental Studies. A team, headed by Ken Gadsby, Gautam Dutt, David Harrje, and Frank Sinden (collectively known as Princeton House Doctors), commenced an investigation into the impact of air exchange on heat loss in buildings (Holladay, 2010). Prominent projects aimed at energy efficiency include the Phillips Experimental House (1975) (Steinmüller, 2008), the DTH Zero Energy House (1975) (Esbensen et al., 1977), the Lo-Cal House (1976) (Heyduk, 2009; Parker, 2009), the Saskatchewan Conservation House (1976), and the Leger House (1977)

(Holladay, 2010). The term "Zero-Energy House," which is now widely used, was initially introduced during the 1970s. The first "intelligent building" was developed as a result of technical advances witnessed in the early 1980s. Hans Aek constructs a dwelling with properties of "Ultra-Low-Energy," while Wolfang Feist promotes the concept of a "Low Energy House" (Feist et al., 2005). In the late 1980s, Wolfgang Feist and Bo Adamson formulated the notion of a "Passive House" in response to energy-efficient houses from the 1970s. The Passive House idea, introduced in the early 1990s, combined all the major design theories as well as algorithms. The inaugural "Passive House Kranichstein" was built in 1991 in Darmstadt, Germany. The Freiburg, Germany-based Fraunhofer Institute for Solar Energy was responsible for constructing the first energy-autonomous house just a year later. The property independently fulfilled its energy requirements with its outstanding insulation and solar power systems, without any external support (Stahl et al., 1994). In 1994, a novel accreditation, Minergie, materialized. Featuring the principles of Ruedi Kriesi and Heinz Uebersax, Minergie recognizes Swiss buildings that consume low quantities of energy, primarily suitable for recent and undergoing renovation structures (Kriesi, 2011). The initial two Minergie residences were built in 1994. In 1998, the Minergie standard was formally accepted. Following three years, the Minergie Association introduced Minergie-P, which is a more rigorous standard equivalent to the Passive House criteria. In 1994, the Heliotrope became the first positive energy home to operate commercially. The home was constructed by the architect Rolf Disch in Freiburg in Breisgau. For the first time, the house generated more energy than it consumed. All of the technologies within the building were powered by renewable sources (Spiegelhalter & Lee, 2012).

Based on his experience in constructing and managing the initial house in Darmstadt, W. Feist developed the Passive House concept in 1995. In 1996, under F. Feist's guidance, the Passive House Institution was founded and began advocating for the standard while setting out specific demands. The concept of an intelligent building has been developing since 1980, with numerous buildings progressively integrating the control of diverse equipment and systems. Building automation systems were initially equipped with individual controls for each machine (Wang, 2009). However, with increasing complexity, they evolved to manage multiple systems concurrently. Nowadays, tracking and managing electrical, heating, air conditioning, as well as security systems is consolidated into a solitary system. The latest advancements have introduced the use of wireless technologies and the internet for monitoring and control. In the era of smart infrastructure, (Wang, 2009) delineated four clearly demarcated phases: integration of single function/dedicated processes from 1980 to 1985; amalgamation of numerous systems from 1985 to 1990; unification of building-level systems from

1990 to 1995; incorporation of computer integrated buildings from 1995 to 2002; and amalgamation of enterprise network integrated systems from 2002 to the present.

I.3. Urban form

I.3.1. Definition of concepts related to urban form

The expression "urban form" is used to refer to the physical characteristics of a city. It refers to an urban area's overall size, form, and configuration. Scale determines how it is going to be interpreted, organized, or studied. Urban form characteristics span from extremely localized elements like construction supplies, facades, as well as fenestration to more general elements like dwelling type, street category, and their spatial organization or layout. Urban form is a term that also includes non-physical elements like density (Živković, 2019).

Urban function can be thought of as the role a city plays in relation to society, the countryside, or other populated areas. It can also be thought of as the activities that take place inside of cities, or as the relationship between urban social requirements alongside urban spatial forms. Urban functions are a morphological characteristic-shaping generator for urban space. Urban space's placement, scale, and shape are directly related to the functional requirements of its residents or society. The pattern or organization of the development blocks, roadways, structures, open spaces, in addition to landscape that make up urban areas is referred to as urban structure. Instead of their individual qualities, it is the relationships between all of these components that help a place come into being (Živković, 2019).

Urban space is an area for socializing. (Lefebvre, 2003) asserts that every sort of society creates a spatiality, which includes the physical space itself as well as ways of organizing and conceptualizing it. In this sense, the physical world, the mental world, and the socially constructed concept of space are all included in spatiality. Space is created as a result of both social behaviours and physical factors. This implies that both ordinary actions and large-scale policies and technologies influence and alter place and time, which are structuring result in particular social patterns and connections, but it also has an impact on values of culture and economic prospects.

In order to define urban space as social, it is important to include its form, function, and structure. Accordingly, "city forms, their actual function, and the ideas and values that people attach to them make up a single phenomenon" (Lynch, 1984).

Forms, structures, as well as urban functions interact with each other and transform themselves in the urban environment, in the city's relationships to the region it influences or manages, and in its relationships with society and the state (Lefebvre, 2003).

Understanding a metropolitan area's, city's, town's, or village's spatial structure and also character requires study of the patterns of its constituent sections, as well as their ownership, control, and occupation. According to (Willams, 2001), urban form can be defined as the "morphological attributes of a city centre at all scales" and is closely tied to scale. A single building, street level, urban block, neighbourhood, or even city, are among the scales where an urban form can be taken into account. According to (Dempsey et al., 2009), these various degrees of spatial disaggregation have an impact on how urban form is perceived, quantified, evaluated, and shaped.

Streets, blocks, plots, along with buildings are the most fundamental types of urban form. Different forms of urban tissues are created by carefully combining city roadways, street blocks, plots, or buildings. Certain of those tissues are easily recognizable and give their towns a distinctive personality. However, there are various definitions of urban form elements that take into account their materiality and encompass both the actors and the environments that sustain them (Lynch, 1984). Physical facilities and people can be separated into features that move between sites or are a part of a system of mobility, as well as features that occupy a single place repeatedly or permanently (Živković, 2019). People can be categorized as locally active or in transit, and facilities can be further divided into adapted places and flow systems, which refers to all the different pipes, wires, highways, tails, and vehicles that transport both goods and people. Various physical and non-physical properties, such as shape, size, scale, land uses, density, building kinds, urban block arrangement, and the distribution of green space, are included in a different classification of urban form elements.

Urban form in a particular metropolis is made up of these various, interconnected parts. These urban form components have been named because it is believed that they have an impact on sustainability as well as behavioural patterns (Dempsey et al., 2009).

I.3.2. Relationship between urban form, microclimate and energy consumption

Microclimates are influenced by urban planning and design elements which include daylight, solar radiation (which causes heat gain), the flow of wind (either shelter from winds or desired ventilation), as well as local temperature (which involves the urban heat island). These microclimates, in turn, influence home energy consumption (Figure I.1). The density of a settlement is significantly related to its dwelling size and type, and hence to the area's solar access, ventilation from the outdoors, as well as the impact of urban heat islands. Typically, street layout design determines roadway orientation and building designs that are important for sunlight access along with wind movements. Open space planning, planting trees, as well as surface coverage all have an impact on urban microclimate, especially solar access along with the impact of urban heat islands (Ko, 2013).

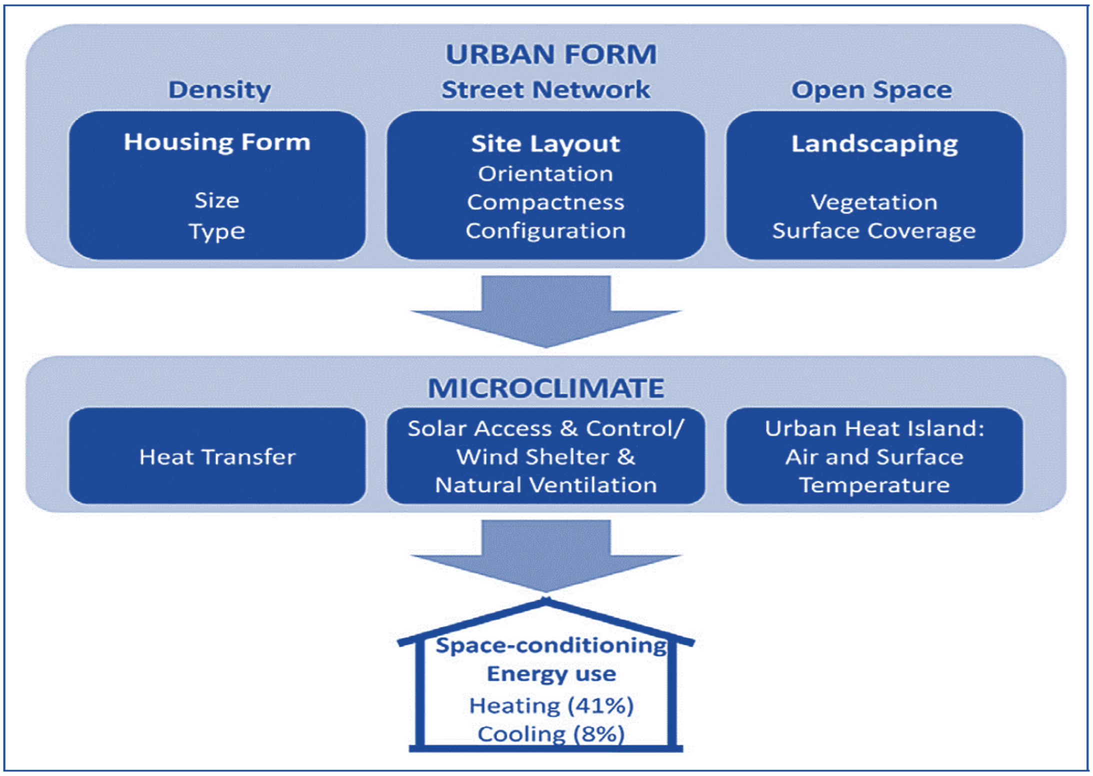


Figure I. 1. Illustration showing the relationship between urban form factors and the energy required for heating and cooling buildings.

Source: (Ko, 2013).

Guidelines for energy-efficient site planning and design have been published by numerous professional as well as academic groups (landscape designers, architects, planners, as well as scientists) ever since (Olgyay, 1963) released his seminal book on construction principles of bioclimatic design of buildings and site planning. Beyond building design, this research looked at how other elements, such as dwelling type, neighbourhood layout, building arrangement, housing density, and planting, could enhance urban microclimates and conserve energy.

Researchers have established precise criteria for urban design in each of the four basic types of climates: hot-dry, hot-humid, cold-dry, in addition to cold-humid since each has an impact on what amount of energy a building requires for heating or cooling (Ko, 2013).

I.4. Concepts related to geographical context

I.4.1. Elevation

In geography as well as cartography, the notion of "elevation" refers to the height of a particular point on the surface of the earth in regard to a reference point, often mean sea level. The measurement of altitude, which is commonly given in meters (m) or feet (ft), is crucial for comprehending a region's topography and geography. The middle point among the highest and lowest tides is used to calculate mean sea level, which is the mean elevation of the ocean surface. point's altitude can be calculated on land by comparing its height with mean sea level. Applications such as cartography, navigating, land-use planning, transportation, engineering tasks, natural resource management, alongside disaster mitigation all depend on elevation data.

Topographic maps frequently employ contour lines to represent it. These lines link places of similar elevation, making it possible for viewers to see the corresponding height, slope, and form of the landscape.

I.4.2. Altitude

In the fields of geography, and space sciences, the term "altitude" refers to the vertical distance or height of a place or object above a given reference level. Although elevation along with altitude are occasionally used synonymously, in some situations they have different meanings.

The height of a location or item above a reference level—typically the surface of the planet or mean sea level—is referred to as altitude in geographic contexts. Common units of measurement are feet (ft) or meters (m). Understanding a region's geography, climate, and ecology is made easier with the use of altitude data.

I.4.3. Relief

In geography and cartography, the concept of "relief" refers to the general contour of the earth's outermost layer, which includes its mountains, valleys, hills, and additional landforms, as well as the difference in elevation. Relief is essential to comprehending a region's topography as well as geomorphology since it gives one a feeling of the landscape's 3-D structure.

Relief can be divided into many groups according to the intricacy of the terrain and the extent of elevation variation. Typical categories consist of:

- Plains and plateaus are examples of areas with little or no variation in height, or flat relief.
- Gentle relief refers to regions with gently sloping terrain and little height fluctuations, such rolling hills.
- Areas with a variety of landforms, including hilly or mountainous landscapes, and more notable elevation fluctuations are referred to as having moderate relief.
- Rugged relief refers to regions that have deep valleys or tall mountains, as well as steep slopes, abrupt height changes, and intricate landforms.

Topographic maps often include contour lines to represent relief. These lines link places of equal elevation, making it possible for viewers to see the slope and form of the terrain. In certain instances, relief may additionally be shown using colour gradients or shading to provide a more natural visual representation of the landscape. Applications like as transportation, tasks in engineering, natural managing resources, environmental research, land-use planning, and disaster avoidance (e.g., identifying regions susceptible to earthquakes or floods) all depend on relief.

I.5. Multiscale spatial factors

According to (Erickson et al., 2014), design attempts to create the future more desirable than the present. this includes planned modifications to the material world.
(Lawson, 2006), for example, claims that three-dimensional as well as environmental design generate objects or locations that may have an important influence on the quality lives of many people. Design for products, architecture, urban design, alongside physical spatial (e.g., urban or even regional) planning are all disciplines in this field. The rising complexity of design processes has resulted in diverse sizes of work, materials, technologies, and needs (Erickson et al., 2014; Lawson, 2006).

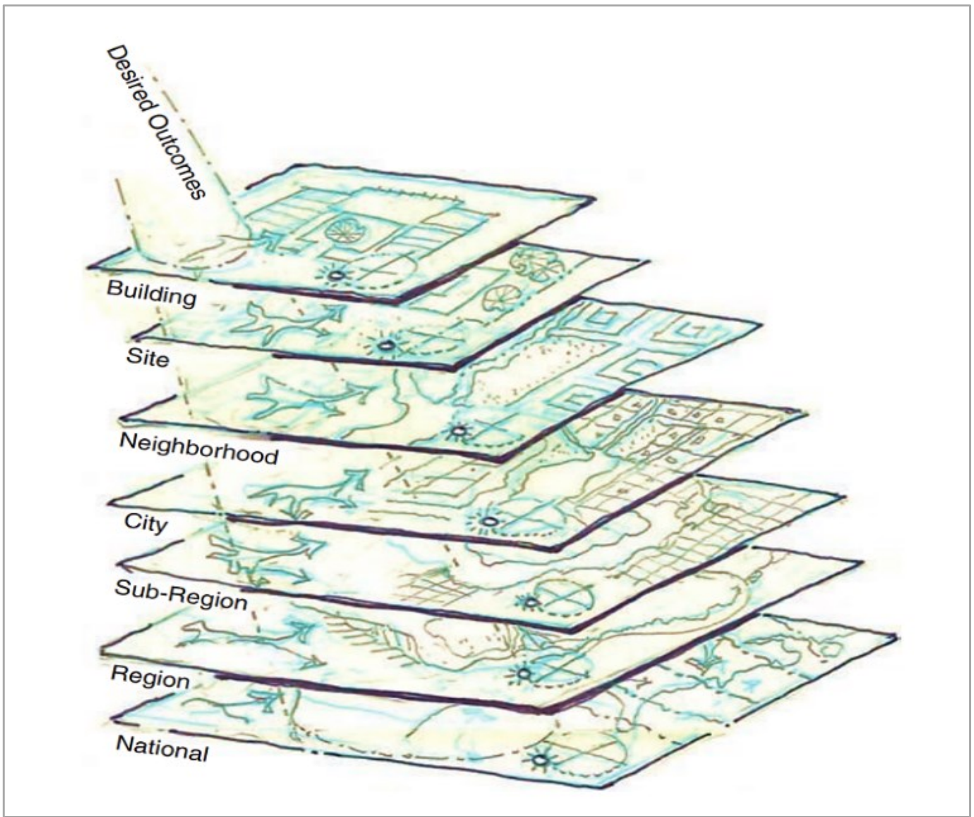


Figure I. 2. Spatial scales appropriate for urban planning & design for climate change attenuation and adaptation.

Source: (Raven et al., 2018).

Integrative adaptation and mitigation in cities can take numerous forms throughout multi spatial scales, urban systems, as well as physical structures (Figure I.2); a diverse set of measures used in the promotion of urban sustainability currently advances this goal (Raven et al., 2018).
For a more accurate examination, the typo-morphological elements in each urban region can be divided down into various scales, which are represented below.

I.5.1. Envelope scale

The boundary between a building's interior and exterior is its building envelope. Regardless of changing environmental conditions, it is the primary factor that establishes and regulates the quality of indoor environments. This crucial aspect of any building is made up of various elements including the walls, fenestration, roofs, foundations, the thermal insulation, the thermal mass, exterior shading devices, and others (Figure I.3).

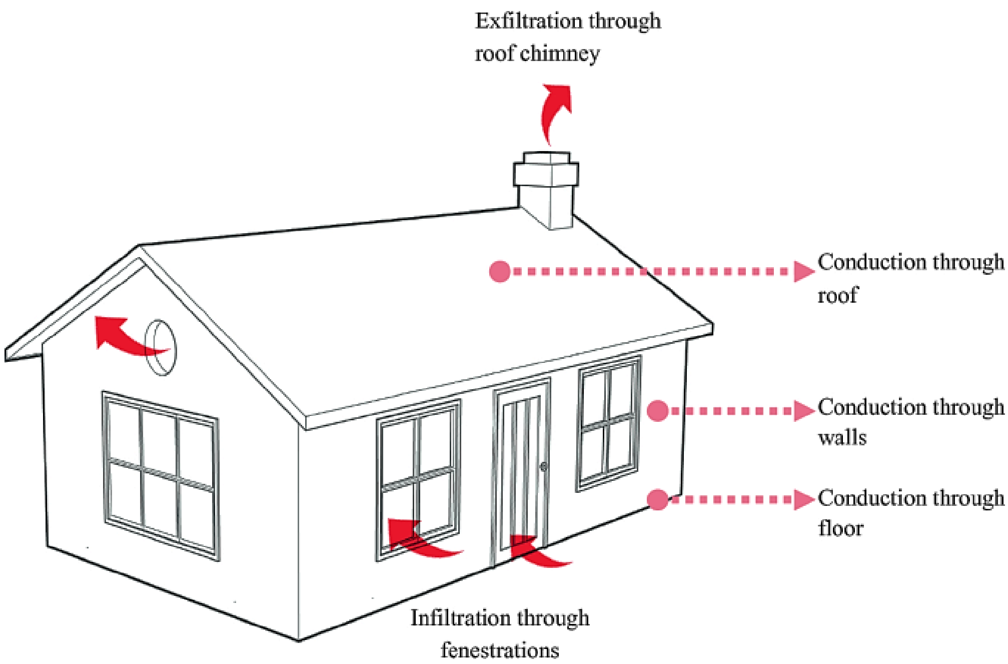


Figure I. 3. The transfer of heat via the building envelope.

Source: (Hachem-Vermette, 2020).

a- Walls

The majority of a building's envelope is made up of walls, which must maintain the building's appearance while also providing thermal and acoustic comfort. The thermal resistance (R-value) of a wall is essential because it has a significant impact on the building's energy consumption, particularly in high-rise structures where there is a high ratio between wall and total exterior area. Centre-of-cavity and transparent wall R-values on the market take into account the impact of thermal insulation. The

impact of the framing factor as well as interface connections, however, is not taken into account (Christian & Kosny, 2006).
Once the relative humidity in the surrounding air exceeds 80%, thermally insulated walls are more likely to experience surface condensation, given that the outer wall's convective as well as radiative coefficients for heat transfer are low. Wintertime and areas with cooler climates and higher humidity levels make this issue worse (Aelenei & Henriques, 2008). The condensation of this moisture on the outside walls of buildings encourages unfavourable microbiological growth, which could shorten the life of the walls and cause other critical circumstances inside the building. Traditionally, walls can be categorized as being made of wood, metal, or masonry, depending on the materials employed in their construction. Other forms of cutting-edge building wall designs are used to raise the energy effectiveness and comfort levels in structures (Aelenei & Henriques, 2008).

b- Fenestration

Openings in the building envelope known as fenestration are predominantly doors as well as windows. A building's fenestration is crucial in ensuring both optimal lighting and thermal comfort. They are crucial from an architectural point of view for the building's visual appeal. Technologies for glazing have significantly improved in recent years. Solar controlling glasses, insulation glass units, low-emissivity (low-e) protective coatings, evacuated glazing, aerogels, and gas cavity fills are some of these technologies (Robinson & G Hutchins, 1994).
In India, simulation research was conducted using five distinct climate regions and ten different glazing types (Singh & Garg, 2009). It was discovered that a window's ability to save energy annually depends not only on its thermal conductivity (U-value) and coefficient of solar heat gain (g-value), but also on its orientation, the local climate, and other building-related factors like insulation levels and floor area.
Windows with a low U-value and a significant maximum transmittance of solar energy are chosen for solar-powered passive heating applications. U-value with solar transmission should be traded off because, in most cases, lowering U-value will reduce solar transmission (Robinson & G Hutchins, 1994). Spectrally discriminating low-e coatings are used in daylighting applications to let in visible solar light while blocking additional wavelengths which are usually liable for solar heat gains. Since the majority of the solar energy captured will be lost to the surrounding air, these coatings are applied on the inner surface of the biggest pane (Robinson & G Hutchins, 1994).
There are two varieties of low-e coatings: hard coating as well as soft coating. The softer coating is often a small layer of silver encased in dielectric insulating layers, as opposed to the hard coating,

which is a tin oxide-based coating. Compared with hard tin oxide-based coatings, soft silver-based coatings usually possess a reduced solar transmittance and bigger infrared reflectance (Hammarberg & Roos, 2003). An antireflection treatment using silicon dioxide increases the visual transmittance associated with low-e tin oxide-based glazing. A transmittance measurement of 0.915 was attained, and the integrated visible transmittance gain was measured to be 9.8% higher (Hammarberg & Roos, 2003). In order to create three-glazed unit windows with an acceptable U-value without reducing visibility, it's preferable to use an antireflection coated low-e glazing.

c- Roofs

Roofs are a crucial component of a building's envelope because they are extremely vulnerable to radiation from the sun and other variations in the environment, which can affect how comfortable an interior is for its occupants.

Particularly in structures with extensive roof areas, including sports complexes, auditoriums, and exposition halls, roofs account for a significant portion of heat gain and loss. The maximum U-value for roofs that were flat in 1965, 1976, and 1985 was 1.42 W/m2 K, 0.6 W/m2 K, and 0.35 W/m2 K, respectively, according to UK building rules.

The UK currently mandates 0.25 W/m2 K or fewer for any new construction (Bousselot, 2010). The significance of roof thermal performance in efforts to improve the total thermal efficiency of buildings is highlighted by the decrease in the U-value over time.

By changing the roof construction, some passive cooling methods could be used in tropical areas. These include domed alongside vaulted roofs, either micro-ventilated roofs, mechanically or naturally ventilated roofs, high roofs, and double roofs. They also include a small cellular roof layout with minimal sun exposure. Other strategies, such as using concrete with a high thermal capacity to reduce peak load demand, covering roofs with plants to offer humidity and shade, and whitewashing surfaces of external roof to decrease solar absorptivity, are also gaining favour. One method of lessening the effect of sunlight on the surface of the roof is roof shade. Local materials like tiles made from terracotta, hay, palm tree branches, inverted clay pots, and other affordable roof shading techniques can typically result in a (6°C) reduction in the temperature inside (Sanjai & Chand, 2008).

Another technique to lessen the effect of sunlight on the surface of the roof is with roof coatings. High emissivity and high solar reflectance, respectively, are the daytime and nighttime parameters that influence the choice of a roof coating. Aluminium-pigmented coatings have a low infrared emittance, which makes them less appealing. A cool coating can lower the surface temperature on a white concrete rooftop by (2°C) at night and (4°C) over an intense summer day (Sanjai & Chand, 2008).

d- Thermal Insulation

Thermal insulation is a substance or mixture of substances that, when used properly, slows the rate at which heat moves through the processes of conduction, convection, as well as radiation. A building's heat flow is slowed down by it, because of its significant thermal resistance. When thermal insulation is used properly, buildings use less energy and can minimize the size of their HVAC systems. By increasing the insulation value of the envelope, a building's energy efficiency can be increased in a straightforward and efficient manner. From the beginning of the 1970s, insulation thickness in buildings has grown, nearly tripling in the north of Europe (Papadopoulos, 2005).

Thermal insulation performs best when it is placed as close to the heat entry surface as possible; for example, in areas with a high concentration of space heating loads, insulation must be placed near to the building envelope's inner surface, whereas in areas with a high concentration of cooling load demands, it should be placed closer to the building envelope's outer surface. Depending on local building requirements and regulations, the thickness of a material used for insulation in a fifty centimetres thick wall is typically between 25 and 30 mm. For various regions in Turkey, an economic model was created to calculate the ideal insulation thickness for outside walls of buildings (Bolattürk, 2008).

e- Thermal mass

Higher heat capacity materials which are capable of absorbing heat, store it, and then release it later are referred to as thermal mass. They include structural elements like a building's walls, doors, ceilings, floors, and furniture that may store thermal energy. By absorbing and gradually releasing the heat generated both internally and externally, it aids in controlling the fluctuation of interior temperature. As a result, the average radiant temperature decreases and the highest indoor loads are postponed or reduced (Antinucci et al., 1992; Balaras, 1996).

The thermophysical characteristics of the structure's material, construction orientation, insulation properties, ventilation, supporting cooling systems, as well as occupancy patterns all have an impact on the thermal mass optimization. When thermal mass has the potential to be cooled by nocturnal ventilation, this passive energy-saving building strategy is more efficient in structures like offices that are empty throughout the night (Balaras, 1996). Mathematical models are used to predict how thermal mass as well as night ventilation affect the cooling demand of buildings (Yang & Li, 2008).

A 27,000 square foot business structure in the north of New York was the subject of a case study where the addition of thermal mass resulted in energy savings of 18 until 20%. The HVAC system was downsized as a result of a decrease in peak cooling and heating loads, which compensated for the capital expenditure made for the addition of thermal mass (M. J. Brown, 1990).

f- Infiltration and airtightness

Infiltration and exfiltration are terms used to describe the flow of air into and out of conditioned space of a structure via cracks, leaks, in addition to other building envelope gaps.
Building indoor air quality is impacted by infiltration in terms of temperature, humidity, and air conditioning load. Additionally, water vapor condenses when penetrated air comes into contact with cooler parts of the structural envelope, which is undesirable for a number of reasons, including the promotion of mildew and mould formation (Persily & Emmerich, 2009).
By reducing infiltration, caulking/ sealing of air permeability cracks or entry can enhance a building's energy efficiency. The airtightness of the construction is unaffected by any of these naturally occurring forces, in contrast to infiltration, which depends on pressures throughout the building envelope. Because of this, it plays a key role in characterisation of the building stock, modelling assumptions, and construction quality control. From the perspectives of energy efficiency and interior quality of air (pollutant or moisture transportation), a building's infiltration as well as airtightness measurements are crucial (Sadineni et al., 2011).

g- Construction year

Through a statistical study of building energy data, (Webb, 2017) critically evaluated both the notion that buildings that are older function worse with regard to comes to energy use and the notion that older buildings do better than we expect. Data collected by the (CBECS) which refer to Commercial Building Energy Consumption Survey as well as (RECS) which refer to Residential Energy Consumption Survey, two surveys of the United States building stock, were used in her dissertation.
Different statistical techniques were used to analyse the survey data, as well as their correlations were examined. The findings indicated that factors other than age had a greater impact on the energy efficiency of the structures. The majority of antique structures have gone through changes, both in terms of physical alterations and use, which is why there is a poor correlation among age with energy performance.
Another study from Switzerland that utilized information from energy performance certifications revealed the thermal efficiency of several archetypal structures (Streicher et al., 2018). Thermal performance, or a building's ability to retain heat, is a function of the structure and the components

that make up the building envelope, which includes the structure's walls, doors, windows, roofs, as well as foundation. Although the thermal efficiency of a building may not be identical with the energy performance, it is a factor that impacts how much energy is used in buildings. In this study, the various building archetypes were defined using age as a criterion. Two groups of structures, one from before 1920 and the other from 1920 to 1945, were the earliest archetypes.

The Swiss system for energy performance certificates collects information on the U-values of building components and energy carriers, and this study concentrated on how the buildings' thermal performance related to those parameters, rather than how much energy they actually used. The thermal efficiency of the current stock of Swiss homes was statistically analysed by the experts. It shown how greatly the (U_{values}) across the various eras differed, particularly in the categories with older buildings. This, it is believed, is due to the older structures frequently undergoing renovations and the replacement or improvement of numerous construction components (Donarelli, 2021).

However, older structures (built before 1945) typically perform thermally worse than newer structures. The so-called "performance gap," or discrepancy between actual and predicted energy use based on estimated thermal performance, is also mentioned by the researchers. Although this disparity is frequently large, it was outside the purview of the research they conducted to analyse it. In this instance, the study only considers the state of the buildings' thermal efficiency, which is one aspect that affects the energy use, rather than actual energy statistics (Donarelli, 2021).

I.5.2. Building archetype scale

Individual building or building archetype study from an energy performance standpoint has a long history (Crawley et al., 2008). It is feasible to identify and quantify the influence of a construction's morphology (i.e., shape, glazing, and orientation) on the energy they demand by evaluating changes in urban form features at this scale.

Nevertheless, since buildings are not often isolated from the effects of neighbouring structures in actuality, looking at the building archetype scale alone does not give enough information to analyse the links between urban design and building energy.

In fact, the shading effects of surrounding structures will modify the energy impacts of isolated buildings at the building archetype size.

The building archetype scale study, in addition to the isolated impacts of building shape, presents a baseline against which the energy performance of building archetypes placed under diverse local shading circumstances may be evaluated. Four urban form aspects are addressed at the building archetype scale:

a- Building shape

The compactness of a building's form is an important component in thermal transmission since more compact building forms encapsulate greater building volume with fewer surfaces through which heat may escape, like (Figure I.4) shows.

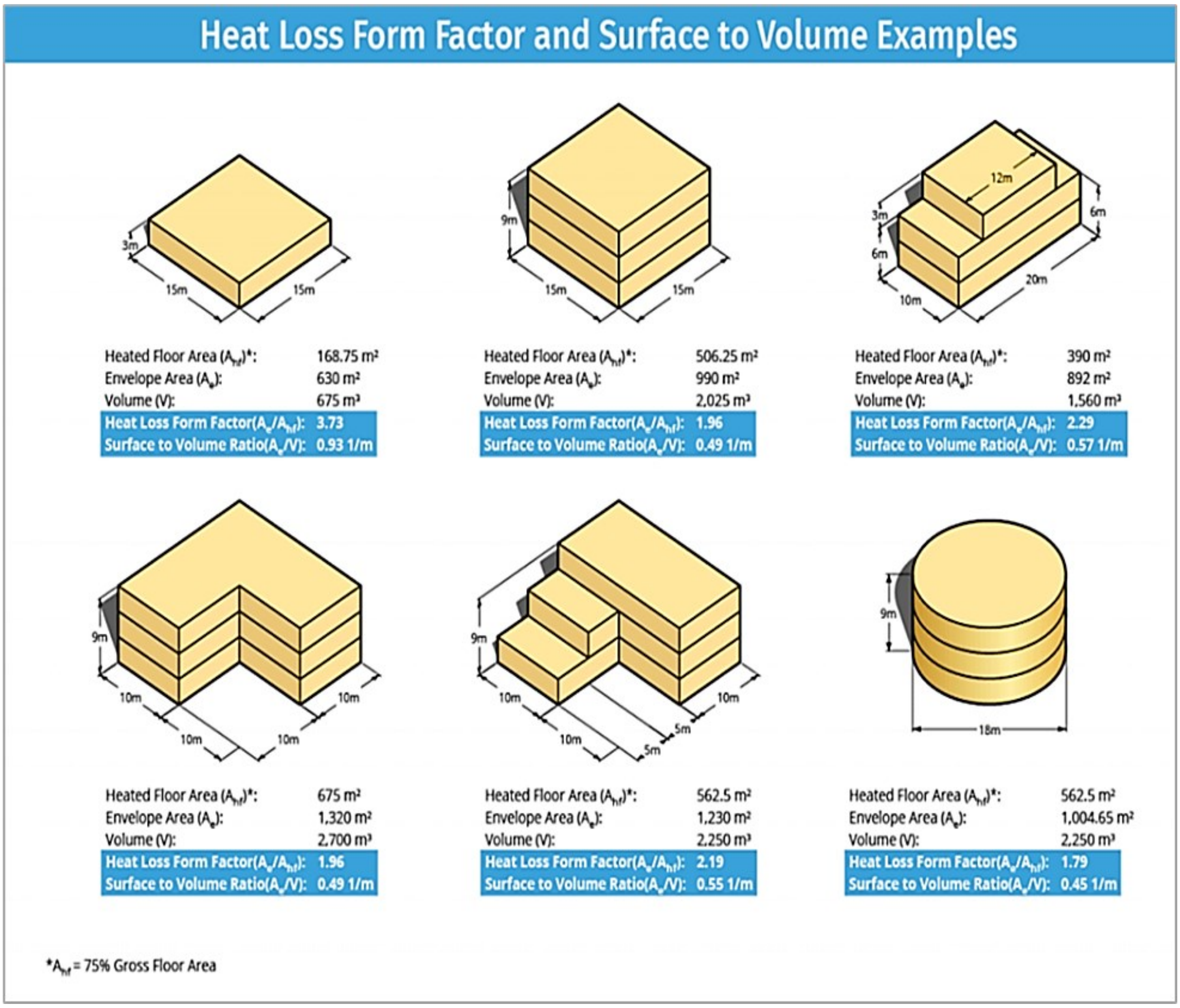


Figure I. 4. Heat loss form factor and surface to volume examples.

Source: (Vidmar, 2019).

The surface to volume ratio, or the proportion between entire building surface area (i.e., external wall, roof, and ground surfaces) and entire enclosed construction volume, is used to measure compactness: ($S_{total}/V_{building}$), commonly abbreviated (S: V).

The Surface to Volume Ratio for a standard single-family dwelling varies from 0.8 to 1.0 1/m, where (Lylykangas, 2009) recommends a Surface to Volume Ratio for a passive house of less than 0.8 1/m or even 0.5 1/m.

b- Glazing distribution

The proportion of a building's glazing allotted to each facade is represented by glazing distribution. Three typical glazing distribution conditions, such as parallel, concentrated, or uniform (Figure I.5), could be employed as examples to qualitatively define glazing distribution.

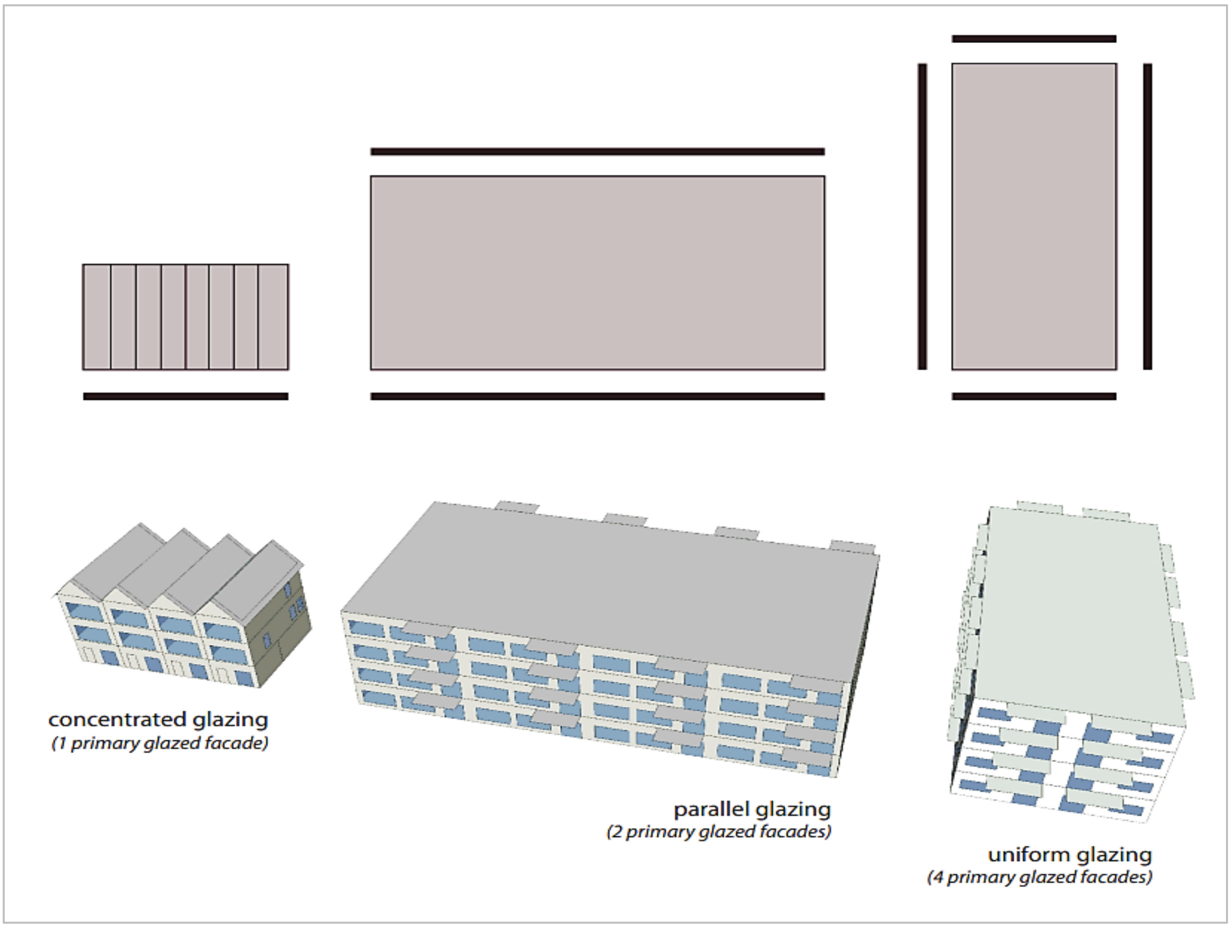


Figure I. 5. Examples illustration of glazing distribution.

Source: (Miller, 2013).

Archetypes having concentrating glazing distribution (i.e., a larger percentage of glazing are concentrating on single facade) are often less influenced by changes in urban horizon angle, whereas archetypes with glazing dispersed equally among all facades (uniform) are most significantly affected. It can be observed that concentrated glazing distributions tend to exhibit lower total glazing ratios than otherwise comparable buildings (Miller, 2013).

c- Glazing ratio

Building energy demands are significantly influenced by the quantity of glazing, notably in terms of the loss of heat via glazed areas and the effectiveness of passive techniques (such as passive heating or daylighting).

The glazing ratio, or the ratio between the total glazed area and the total surface area of the building, calculates the proportional amount of glazing in the structure in relation to the total surface area of the building (A glazing / S total). A simulation-based investigation on two aspects - differing sky circumstances (cloudy or even sunny) and various window enlargement methods (vertical and horizontal) in various orientations - was carried out by (Mahdavi et al., 2013) to ascertain the Window-to-Wall Ratio (WWR) in high-rise office buildings (Figure I.6).

To compare the two forms of window enlargement, a baseline window with a maximum allowable size (50%) is used, which is then shrunk at each stage.

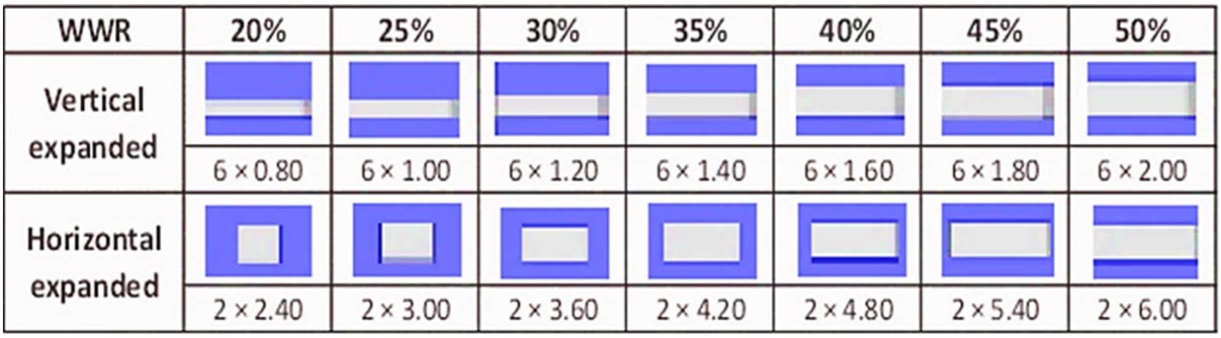


Figure I. 6. WWR percentage according to two expanding methods.

Source: (Mahdavi et al., 2013).

The following alternatives can be drawn from the research of daylight appraisal of an office area in various WWRs, did by (Mahdavi et al., 2013) also. The optimal WWR for an office space in an overcast sky is 25% in a horizontal expanding window, which is equivalent to a 3 m wide and 2 m high window, while the best Window-to-Wall Ratio in a vertical expanding WWR is 35%.

While, in a sunny day, the ideal Window-to-Wall Ratio is 35% in a vertical expansion window, which is 6 m wide and 1.40 m tall. The percentage of 30% for the WWR, on the other hand, is the most suitable choice for a horizontal expansion window.

In comparison to vertical extension windows with the same acceptable area and daylight value, horizontal extension windows are lower in size (area). As a result, during daylight hours, this style of window sees reduced solar heat gain. It should be known also that the height of the office room was estimated to be specifically 4 m in this study. However, if the room height and window expansion procedures are different in future research, different findings may be achieved.

d- Orientation

Building orientation refers to how a structure is arranged on a horizon plane or how the sun moves across the sky at angles among 0° and 360° (Figure I.7).

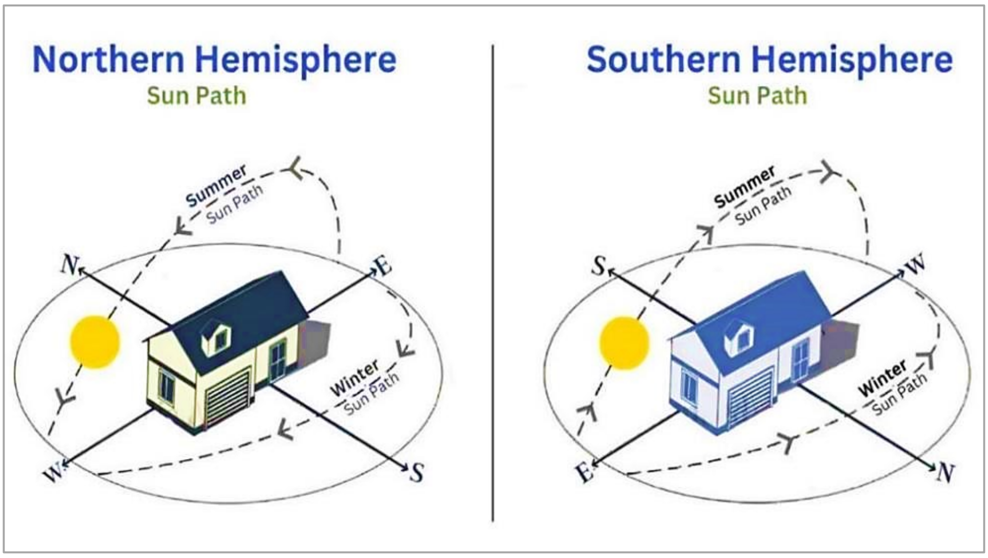


Figure I. 7. Orientation of the building with respect to the sun's path in the northern and southern hemispheres, in winter and summertimes.
Source : (AppliedVastu Website, n.d.).

As a rule, north is 0° or 360°, east 90°, south 180° and west 270°. The aim of the correct orientation of a building is to minimise the effects of solar gain in the summer and maximise natural lighting and access to and conservation of solar energy in the winter; rectangular buildings exhibit this approach more evidently (Straube, 2014). Thus, in various environmental situations, well-oriented elongated designs have been frequently employed (Erdim & Manioğlu, 2014). Their wider facades, oriented to confront the cool season, allow for increased daylighting during the winter months, while summer insolation is moderated by shorter facades oriented to withstand the hottest months (Guedes, 2013). The greater the reduction in energy consumption for cooling, the less surface area is exposed to solar radiation. In particular, each façade in each hemisphere receives a different amount of exposure to the sun. In general, south-facing facades in the northern hemisphere and north-facing facades in the southern hemisphere receive the summer sun at its highest elevation and the winter sun at its lowest elevation (Guedes, 2013). In the southern hemisphere, for example, the sun makes a downward arc in winter and an upward arc in summer. As a result, north-facing windows receive twice as much winter sun as east and west facing windows, helping to warm and lighten the interior of the home. To keep the house cool, they must be shaded from the intense summer light. In winter, autumn and spring, west- and east-facing windows receive little sunlight; in summer, they receive plenty. If it does not interfere with ventilation, windows should be kept small and well shaded, especially those facing west. South-facing windows, on the other hand, receive only early morning and late afternoon sunlight in summer and no direct sunlight at all in winter. Although the windows should be small, they can be quite helpful for cross-ventilation and passive cooling, as summer winds often blow from the south. South-facing windows require little or no shade above the Tropic of Capricorn and no shade from the direct sun, making it a desirable orientation for views (BUILD Website, n.d).

e- Building activity

The impact of urban form factors on building energy is significantly influenced by building activity (such as residential and commercial purposes).

The ratio of commercial floor area to total floor area ($A_{commercial}/A_{building}$) is used to calculate building activity. According to (K. B. Lindberg et al., 2019), in their study of different types of non-residential building activity in Norway, the average annual energy consumption was calculated for each of the building types in the sample, divided into heat and electricity consumption load data, as shown in (Figure I.8). The numbers are compared with Enova's building statistics data for 2011 (ENOVA, 2012) to check the representativeness of the sample, as the measurements were taken between 2009 and 2011. The Enova building data are based on thousands of buildings, although they only provide data on total annual consumption. When the two are compared, the average yearly energy usage within each group is appropriate, while energy demand in kindergartens is a bit higher and consumption in hotels is a little bit lower in the study samples. This samples exhibit reduced energy use for shops, malls, as well as hospitals when compared to estimations given by the Norwegian Water Resources & Energy Directorate (NVE) in 2015 (Langseth, 2016).

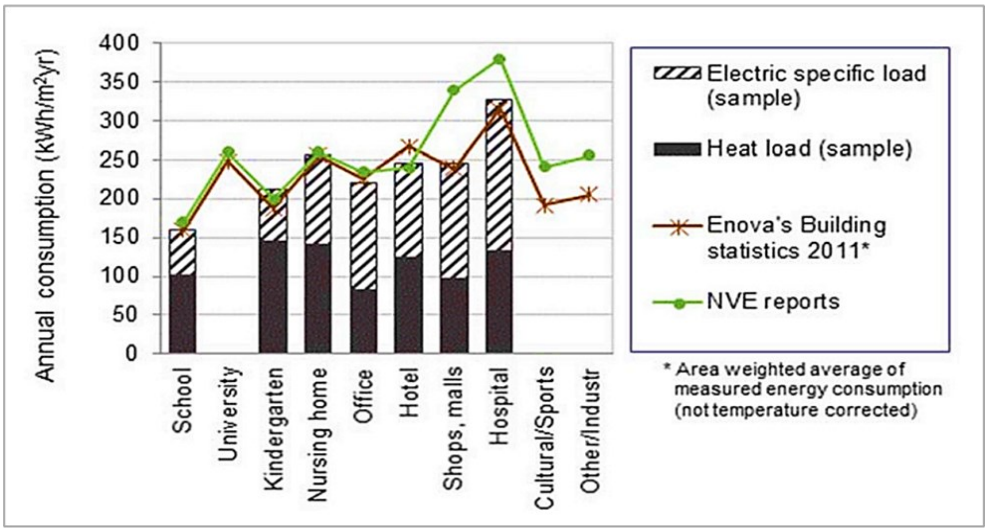


Figure I. 8. Each of the building categories in the sample's average yearly energy usage (kWh/m2yr) is shown (as bars) in comparison to the national Enova's Building statistics 2011 (ENOVA, 2012) and NVE (Langseth, 2015) data.

Source : (K. B. Lindberg et al., 2019).

I.5.3. Local shading (LS) scale

The physical environment (i.e. the urban structure) in which the building is located will influence the energy of the building primarily through constraints on access to the sun (i.e. shading of the building). In many cases, the urban structure can be very complex, with a wide range of shading conditions (e.g. various building shapes, heights and spacing), making it difficult to establish obvious correlations between urban form attributes and building energy (Miller, 2013).

Furthermore, the models of urban pattern scale required to reflect this complexity require lengthy energy simulation processing times, limiting the amount of urban structure modifications that may be realistically examined within the timeframe of a project.

Due to the time constraints of urban pattern scale energy simulations, it was critical to devise a method for limiting the entire number of urban patterns that would be modelled while increasing the quantity of urban form variations examined. As a result, various kinds of parametric analysis investigations at the local shading scale were undertaken. The LS scale indicates a single building archetype as well as the structures immediately adjacent to every construction archetype facade (Miller, 2013).

One characteristic of urban form is considered at the scale of the LS:

In addition to building form, factors such as spacing and layout that define the relationships between buildings in an urban environment also affect energy consumption (Mitchell, 2005). These factors are particularly important when solar access is taken into account (Ratti et al., 2005). At the neighbourhood level, the spacing and layout of buildings - which can be quantified in a number of ways, such as urban skyline angles and obstruction of sky views - have a major impact on the availability of solar energy. In addition, separate concerns about solar access apply to horizontal and vertical surfaces (such as walls and roofs).

(Compagnon,2004) found that total sun exposure in a study neighbourhood can be three times greater than radiation exposure on roofs alone, highlighting the importance of vertical surfaces (i.e. building facades) in absorbing solar energy. He also notes that vertical surfaces are more influenced by the surrounding urban structure than roofs, and horizontal surfaces in particular.

By means of the urban heat island impact, urban structure also has an impact on building energy. According to (Ewing & Rong, 2008), there are a number of factors that contribute to the UHI effect, such as the expansion of man-made surfaces that reflect solar radiation, the loss of vegetation and its cooling and shading benefits, and the increase in the quantity of heat-generating activities like vehicle traffic.

I.5.4. Urban pattern scale

Although there is a considerable deal of variation in a city's characteristics, most urban forms have several fundamental traits (Lynch, 1984; Anderson et al., 1996). Building on these similarities, the examination of urban patterns develops abstract categories that permit generalization across numerous, specific situations. And a pattern, in its broadest sense, is any type of recurrent structure or feature (Marshall, 2005).

An urban pattern is typically defined as a comparatively small number of elements or parts (such as streets, parcels or buildings…) that are connected by a regular, repeated set of systematic links (Miller, 2008; Marshall et al., 2010). This is because understanding the parts is a prerequisite for understanding the whole (Lynch, 1981).

In order to extract relevant and valuable information for a particular goal, these linkages typically reflect traits like connectedness and orientation rather than metric data like actual lengths and areas (Marshall, 2005). In contrast to standardization, relationships indicate resemblance and continuity (Habraken & Teicher, 2000)

Urban environments must necessarily be understood and measured spatially. According to several research, like (Anderson et al., 1996; Marshall, 2005), urban form is made up of spatial patterns or qualities.

Methodologically, diverse approaches have been used to describe and analyse urban form using patterns, incorporating a range of both quantitative and qualitative systems of classification as well as numerous kinds of analysis and depiction.

Some research, such as (Steiniger et al., 2008), has automated the categorisation of metropolitan areas or building stock using pattern-based concepts. Others simulate future scenarios at different scales using patterns to approximate the current urban environment.

Analysis of environmental indicators, including energy and greenhouse gas emissions, can then be carried out, depending on the amount and type of data integrated into the patterns.

Patterns are also used as data and engagement tools in public planning processes, allowing stakeholders to contribute to the creation of patterns or to translate patterns into key policy decisions.

There are many different techniques for modelling urban patterns, depending on the scale of the issue under consideration (such as urban structure, land use, street pattern or building type), which can be categorised in a variety of ways, but their application has been rather inconsistent (Marshall, 2005), which is also reflected in the variety of classification techniques used.

The urban form measures at the urban pattern scale are:

a. Density

Density is the most commonly utilized urban form feature related with energy (Silva et al., 2017), and many other definitions are accessible in the relevant literature.

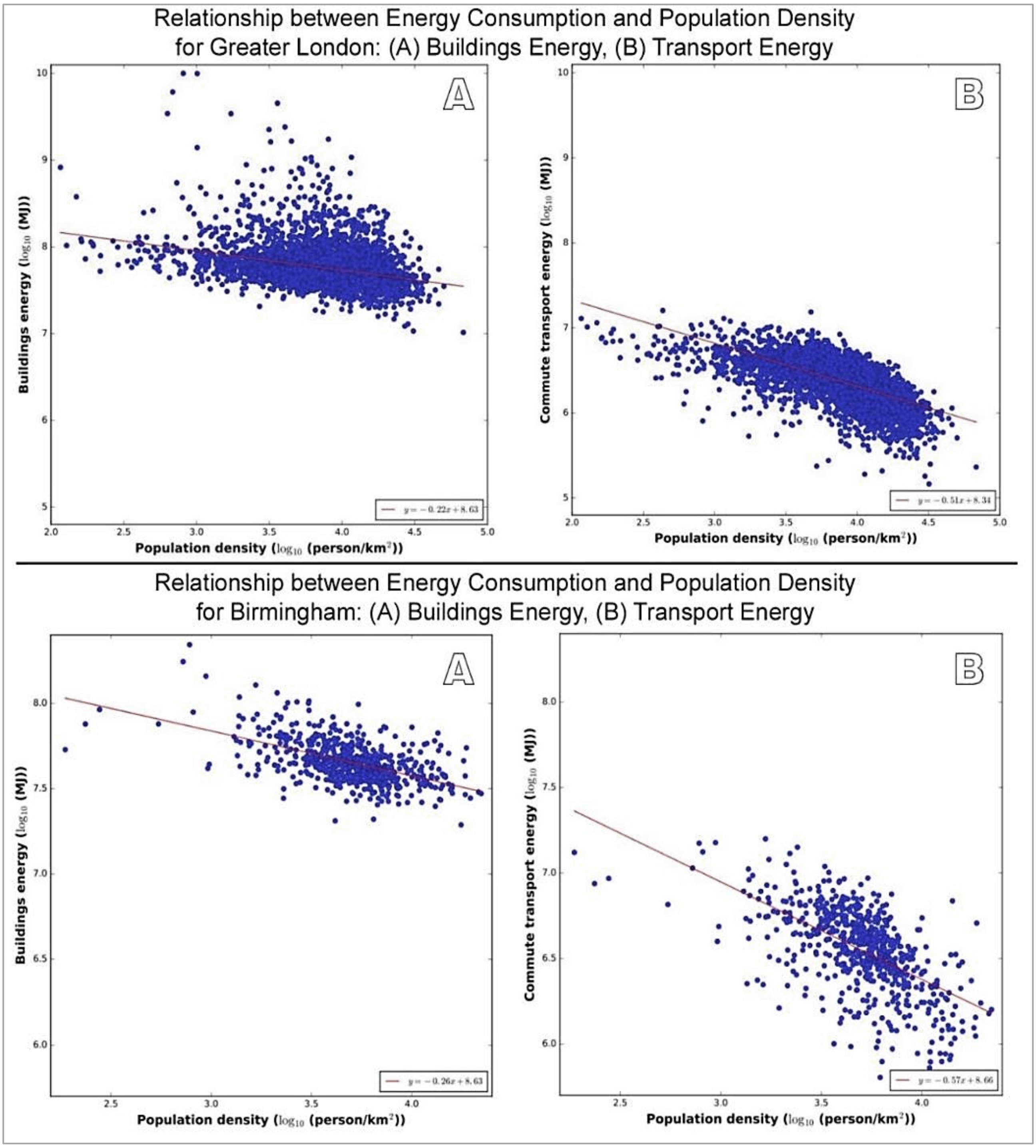


Figure I. 9. Relationship between Energy Consumption and Population Density for Greater London and for Birmingham: (a) Buildings Energy, (b) Commute Transport Energy.

Source: (Osorio et al., 2017).

The amount of energy saved increases with urban density. However, Bertaud highlighted the significance of spatial organization and argued that the population distribution in a city is also a significant determinant in energy consumption since it influences travel patterns. He claims that using average density alone as a measure of urban density is basic since it ignores the geographical distribution of the people (Bertaud, 2001). Using a correlation and scaling law method, the research of (Osorio et al., 2017), in England, gives a knowledge of the relationship between energy usage and urban design factors, where the correlation strength between density factors and energy usage was determined to be reasonable (Figure I.9); knowing that the findings are consistent with previous research (Boarnet & Crane, 2001; Naess, 2012), which suggests that more populated areas have higher energy efficiency. Further investigation indicated higher association coefficients between population density and commuting energy usage.

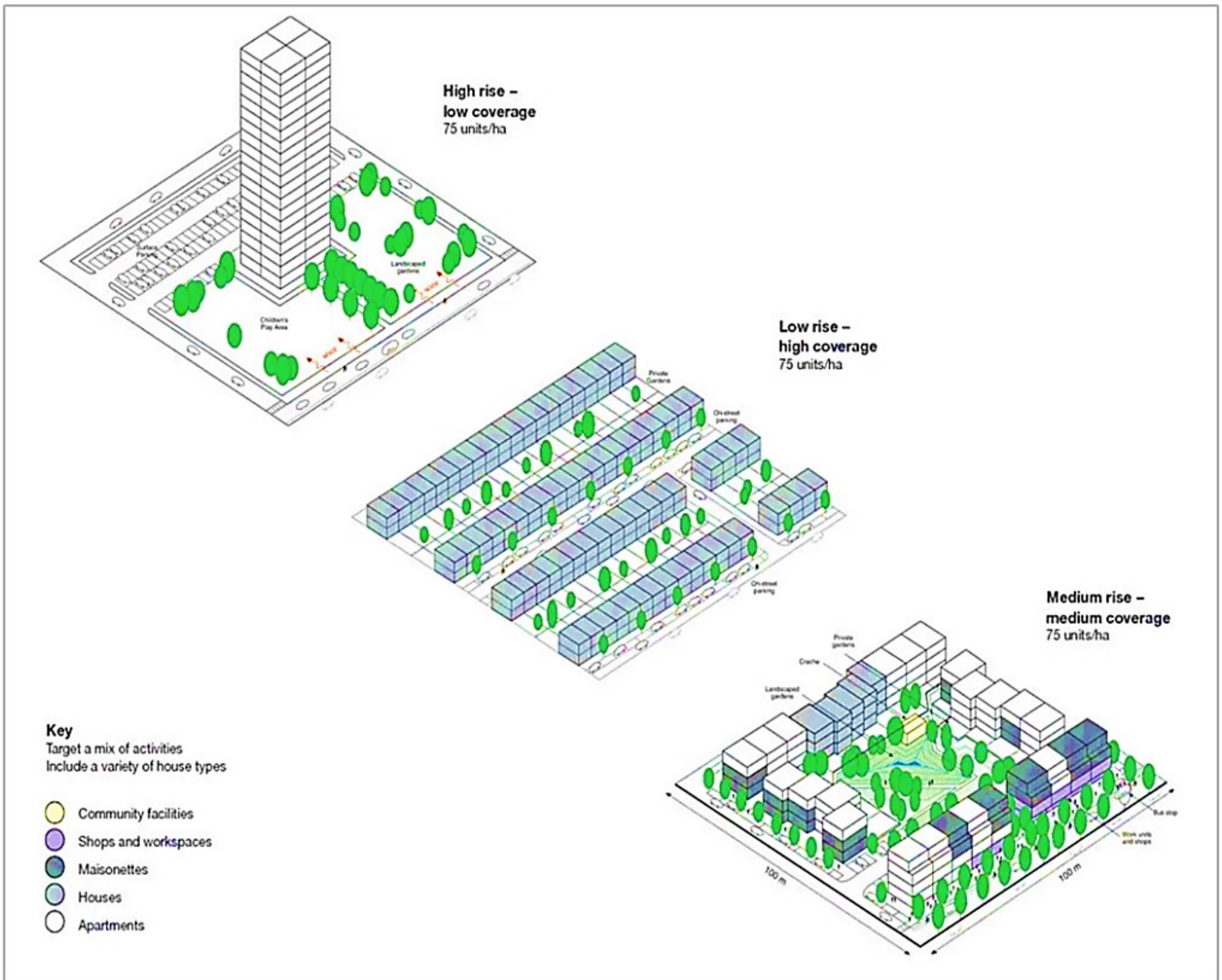


Figure I. 10. Different spatial layouts of 75 housing units in the same area.

Source: (Ginty, 2015).

Taking into account the building density, it is once more rudimentary to only use the ratio of buildings to total area as a density indicator. Due to the fact that the same ratio can be achieved by using various spatial configurations (M. Berghauser Pont & Haupt, 2007).

Here is in (Figure I.10) an illustration of how the same number of homes might be distributed in the same area in several ways.

a.1. Building height

There aren't many studies that compare the performance of identical constructions while taking height as the changing parameter.

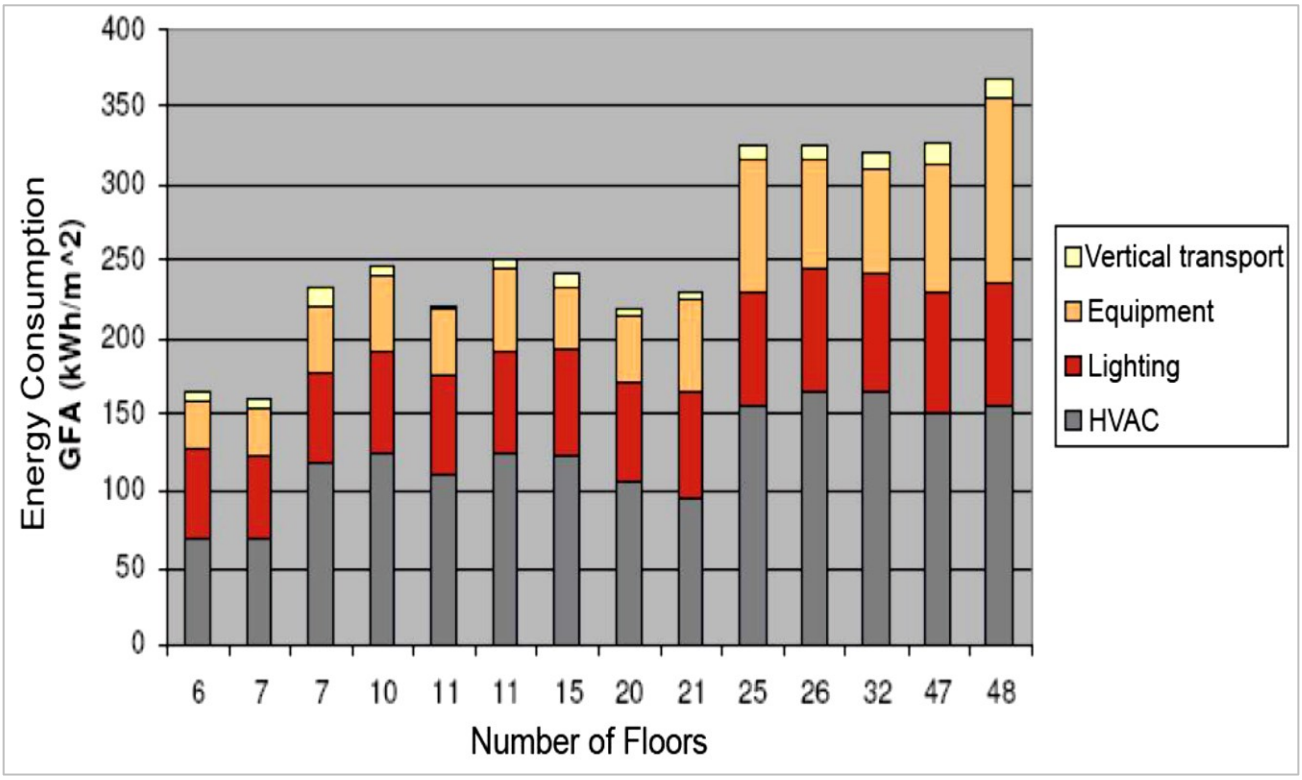


Figure I. 11. Energy usage per unit floor area correlates to building height.

Source: (Elotefy et al., 2015).

A study conducted in Hong Kong on twenty-five buildings revealed a correlation between rising energy use and building height (Elotefy et al., 2015), as the (Figure I.11) depicts a comparison of building elevations as well as their corresponding energy usage per unit floor area.

Tall structures are typically higher and separated from the surrounding built environment's urban pattern.

This has the effect of requiring more energy for mechanical water heating and cooling, as well as for moving supplies and users to higher storeys (Yeang, 2008).

(Van Den Dobbelsteen et al., 2007) conducted exploratory research on the energy and material performance of six common spatial layouts. The study revealed a fundamental correlation between horizontal, compact, and vertical space organization. The tower and the caterpillar, which represent the two extremes, were found to be 90% energy and weight efficient, with only a 10% reduction in performance compared to the most compact sample.

Subsequent research examined actual structures, including the Commerzbank in Frankfurt, which was then the tallest office building in Europe. The study used the Dutch LCA-based GreenCalc tool and found a significant decrease in both material and weight efficiency compared to a reference building. The improvement ratio was 0.63 (multiplied by the reference) for energy and 0.27 for materials. Further research is required, although it has been established that while weight and energy increase with height per square metre, they begin to rise sharply at 36 floors.

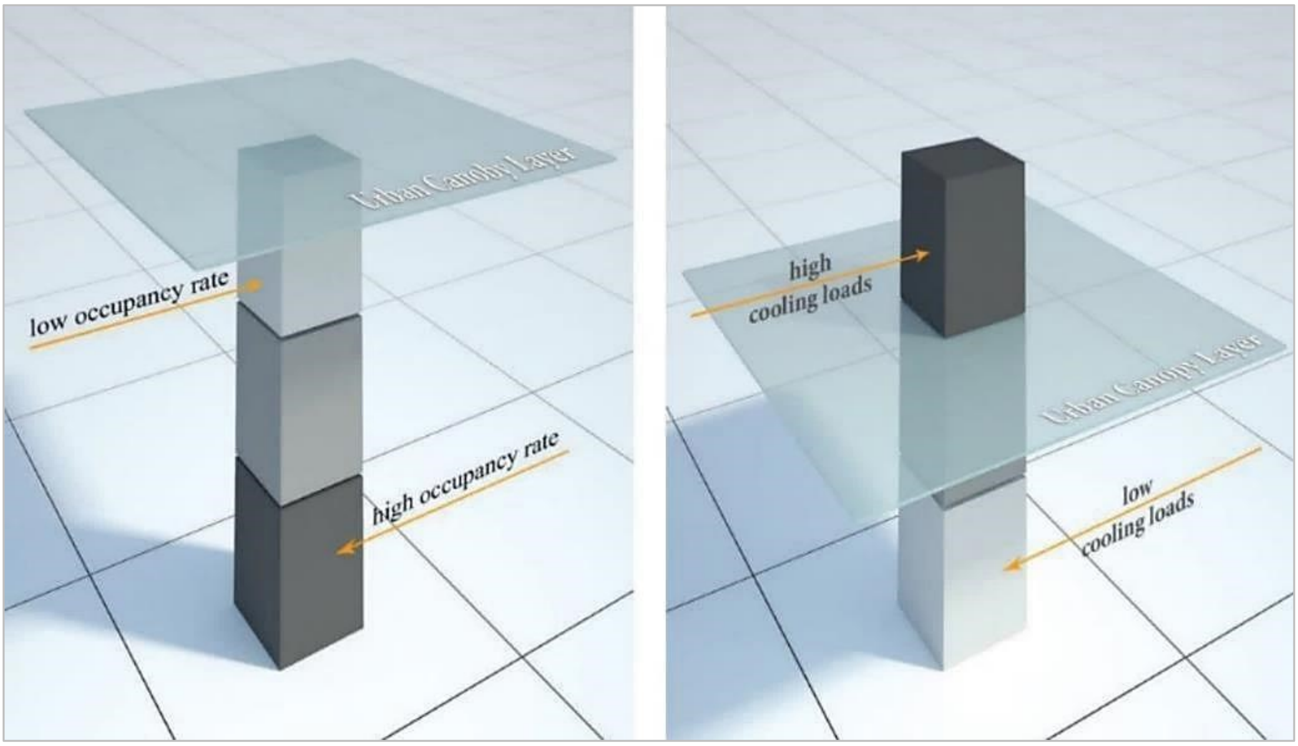


Figure I. 12. Building function vertical distribution in relation to the urban canopy.
Source: (Elotefy et al., 2015).

According to Elotefy et al. (2015), functions that require significant energy for cooling should be set to a higher level in hot climates to take advantage of the cool air and reduce the cooling load, provided that those levels are above the urban canopy. As shown in (Figure I.12), in colder regions, functions that require a lot of energy for heating should be turned down to decrease the load on the heating system.

In areas with a high concentration of tall buildings where the entire structure is covered by an urban canopy, the degree of heat loss decreases with height. As shown in (Figure I.12), it is recommended that the function with a high occupancy rate be located on the lower floor of the building.

a.2. Distance between buildings

As a general rule, the probability of two buildings being part of the same cluster increases as the distance between them decreases.

Many countries' planning requirements mandate that dwellings must receive direct sunlight, even during periods of low sunlight angles, to ensure a healthy environment and energy efficiency. The spacing between small, low-rise residential structures is typically small, while the spacing between large or high-rise residential structures must be significant. (Figure I.13) demonstrates that this requirement can be met by considering the longest shadow that a building can cast in the direction of the sun (Zhan, 2003).

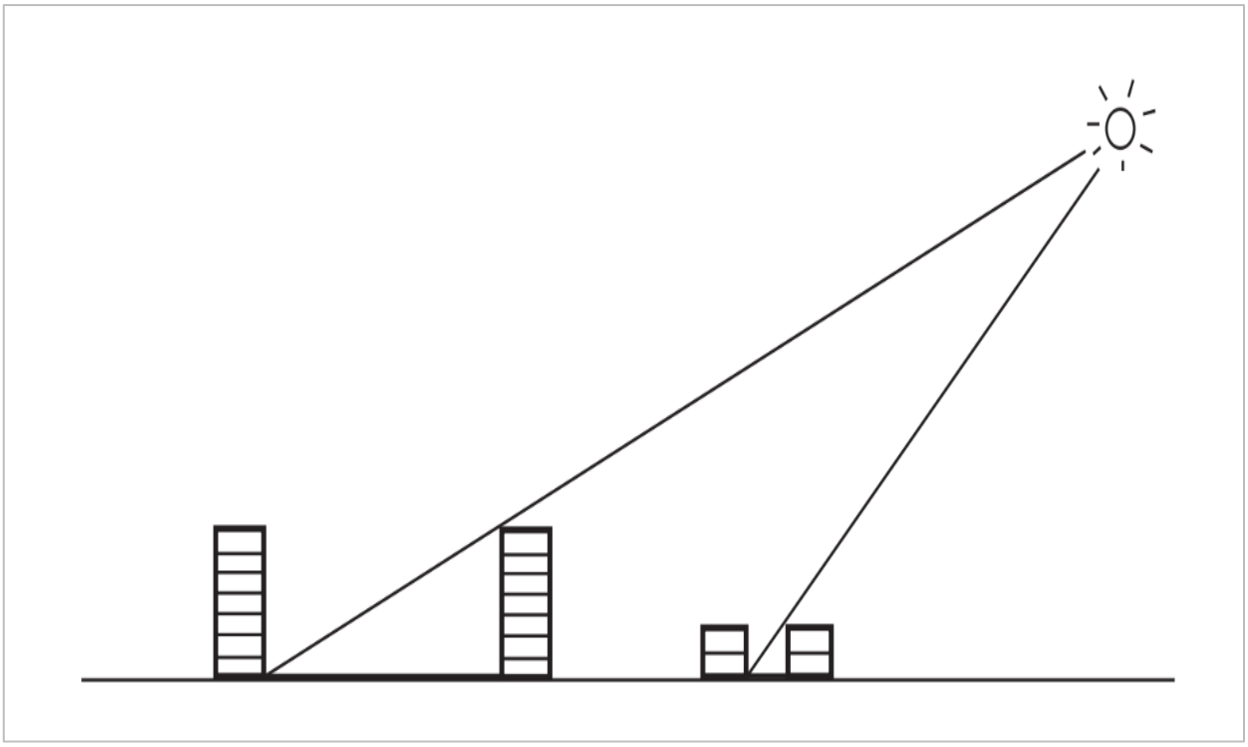


Figure I. 13. The relationship between the minimal distance for avoiding shadow, building height, along with sun angle on a flat terrain area.

Source: (Zhan, 2003).

Land-use laws that govern geographical zones and building heights often require a minimum distance between residential structures. This requirement can be reduced when the building height is constant and the site is closer to the equator. This condition and association are valid for residential zones.

However, other land use categories and various types of land use may have different rules. Real-life conditions can be highly complex, especially in urban areas where buildings may have similar size, shape, orientation, and height, which can also affect spatial grouping. Therefore, in addition to the shortest distance, it may be necessary to consider and use similarity measures based on these variables as part of spatial clustering (Zhan, 2003).

a.3. Urban and activity intensity

Newman and Kenworthy, for example, used "urban intensity" to refer to population or employment per urban area (P. Newman & Kenworthy, 1999), while in later study they used "activity intensity" to refer to population and jobs per urban region (P. Newman & Kenworthy, 2006).

Urban intensity is defined as the quantity of spatial connections and interactions that a district's ground floor can support; street networks that can support both higher concentrations and a wider variety of activities are deemed to be more intense.

When it comes to talk about "activities along streets," it refers to concerning both businesses and individual actors who operate on the local streets.

Retailers, service providers, restaurants, and bars that frequently provide their products and services are all included in economic establishments.

On the flip side, "individual agents" refers to merchants, performers on the street, and service providers (such meal kiosks) which do not have a fixed location from which to conduct their business and usually work from movable counters (Sevtsuk et al., 2013).

Through the use of an accessibility metric, it is possible to identify the intensity of activities in a specific area. For this goal, a variety of accessibility metrics could be used (Bhat et al., 2000; Sevtsuk & Mekonnen, 2012). The ArcGIS environment's Urban Network Analysis toolkit enables one to measure the number and types of amenities that can be reached on foot from a specific place on the network as well as to record the spatial characteristics of the routes which lead to those services (Sevtsuk et al., 2013).

In 46 cities, (P. W. G. Newman & Kenworthy, 1989) popularized a straightforward curve between population density with the energy used by each resident as a result of transportation. Energy usage appears to be connected with these high densities, as seen in (Figure I.14) which study correlation between energy consumption and urban intensity in 46 selected cities around many continents.

This research depends on a database which does not include cities in South America or Africa, which may limit the applicability of this finding.

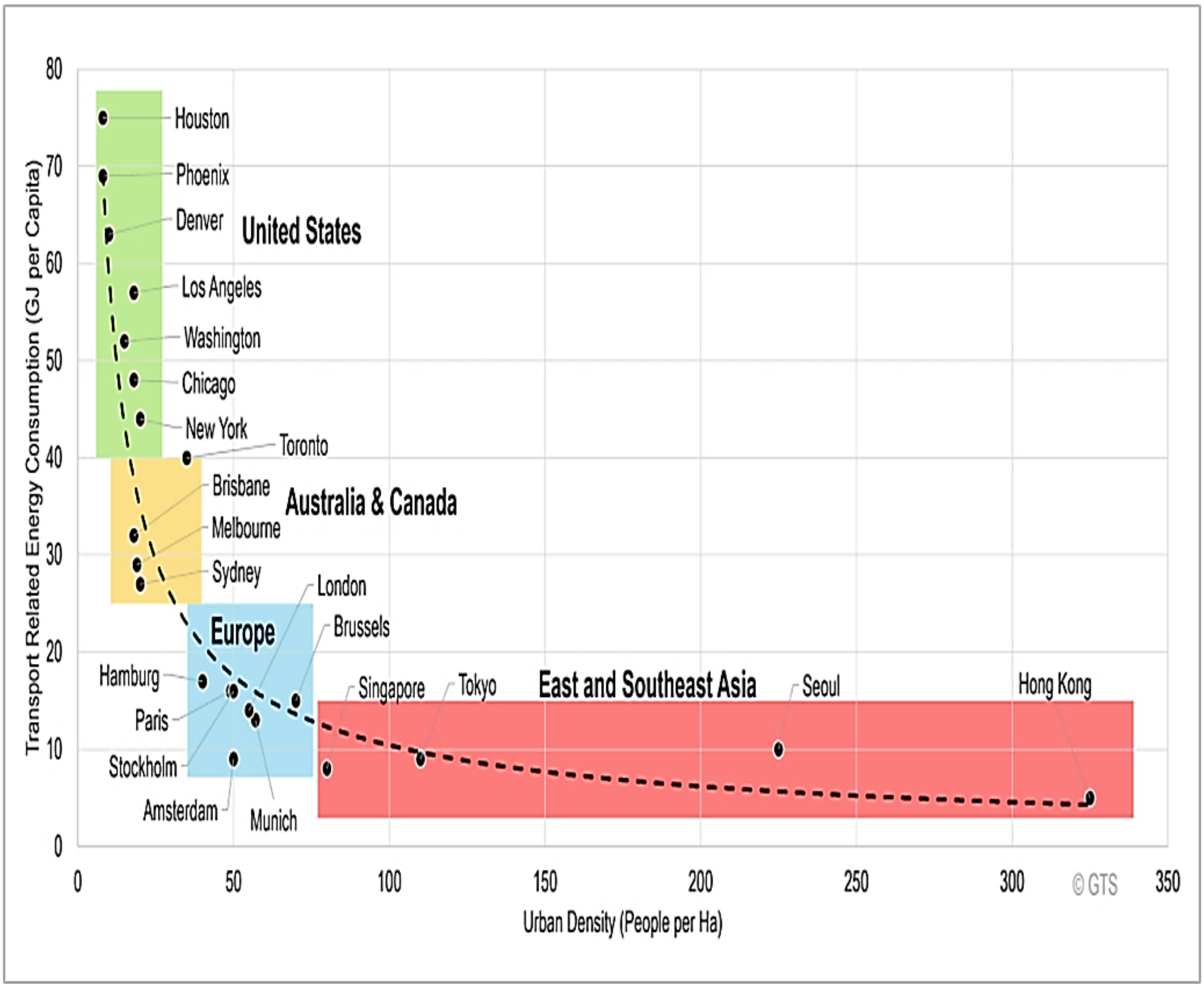


Figure I. 14. Correlation between energy consumption and urban intensity in 46 selected cities. Source: (Kenworthy & Laube, 1999).

a.4. Floor space index (FSI) or Floor area ratio (FAR) or Plot ratio

Floor area ratio (FAR), floor space index (FSI), or plot ratio refer to the ratio of a construction's gross floor area to the total built area. These are commonly used density indicators (see Figure I.15). It is important to note that this ratio can be achieved through high-floor buildings with small footprints or large-footprint structures with low floor ratios (M. Berghauser Pont & Haupt, 2007).

FAR and FSI have the same meaning but are expressed differently. For example, FAR is expressed as a decimal, while FSI is expressed as a percentage. The FSI may vary between cities and even within a city, depending on the area. In fact, FSI may change within a single location based on the total number of floors in the building. FSI is determined by the city zone, building type, and other features (SOBHA Website, 2022).

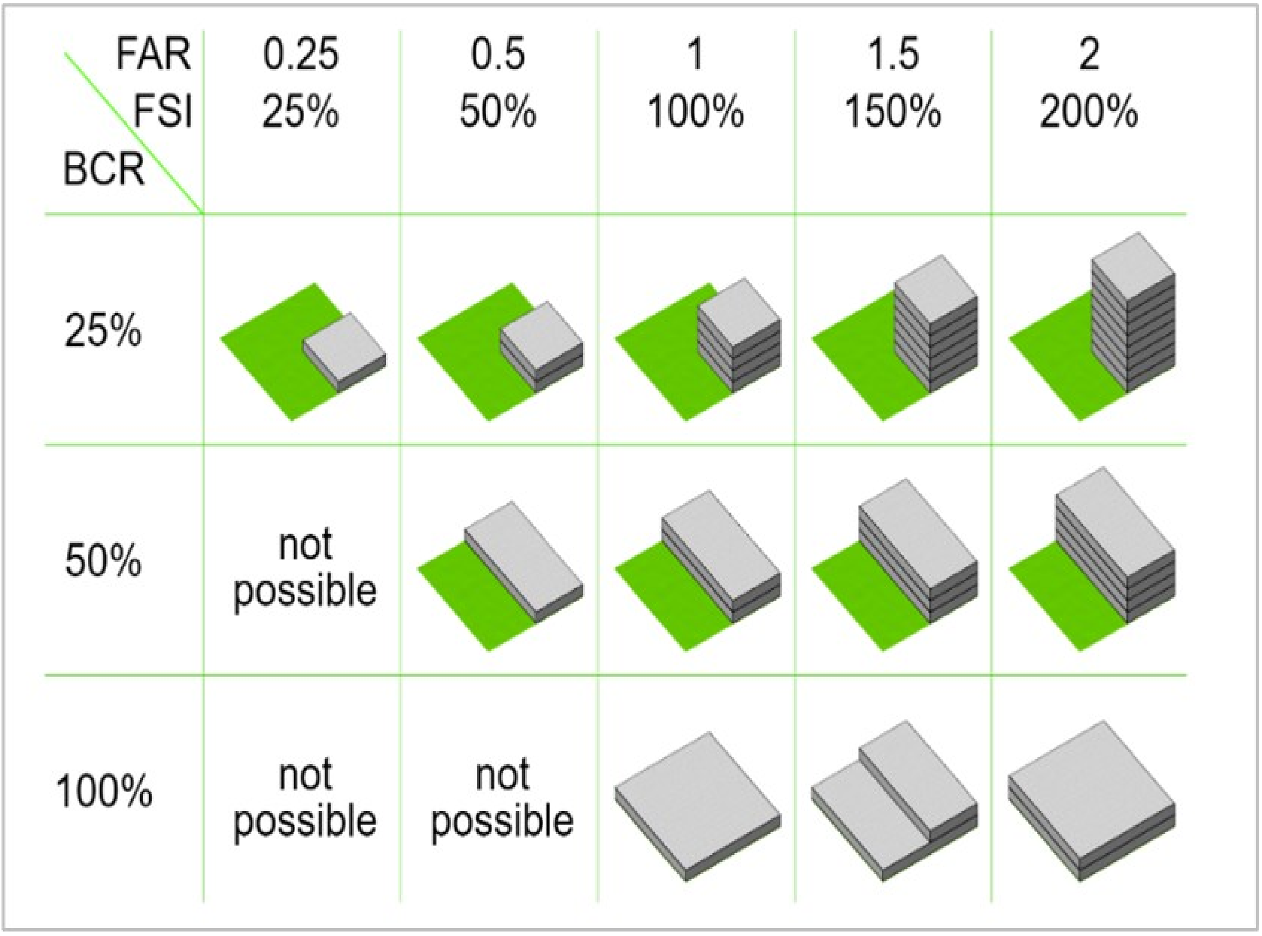


Figure I. 15. Comparison of floor area ratio (FAR) and floor space index (FSI) with building coverage ratio (BCR).

Source: (Cmglee, 2019).

a.5. Ground space index (GSI) or Site coverage

Site coverage requirements aim to prevent the negative impacts of overdevelopment and ensure appropriate growth on a site. The planned building layout should include enough space for circulation, parking, and protection of sunlight and daylight. Preliminary site coverages are used so that future growth of new facilities can be accommodated without jeopardizing other requirements for open space, parking, and landscaping.

The site coverage is calculated by dividing the total ground area inside the site perimeter by the total ground area covered by buildings. In certain situations, such as those found in densely populated urban areas as well as abandoned or obsolete sites, the planning department may decide to modify the aforementioned restrictions (Wicklow, n.d.).

Quan et al. (2020) conducted research on six simulation test cases with a fixed floor area ratio of 3. These cases were selected as target samples for further investigation (see Figure I.16).

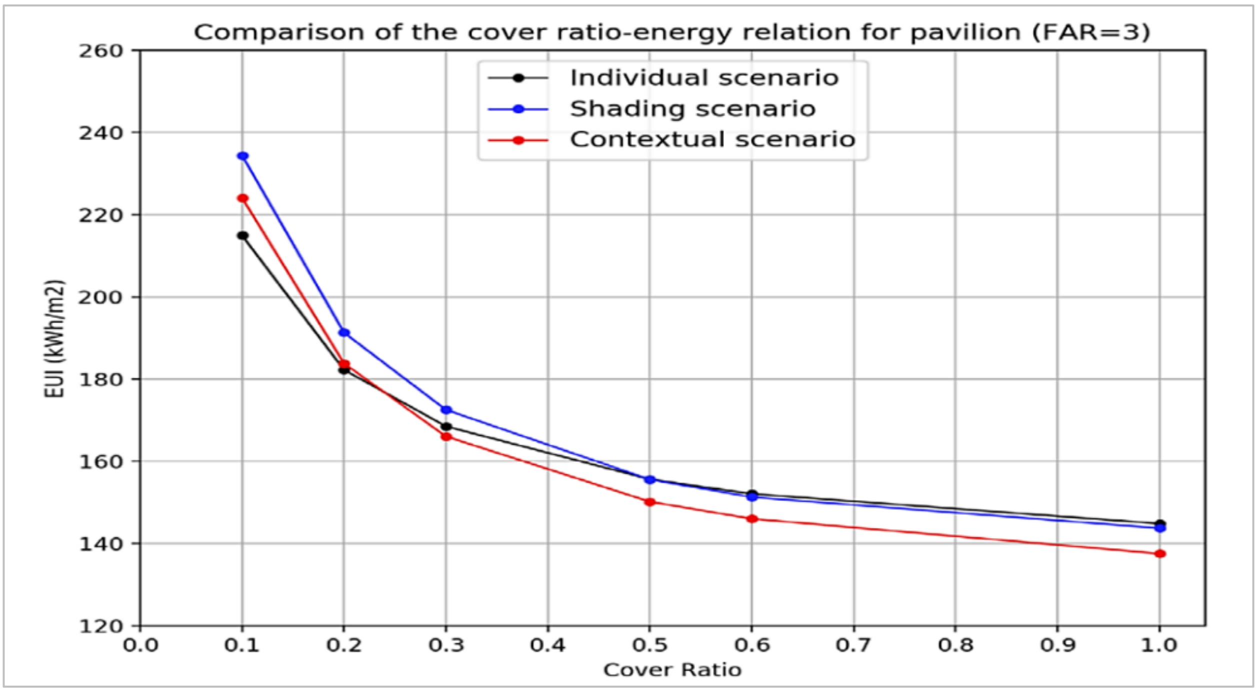


Figure I. 16. Building coverage ratio and energy consumption intensity correlations for pavilion buildings with a fixed FAR of 3.

Source: (Quan et al., 2020).

The study displayed the energy consumption intensity values against the coverage ratio values. The findings indicate a clear correlation between building energy intensity and building coverage at identical densities. Similar trends were observed when the research was extended to examples with different floor area ratios. The correlation between the rate of coverage and construction energy usage intensity is typically described by a straightforward negative curve. Building energy usage intensity usually follows a similar negative pattern.

a.6. Subdivision indicator

According to Bourdic et al. (2012), a simple metric can be used to determine the granularity of the urban environment and its potential impact on energy behaviour. This metric considers the quantity of parcels per area and can help assess density, even though it may not be a standard indicator. The spatial configuration of urban features is believed to be affected by the granularity of the urban environment.

a.7. Building (dwelling) unit density

Another density indicator, which is building unit density, is the total number of buildings in a zone or a neighbourhood divided by whole area of this zone or neighbourhood.

(Mohajeri et al., 2016) compared Geneva's mean building unit density to the city's annual sun irradiation in order to further investigate the impact of urban density on the potential for solar energy (Figure I.17).

An essential metric, especially for policymaking in infrastructure planning, is the measurement of building density in terms of the number of structures per unit land area.

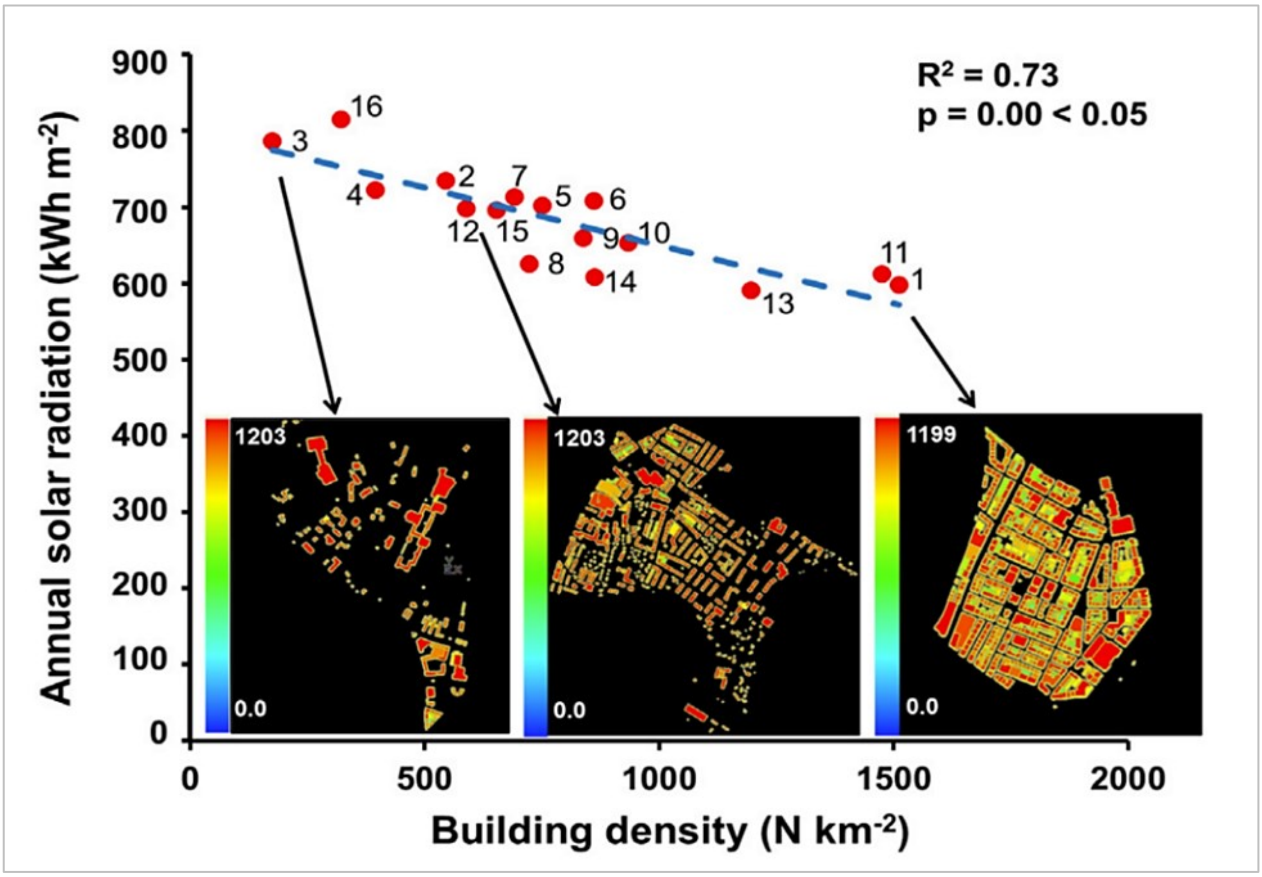


Figure I. 17. Building unit density (number, N, per square kilometre) and annual solar irradiation (kWh m2) for three neighbourhoods are given. For the linear correlation, the value of the determination coefficient and the corresponding significance (P_{value}) at 5% are provided. Source: (Mohajeri et al., 2016).

The findings indicate that sun irradiation diminishes as building unit density rises. This means that the solar radiation received by more compact neighbourhoods is proportionately lower. Mutual shading of buildings in densely populated city blocks prevents building surfaces, especially the facade, from being exposed to excessive solar radiation. But mutual shading has much less impact in neighbourhoods with independent, terraced architecture and modest building density. As the variation in building density can be attributed to 73% of the variation in solar radiation, the value of the determination coefficient is 0.73.

a.8. Open space ratio (OSR)

The Open Space Ratio (OSR) is a tool used to assess the amount of open space in a given location. It determines the ratio of open space by dividing the area not built upon by the floor area. The OSR also measures ground and daylight levels and indicates an area's spaciousness (Boumaraf & İnceoğlu, 2022). The study by Raslan et al. (2022) uses the 'spaciousness' variable (Open Space Ratio) to classify open spaces quantitatively. The assessment of the open space's size and sufficiency in relation to the overall developed area is implied.

Empirical research on urban fabric suggests that reasonable values of spaciousness range from 0.06 to 0.3 (García-Pérez et al., 2020). The results are divided into five categories, ranging from 'very high' (adequacy under 0.3) to 'very low' (adequacy over 0.9). (Figure I.18) shows three examples of in-between spaces typologies (Raslan et al., 2022).

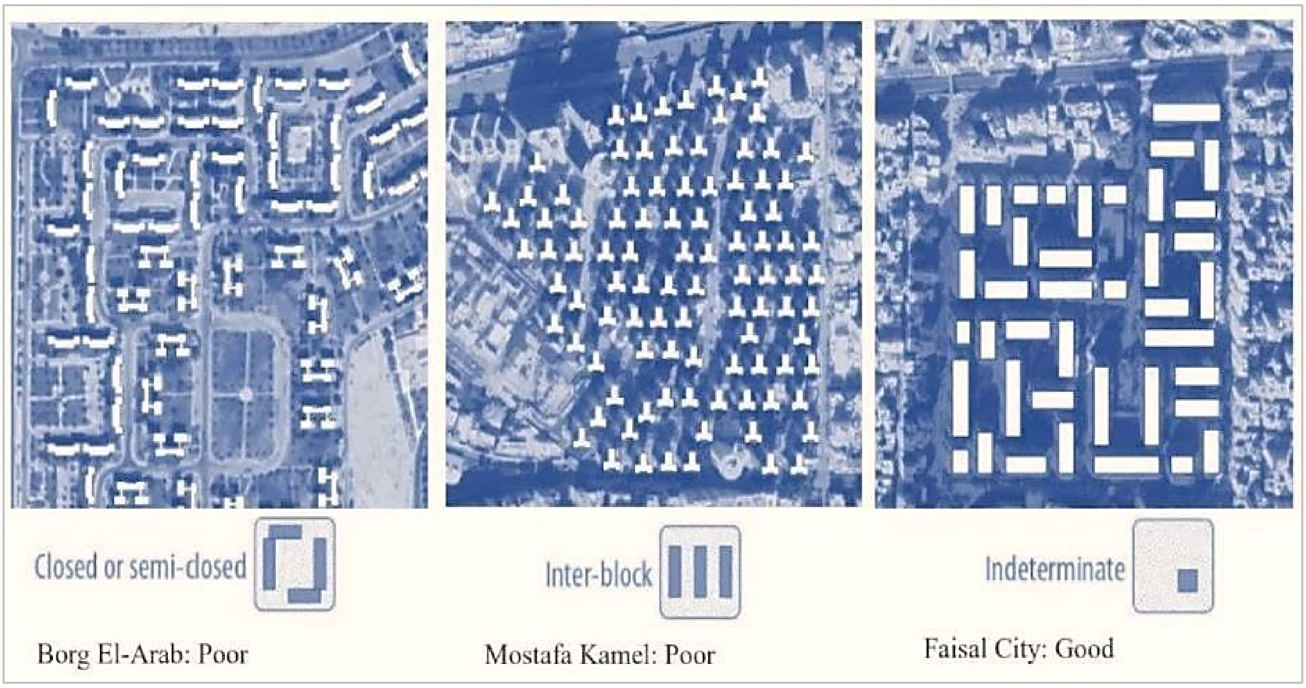


Figure I. 18. Typology of In-Between Spaces in three selected study cases.
Source: (Raslan et al., 2022).

Enclosing open spaces can change how they are used, who owns them, and how they are managed. Research by Minoura (2016) shows that there are many types of residential open spaces: enclosed or semi-enclosed, inter-block, and indeterminate. These are ranked from highest to lowest level of enclosure. The study examines the framework of open spaces and finds that quality is good when levels of confinement and space are very high or high. According to García-Pérez et al. (2020), housing projects are deemed to be of 'standard' quality if they receive at least average scores for enclosure and space. Any alternative scenarios result in 'poor' quality values.

According to (H. Yu et al., 2020), the building's open space ratio is the ratio between the site suitable for supporting the underground pipes of geothermal heat pump systems and the building's land surface. This indicator is crucial in the integration of renewable energies. Technical land-use management rules for urban planning generally specify the open space ratio.

Estimating open space rates can be done by measuring greenery and parking rates.

Cheng et al. (2006) extended previous work by simulating additional models and varying the location of structures on the site. Their findings indicate that layouts with taller buildings, less site coverage, and more open spaces are preferred over those with lower structures and more site coverage in terms of daylight. This shows a direct correlation between daylight entry and OSR, highlighting the importance of the latter in direct sunlight benefit in terms of health and energy efficiency.

b. Diversity

In the context of diversity, 'mixed use' refers to the combination of various land uses, including residential, commercial, recreational, and industrial. Previous studies have demonstrated that the extent of mixed use significantly affects travel patterns (Cervero & Kockelman, 1997; L. Zhang et al., 2012; Manaugh & Kreider, 2013).

When business, commercial, and leisure centres are located far from residential areas, people often resort to using motorized transportation to meet their needs.

However, if there is an increase in the amount of land with mixed uses, people can fulfil their demands by walking or riding a bicycle (Manaugh & Kreider, 2013). Mixed land uses have a significant impact on travel habits and are strongly correlated with the energy consumption of cities. When implemented effectively, they can help to reduce the demand for transport energy (P. Zhao et al., 2017). To measure diversity, researchers have proposed several indicators:

b.1. Mixed use index

A triangular matrix was recently created by van der Hoek to measure the level of mono-functionality against multifunctionality.

The Mixed-Use Index (MXI) is the name of the methodology. Monofunctional urban areas are those that only serve one function, which might include housing, workplaces (industrial areas or office parks), or amenities (for leisure activities like sports, retail, etc.).

Once two of those three functions exist, urban environments are bifunctional; but if all three are present, they are multifunctional (van den Hoek, 2008). The proportion of city blocks occupied by housing, employment, and facilities were determined by the original MXI model. Apartments, condos, and town homes were among the residential dwellings that fell under the "housing" function. Offices, factories, and laboratories are all part of the "work" function.

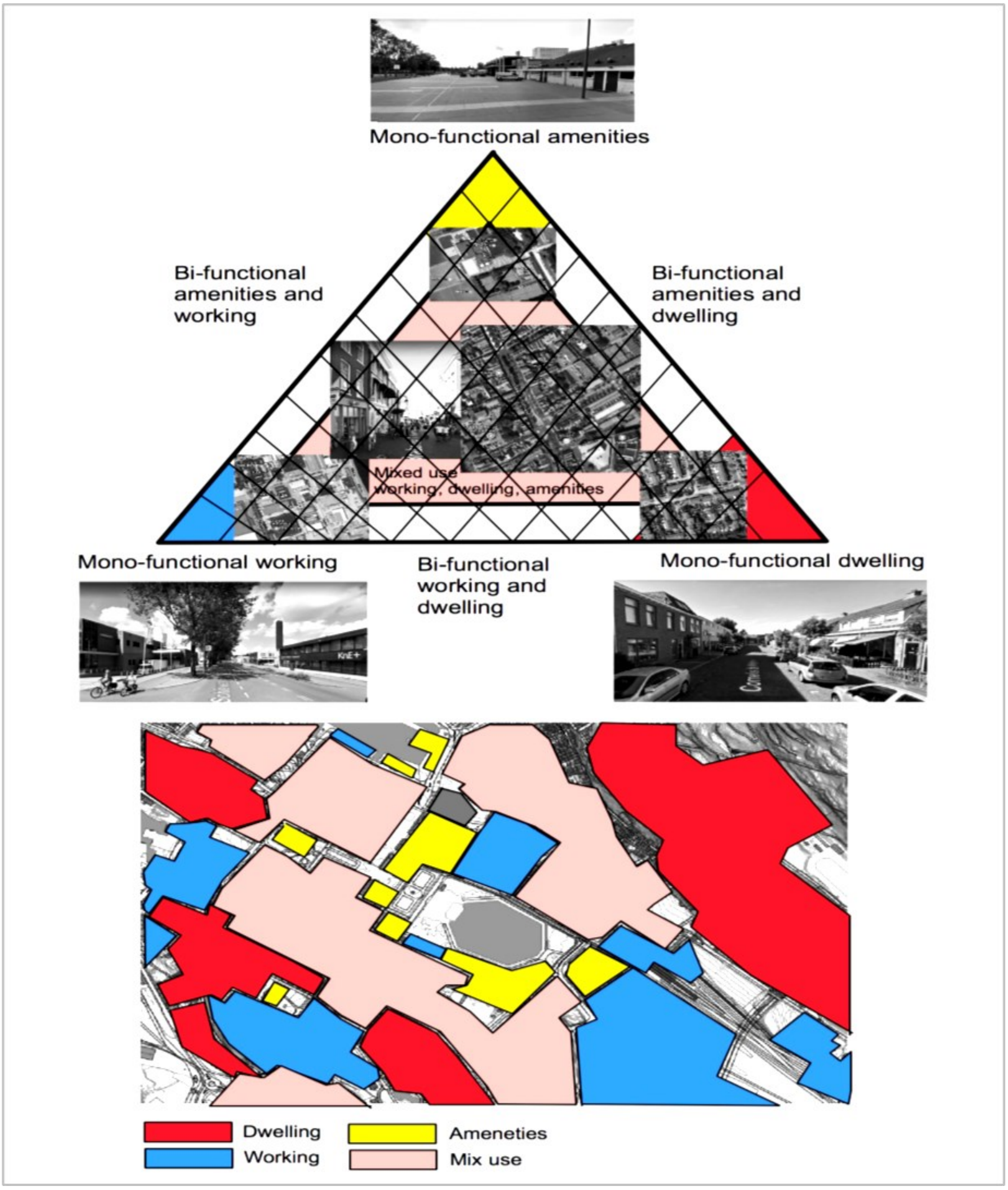


Figure I. 19. Application of the Mixed-Use Index triangle on Bergen city centre in Norway. Source: (Nes, 2019).

Commercial infrastructures like malls, schools, and universities as well as recreational facilities like stadiums, movie theatres, performance venues, and museums are all included in the "amenities" function (Nes, 2019). (Figure I.19) as example presents an application of MXI on Bergan city in Norway.

b.2. Dissimilarity Index

To gain a better understanding of spatial complementarity, it is crucial to examine the dissimilarity of land uses within a specific geographic area. A dissimilarity index (Cervero & Kockelman, 1997; Maria Kockelman, 1997) is used to assign a dominant land use to each hectare (equivalent to 2.47 acres) of land, based on how dissimilar it is from the uses of neighbouring hectares. The index value of the central square increases as more adjacent squares, are added, as shown in (Figure I.20). The functions of these adjacent squares differ from that of the central square.

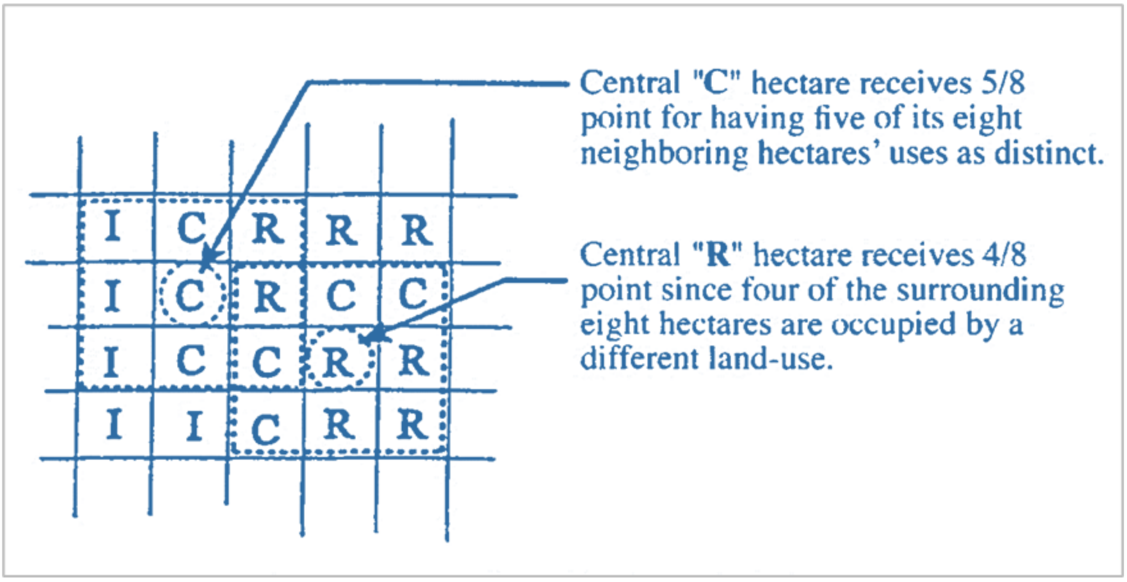


Figure I. 20. Computation of the dissimilarity index.

Source: (Cervero & Kockelman, 1997).

The overall mix of a tract travel analysis zones is defined as the average of all these point accumulations over all active units. However, as noted by (Mitchell Hess et al., 2001), the index appears insensitive to the quantity of uses that are distinct from the central square and only measures whether adjacent squares differentiate (or not) from the square at the centre.

b.3. Entropy Index

For mix land-use studies, assessing land-use mix is essential. There are many ways to do this, including using the entropy index, the dissimilarity index, the distance to walkable destinations (amenities or transit stations), and the quantity of amenities nearby (B. Brown et al., 2009). The data's randomness, segregation, diversity, or compressibility are all measured by the entropy index. A land-use mix shows a pattern of mixing and separating various land uses. Therefore, the entropy index is the index that scholars use the most frequently to reflect the mix of land uses within a certain geographic area (Frank et al., 2005; B. Brown et al., 2009; Dur & Yigitcanlar, 2015). In addition to a three-category mix of single family, multi-family, commerce as well as services, office, entertainment, institutional, in addition to industrial land uses, (Frank & Pivo, 1994; Frank et al., 2005) defined the evenness of the distribution of developed square footage among these seven land-use categories. The range of the entropy index is 0 to 1, with 0 denoting homogeneous single use and 1 denoting heterogeneous maximum land-use mix.

The association between residents' travel behaviours, perceptions alongside the land-use mix measure (entropy index) is depicted in (Figure I.21).

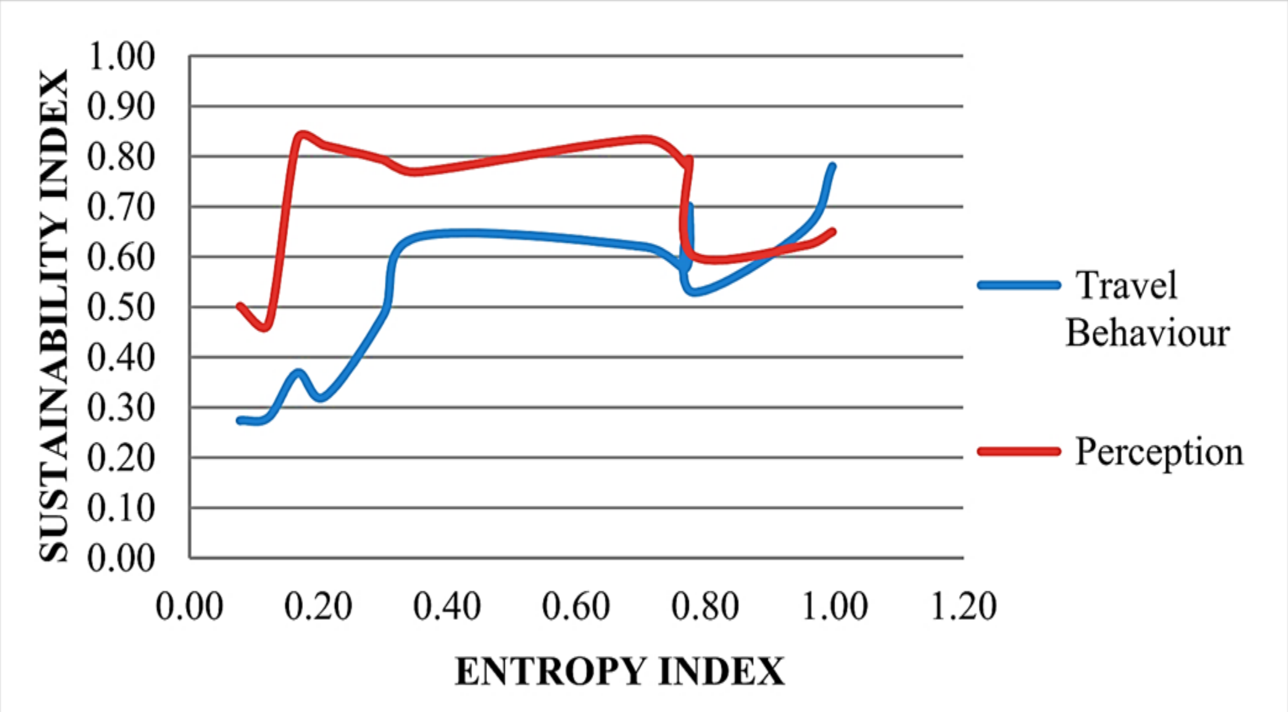


Figure I. 21. Entropy index along with the sustainability index are represented in a scatter plot. Source: (Bahadure & Kotharkar, 2015).

Residents' perception of the sustainability index score is greater than the travel behaviour score. Low sustainability is associated with a low entropy index score or a low land use mix. Moderate to high land use mix or moderate to high entropy index score is associated with moderate to high sustainability.

The land-use mix (entropy index) and travel behaviour have a 0.88 correlation, demonstrating a strong relationship between the two. Whenever the land-use mix becomes high, travel behaviour is sustainable, and vice versa.

The perception as well as land-use mix entropy indices have a weak association of 0.10, as indicated by the correlation coefficient. It means that although a favourable view is influenced by sufficient facilities, good infrastructure, and reduced pollution. Land-use mix has no direct impact on perception.

Neighbourhoods with a balanced land-use mix in the research regions were unsatisfactory because they lacked infrastructure. As a result, the weak connection is felt (Bahadure & Kotharkar, 2015).

b.4.Structural objectivity

In order to reduce the environmental impact of cities and increase their energy efficiency, a system based on numerous evaluation methods and tools has been created.

This system could be used by governments, property developers, citizens, in addition to architects, urban planners and even stakeholders, to better understand how built forms interact with energy use, and to foster a research-based conversational approach.

However, it would be wrong to regard the indications as absolute target levels. If this were the case, the relationship between the parts and the whole would be lost, fragmenting the whole urban concept into several sets of technical targets. It is preferable to suggest a series of values rather than set strict targets for indicators. This gives stakeholders a degree of flexibility and enables them to take account of the complexity of urban concerns.

In order to achieve the structural objectivity established by local authorities and planning agencies, this system needs to be adapted to the specificities of the project by adjusting the variables (Bourdic et al., 2012).

In short, to improve the energy efficiency as well as the environmental impact of cities, a 'structural objectivity' indicator has been proposed to determine the difference between the desired distribution and the current one, taking into account the objectives set by local authorities and policy makers (Bourdic et al., 2012).

c. Green Areas

c.1. Spatial distribution index

An essential component of urban equity is the spatial distribution of urban components such as parks, shops and amenities.

The term 'spatial distribution' refers to how these components are distributed within a zone, either in an equitable or inequitable way.

If the number of elements (e.g. park area and green spaces) on a larger scale (e.g. city) is uniformly distributed across districts, a fair geographical distribution is achieved. If a city has 100 ha of parks and is divided into ten districts, an equitable geographical distribution is 10 ha in each of the ten districts. The higher the index, which measures how uniformly green spaces are distributed inside an urban area, the better is the distribution, in terms of energy and environment (Bourdic et al., 2012).

c.2. Green plot ratio

The Green Plot Ratio (GPR) is originally conceptualized by borrowing from the Floor Area Ratio (FAR). It is a method for assessing the quantity of green space necessary in urban areas and can be used to measure vegetation (Nayeem, 2016).

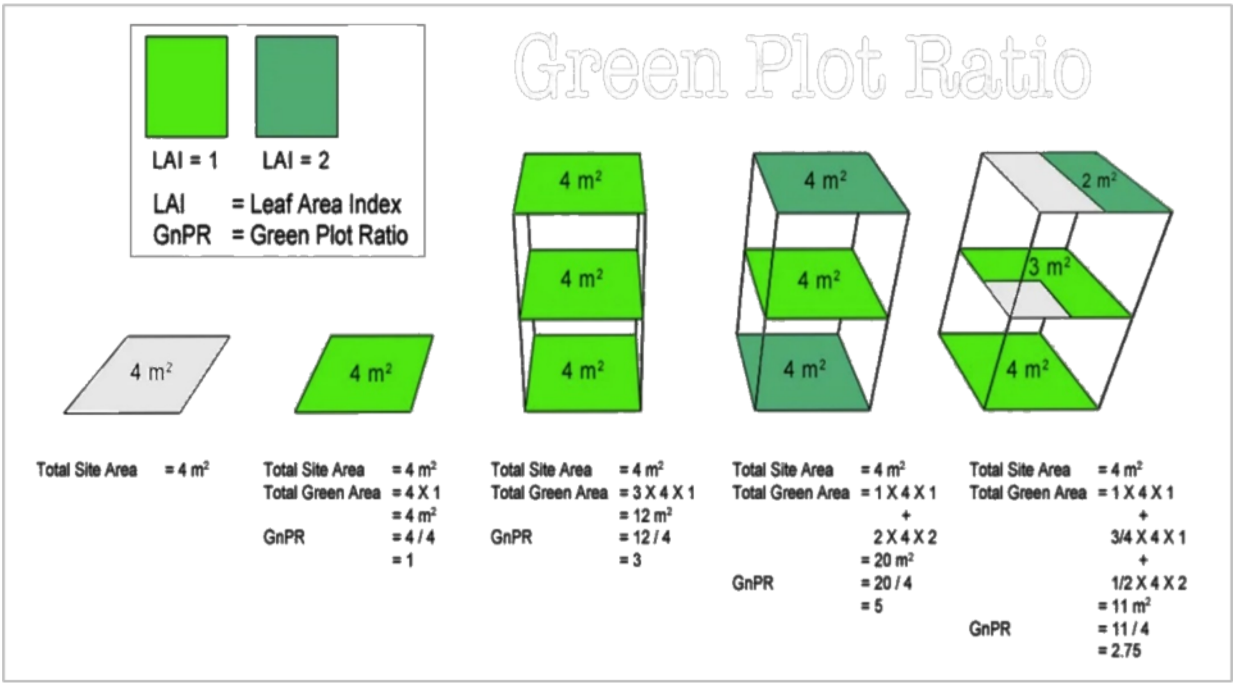


Figure I. 22. Examples of the determination of green plot ratio.

Source: (Jusuf, 2014).

The density of greenery is quantified by measuring the GPR over an area. It is produced using the average in terms of greenery on the whole plot using the Leaf Area Index (LAI) compared to the total plot area as developed by (Ong, 2003), knowing that the (LAI) index, which is equal to half of the total green leaf area for each horizontal plane surface, is a fundamental structural feature of vegetation. As the leaf surface serves as the main interface for energy and mass exchange, and consequently critical activities such as canopy interception, evapotranspiration, and gross photosynthesis occur (Fang & Liang, 2014). The green plot ratio is the product of the surface area of all types of greenery and the associated LAI value, divided by the total plot area (Jusuf, 2014). (Figure I.22) shows how GPR is determined. Many researchers, architects and urban Planners, along with CESMA (a subsidiary of the Singapore Housing, and Development Board) collaborated on the design of the Liuxiancun, New Town in China. Despite the fact that the requirements did not necessitate it, the method taken was to apply ecological measures as essentially and broadly as possible. Bioclimatic design, natural landscape preservation, energy conservation, smart building design and extensive green spaces were among the strategies employed.

Given that sixty percent of the site has been protected and returned to nature, plants provide visual relief, aesthetics, and environmental benefits while decreasing the demand for mechanical artificial lighting and ventilation. One of the key improvements was the construction of a subterranean parking area that could be ventilated by big planted skylights. This concept will also save money and energy by eliminating the need for artificial ventilation while still delivering daylighting, ventilation, and other ecological advantages through plants (Ong, 2003).

c.3. Green area geometry or mean shape index

The study of (Jaganmohan et al., 2016), investigated the impact of the shape, size, and type of green areas, and evaluated the cooling impacts of urban green areas over housing neighbourhoods for 62 green spaces in the city of Leipzig, in Germany.

In most cases, an increase in green space increases the cooling effect. This shows that many small green spaces scattered around a metropolis may not have a significant cooling effect on their immediate surroundings. In general, forests were found to offer greater temperature differences and cooling distances than parks. The fact that urban forests offer better cooling than urban parks must be taken into account in urban planning.

d. Compactness

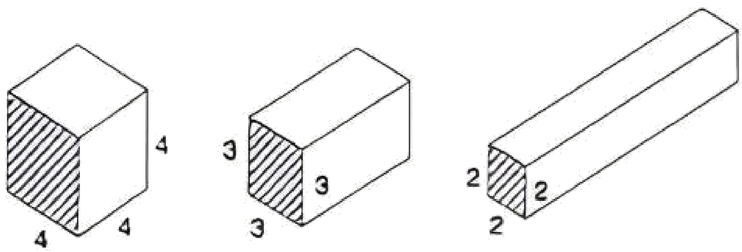
Even though, there is no universally accepted definition of a compact city, the definitions all come to an agreement that the compactness consist of intensification of development, according to (Tsai, 2005). There are various discussions in the previous works about how a compact city must be, or which components of cities require to be compact as (Burton, 2002; Calışkan, 2004; Jabareen, 2006; Ye et al., 2015; Mohajeri et al., 2016). Rather than discussing urban compactness, this section addresses the compactness word for buildings in terms of energy relevance. In this context, compactness refers to measuring the geometrical features of buildings.

The exposed surface areas to the outside are controlled by the building's shape, which indicates that building geometry influences solar exposure, loss of heat, and sunlight (Pacheco et al., 2012).

In the words of (Silva et al., 2017), compactness can be considered as a proxy for the geometry of the building; therefore, the relationship between compactness and the energy performance of the building needs to be considered. Buildings require less heating as they become more compact; on the other hand, they require more cooling. Compactness is detrimental to both cooling and heating, although not always in the same way (Silva et al., 2017). Several indicators for measuring compactness are proposed:

d.1. Surface-to-volume ratio (SVT)

The surface-to-volume ratio is an indication of the exposed envelope of a building that has an impact on energy consumption. It is a typical measure that reflects how heat moves through structures and is related to heat gain and loss, which are the main determinants of a building's energy efficiency. If the thermal transmittance of the building material is constant and heat loss to the ground is minimal, the indicator is frequently used to describe the overall heat loss of a structure (Ratti et al., 2005). A high surface/volume ratio implies a large exposed surface area for each volume, which favours the evacuation of heat from structures. The area-to-volume ratio can represent the amount of solar radiation captured for each building volume, making it another important characteristic for the degree of heat gain of a structure through solar exposure. The area-to-volume ratio also inadvertently illuminates the impact of daylighting and ventilation from the external environment on buildings, as it partly explains the size and design of the construction (Ratti et al., 2003). Consequently, the surface/volume ratio, which is linked to a number of actions, determines how buildings will be heated and cooled in winter and summer respectively. For this reason, a great deal of relevant research has examined it directly or indirectly. It is therefore considered a crucial criterion for energy-efficient urban design (Oh et al., 2021). The S/V ratio should be minimised as much as possible in hot and dry conditions in order to reduce heat gain. The S/V ratio should also be reduced as much as possible in cold, dry areas to reduce heat loss. In hot and humid areas, the priority is to create ventilated spaces. The S/V ratio will not necessarily be reduced accordingly (CLEAR Website, n.d.). (Figure I.23) shows three examples of different S/V ratios for the same volume, with different shapes and surfaces.



Solid shape type	Surface area (S)	Volume (V)	Ratio (S/V)
A	96	64	1.5
B	103.2	64	1.61
C	136	64	2.13

Figure I. 23. Examples of different S/V ratios with a same volume, and different forms and surfaces. Source: (CLEAR Website, n.d.).

d.2. Facade-to-site ratio

The facade-to-site ratio indicates how many facades make up a certain unit area. Due to the many reflections of radiation from the solar sources between building facades, an elevated facade-to-site ratio will raise the mean UHI intensity. More vertical surfaces will collect more short-wave radiation, raising the air temperature when this heat is released into the atmosphere as well as the number of vertical surfaces.

When solar radiation and sun altitude are high in summer, this parameter has the greatest impact on the urban environment, and it is the second most important urban factor in Sweden, according to the findings of (Mutwali, 2023). This research also looks at the impact of the built environment on climate change in different Swedish urban fabrics. The average UHI increased from 0.78°C to 0.82°C and from 0.20°C to 0.27°C during the summer and winter months, respectively, as the facade-to-site ratio varied from the lowest value (0.39) to the highest value (2.39). The way to obtain the facade/site ratio indicator is to calculate the ratio between the total surface area of the facade and the surface area of the site, as shown in (Figure I.24).

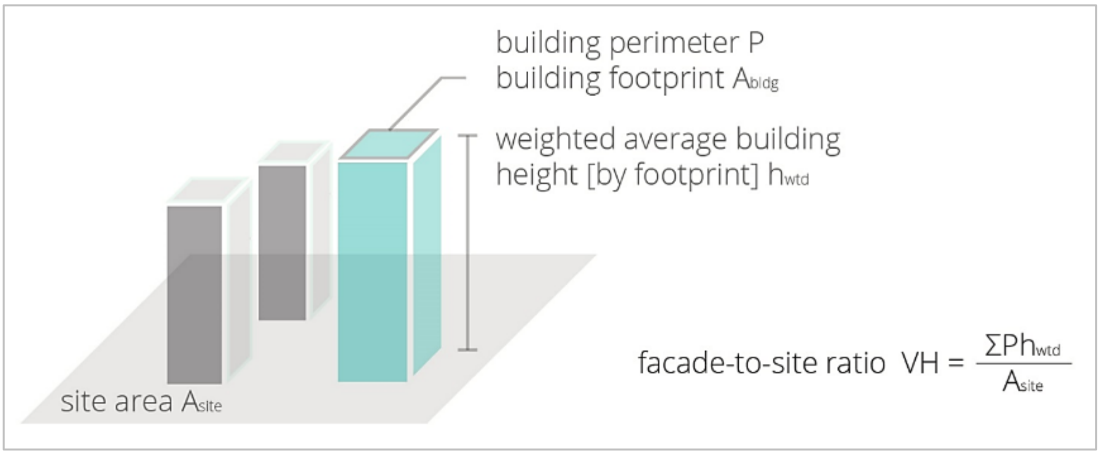


Figure I. 24. The geometric parameter of facade-to-site ratio.

Source: (Urban microclimate website, n.d.)

d.3. Built compactness

The area's compactness can be multiplied by the percentage of the area that is actually occupied by structures to provide an indicator of built-compactness. These numbers can be compared to densities for the same collection of locations (Marshall et al., 2010).

Marshall et al. (2010) conducted research on urban compactness and indicators other than density in various UK cities. (Figure I.25) illustrates the correlation between building density and compactness, indicating that built compactness affects energy consumption and sustainability. The concept of built-compactness takes into account not only the characteristics related to the two-dimensional boundaries but also the third dimension that runs through what is built upon that boundary. This provides a three-dimensional perception of compactness, unlike the previous area-based form of compactness referred to as area compactness (Marshall et al., 2010).

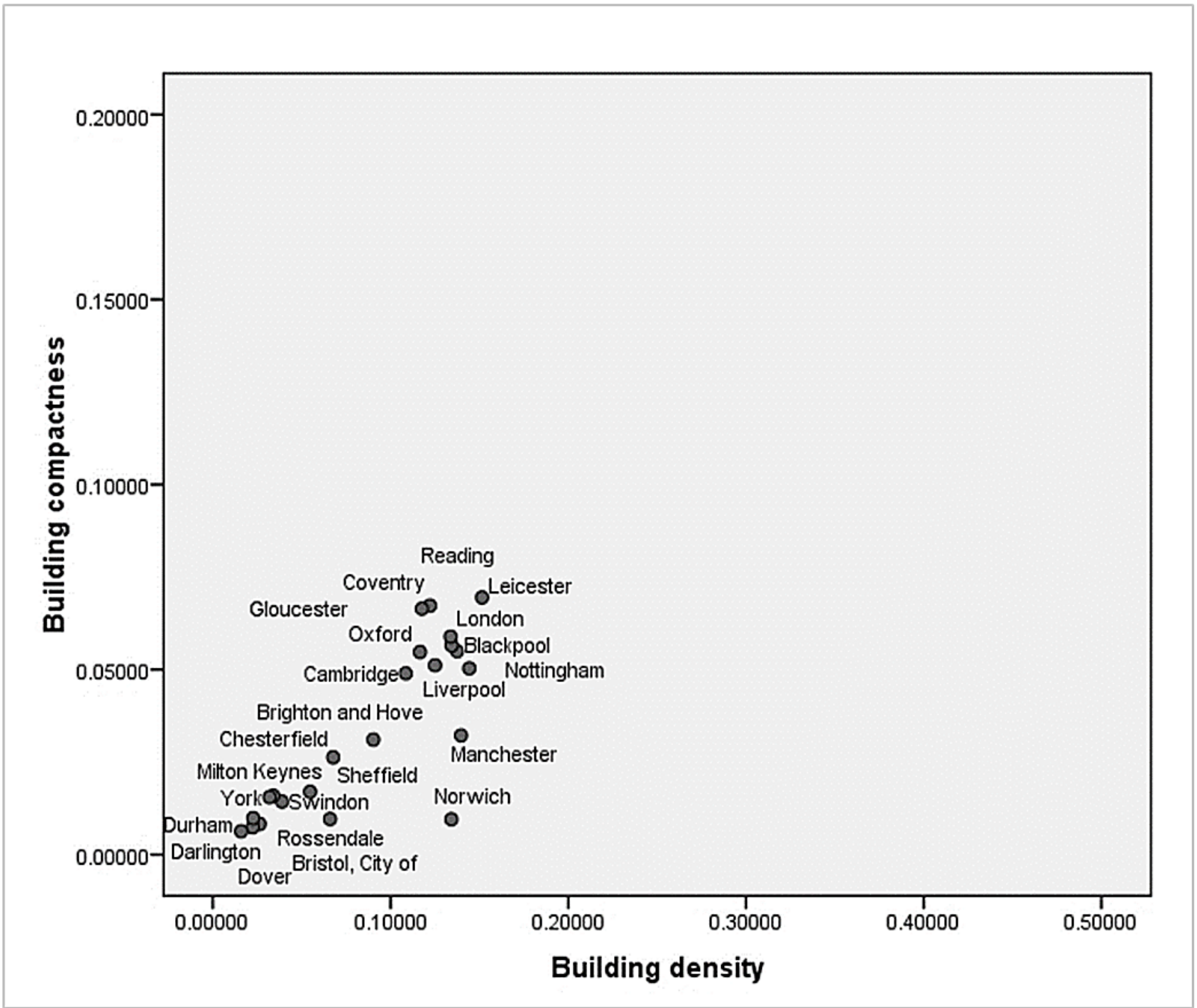


Figure I. 25. The correlation between building density and built compactness.

Source: (Marshall et al., 2010).

d.4. Volume area ratio

Volume-area ratio, defined as the ratio of the total volume of structures to the total site area, was used by (Mohajeri et al., 2016) to investigate the correlation which is between the compactness character and solar energy potential. The findings showed that the potential for capturing solar energy reduces as the indicator of compactness which is Volume area ratio rises; like the (Figure I.26) displays.

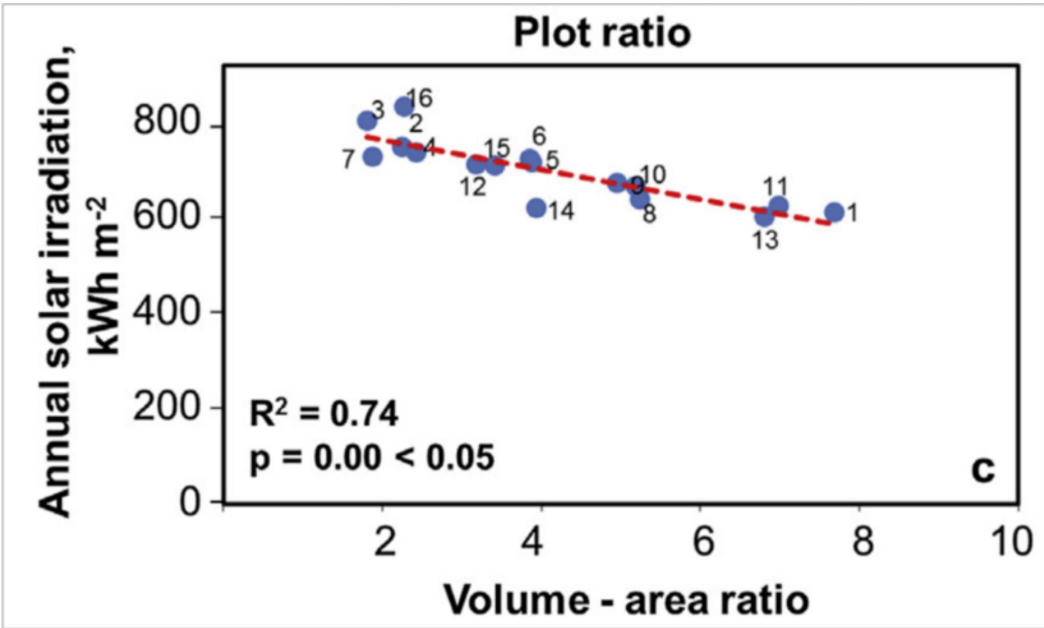


Figure I. 26. Annual solar irradiation (kWh m 2) versus (c) volume area ratio for the 16 neighbourhoods.

Source: (Mohajeri et al., 2016).

d.5. Size factor and form factor

Size factor and form factor are two other indicators of compactness, mentioned by (Bourdic et al., 2012), the Size Factor, which corresponds to the equivalent cube of its length; and the Form Factor, a parameter that is dimensionless and has been adjusted to remove the bias produced by the varying sizes of the items under consideration.

e. Shading

Due to its impact on solar radiation receiving and sunlight, mutual shading is a crucial factor for the energy efficiency of buildings in urban environments. (Han et al., 2017) used fictitious models to explore the effects of shade on energy usage in actual urban instances in Italy under varied climatic conditions. Their modelling results showed that the shading impact increased the need for lighting and heating. Furthermore, locations with warmer temperatures and denser metropolitan regions had a greater impact from shadowing.

(Takebayashi et al., 2015) investigated the possibility for Osaka buildings to produce solar energy, where they came to the conclusion that the potential was diminished by a percentage of 22.4 when the effect of shading was taken into account as opposed to when it was ignored.

However, there are times when the mutual shading impact does not have big unfavourable effects. For instance, (C. Yu & Pan, 2018) looked into the effect of shade in Hong Kong's subtropical environment. They ran simulations without or with taking the effects of shading into account using 4 typical office structure examples. Results indicated that shading effects could reduce overall yearly energy needs by up to 8.48%. Several indicators for measuring shading are existing:

e.1. Urban horizon angle (UHA)

The aspect ratio may be linked to another indicator. The 'Urban Horizon Angle' is denoted by UHA. It is the average angle between the horizontal plane on which the facade is located and the highest horizontal edge of buildings visible from a location on the facade (see Figure I.27). This spot can be found on the ground (Ratti et al., 2005).

Alternatively, Yun and Steemers (2009) apply the same notion by imagining a point not on the ground but in the centre of a window. They call the angle the obstruction angle. Their study examines the impact of variables such as street orientation and technology type on the manufacture of photovoltaic modules incorporated into building facades.

The research conducted by Changalvaiee et al. (2017) assessed the effect of urban openness parameters on theoretical energy consumption using cases of urban morphological forms from the city of Isfahan in Iran. The study found that while the simple level of various urban openness measures, including UHA, only showed a significant correlation with heating energy demands, the more complex measures (occlusivity and total permeability) had a high correlation with both cooling and heating energy demands.

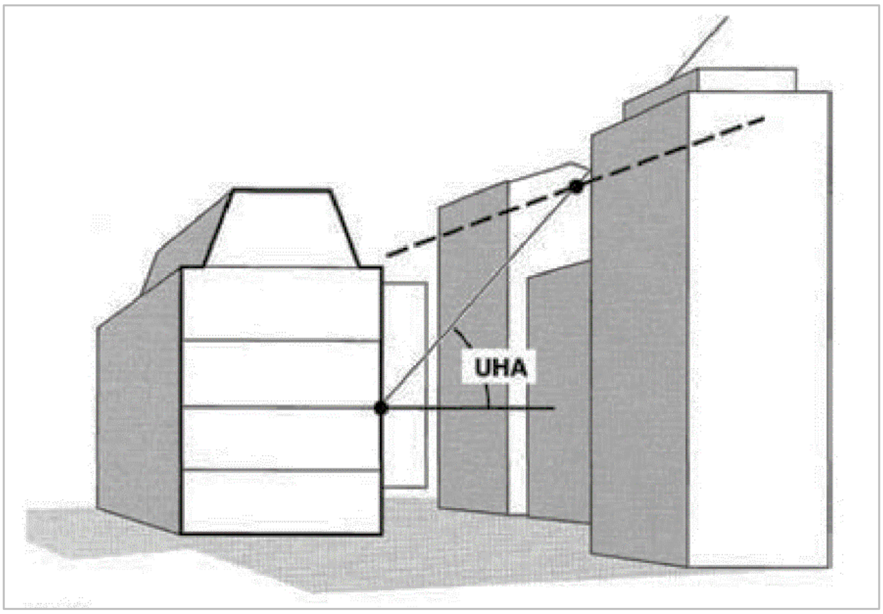


Figure I. 27. The definition of Urban Horizon Angle (UHA).

Source: (Baker & Steemers, 2000).

e.2. Obstruction sky view (OSV)

The energy that falls on a specific facade originates from both the sky and radiation reflected by opposite facades. The LT model (LT stands for lighting as well as thermal, and the LT technique was initially designed as a computer-based method that permits the forecast of consumption of energy in non-domestic structures during the concept design stage) was used for estimating the latter component (opposite facades). It was created to assist designers in determining how a building's energy usage may connect with the early architectural criteria. This is known as obstruction sky view (OSV), and it is similar to what is known as urban horizon angle (UHA) for the obstructing facades (Ratti et al., 2005). Obstruction sky view is an angle used to calculate the luminance of obstructed facades in relation to their view of the sky (M. Zhao, 2014).

e.3. Sky view factor (SVF)

The sky view factor, which is represented in (Figure I.28) is important in describing urban climatology and its spatial changes (Oke, 1973; De Morais et al., 2018). This part of perceptible sky designates the geometry of the street and the density of the buildings (Gál et al., 2009; Zhu et al., 2013; Theeuwes et al., 2017; Middel et al., 2018).

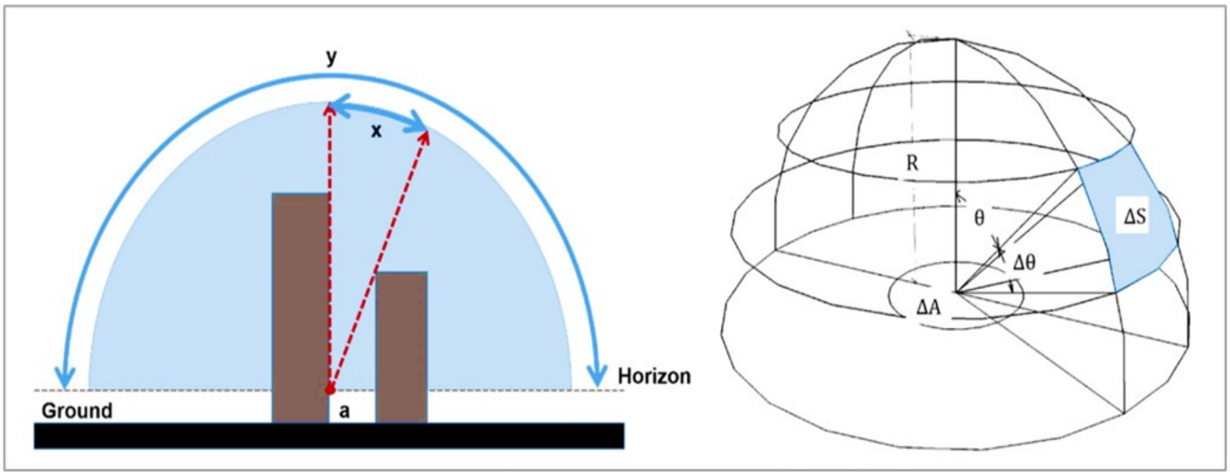


Figure I. 28. Calculation method of SVF.

Source : (J. Zhang et al., 2019).

A limited sky view increases net heat storage inside buildings and raises the UHI. Trees inhibit SVF as well, but while they do not store much heat, they do limit incoming long-wave radiation (Van Der Hoeven & Wandl, 2015; Klemm et al., 2015).

(Theeuwes et al., 2017) published that the daily maximum UHI for cities in northwestern Europe can be associated with meteorological data of the SVF vegetation fraction in rural areas, namely: solar irradiance, diurnal temperature range and wind speed. The empirical association was authenticated using citizen weather stations distributed across the city (Bell, 2014).

In addition to UHI research, SVF is also used in rural areas. Riverbed morphology studies, for example, use the sky visibility factor to estimate vegetation and water properties according to (Bartnik & Moniewski, 2011). On a broader scale, the same factor can be used to reduce solar irradiance over complex terrain (Antonanzas-Torres et al., 2014). For urban temperature prediction, numerical research has used both SVF and vegetation fraction. Improved modelling of the urban structure led to better wind and temperature simulations (De Morais et al., 2018).

The geometric model of solar and longwave environmental irradiance has been used in several investigations of mean radiant temperatures in metropolitan areas (F. Lindberg et al., 2008; F. Lindberg & Grimmond, 2011; Thorsson et al., 2014). To analyse heat-related mortality, the model integrates SVF and other city characteristics with meteorological observations, such as relative humidity, air temperature and solar irradiance...

The sky visibility factor (SVF) is a visibility statistic that calculates the percentage of visible sky at a particular place on a half-sphere (Kokalj et al., 2011). For particular radius directions, the algorithm computes the vertical angle of elevation with respect to the horizon. On a high point, the proportion of visible sky is large, whereas in an excavated setting, the proportion of visible sky is little (Saligny, 2014).

e.4. Aspect ratio

Another useful indication to examine in performance assessment studies is the aspect ratio, which refers to the ratio of a structure height to street width. Previous research has found that aspect ratio has a considerable effect on the intensity of urban heat islands (Theeuwes et al., 2014; Oke, 1981), sunlight availability (Strømann-Andersen and Sattrup, 2011), beside demand for energy (Ali-Toudert, 2009), as well as the potential of solar renewable energy (Hachem et al., 2013).

While explaining the association between aspect ratio with UHI, (Theeuwes et al., 2014) called attention to two essential mechanisms. First, heat is held inside the canyon because of the trapping of longwave radiation when building heights and roadway widths rise. This heat raises the temperature within the canyon, enhancing the UHI effect.

Furthermore, the shading effect has a greater impact in valleys when the width of street is short and the construction heights are high, resulting in a cooler canyon during the day. At night, temperatures in the canyon are significantly lower due to the strong thermal inertia. As a result, a greater aspect ratio leads to a lower Urban Heat Island according to (Theeuwes et al., 2014) also.

The aspect ratio of a building defines the size of the surface area where heat is transmitted into and out of the environment.

Reducing the surface area reduces energy transfer according to (McKeen & Fung, 2014), who have done geometric research that demonstrates that adjusting the aspect ratio allows for varied surfaces for the same floor area.

Heat transfer will be greater in designs that require a larger surface area. On smaller buildings, the influence of the aspect ratio on the exterior surface will be more significant, as it is shown in (Figure I.29), where 1:1 aspect ratio also was marked by the smallest surface area. However, in the case of solar radiation, the optimum aspect ratio achieves a balance between heat loss and heat gain.

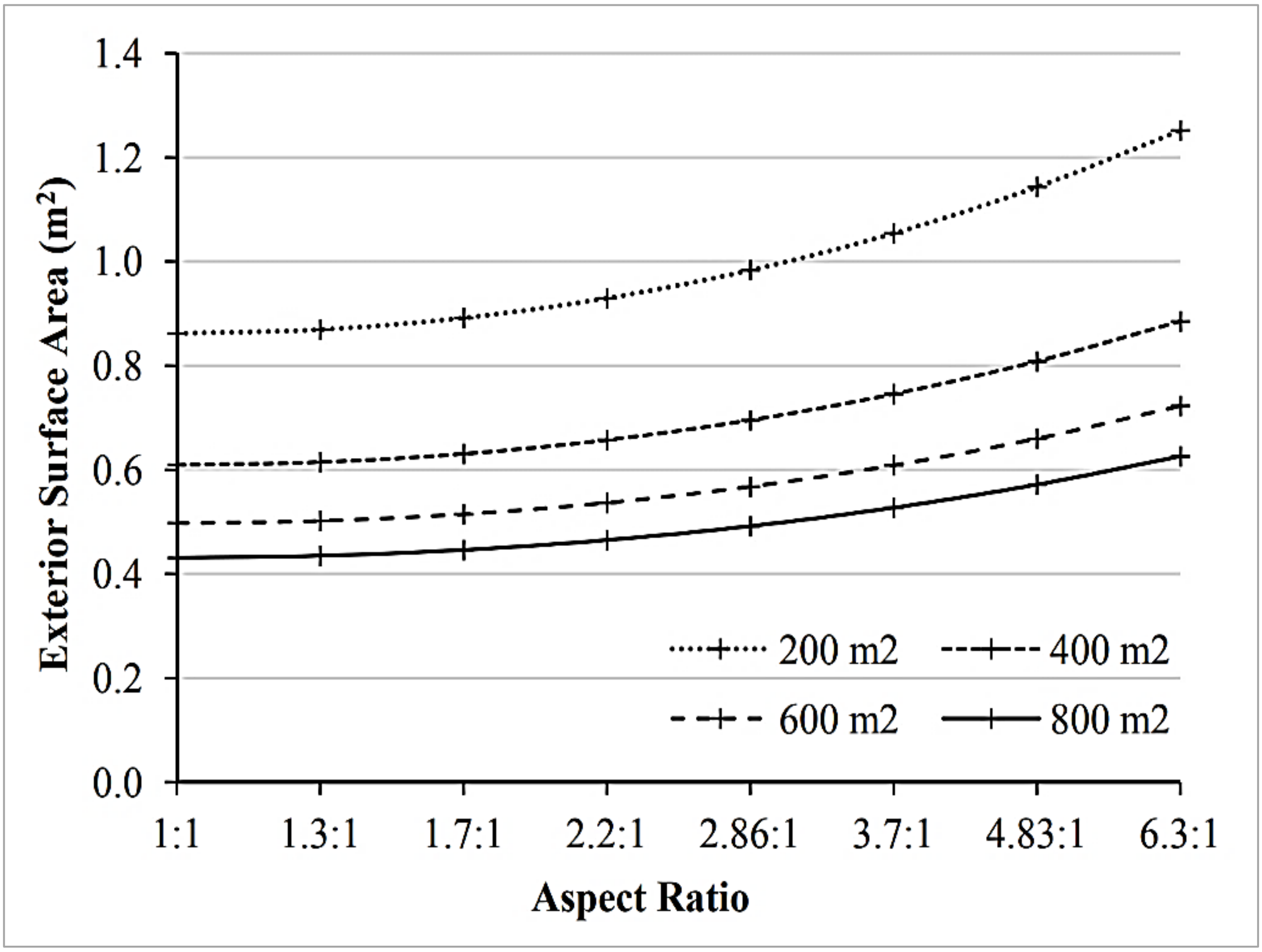


Figure I. 29. Exterior wall surface area / square meter of floor space for different building footprints assuming a 3 m floor-to-floor height.

Source: (McKeen & Fung, 2014).

f. Passivity

The passive zone idea was created by (Ratti et al., 2005) to be able to estimate the potential for each area of a building to utilize sunlight, daylight, alongside ventilation.

The areas of the building that are naturally illuminated and ventilated are known as passive zones (Figure I.30), and they stretch for about 6 m, or two times the height of the highest point from the facade; the other areas are known as non-passive areas (Ratti et al., 2005).

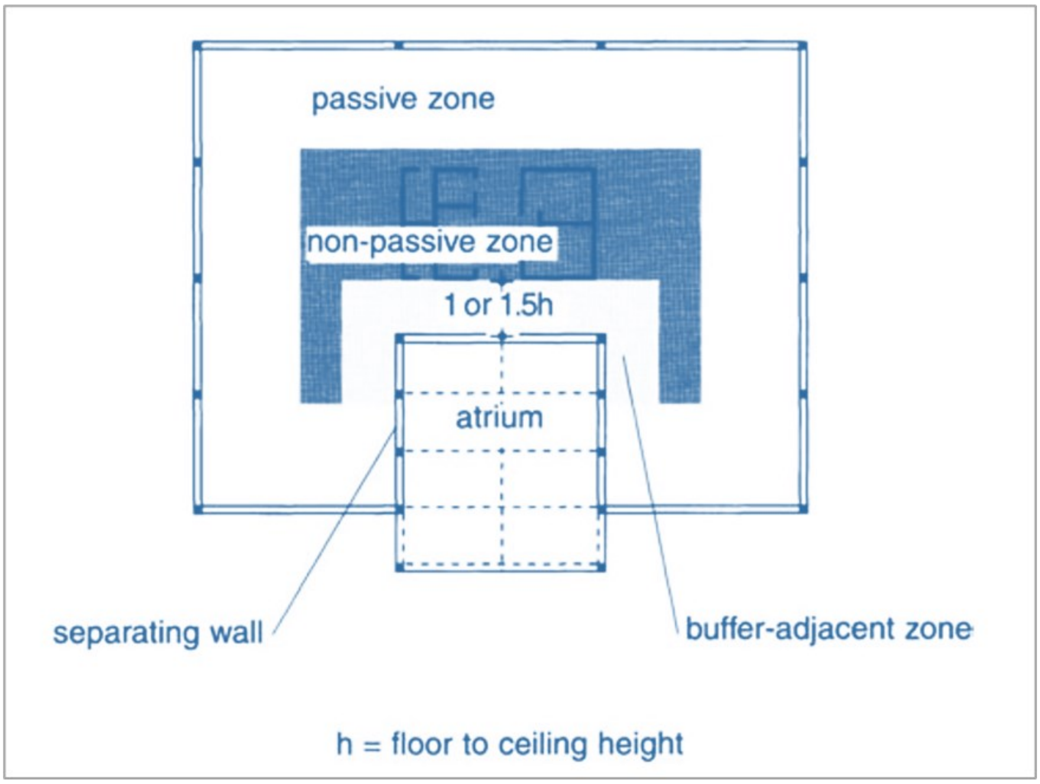


Figure I. 30. An atrium reduces the passive zone depth, which is double the height from floor to ceiling for a facade without obstructions.
Source: (Baker & Steemers, 2000).

Numerous indicators for measuring passivity are existing:

f.1. Passive/non passive ratio

It was recommended by (Ratti et al., 2005) to utilize the proportion of passive to non-passive zones to be a criterion. Despite the fact that this measure appears to have an impact exclusively on the building's design, it is nonetheless regarded as important urban form indicator because it affects the building's shape (Borlin et al., 2013).

Zhu et al (2013) studied the impact of climate on the energy efficiency of passive and non-passive zones of an office building in three Chinese cities. The study highlights the importance of taking climate into account when designing energy-efficient buildings. The results highlighted the preference for non-passive zones in Urumqi, a city with an extremely cold climate. On the other hand, passive zones facing south performed well in Beijing and Lhasa, where temperatures are warmer.

It is predicted that energy performance will improve with increasing passivity ratio. Wide fenestrations ratios and inadequately insulated facades, on the other hand, can lead to excessive loss of heat in the wintertime and overheating in the summertime, making passive areas more energy-consuming than non-passive areas (Ratti et al., 2005).

f.2. Plan depth

The method used for determining the depths of buildings in plans was created and described in earlier research by (Steadman et al., 2009). Each block's volume is divided by its entire exposed wall area. If the surface areas that comprise the long walls are counted without considering the surfaces of the short end walls, this yields a result which would correspond to precisely equal to half of the plan depth within the case of an extended isolated block with a simple rectangular form.

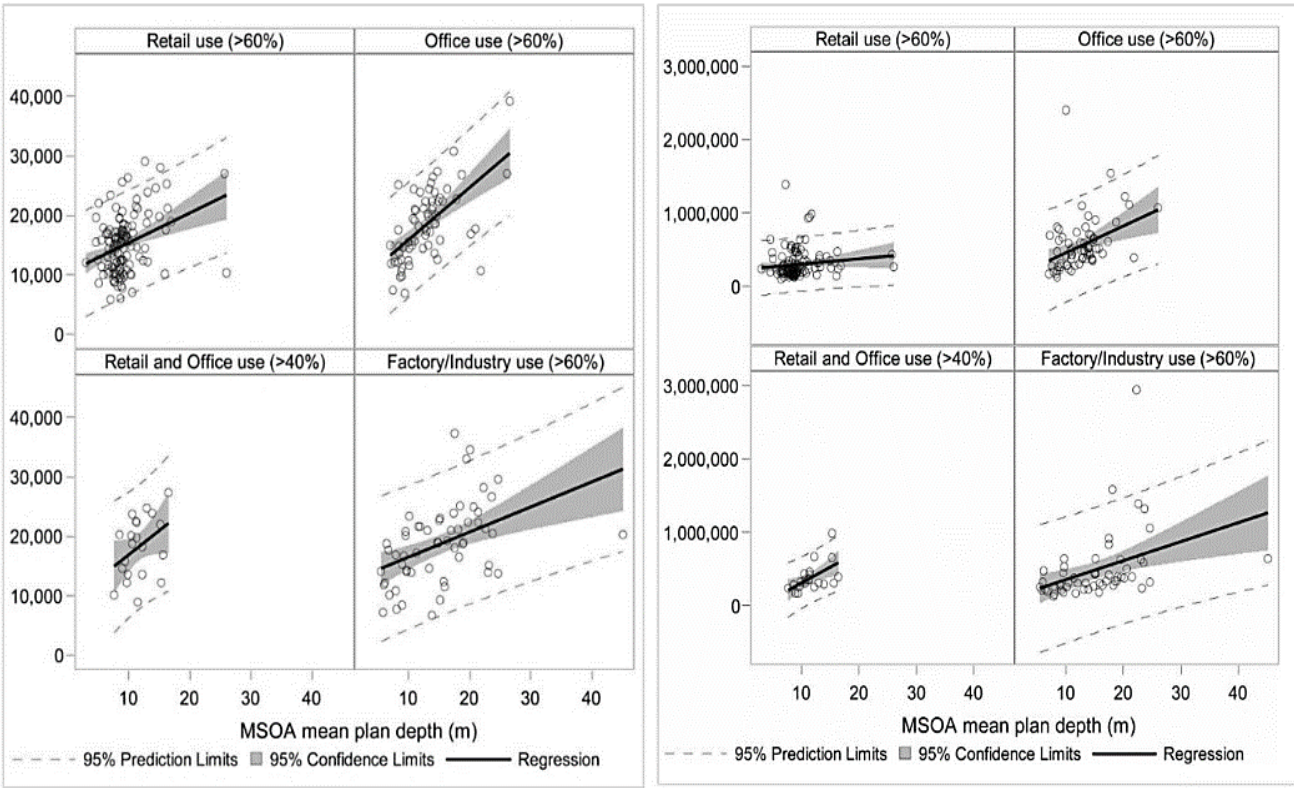


Figure I. 31. Correlation between mean demand for electricity (right), mean gas demand (left), as well as mean medium level super output area plan depth for locations with a large percentage of a single non-domestic floor space usage.

Source: (Steadman et al., 2014).

According to (Steadman et al., 2014), who used an empirical alongside statistical approach in their research about the relationship between energy and urban built form, in the context of London in the UK, electricity and gas use is positively correlated with plan depth in the mid-level super output areas (MSOA) of the different scenarios, as shown in (Figure I.31) above.
The depth of the building has an impact on the heat acquisition and loss rates, as well as varying with the geometric shape of the structure, in particular the proportion of exposed surface area to volume. Heat gain and heat loss rates also vary according to the envelope materials, particularly the amount of glazing. The depth of the plane is certainly crucial when it comes to the use of air conditioning, when the depth of multi-storey structures reaches 14 or 15 metres, air conditioning is usually required (Evans et al., 2017).

g. Orientation

While trees as well as structures act as a physical barrier to winds, air movement inside the urban canopy zone is typically slower compared to rural settings. As a result, street orientation in relation to the current winds can have a significant impact on how winds penetrate urban roadways as well as canopies layer wind velocity. Because rural breezes or winds from the seashore bring cooler air into cities, orienting key roadways to prevailing winds might lead in cooler temperatures of air within the city. Because of the shadowing offered from the street's constructions, the solar orientation of roadways may have a certain impact on outdoor thermal comfort, reducing pedestrian discomfort from temperature during the day. The effects of sun orientation are more pronounced in subtropical latitudes compared to tropical as well as temperate latitudes, particularly during the summer. North-south (N-S) streets will have less surface irradiance during the summer than east-west (E-W) streets, meaning that they're more likely to offer higher thermal comfort outdoors for walkers. However, north-south orientations in streets with a low ratio of aspect (H/W less than 0.5) provide significantly higher summertime cooling loads on structures than East-West orientations, potentially contradicting with outdoor comfort demands. Given this conflict, it is reasonable to conclude that the planning of street orientation should achieve an equilibrium between both outdoor and indoor circumstances in both summer and winter, while also taking into account the special qualities of the urban area (latitude, climate), and the street ratio of aspect (Aleksandrowicz et al., 2017).

h. Albedo

The change in the reflecting characteristics (Figure I.33) of the surface is a unique climatic impact caused by urbanization that has received less attention than it deserves.

The purpose of focusing on this factor is to examine the climatic effects of urbanization, particularly on albedo - the ratio of incoming to outgoing radiation from the sun for a given surface.

Urbanization has numerous impacts on surface albedo, reducing it by introducing dark surfaces, altering surface shape to better capture solar energy, and reducing snow cover during winter. Increasing cloud cover and air pollutants, as well as aerosols, can also contribute to it (Bazrkar et al., 2015).

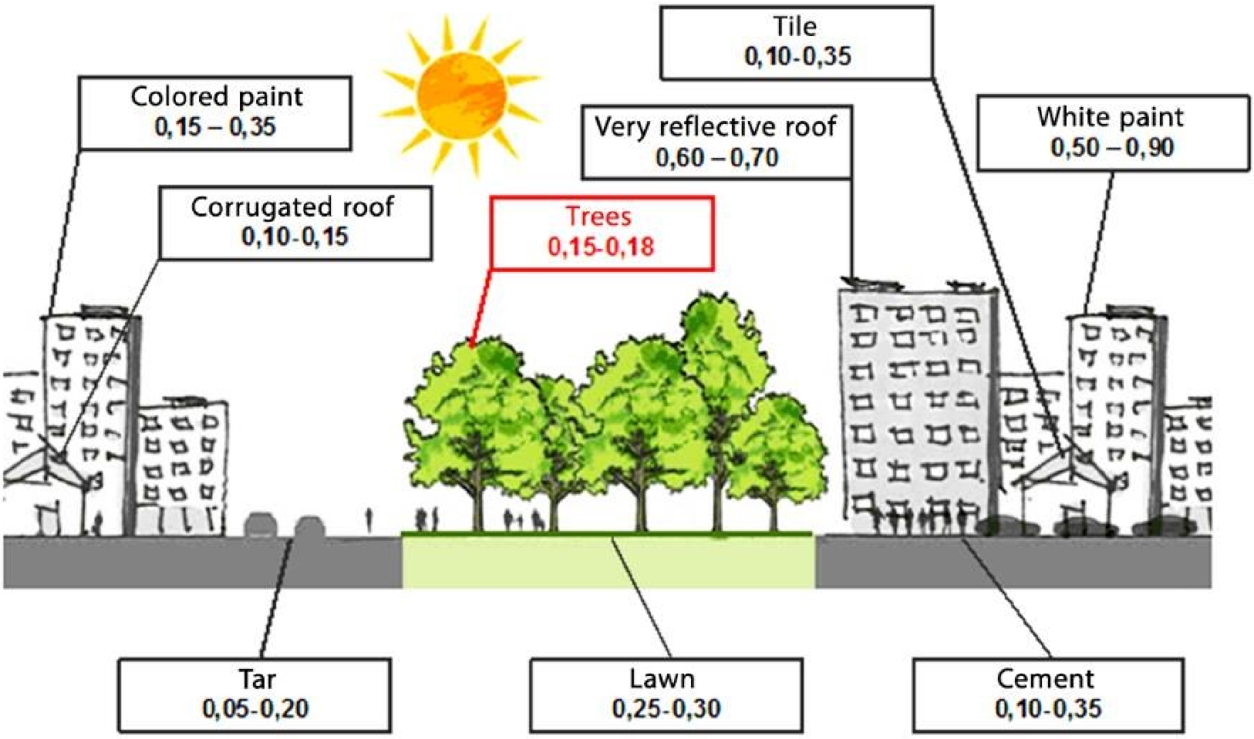


Figure I. 32. Examples of albedo by type of material.

Source: (Zoca & Papin, 2014).

Certain influences, such as changes in surface humidity patterns or temperature variations to the windward side of cities, can both decrease and increase it, with the overall effect being highly dependent on local conditions. This change in albedo has a negligible radiative effect. This is mainly due to the fact that metropolitan areas cover only 0.44% of the earth's surface, according to the best estimates. While the climatic consequences of albedo modification by urbanisation are minor on a global scale, they are very different on a regional scale in terms of local sizes.

The tiny footprint of today's urban areas is nevertheless more than twice the estimate given in the IPCC's latest assessment report (AR4). With the projected increase in urban population, the modest global effects will become increasingly important and will need to be taken into account in future research on climate change and land use (Bazrkar et al., 2015).

I.5.5. Meso-scale geographic physical factors

Topography refers to all geographical elements that impact the development of cities. This includes steep slopes, which can be challenging to build on but offer good views and exclusivity (such as Hollywood), or segregation for less affluent neighbourhoods (like slums in Mexico City). Vast, flat landscapes encourage low-density construction due to the availability of space.

Natural resources such as lakes, rivers, and seas can either limit or encourage urban growth. For example, cities like Chicago and Southampton are constrained by these resources, while cities like Los Angeles and London thrive along their coasts. In Liverpool, Cardiff, and Toronto, the city centres for retail and commerce are located around the waterfront and ports. Urban regions are often developed and prosper due to the availability of resources such as coal in Cardiff, wood in Chicago, and steel in Sheffield.

Construction is more or less feasible on different types of land. Chicago was built on swampland, which was elevated to enable future growth. Similarly, Venice is situated on swampland, but its expansion is limited due to the use of canals as highways (Cartwright, 2018).

Yaşar et al. (2018) conducted a study analysing Yıldızlı Mass Housing in Turkey as a case study for various topographies (see Figure I.33).

Employing the *Design Builder* energy simulation software, it was assumed that the plan was situated on a variety of topographies, including a hillside (S), a valley, a plain, and a hill. Then, in the context of various topographies, air conditioning and heating loads, solar gains, and shadowing of structures were examined.

Of the five situations analysed as part of the study, sitting on the southern slope of a mountain proved to be the most advantageous in terms of heating load, as the southern slope of the hill receives more sunlight. It was then good on plain, valley, hill and then hillside (N) successively. The facility on the north side of the mountain, on the other hand, was considered the most ideal site for minimising cooling loads. This was followed by facilities located on the hill, valley, plain and south side of the mountain.

The study shows also that in a moderately humid climate, the heating load exceeds the cooling load. Consequently, the hamlet of Trabzon, located on the southern slope of a mountain, minimises the heating demand.

The simulation results demonstrated the importance of reducing energy consumption in buildings located on different topographies from the earliest stages of building design.

To save energy, architects together with urban planners must consider the influence of diverse topographies on energy use.

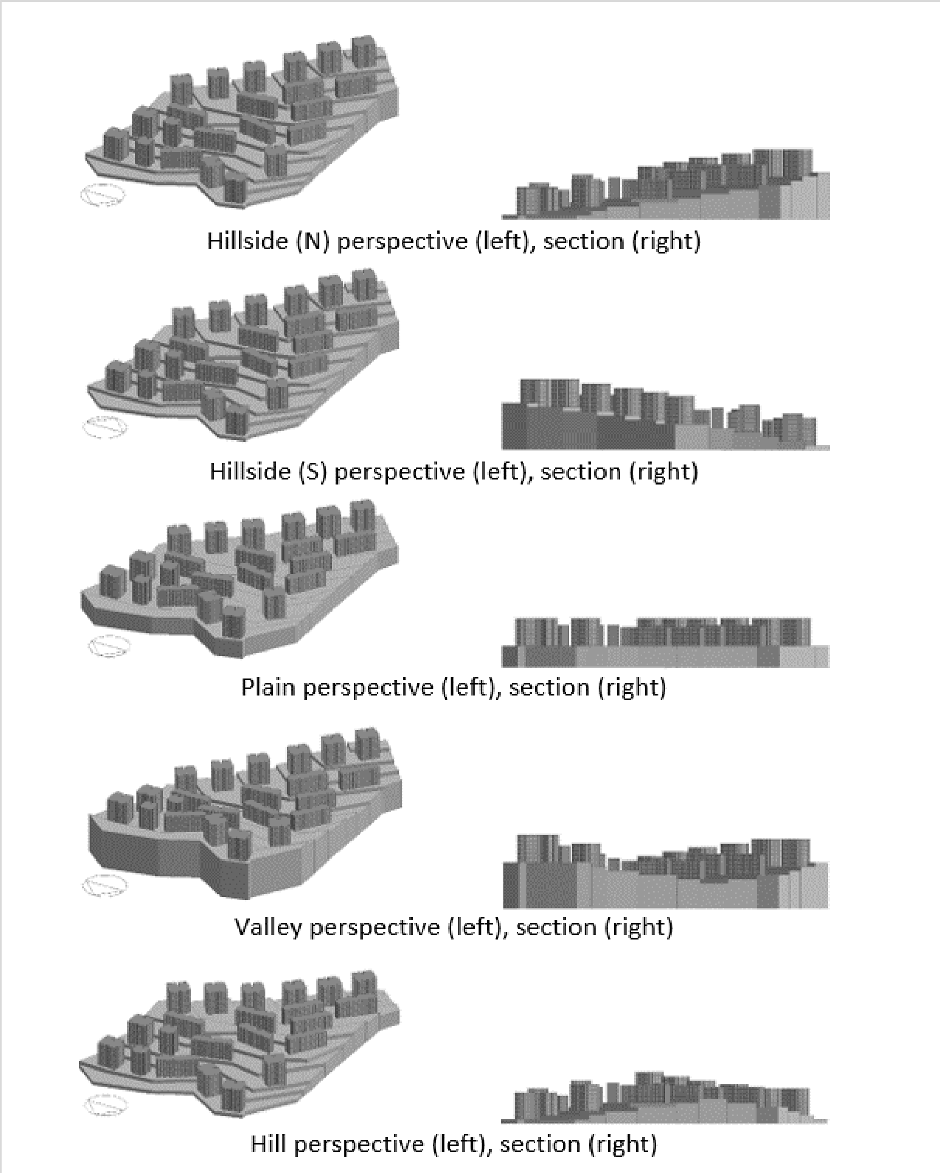


Figure I. 33. Perspective and section of the different topographies.

Source: (Yaşar et al., 2018).

Geiger (1965), Holland and Steyn (1975), and Kirkpatrick and Nunez (1980) have shown that the topography of a region on Earth's surface affects the amount of solar energy received. Local variations in sunlight can be caused by features such as changes in elevation, slope, slope orientation, and shadowing. For instance, the arrangement of slopes in mountainous and hilly terrains significantly affects the amount of solar radiation that reaches the surface. In harsh terrains, certain south-facing sites may not receive any direct radiation throughout the year due to the surrounding high hills (Aguilar et al., 2010). Therefore, landscape design plays a crucial role in passive solar architecture. To prevent obstruction of sun radiation during winter, it is recommended to consider planting deciduous trees on a south-facing slope.

I.5.6. Large scale atmospheric and climatic conditions

a- Climate and atmospheric conditions

The position of the sun in the sky at a particular location is determined by two key variables: the time of day and the season. The amount and type of solar radiation that reaches the Earth's surface is influenced by the atmosphere that surrounds it. Cloud cover and air pollution can affect the amount and type of solar radiation (direct or diffuse). For daylighting in buildings, a diffuse sky condition is optimal (Hachem-Vermette, 2020).

b- Location

The primary means of conveying the geographical location of an area is through its latitude, which indicates its location with respect to the equator. As latitude increases (either north or south of the equator), seasonal fluctuations become more pronounced. In regions with higher latitudes, days are longer in the summer and shorter in the winter compared to regions near the equator. Furthermore, locations with greater latitude experience larger seasonal variations in dawn and sunset times, as well as lower levels of solar radiation per unit area, in comparison to locations closer to the equator (Hachem-Vermette, 2020).

I.6. Conclusion

This initial chapter offers numerous clarifications regarding energy-related concepts, as well as those connected to urban form and the geographical surroundings. It illustrates the significance and essentiality of energy, and its development from ancient times to the present day. Throughout human history, individuals have sought effective ways to utilize energy potential since his inception on the planet. Energy consumption is closely linked to spatial factors, as stated in previous literature. These factors can be categorized as natural, relating to climate and geography, or anthropogenic, relating to urbanization and construction. These factors can be categorized according to their spatial scale, from the thermal characteristics of the building envelope to the scale of the city and the territory, or even a very larger scale.

The interaction of these different factors influences the accessibility of solar radiation to the exterior and interior surfaces of buildings, as well as the local microclimate in the urban environment and even inside the building, which automatically influences heating, cooling and lighting requirements, making all the difference in terms of energy demand. Subsequently, controlling inhabited urban space, whatever the scale, is a very effective way of controlling energy use.

CHAPTER II

Worldwide climate change issue

II.1. Introduction

An alarming threat to humanity is apparent. The dangerous convergence of urbanisation and climate change, caused by the intense man-made forces unleashed by the development and exploitation of nature during and after the Industrial Revolution. Furthermore, this phenomenon endangers social stability, economic health and quality of life. However, amidst this troubling situation, there lie numerous opportunities. Urban development offers opportunities to create integrated strategies for mitigating and adapting to the impacts of climate change. However, urban areas, with their high concentration of population, industry, and infrastructure, are likely to experience the worst of the detrimental effects. Therefore, it is crucial that residents, businesses, and authorities in urban centres play a key role in determining these strategies. Many urban centres are undergoing rapid and largely unregulated population growth, thereby accelerating the process of urbanisation, despite some cities experiencing a decrease in population. This growth is predominantly concentrated in slums and informal settlements within developing nations, resulting in the urban areas with the highest population growth being the least equipped to cope with the effects of climate change. These regions often face significant vulnerabilities concerning their infrastructure, social and economic justice, governance, and other factors. Due to the rapid pace of climate change, the dangers it poses to these urban areas are expected to worsen. The urban poor will be disproportionately hard hit by its effects in both developed and developing nations.

This chapter provides a comprehensive review of climate change, from the global to the local scale, as well as a chronological summary of international meetings and events dedicated to promoting the principles of sustainable development and solving environmental problems. It also covers the sectors that contribute to the current situation, the link between climate change and cities in terms of urban adaptation, and the main organisations that study climate change.

In addition, the chapter deals with energy consumption and greenhouse gas emissions at the urban and architectural level, as this was a major focus of this research, which guided to provide an insight into international labels and standards, as well as the different types of high-performance buildings designed to achieve superior energy efficiency and environmental sustainability.

II.2. Climate change concept

The warming of the Earth's climate is an undeniable fact. According to the IPCC, there has been a temperature increase of 0.74°C between 1906 and 2005, which is supported by global and continental models and observations. Although the extent of their contribution remains uncertain, urban areas have played a significant role in this trend (Trenberth et al., 2007). (Figure II.1) illustrates and compares the potential impact of increasing greenhouse gases in the atmosphere on temperature, snowfall, and ice coverage. It analyses recorded measurements from 1958 against projected values for 2100 (Youngman et al., 2010).

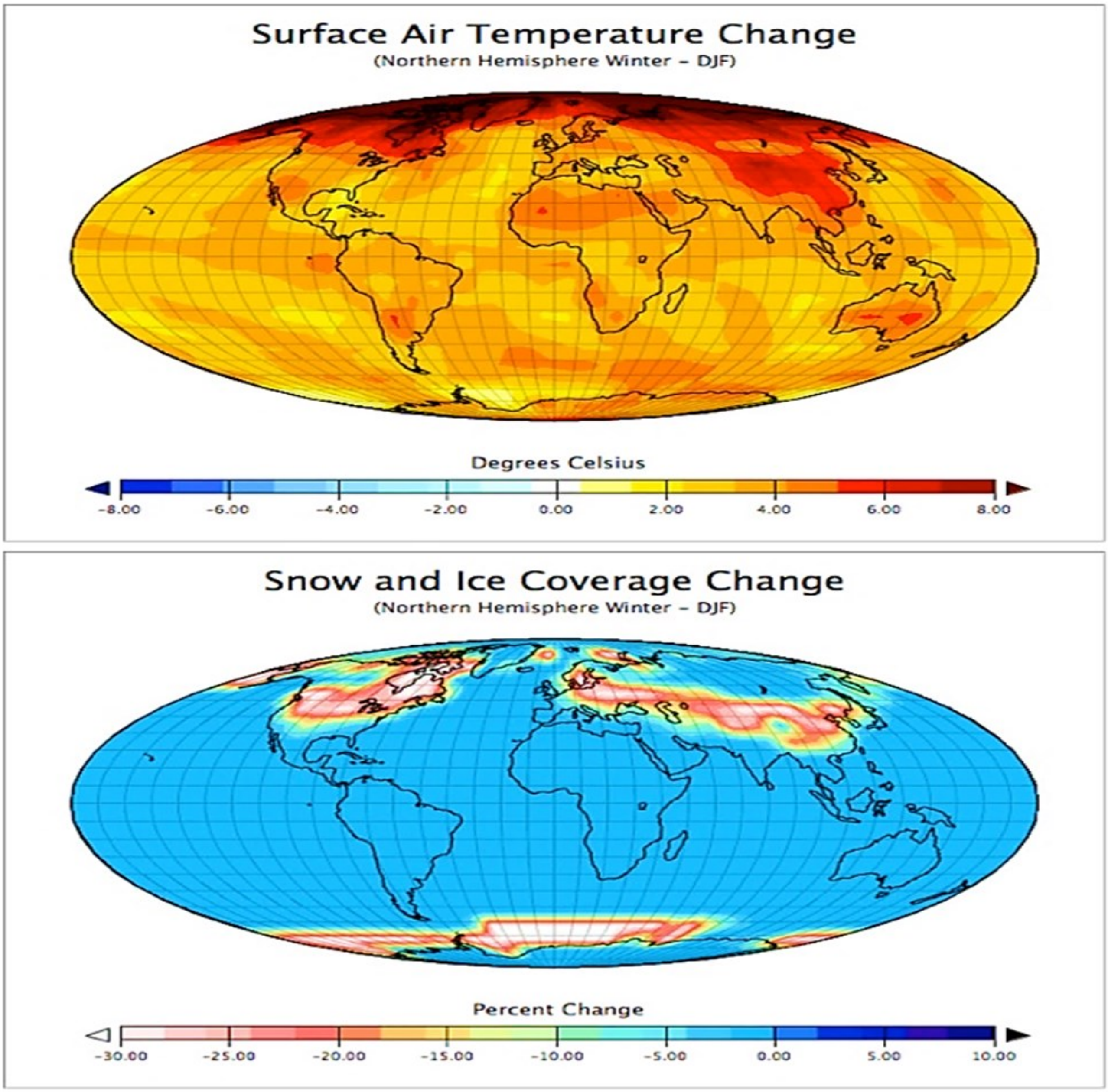


Figure II. 1. A highly extreme IPCC scenario, A1F1, from a "control simulation" is run on the EdGCM program to estimate increases in temperature and snow and ice covering for the year 2100. The "control simulation," which was also performed using the EdGCM, used greenhouse gas values from 1958 to mimic the environment for the years 1951 to 1980.
Source: (Youngman et al., 2010).

Greenhouse gas emissions have built up in the atmosphere due to human activities like burning fossil fuels, widespread industrial pollution, deforestation, and land-use policies, among others. Furthermore, the oceans and vegetation's ability to absorb greenhouse gases has reduced. As a result, the Earth's natural ability to balance the carbon cycle has declined, which explains the current alterations in global mean temperatures. CO2, methane, nitrous oxide, halocarbons, and various fluorinated gases are the primary GHGs produced by human activity. There emissions are represented in the (Figure II.2), which shows the quantity of emission of each type of them within the period between 1990 and 2015.

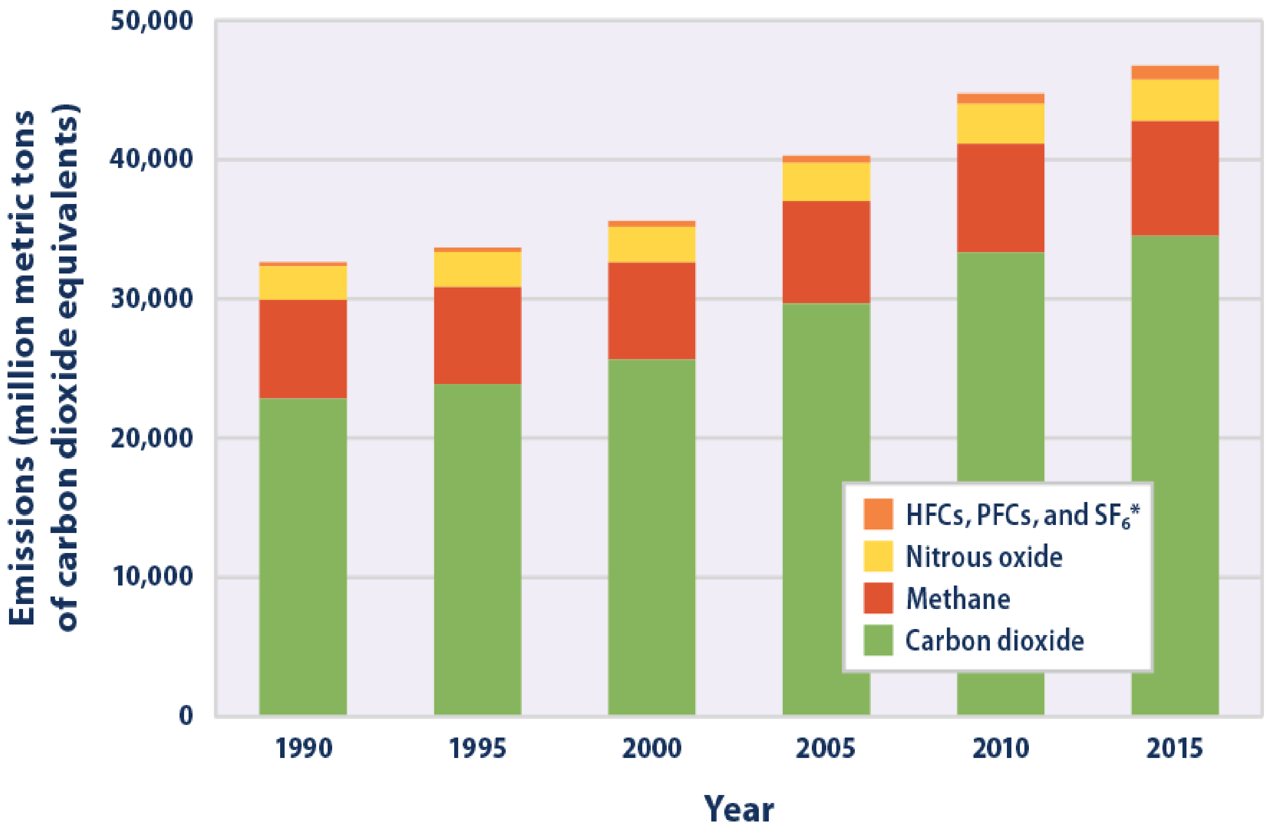


Figure II. 2. Global Greenhouse Gas Emissions by Gas types, 1990–2015.

Source: (US EPA, 2016).

Since not all of these gases have the same impact on climate change, their CO2 equivalent (CO2 eq) is typically used to compare different emissions because it is a useful unit of measurement (United Nations Human Settlements Programme, 2011).

As it's shown in (Figure II.3), these different kinds of gases are a result of many types of scopes; *scope 1* which include direct emissions by sources that are controlled or owned by the government, and this includes all emissions from an organization's or under their control's activities, such as fuel consumed in controlled or owned boilers, furnaces, and automobiles, as well as emissions from chemical manufacture in owned or even controlled process equipment.

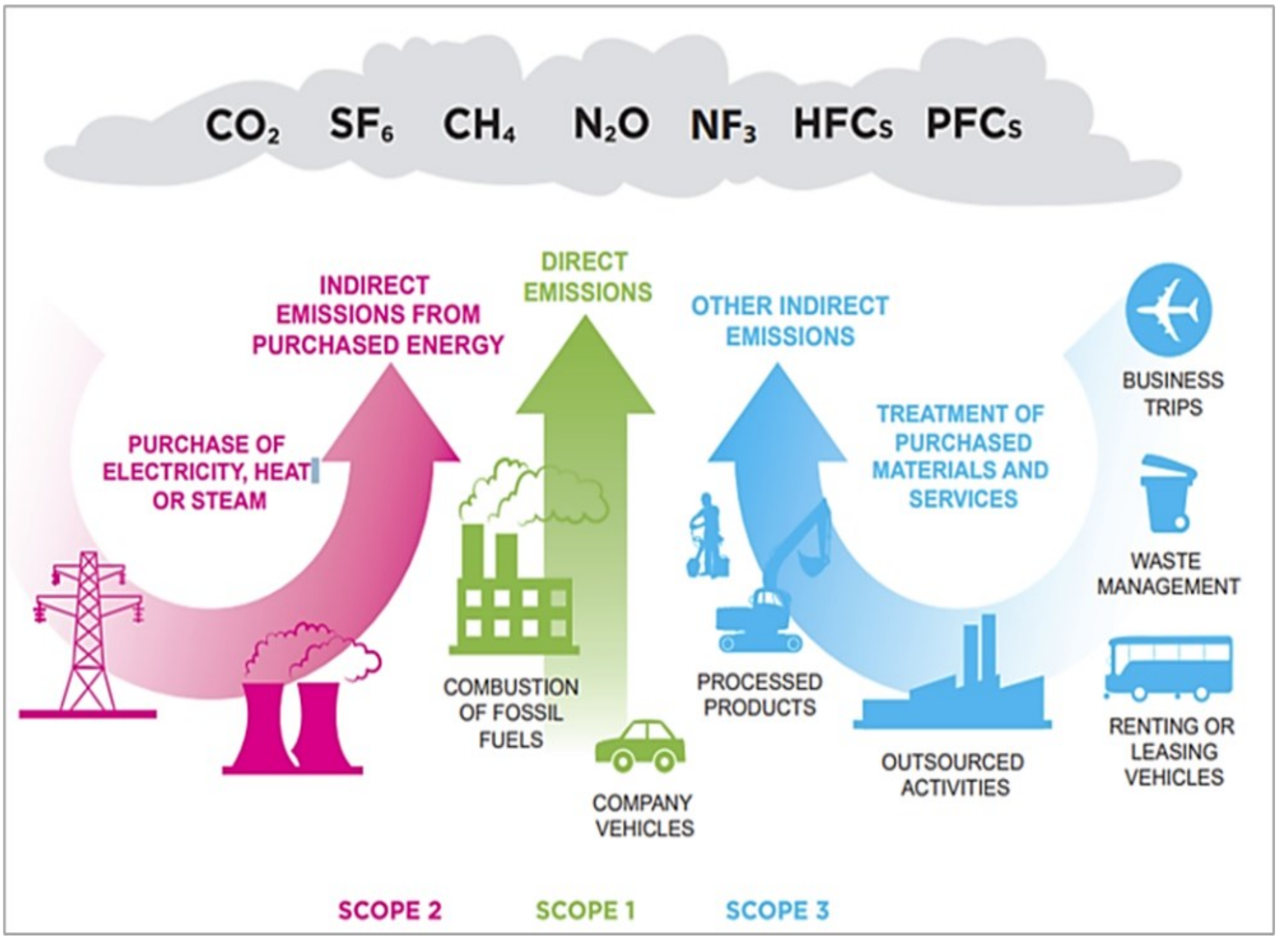


Figure II. 3. The three scopes of greenhouse gas emissions.

Source: (Greenhalgh, 2020).

Direct carbon dioxide emissions from biomass burning are not included because they are reported separately, and any greenhouse gas emissions that are not covered by the Protocol of Kyoto, such as CFCs as well as NOx, are not recorded under *Scope 1* but can be reported separately by a corporation. *Scope 2* presents the indirect greenhouse gases emissions from purchased energy generation. This includes indirect emissions by a company's consumption and purchase of electricity. Emissions like this are produced by the supplier throughout the energy generation process.

Scope 3 involves all indirect emissions occurring along the value chain. This includes emissions by sources which the company does not possess or manage, such as company travel, procurement, waste products, as well as water. They refer to those not covered by *scope 2* and expand the reach of accounting for greenhouse gas emissions across the reporting company's whole value chain, involving downstream as well as upstream emissions (Greenhalgh, 2020).

Not all countries have contributed equally to global warming, like the (Figure II.4) illustrates. Developing countries accounted for only 25% of developed countries' per capita emissions.

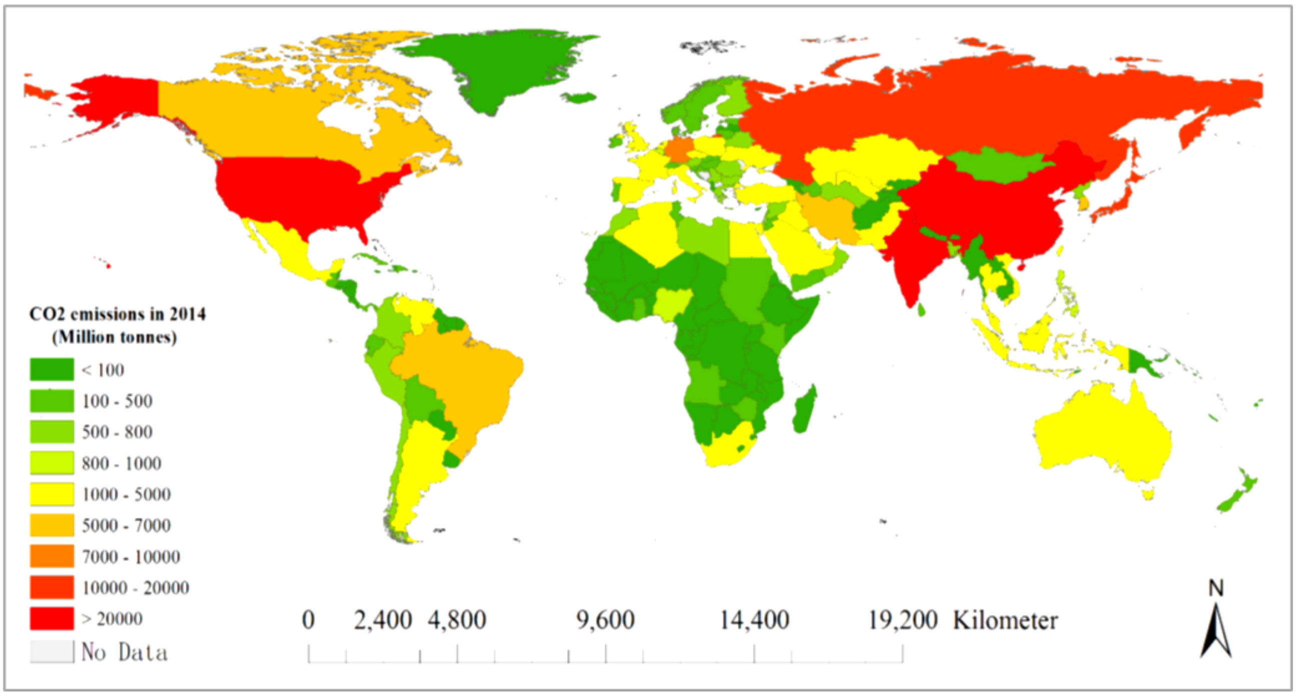


Figure II. 4. Worldwide CO2 emissions from cement manufacturing and the combustion of fossil fuels in 2014.

Source: (Olivier et al., 2015).

And today, the majority of CO2 emissions are produced by just a few developed and emerging countries, where also the (Figure II.5) confirms that the great percentage of gas emissions in the period between 1990 and 2018, were in the United States of America, the European Union, the central as well as the east of Asia, and the pacific.

These discrepancies in contributions lie at the centre of global discussions on environmental justice and at the heart of the difficulties the international community faces in coming up with workable and just solutions (Ritchie, 2019).

Therefore, humanity faces two pressing issues that urban centres can assist in resolving: it must adapt to climate change and urgently mitigate all of the human-made forces that are aggravating it. Urban areas in particular can contribute to the adoption of development patterns that would keep the rise in the average global temperature to +2 or +2.4°C above pre-industrial levels, in line with the UNFCCC's target (Groc, 2021).

Understanding the role played by transportation, heating and cooling systems, industry, as well as other urban activities and infrastructures as emitters and direct causes of climate change will be crucial to the study of how urban centres contribute to it. Urban centres' impacts on the carbon cycle and the climate system fall into two categories: those related to aerosol, GHG, and solid waste emissions, and those related to land use (United Nations Human Settlements Programme, 2011).

Different factors affect energy consumption and emissions in cities, including population categories, economic activity, and infrastructure. To reduce global warming, it is essential to consider these factors when developing strategies for sustainable cities. The city's climate and natural and economic resources also play a significant role.

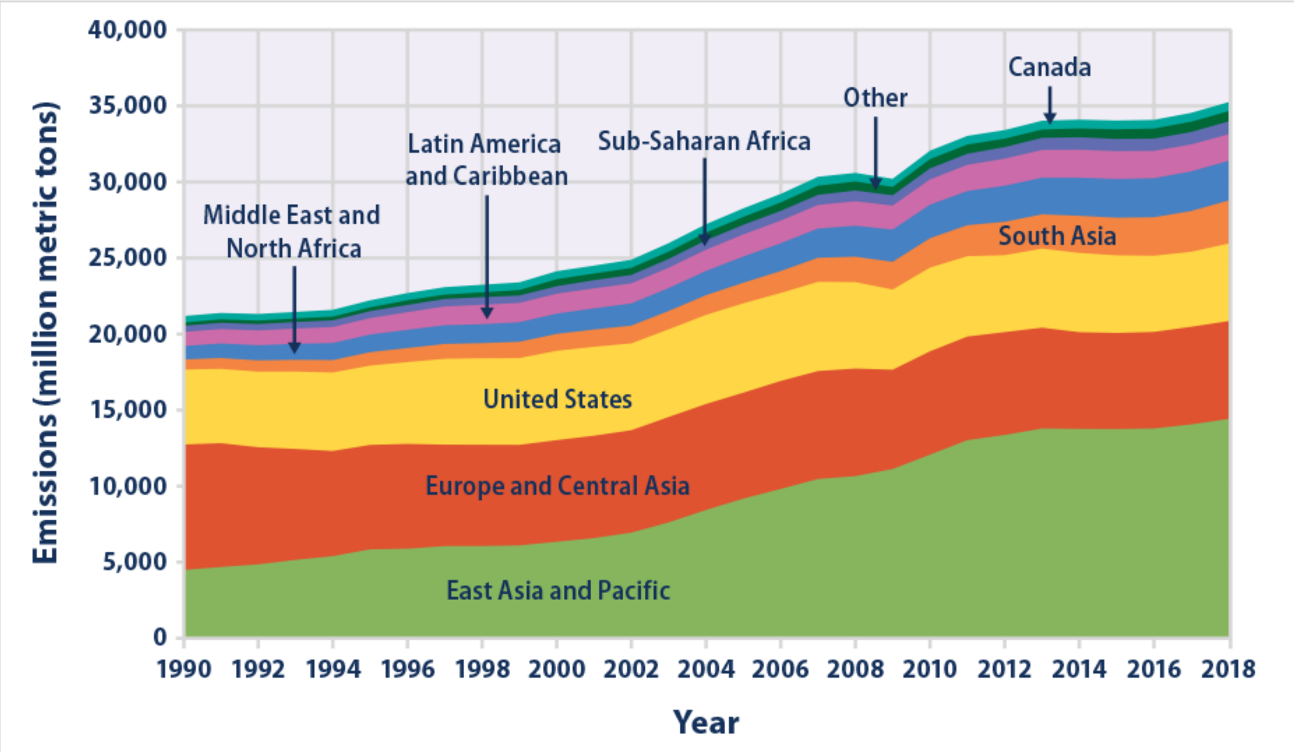


Figure II. 5. Global Carbon Dioxide Emissions by Region, 1990–2018.

Source: (US EPA, 2016).

GHG emissions are affected by various factors, including the size, growth, structure, and density of the urban population, as well as the degree of wealth. It is important to note that not all urban areas are not with the same compactness, and don't contribute with the same degree in carbonic emissions (as shown in Figure II.6). Regions with low density continue to contribute significantly to emissions due to excessive mobility requirements, lack of viable alternatives to private automobiles, and limited opportunities for shared building envelopes. The design and planning professions will increasingly need to focus on renovating regions for better land use efficiency. This is true regardless of whether these patterns are a result of planning or a lack thereof (UN-HABITAT, 2012).

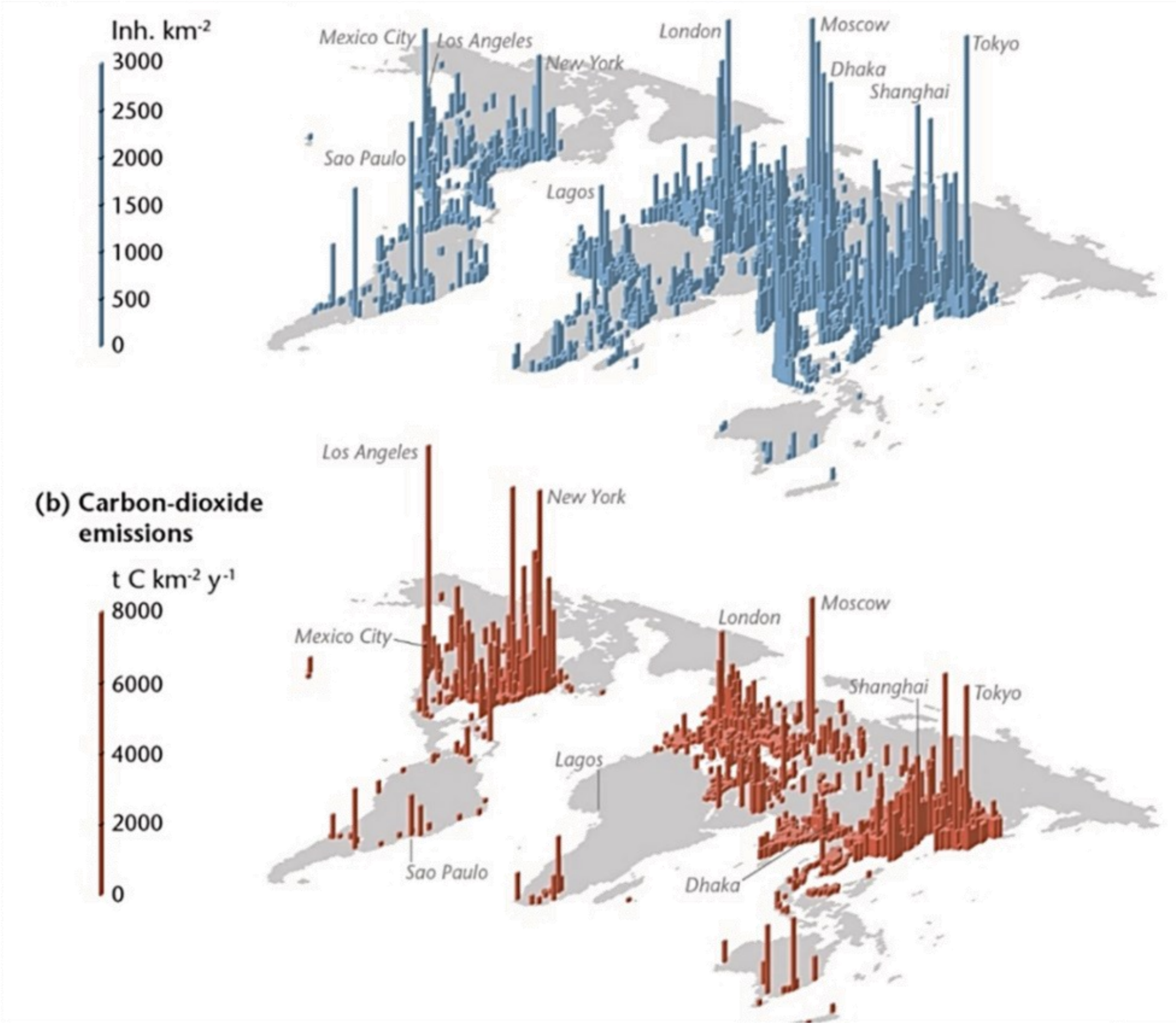


Figure II. 6. Each bar symbolizes an entire metropolitan region, which includes frequently much lower-density suburbs as well as the city itself and the surrounding, continuous urban footprint. Source: (Raven et al., 2018).

Urbanization can increase people's vulnerability to climate hazards. To fully understand how climate change will affect people, it's not enough to look at the vulnerability of urban infrastructure to these risks. Cities' adaptive capacity depends on several crucial components, including urban resilience, development, governance, and equality between socioeconomic groups and genders. These factors must be considered when implementing successful adaptation measures (X. Li et al., 2022). The impact of climate change is not evenly distributed among all demographic groups in urban areas. Besides age and gender, other factors such as human, financial, physical, natural, and social capital influence how quickly and easily different segments of the urban population can adapt to changes. Studies indicate that women, the elderly, children, minorities, and the most impoverished urban populations face particular vulnerability, whereas the richest groups are the least vulnerable (United Nations Human Settlements Programme, 2011).

II.3. Measuring greenhouse gas emissions

International standards for monitoring greenhouse gas emissions have been established by the IPCC. They have devised a precise set of criteria for the creation of national inventories, but do not provide detailed instructions for assessing emissions at the local authority level. Numerous attempts have been made to compile a relevant inventory of emissions at the city level due to the increasing recognition of the importance of urban centres in contributing to global greenhouse gas emissions and the overall reduction objective. The Local Governments for Sustainability (ICLEI) initiative established the International Local Government GHG Emissions Analysis Protocol. This protocol provides a framework for calculating city-level GHG emissions. The most recent draft of the international standard for measuring greenhouse gas emission levels in cities defines a standardized approach to estimate GHG emissions within urban boundaries, which aligns with the Protocol (United Nations Human Settlements Programme, 2011).

Industries and enterprises are increasingly evaluating their GHG emissions due to growing awareness of the environmental impact of their operations. The Greenhouse Gas Protocol provides a means for private sector participants to support the global objective of reducing GHG emissions.

However, current methods of measuring GHG emissions have yet to resolve complex issues related to reference figures. The carbon footprint of individual consumer purchases should be better understood to conduct a comprehensive consumption-based analysis. Urban boundary delimitation presents a challenge when performing these analyses. Depending on the spatial definition of limits within an urban area, its potential impact on global warming can vary up to two-fold, even within one country.

Urban consumption patterns in the industrial and energy sectors often conceal greenhouse gas emissions. For example, some highly polluting and carbon-intensive manufacturing processes have relocated from affluent countries to developing ones to take advantage of cheaper labour and looser environmental regulations (United Nations Human Settlements Programme, 2011).

II.4. Overview of the current global ecological condition and efforts to adapt

The 1979 First World Climate Conference, organised by the World Metrological Organization, emphasised the importance for countries globally to predict and stop human-caused climate changes that could harm people's well-being (Zillman, 2009). The conference resulted in establishing the

World Climate Research Program. Its aim is to explore how foreseeable the climate is and how human actions impact it (WCRP, 2013). This prompted the Intergovernmental Panel on Climate Change (IPCC) to be established in 1988 by the World Metrological Organization and the United Nations Environment Program (Peake & Smith, 2009). During the 2nd World Climate Conference in 1990, the IPCC published its initial evaluation report. This conference, like the previous one, highlighted the risks of global warming and led to the formation of UNFCCC. The 1997 Kyoto Agreement, under UNFCCC supervision, intended to force nations, particularly those mainly industrialized, to decrease their greenhouse gas emissions (UNFCCC, 2013). A number of reports and agreements, including the Kyoto Protocol, Agenda 21, and the First as well as Second Assessment Reports of the IPCC (released in 1990 then 1996, respectively), were also endorsed in the 1980s and 1990s. Climate change related ideas such as mitigation and adaptation have developed over the years. This made climate change a scientific topic that allowed researchers from different fields to gain new perspectives. The following debate summarises the progress made in climate change science, specifically in the adaptation area. The developing subject of climate change awareness and adaptation has made great strides over the first ten years of the twenty-first century and has attempted to address numerous interdisciplinary and cross-cutting concerns.

However, (Hunt & Watkiss, 2011) observed that "cross-spectral impacts and adaptation linkages" were not acknowledged in the research on climate change. Furthermore, according to (Berrang-Ford et al., 2011), the number of adaptation studies has steadily increased. Most of these studies featured proactive adaptation, which involves taking measures in advance of changes in weather patterns, along with assessments of vulnerability and the natural system. Their research also revealed that more than 64% of adaptation studies were conducted in the utility sector, encompassing electricity, water, and flood management. Comparatively, 38% of the research were in the infrastructure and transportation sectors, which have the ability to make adaptation with physical planning along with urban design (such as coastal engineering constructions). (Ford et al., 2011) estimate that 90% of what they refer to as "non-structural" is normative. In other words, instead of focusing on structural measures, such as coastal protection and transportation, these studies focus on the establishment of management strategies, rules, and regulations to direct present and/or upcoming adaptation plans and policies. According to (Berrang-Ford et al., 2011), the majority of these research focus on concepts like adaptable capacity, vulnerability assessments to climate change, conceptual frameworks, and broad adaption strategies rather than real adaptation measures. These theoretical procedures and guidelines are frequently "insufficiently developed to have substantively progressed over the planning and evaluation stages" (Berrang-Ford et al., 2011). The sectors linked with constructed infrastructure, energy, and transportation have received less attention from climate change research than those largely related to sea level rise, excessive heat, health, and water resources (Hunt & Watkiss, 2011). According to the research of (Reckien et al., 2014) on the climate change policy among 200 urban regions in Europe, 72% of these locations don't have any adaptation strategies and 35% don't have specific mitigation strategies in place.

Last but not least, the assessment of (Roggema et al., 2012) recognized the many emphases of adaptation research, including those that address governmental along with institutional strategies, in addition to the basic terminology connected to climate change. Their research also showed that urban form, urban design, and spatial planning have been surprisingly underrepresented in the constantly expanding corpus of research on climate change adaptation. Others have also determined that the bulk of adaptation research to date emphasize on adaptation-related topics and seldom touch on the intricate relationships between the biophysical, economic, and environmental factors that affect an urban zone (Hunt & Watkiss, 2011).

In fact, the majority of the literature on adapting to climate change recognizes this inadequacy and therefore calls for better urban design and planning, emphasizes the calibre of buildings, infrastructure, and services, and promotes land use planning and management that would all work to increase the resilience of urban areas (Revi et al., 2014). Resilience is a relatively new notion in urban planning discourse, especially in relation to climate change adaptation, despite the fact that it has been explored in the socio-ecological field since the 1970s (Davoudi et al., 2012).

By outlining three non-climatic scenarios that could still influence the sensitivity of the urban system to climate changes (namely socio-economic, land use, and environmental factors), the Third Assessment Report of the IPCC in 2001 highlighted the potential impact of global warming on urban centres. Instead of concentrating on a system's vulnerability or flexibility, consider the economic and social landscape which includes governing structures at different levels, patterns of technological change, and societal principles that forecast greenhouse gas emissions. Projects to modify land use and land cover involve techniques that are considered essential to understanding global warming and its effects. Both types of changes greatly affect the way the climate works, which, in turn, alters land cover by influencing the release of greenhouse gases and carbon fluxes. Even the characteristics of eco-systems as well as their susceptibility to climate change may be influenced by the conversion as well as transformation of land usage (IPCC Authors, 2003). For instance, (Moglen & Kim, 2007) investigated how changing both land use and land cover may be used as a method to gauge imperviousness, which is thought to be a good indicator of environmental degradation. In order to deal with climate variability, they consequently suggested setting limitations to imperviousness that vary from seven to eight percent of any given region. Last but not least, the environmental scenario discussed future environmental changes that are not related to the climate but might still have a large impact on it, such as changes in the composition of the atmosphere, marine pollution, and the availability, usage, and overall quality of resources such as water (IPCC Authors, 2003).

The findings from the IPCC's Third Assessment Report show that temperatures will increase, resulting in more hot days and heatwaves.

These changes will have a significant impact on urban planning and design. They could harm people's health, particularly the elderly and those living in urban poverty, leading to higher rates of disease and death. Furthermore, while sea level increases varied locally between 1901 and 2010 at a rate of 1.7 mm/year, it is expected that between 2081 and 2100, the rate of growth will be close to 8 mm/year, although local levels and risks may differ (Pachauri et al., 2014).

Sea level predictions indicate an increase in the chance of landslides and floods, as well as greater intensity of tropical storms and wind. These phenomena would have a significantly adverse effect on human settlements when accompanied by more intense rainfall (IPCC Authors, 2003). A 38 cm increase in sea level between 1990 and 2080 could cause about 93 million people to be relocated every year due to flooding from storm surges. This number would be five times higher than the current amount, according to earlier studies like those by (Nicholls et al., 1999) and the Third Assessment Report of the IPCC's premonitory predictions.

Studies suggest that adopting the Kyoto Protocol entirely may not be adequate to halt global warming. The Protocol aimed to diminish greenhouse gas emissions from 1990 by 5.2% by 2012, as it could delay climate change by six years by the latter part of the 21st century (Peake & Smith, 2009). The necessity of global warming adaptation research to pursue sustainable development is justified by the unavoidable repercussions of worldwide warming. In fact, a number of studies, including those by (Burton, 2002; Smit et al., 2001), highlighted the importance of empirical data on adaptation.

These studies brought attention to the following issues: Unexpected events are highly likely because of the following factors:

1) climate change and its effects cannot be avoided.

2) anticipation and preventative mitigation measures are more effective and cost-efficient compared to forced alongside emergencies adjustment.

3) climate disturbance could be quicker and stated than current projections suggest; consequently, improved mitigation actions may provide immediate advantages.

4) eliminating incorrect practices may also provide instantaneous advantages.

Undoubtedly, the unifying factor across each of these six disorders is adaptation to climate change. The creation of concepts like maladaptation (Barnett & O'Neill, 2010), adaptation based on the environment (Travers et al., 2012; Doswald et al., 2014), as well as community-driven adjusting (Huq & Reid, 2007; Emma Lisa Schipper, 2014) has contributed to the literature on coping with climate change. Planning experts frequently assert that nothing has been done to address these climatic variables in the design and planning field (Roggema et al., 2012).

II.5. Main organizations engaged in climate change research

a. *The Intergovernmental Panel on Climate Change is known as IPCC*

The premier international organization for evaluating climate change is the Intergovernmental Panel on Climate Change (IPCC). In order to present the world with a clear scientific perspective on the current state of knowledge on climate change and its possible environmental and socioeconomic impacts, it was founded by the UNEP (United Nations Environment Program) alongside the World Meteorological Organization (WMO) around 1988.

b. *UNFCCC (UN Climate Change) Secretariat*

The UNFCCC Secretariat helps the flow of reliable information on the application of the Convention, the Kyoto Protocol, and the Paris Agreement as well as providing organizational assistance as well as technical guidance to the UNFCCC negotiations & institutions.

c. *UN Office for Disaster Risk Reduction (UNDRR)*

The UN Office for Disaster Risk Reduction advocates for suitable measures to adapt to projected hazards related to climate change and coordinates and supports actions within the UN system in the field of disaster preparedness and mitigation.

d. *Green Climate Fund*

A part of the UN Framework Convention on Climate Change's financial system is the Green Climate Fund. Its goal is to stimulate and direct financial resources toward poor nations to make it possible for them to put mitigation and adaptation plans in place for climate change.

e. *UNEP - United Nations Environment Programme - Climate Change*

The UN system's spokesperson for the environment is UNEP, which was founded in 1972. In order to encourage the responsible exploitation as well as sustainable development of the world's environment, UNEP serves as a catalyst, representative, educator, and facilitator.

f. WMO - World Meteorological Organization

The World Meteorological Organization (WMO) is a specialized organization within the UN system that organizes global meteorological pattern monitoring, particularly that of trends related to climate change (Dag Hammarskjöld Library, 2023).

II.6. History of conferences and actions on the environment

1950: First report on the state of the environment published by the International Union for Conservation of Nature (IUCN).

1960s: First Multilateral Environmental Agreements (MEAs) adopted by the United Nations.

1972: - The Club of Rome denounces the dangers of exponential growth from the point of view of the depletion of resources, pollution and the overexploitation of natural systems.

- The Stockholm Conference leads to the creation of the United Nations Environment Program (UNEP).

1972-1992: Development of a second generation of AMEs, which become cross-sectoral and global. The following will be concluded, among others: the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Washington, 1973), the Vienna Convention for the Protection of the Ozone Layer, the Montreal Protocol Substances that Deplete the Ozone Layer (1978), the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and on their Disposal (1989).

1980: The IUCN proposes the term "sustainable development".

1987: The World Commission on Environment and Development, known as the "Brundtland Commission" (named after Mrs. Gro Harlem Brundtland who chairs it), establishes the term "Sustainable Development".

1990: Creation of the Global Environment Facility (GEF). The GEF provides more than 65% of UNEP funds.

1992: United Nations Conference on Environment and Development (UNCED), named the first Earth Summit, in Rio de Janeiro, or the adoption of Agenda 21: global program of actions to be implemented by governments, development institutions, UN agencies and independent sector groups in all areas where human activity affects the environment in the 21st century.

1992-2001: The Rio Conference facilitates the establishment of new global MEAs, in particular those relating to fish stocks and highly migratory species in 1995, as well as various regional AME's.

1997: - Second Planet Earth Summit in New York which takes stock of the commitments made in Rio and notes the disagreement between the European Union and the United States on the reduction of greenhouse gases.

- Kyoto Climate Agreement. According to the Kyoto Protocol, 38 industrialized nations (the United States of America, Canada, Japan, nations of the European Union, and nations of the former Soviet Union) are required to reduce their emissions of greenhouse gases by an average of 5.2 percent between 2008 and 2012 (i.e., 8% for the European Union, and 0% for France) in comparison to 1990 levels. A trading system for permits to emit greenhouse gases has been established. The application of the Kyoto Protocol will face increasing challenges over the course of the conferences that follow (Buenos Aires in 1998, Bonn in 1999, and The Hague in 2000), particularly for ensuring the successful execution of these flexibility processes.

2001: The new President of the United States, George W. Bush, announces in March that he renounces regulating greenhouse gas emissions and affirms his opposition to the Kyoto protocol.

2002: United Nations Summit on Sustainable Development, in Johannesburg

2005: Entry into force of the Kyoto Protocol.

2007: - International Climate Conference in Bali: The latest IPCC report concludes that the signs of global warming are unequivocal and calls for rapid action by all countries.

- The Bali Action Plan aims to allow the negotiation of a post-Kyoto agreement during the 15th conference (COP15) to be held in Copenhagen in 2009.

2009: - G8 Summit (10/07/2009): The G8 pledged to reduce global greenhouse gas emissions by 50% in 2050 and those of industrialized countries by 80% compared to 1990.

- International Climate Conference in Copenhagen from 7 to 18 December. It was initially planned to adopt an international agreement to follow on from the Kyoto protocol.
- However, only a non-binding agreement was adopted. It aims to halve greenhouse gas emissions by 2050 compared to 1990 levels in order to limit the temperature increase to 2°C in 2100 compared to 1850.

2010: - World Conference on Biodiversity in Nagoya.

- Conference of Parties in Cancun.
- (COP16) from November 29 to December 10. Signatory States to the United Nations Framework Convention on Climate Change

-(UNFCCC), to establish objectives and make decisions aimed at preventing global warming and its effects. A global agreement has been approved. The Copenhagen Agreement, which limits global warming to 2°C above pre-industrial levels, is intended to be strengthened.

2011: Durban Conference (December): An agreement for the creation of a Global Compact in 2015 is signed and a research group is formed.

2012: The Sustainable Development Goals (SDGs) were developed as a follow-up to the Millennium Development Goals by a research group. The Earth Summit in Rio (Rio+20), June 20 to 22: "The Future We Want", an agreement covering the main principles of sustainable development, was signed. It regenerates the promises already made at previous summits and establishes an immediate action framework for the elimination of poverty as well as the protection of the environment. (Préfet de Seine-et-Marne, 2012).

2015: - UN Sustainable Development Summit.

- 21st Conference of Parties (COP21): UN Framework Convention on Climate Change.

2018: Global Warming of 1.5 ºC (IPCC Special Report).

2019: UN Climate Action Summit.

2021: IPCC Reports for Assessment Report 6: The Physical Science Basis website.

2022: IPCC Reports for Assessment Report 6: Impacts, Adaptation and Vulnerability website (Dag Hammarskjöld Library, n.d.).

II.7. The contribution of urban areas to climate change

For a number of reasons, it is essential to study the impact of metropolitan areas on climate change. Firstly, cities and the way they operate are linked to a wide range of activities (Figure II.7) that contribute directly to greenhouse gas emissions (such as transport, energy production and industrial production). And let's not forget that food, water and consumer goods are necessities for metropolitan areas, and that their manufacture can result in GHG emissions outside the cities themselves. Secondly, by measuring the carbon footprint of different cities, it would be possible to compare them and encourage collaboration and competition between them with the aim of reducing emissions. Thirdly, to accurately determine who is responsible for what is happening, it is important to understand how cities contribute to climate change.

Last but not least, with regard to the issue of responsibility, it is essential to understand the distinction between studies of carbon dioxide emissions that use production statistics and those that rely on consumption data (Gao et al., 2018).

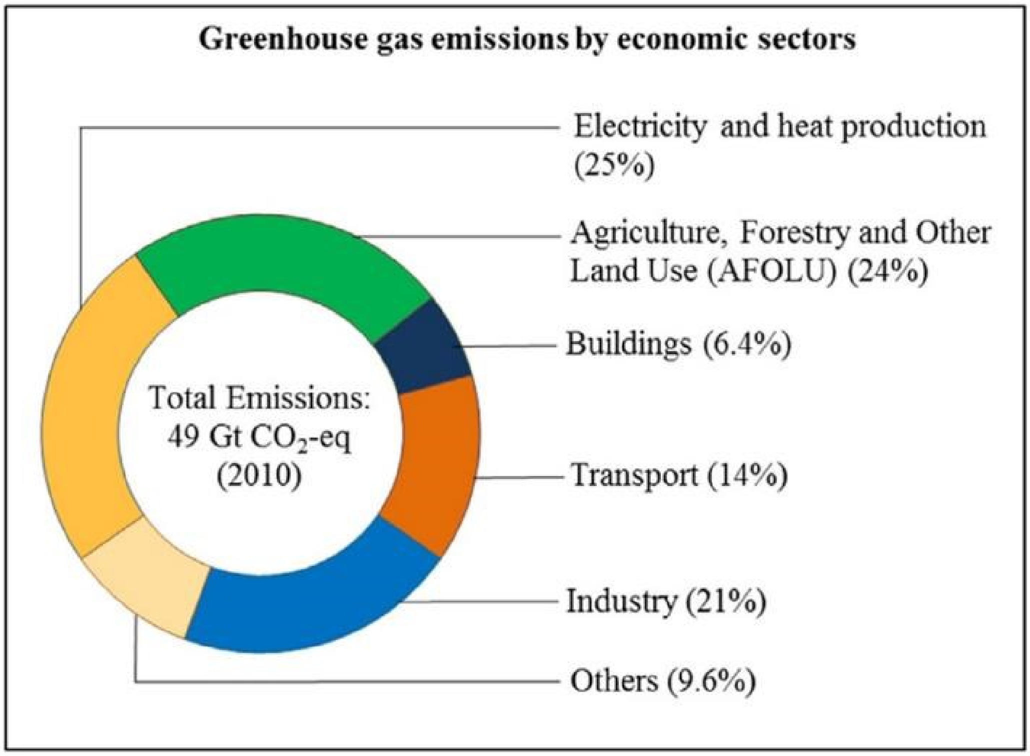


Figure II. 7. Percentage of direct GHG emissions from the main economic sectors in 2010 compared with total anthropogenic GHG emissions (Stocker et al., 2013).
Source: (Gao et al., 2018).

The energy sector was responsible for about two thirds of global carbon dioxide emissions in 2012. Additionally, CO2 emissions from energy constituted approximately seventy percent of human-made greenhouse gas emissions in industrialized countries. These figures are based on the International Energy Agency's 2015 report titled Energy Technology Perspectives.

The main environmental health risks in the energy industry encompass atmospheric pollution, carbon dioxide emissions, occupational hazards, and the possibility of sporadic large-scale accidents. These factors (Figure II.8) collectively account for a disproportionately high proportion of environment-mediated diseases and fatalities around the world compared to other industries (Prüss-Üstün et al., 2004; K. R. Smith & Haigler, 2008).

Furthermore, the combustion of petroleum-based products, particularly the use of fossil fuels, results in air pollution, such as particulate matter (PM), nitrogen oxides (NOx), and sulphur dioxide (SO2), which increases the rate of death and disease (Cifuentes et al., 2001; K. R. Smith & Haigler, 2008), alongside countries that are developing experiencing the greatest effects due to the increased utilization of coal as well as the generally less strict emission control regulations. According to estimates, ambient particulate pollution is responsible for around 3.2 million premature mortalities worldwide, or about three percent of the worldwide burden of diseases (Lim et al., 2012; K. R. Smith et al., 2015; Forouzanfar et al., 2016).

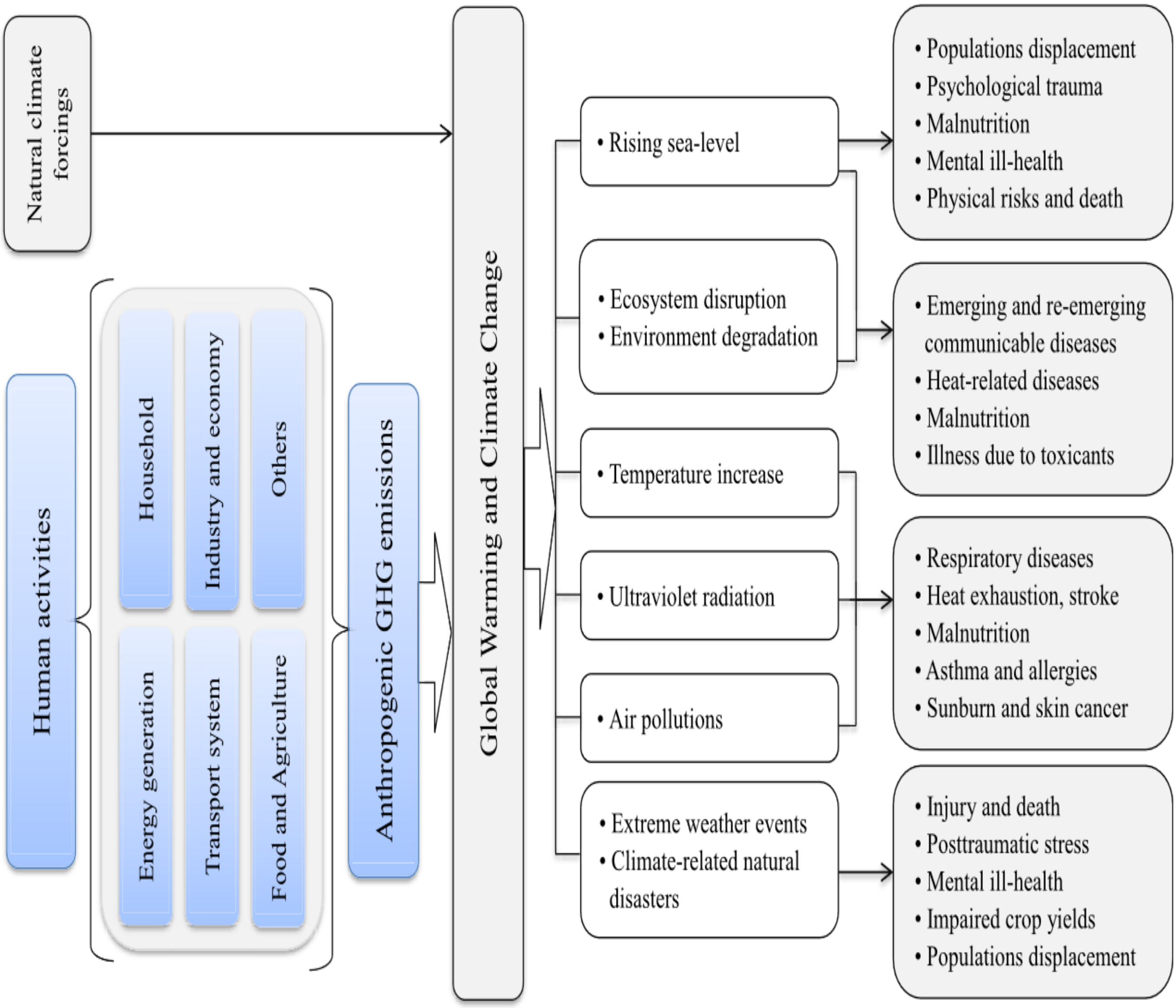


Figure II. 8. principal causes of climate change as well as potential channels by which it affects public health.

Source: (Gao et al., 2018).

The WHO has listed air pollution as a part of the top ten contributors of the world's epidemics. Given that the sources of greenhouse gas emissions along with pollutants in the air in the energy industry are largely the same, it is important to emphasize that advances in a variety of green energy technologies, such as decarbonizing energy production, enhancing efficiency in energy use, as well as transitioning to a different energy structure, have a significant potential to reduce climate change, reduce air pollution, and benefit ancillary well-being (Gao et al., 2018).

II.7.1. Transport sector

The transport sector is presently the second-biggest energy consumer behind industry, accounting for nearly sixty percent of global oil consumption and also thirty percent of all supplied energy globally (Atabani et al., 2011). Automobiles, including, buses, as well as trucks, are a major source of human greenhouse gas emissions worldwide.

According to estimates by (Ribeiro, 2007; Woodcock et al., 2009), transportation systems are responsible for 23% of global energy-related GHG emissions, with 74 percent of the total emissions coming from land transportation (cars, buses, as well as trucks).

Globally, emissions of greenhouse gases from transportation systems are expected to rise quickly and could be as much as eighty percent greater in 2030 compared to what they were in 2007 (Ribeiro, 2007; Xia et al., 2013; Woodcock et al., 2009). Additionally, both in developed and developing nations, traffic-related pollutants like PM as well as NOx have a significant and direct influence on public health (Begg et al., 2007; Sofiev et al., 2018; Yim & Barrett, 2012).

According to estimates, the proportionate contributions of buses, trucks, motorcycles, and automobiles to PM2.5 concentrations are 69%, 23%, 5%, along with 3%, respectively, while the transport system contributes approximately sixty percent of all PM2.5 (Sá et al., 2017).

Heavy-duty trucks are the greatest source of NOx emissions from motorized vehicles internationally, in addition to producing significant amounts of SO2 and PM (Takeshita, 2012). The manufacturing of lower-emission and more efficient motor vehicles (cars, buses, and trucks), as well as encouraging the development and study of affordable environmentally friendly alternatives to diesel engines, have the possibility of helping improve the climate, the quality of the air, as well as the general well-being. The harmful air pollutants produced by motor vehicles include PM, NOx, VOCs, as well as CO. A number of the pollutants, including NOx and BC, are additionally climate-active. Transport systems are now a significant source of urban air pollution and greenhouse gas emissions, especially in emerging metropolitan centres throughout the world (Woodcock et al., 2009; Y. Li & Crawford-Brown, 2011; Chang et al., 2017).

II.7.2. Food and agriculture

Agriculture is predicted to produce up an approximate fifty percent increase in greenhouse gas emissions by 2030, in accordance to the IPCC, accounting for 10 to 12 percent of all worldwide emissions of greenhouse gases (P. Smith et al., 2007).

In addition, agriculturally driven land use changes like overgrazing as well as deforestation are responsible for an additional 6 until 17% of worldwide greenhouse gas emissions (Bellarby et al., 2008). The ensuing important elements should be borne in mind, in order to properly respond to these emissions of greenhouse gases concerns in the agricultural sector.

The first largest contributor to carbon dioxide emissions, and about eighty per cent of all agriculture-related emissions, was livestock production (which includes the use of energy and fertiliser to grow grain to feed the animals), CH4 from the digestive processes of ruminants, and transport of animal products for processing and sale (McMichael et al., 2007; Steinfeld et al., 2006; Younger et al., 2008). Furthermore, farming produces nearly fifty percent of all food-related greenhouse gases, involving carbon dioxide from deforestation alongside agriculturally-induced changes in land use, nitrogen dioxide from pasture along with arable land utilized to cultivate feed crops, as well as emissions of CH4 from livestock (Steinfeld et al., 2006; Reisinger & Clark, 2017).

In the past few decades, the rise of agriculture—particularly for dairy and cattle farming—has sped up the clearing of forests. As an example, it is stated that pasture and feed crops are currently grown more than seventy percent of the Amazon's once wooded area (Steinfeld et al., 2006).

Finally, only a small number of studies, like (Biesbroek et al., 2014; Macdiarmid, 2014; Springmann et al., 2016) have examined the effect of consuming local, seasonal, or sustainable food on greenhouse gas emissions, and the findings are inconclusive and inconsistent. To identify the true relationships and impacts of these elements, more studies are needed in this field.

II.7.3. Residential and household sector

Even though they only make up 4.3% of the world's population, American homes alone are either directly or indirectly accountable for twenty percent of the world's annual emissions of greenhouse gases (Weber & Matthews, 2008; Jones & Kammen, 2014).

According to (Wilkinson et al., 2009), the United Kingdom's residential structures generate roughly 140 megatons of carbon dioxide (CO2) annually, or about twenty-six percent of all emissions in the nation. Housing structures were estimated by the IEA to be directly responsible for almost eighteen percent of the world's carbon dioxide emissions in the year 2008, with eleven percent of those emissions coming from residential consumption of grid electricity as well as district heating and the remaining resulting from household-level cooking and heating via energy from fossil fuels (biomass was excluded) (Dora et al., 2011). According to (Haines et al., 2009), the major source of greenhouse gases in high-income nations like the UK along with the USA is the high energy usage of cooling, heating, as well as electricity. The situation is different in the world's poorest areas. Almost ten percent of the worldwide energy is consumed by the poorest fifty percent of families, who mostly use biomass or coal for cooking, heating, as well as lighting (Goldemberg et al., 2004). According to (Anenberg et al., 2011; IPCC, 2011), household use of wood-based fuels accounts for around 7% of world energy consumption and is often linked to inappropriate forest harvesting that has a detrimental impact on atmospheric carbon dioxide uptake. In light of all these methods, it is possible that the household sector contributes more to global greenhouse gas emissions than has yet been acknowledged.

Household air pollution from cooking as well as space heating is linked to nearly 3.5 million premature mortality per year, or 4.4 percent of the world's total burden of disease, mostly in women and children in developing countries (Wilkinson et al., 2009; Lim et al., 2012).

Pollution from indoor environments is now recognized as one of the primary environmental contributors of ill health around the world. According to estimates made by (Bailis et al., 2005), household biomass uses between the years 2000 until 2030 within the sub-Saharan region of Africa will result in approximately eight million fatalities from respiratory illnesses in children as well as 1.7 million fatalities from chronic obstructive pulmonary disease, also known as in adult women. As a result, there is opportunity for the residential alongside household sector to engage in action to slow climate change and profit from enhanced wellness (Wilkinson et al., 2009; Dora et al., 2011), while some of these a mutually beneficial approaches have been demonstrated or estimated to be economically feasible. Given the complexity of the problems, mitigation plans for wealthy nations often concentrate on lowering household energy use along with increasing energy efficiency through technological advancements in materials, fuel switching, as well as behavioural changes. However, no one intervention is going to be sufficient (Gao et al., 2018). For British housing, for example, the magnitude and direction of impacts on human well-being can vary depending on how housing-related measures (energy efficiency measures) are implemented and sustained, while the holistic approach that combines building structure, air circulation, fossil fuel substitution and behavioural changes results in the greatest cost benefits, resulting in 0.6 MT CO2 savings and 850 fewer DALYs per million people per year, compared to the 2010 reference scenario. The goal of greater energy efficiency can, however, have adverse consequences for indoor air quality and lead to biological pollution. As a result, buildings must have sufficient ventilation, such as ventilation systems featuring heat recovery and air filtering (Vardoulakis et al., 2015). Properly planned and implemented household measures in low-income nations can lead to cost-effective health benefits. These measures include increasing household solid fuel combustion efficiency (Dora et al., 2011), promoting modern low-emission appliances, replacing conventional cooking and space heating procedures with clean household fuel alternatives as well as low-emission cooking appliances (Wilkinson et al., 2009; Ochieng et al., 2013). According to an Indian study, efforts to create low-emission biomass cooking appliances and distribute them to households currently using traditional stoves could save 80 MT of

CO_2 equivalent per year and prevent more than half a million premature deaths of low-income women and children through reduced air pollutants (Venkataraman et al., 2010).

Given that 41% of all households worldwide rely on solid fuel for food preparation, especially those living in poverty in developing communities (Pachauri et al., 2014), strategies such as providing low-cost, reliable low-emission appliances and clean cooking energy options for poor households in nations with the highest levels of indoor air pollution (Venkataraman et al., 2010) can also offer revolutionary opportunities to simultaneously improve the physical and mental well-being of vulnerable groups, particularly women and children, while reducing local greenhouse gas emissions (Dora et al., 2011; Wilkinson et al., 2009).

II.7.4. Industrial and economic processes

According to (Atabani et al., 2011; Watts et al., 2017), the industrial sector consumes more energy than transportation systems globally by 30%, and its global greenhouse gas emissions are equivalent to those of the agricultural sector (McMichael et al., 2007).

Industrial and commercial operations release dangerous air pollutants, such as PM, NO_x, SO_2, and BC, which have an immediate impact on public health. Research conducted in the United Kingdom (Yim & Barrett, 2012) indicates that industrial combustion pollutants cause over 800 premature deaths annually.

Therefore, for the industrial as well as the economic sectors, greenhouse gas reduction can be reasonably expected to have beneficial health consequences because of the reduction in air pollutants obtained through a range of measures, notably abandoning fossil energy production (Thambiran & Diab, 2011), improving energy efficiency (Liu et al., 2013), adapting industrial as well as energy patterns (Wu et al., 2015), boosting the application of clean and renewable energies (Zhai et al., 2011), raising investment in low-carbon technologies (Aunan et al., 2004), and the implementation of a green development mechanism, especially in fast-developing nations (Vennemo et al., 2006).

If each of these measures are properly put into place and coordinated, they may work in unison to solve the problems brought on by air pollution, global warming, and the threats to public health that go along with them.

A 77 percent of carbon dioxide emissions reduction across the Mexican economy, for instance, could prevent 2718 premature mortality due to the corresponding drops in ozone as well as PM concentrations compared to the Bottom-Up Approach (BAU) scenario, according to hypothetical global warming mitigation procedures scenarios (Crawford-Brown et al., 2012).

II.8. Framework for more sustainable & resilient cities

Urban design and city planning involve a variety of disciplines that are necessary for informing governance, management, and sustainable systems to support resilience to climate change. They have geographical outcomes with implications for climate change and define responses to them (refer to Figure II.9). The geographical structure of a city, from metropolitan area size to neighbourhoods, significantly impacts per capita GHG emissions. A 10% reduction in urban expansion results in a 6% decrease in per capita carbon dioxide emissions (Laidley, 2016). While compact urban design typically facilitates climate change mitigation, it can, in contrast, aggravate local climate impacts, thus requiring innovative adaptation strategies.

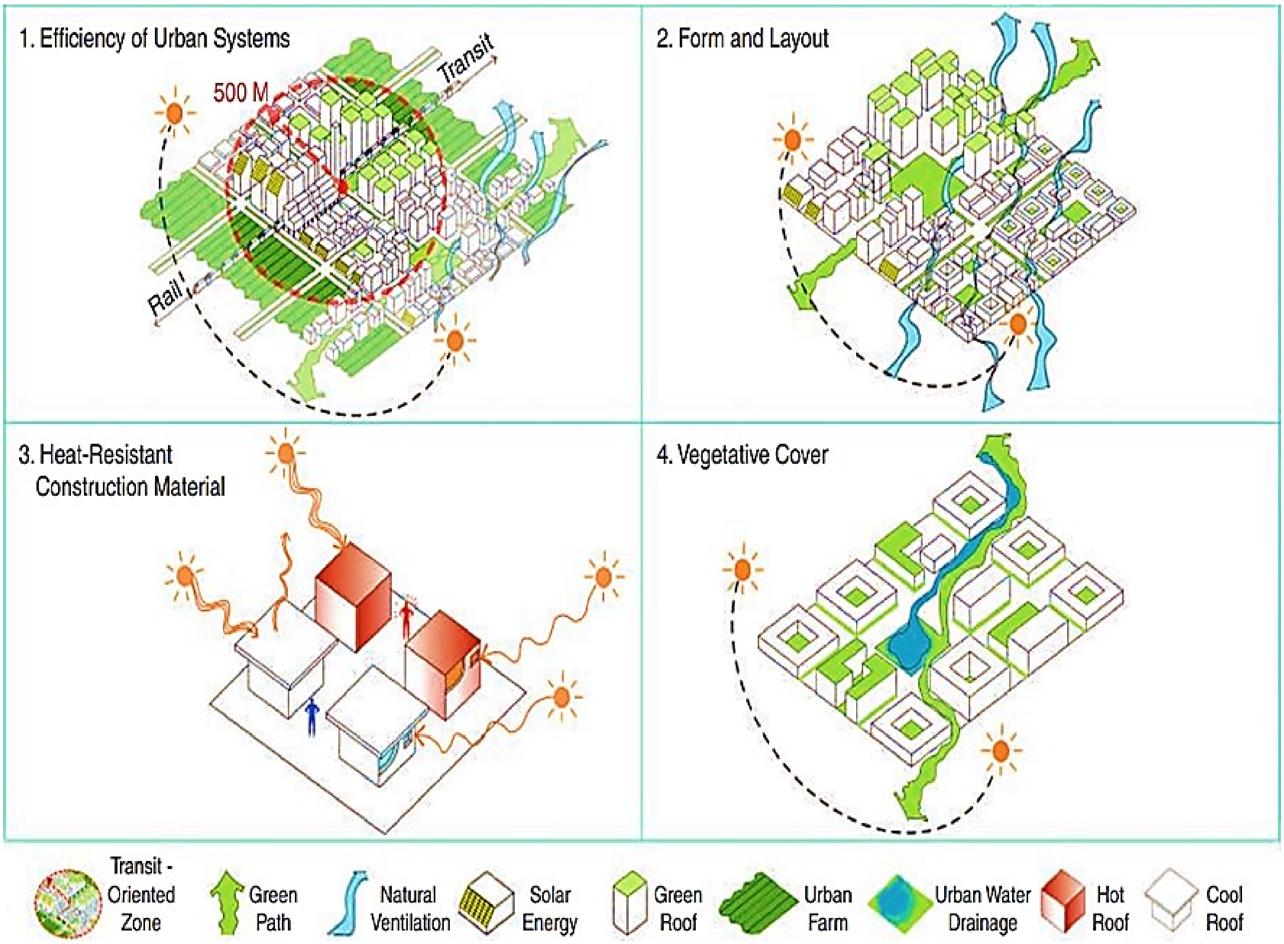


Figure II. 9. Urban designers and planners employ the following methods to enable integrated adaptation as well as mitigation in cities: (1) lowering emission of carbon dioxide and wasting heat through energy efficiency, accessibility to public transportation, and walkability, (2) altering the shape and design of buildings as well as urban areas, (3) the application of reflecting surface coatings and heat-resistant building materials, and (4) expanding the amount of vegetation. Source: (Raven et al., 2018).

Planning and design strategies increasingly offer mutually beneficial solutions for densely populated cities, following extensive research in this field. Despite this, many metropolitan areas remain underdeveloped and will need to reduce greenhouse gas (GHG) emissions and prepare for the effects of climate change. In addition to the necessary levels of compactness, modern urban development must prioritise consideration of location. Urban climate interventions must be planned and designed according to a four-phase methodology, as shown in (Figure II.10).

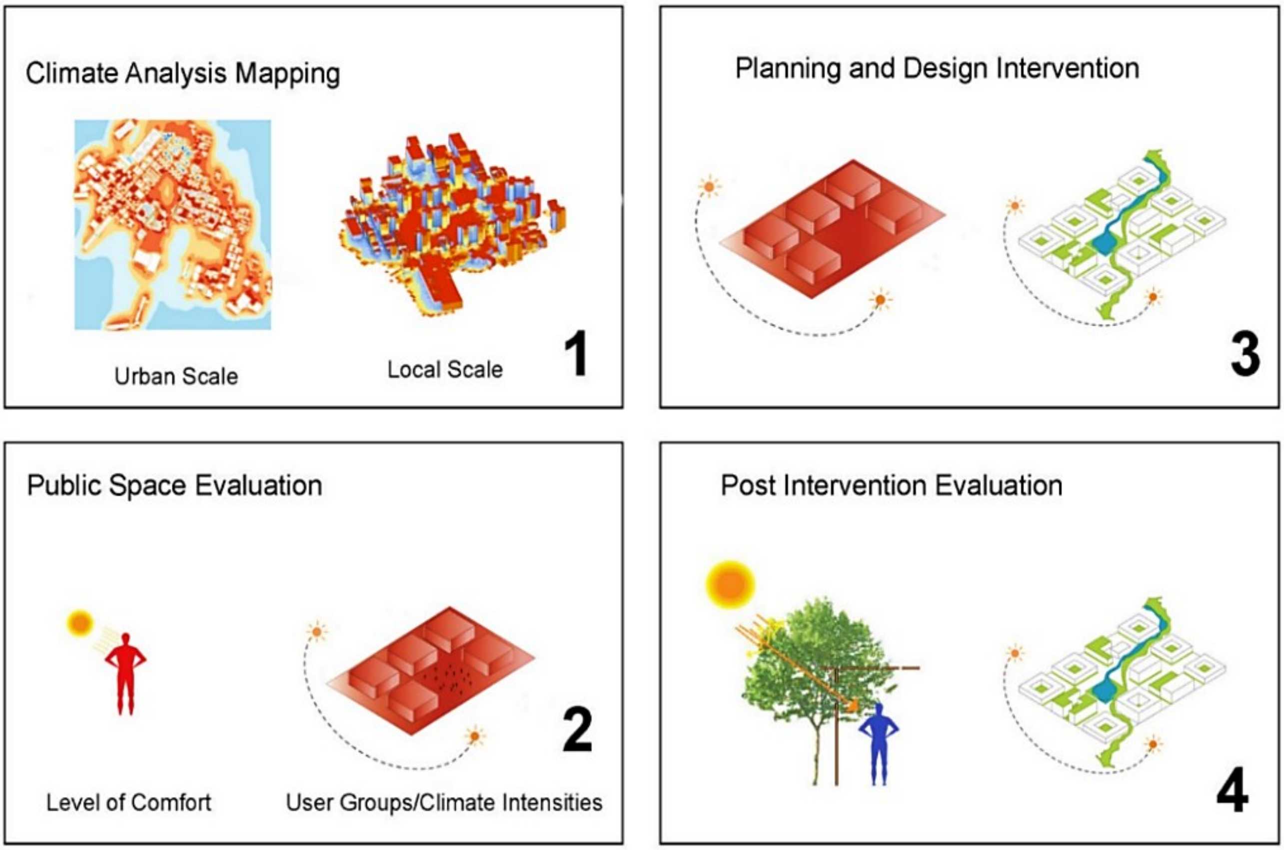


Figure II. 10. Urban climate planning and design process.

Source : (Raven et al., 2018).

II.8.1. Climate Analysis and Mapping

Understanding the global climatic conditions and the specific local climates within inner cities, and their reciprocal relationships, is the initial stage in tackling climate concerns in urban planning and design. Several factors need consideration, including the frequency and regional occurrence of air mass exchange (ventilation), as well as their frequencies. Additionally, the seasonal evolution of the thermal and air quality impacts of the urban climate (such as stress areas, solar radiation, shading conditions), the regional representation and assessment of the impact area in addition to stress areas, as well as the energy optimisation of the geographical distribution based on the urban climate study, taking into account heat load areas, air temperatures in cooler areas, and building density.

Identifying metropolitan areas that suffer the most from extreme weather events, rising temperatures, and increased precipitation requires climate assessments as well as maps. A climate analysis map can be developed in stages, incorporating spatial reference data.

The level of spatial resolution is adjusted based on the planning required. Climate analysis tools for urban planning often use maps that show urban heat hotspots and flood-prone zones. To create an urban climate map, the Geographical Information System must integrate topographic data, buildings, surface roughness, and vegetation (Raven et al., 2018).

II.8.2. Evaluation of Public Space

Urban planning assessments should consider the local climate of the city. The use of urban climate maps is becoming more prevalent in urban development and open space planning.

To anticipate potential land-use alterations, inclusive approaches, including dynamic geospatial information systems, surveys, and quantitative representations and specifications for space and time, should involve the public at all stages.

At a regional level, the primary goals of planning actions are to protect areas with important climatic functions, which include regions with a high level of heat, sufficient fresh air, and effective ventilation flows (Raven et al., 2018).

II.8.3. Planning and Design Interventions

Improving thermal conditions as well as air quality is the goal of the design and planning of actions that are pertinent to urban climatology:

• Reducing heat islands, a sign of thermal comfort or even discomfort, via the design of public spaces.

• Improving urban ventilation through wind corridors and air exchange.

• By removing obstacles to air exchange, stagnant air in stationary temperatures inversion situations can be avoided.

• The upkeep and development of regions that produce fresh air or cold air in order to increase air exchange and enhance air quality.

Maintaining cool air and promoting fresh air generation sites and ventilation paths, along with considering the orientation, height, as well as development density of buildings, are examples of regional standards. These standards can be implemented through urban planning for land use, in line with building codes. Additionally, mandatory requirements for open spaces may also be included in the zoning plan as a result of urban climate evaluations.

It is crucial to investigate regional regulations to ensure that both regional and urban planning consider climate-related issues (Raven et al., 2018).

II.8.4. Post-Intervention Evaluation

In order to assess the effectiveness of city design and planning interventions in promoting microclimate, it is necessary to conduct field measurements. The infrared thermal imagery along with population surveys can be utilized to compare temperature differences before and after an intervention. By extending moderate temperature periods, climate-resilient solutions can enhance public health and lead to energy savings (Raven et al., 2018).

II.9. High-performance Labels

Improving building performance is crucial in the worldwide energy context. In recent years, a lot of countries created certification systems, as shown in (Figure II.11) to measure how eco-friendly and energy-efficient buildings are. This objective is to decrease energy consumption and environmental impact throughout the building's life stages, such as when being developed, managed, and operated.

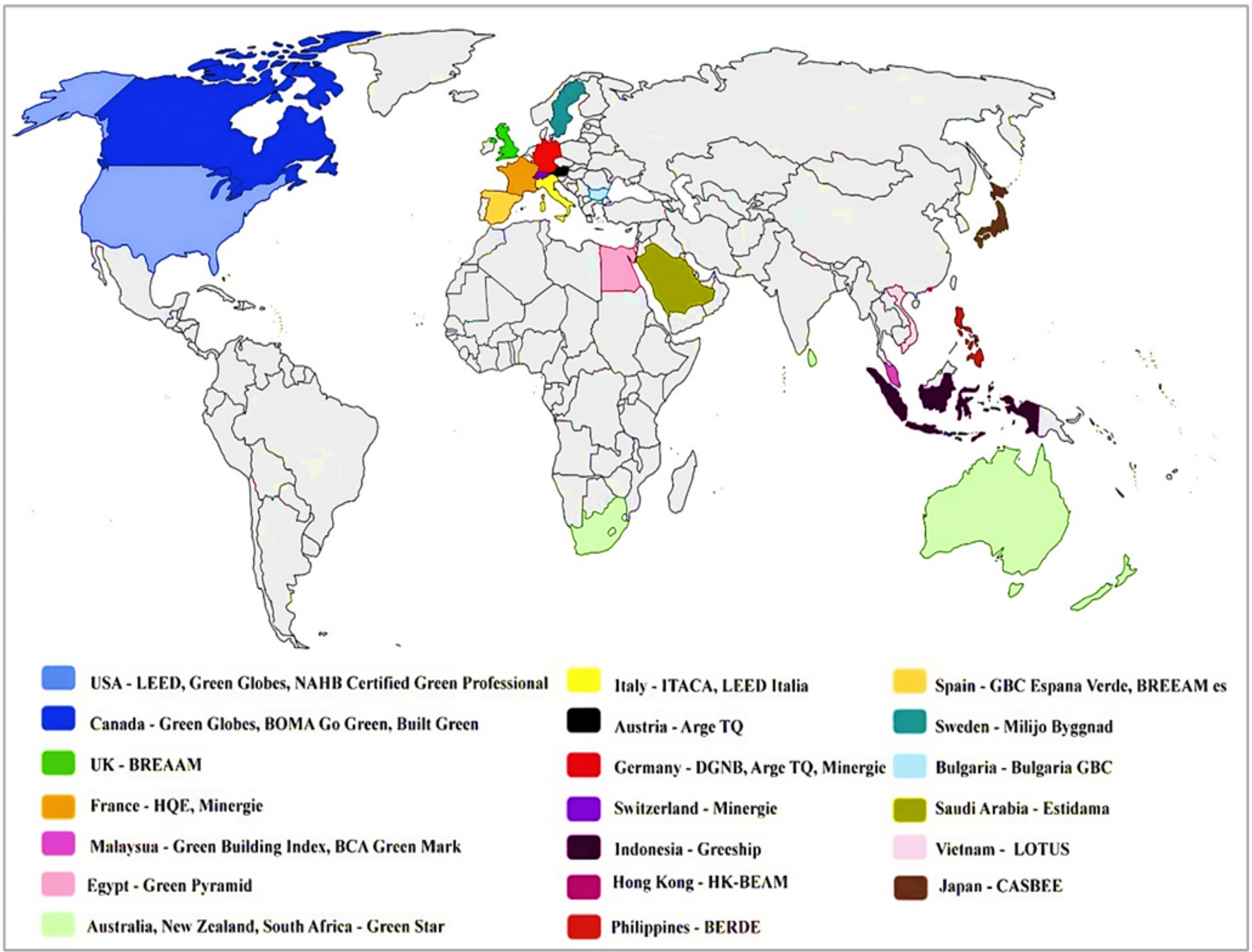


Figure II. 11. International map of sustainable building labelling systems.

Source : (Mattoni et al., 2018).

II.9.1. Energy labels

Energy labels highlight energy production, renewable sources, and efficiency. They became popular after the oil crises of 1973 and 1979. In Europe, they were based on the German passive building concept and implemented by the Passivhaus label. Switzerland adopted the concept through the Minergie label, and France through the Effinergie label. The designations 'zero energy buildings' (Minergie A) and 'positive energy buildings' (BEPOS Effinergie) were later adopted.

The concept of a 'Net Zero Energy Building' is based on good energy performance benchmarks for housing in the United States, or regular surveys of usage for non-residential structures. The aim is to reduce peak periods on electricity grids (Carassus, 2016). (Figure II.12) below compares three energy labels based on different aspects.

	PASSIVHAUS	MINERGIE	EFFINERGIE
Country	*Germany*	*Switzerland*	*France*
Creation	*1980*	*1998*	*2007*
Certifier	*Passivhaus Institute*	*Minergie*	*Cequami, Promotelec, Cerqual, Certivea*
Energy usage	*Heating, hot water, cooling, lighting, other uses*	*Heating, hot water, cooling*	*Heating, hot water, cooling, lighting*
Requirements	*Heating 15 kWh ef/m²/year All uses 120 KWh ep/m²/year*	*New housing 38 KWh ep/m²/year Existing housing 60 KWh ep/m²/year modulated*	*New housing 40 KWh ep/m²/year Existing housing 80 KWh ep/m²/year modulated*
Temperature	*20°C*	*20°C*	*19°C*
Primary/final electricity coefficient	*2,85*	*2*	*2,58*
Surface	*habitable*	*heated premises*	*excluding net work*

Figure II. 12. Comparison between 3 energy labels.

Source: (Carassus, 2016).

II.9.2. Environmental labels

Environmental labels for buildings incorporate energy efficiency as well as environmental, comfort, and health criteria. This second generation of labels, introduced in the 1990s, considers not only energy but also environmental, comfort, and health factors. Various environmental labels were developed later, such as the French HQE, American LEED, UK's BREEAM, Japanese CASBEE, Australian Greenstar, German DGNB, Swiss Minergie Eco, Brazilian AQUA, and Indian GRIHA (Carassus, 2016). (Figure II.13) compares three ecological labels based on different aspects.

	BREEAM	LEED® CERTIFICATION	HQE®
Country	*United Kingdom*	*United States*	*France*
Creation	*1990*	*1998*	*2005*
Certifier	*BRE Global*	*USGBC*	*Certivea, Cerqual, Cequami, Cerway*
Targets	*energy, water, pollution, materials, transport, ecology and land use, health and comfort*	*site, water management, energy, materials and resources, interior design, innovation and process*	*site, materials, worksite, energy, water, waste, maintenance, hygrothermal, acoustic, visual, olfactory, quality of spaces, air and water*
Evaluation	*Pass, Good, Very good, Excellent*	*Certified, Silver, Gold, Platinum*	*Pass - Good - Very good - Excellent - Exceptional*

Figure II. 13. Comparison between 3 environmental labels.

Source: (Carassus, 2016).

II.9.3. Labels made on factors related to the idea of a responsible building

This type of labelling is associated with the concept of responsible building, including low carbon emissions, biodiversity, and quality of life. For example, American labels such as Living Building Challenge™ and Well Building Standard, as well as the French label 'Bâtiment Bas Carbone' (BBCA) and Biodivercity labels, have gained popularity. In 2016, the 'Bâtiment Bas Carbone' label was launched in France with the goal of reducing CO2 emissions over a building's lifespan. This is achieved through rational building design and managed building operations, which value the storage of CO2 and recycling of waste from construction sites (Carassus, 2016).

II.10. High performance buildings

High-performance buildings are structures that achieve energy efficiency and greenhouse gas reduction levels surpassing regulatory demands. This involves delivering a considerably enhanced level of performance compared to mandates set by building codes and other regulations. To create high-performance buildings, architects, designers, along with constructors commonly utilise established methodologies, tools, techniques, and materials. The aim is to ensure that the completed buildings use very little energy for heating, cooling, lighting and ventilation during operation. This is achieved by implementing energy-efficient systems during the design stage and utilizing innovative materials in the construction process. Below there are some examples of this kind of buildings:

II.10.1. Passive housing

The most exacting heating standard is for passive housing. A high efficiency exterior safeguarding structure, high performance glazing and doors, without thermal bridge, beneficial sealing, in conjunction with the recuperation of heat, mechanically powered ventilation to guarantee the quality of indoor air, with no active heating. Heat from direct sunlight, occupants, and indoor daily devices are typically required.

The regulation stipulates that the energy used for heating cannot exceed 15 kWh/m2/year, regardless of the weather conditions, assuming a constant internal temperature of 20°C. In 2012, 57,000 structures across 31 European nations complied with this regulation. Early European structures had minimal insulation, resulting in a 6-12 times reduction in heat load in southern Europe and up to 30 times in colder regions (IPCC Authors, 2014).

II.10.2. NZEB

The term "near-zero energy building" (NZEB) is utilised within the European Union and has connections to related terms such as "zero energy building" (ZEB), "net-zero energy building," and "zero net energy building.". It is important to note that the usage of these terms may vary depending on the nation, organisation, city, or report. Heat pumps, energy-efficient windows, solar panels, thermal insulation, and other technologies are deployed to produce the amount of renewable energy utilized annually by buildings, equal to off-site renewable energy production. The aim is for the greenhouse gas emissions of these buildings to be lower than comparable non-net zero structures. Nevertheless, there are scenarios in which it decreases energy consumption and carbon gas emissions in other areas. In addition to the aspiration of reducing environmental impact, zero energy buildings are often driven by financial incentives (Goodier, 2023).

II.10.3. BIPV

The installation of photovoltaics (PV) into the envelope of the building is known as building integrated photovoltaics (BIPV). The PV modules act as both a power generator and the exterior skin of the building, taking the place of traditional building envelope materials. The additional expense of photovoltaics is decreased as well as its total operational cost is enhanced by avoiding the price of traditional materials. In other words, BIPV systems frequently cost less in the long run than PV systems that require separate, specialized mounting systems (Strong, 2016). A comprehensive BIPV system includes the following components:

1- The PV modules (thin-film or even crystalline, translucent semi-transparent, or deliberately opaque).

2- The charge controller (in stand-alone systems) to regulate power entering and leaving of batteries storage banks.

3- The power storage systems, which is often made up of the power grid in utilities-interactive systems or a collection of batteries in separate systems.

4- A Power conversion equipment, such as an inverter, to convert the DC output of the PV modules to AC compatible alongside the utility grid.

5- The backup power sources, including diesel generators (optional; commonly used in stand-alone systems).

6- AN appropriate mounting and support hardware, wiring, along with security disconnects.

II.10.4. Green building

The term "green building" (also referred to as "green construction" or "sustainable building") covers the entire life cycle of a building, including its planning, layout, construction, operation, upkeep, renovation, stewardship of the environment, resource conservation in the building's construction as well as its execution process, as well as demolition (PNNL Website, 2021).

Green building differs slightly from zero energy building in that it considers all environmental effects, including resource use along with water pollution, whereas zero energy building only considers the use of energy by buildings and the capacity to generate an equivalent amount of energy from renewable sources (Goodier, 2023).

II.10.5. Positive-energy building

The zero use of energy building is expanded upon by the positive energy building (PEB). In order to realize the usage of clean energy as well as renewable energy, it uses new technology and goods, such as solar panels, as well as recycled building materials whenever possible. It creates electricity for the purpose of earning money in addition to saving energy and carbon (IPCC Authors, 2014).

The energy generated in PEB is not only greater than that needed to operate the building, but it can also be used to refuel electric vehicles.

II.11. Conclusion

The main environmental problem the world is facing is climate change, which is causing the planet to warm up at an unsustainable rate. The issue is worsened by uncontrolled urbanization, which results in an increase in human-caused greenhouse gas emissions. As a result, cities have high energy demands that make the urban environment neither healthy, nor sustainable.

Through international gatherings, conferences, and protocols, a number of organizations and authorities have been established globally to carry out high-level research on the effects of climate change on the planet. Developing mitigation and adaptation strategies for climate change is their main goal, and the different meetings and conferences are in continuous increasing since more than four decades. Earlier studies have shown that urban agglomerations, through their various sectors, contribute to the emission of different types of dangerous greenhouse gases, which have an impact on the health and lives of people and affect the natural environment and biodiversity. This demonstrates the critical role that cities must play in combating climate change through sustainable development that makes use of the technical and resource capacities of the city while also considering the welfare of its residents and the preservation of natural ecosystems. For a climate intervention of this measure to be successful, tactics such as mapping climate analysis, evaluating public spaces, designing interventions and conducting post-intervention assessments need to be put into practice at the design and planning stages.

Over the past thirty years, many energy and environmental labels for both buildings as well as towns and cities have been developed, which are considered to be quality indicators aimed at achieving better levels of energy and environmental performance, based on a public technical framework and implemented on a voluntary basis. Labels are employed voluntarily and supported by a public technical reference system, and are connected to the entire structural lifecycle, including urban planning, design, construction, renovation and operation.

In addition to the application of passive concepts and interventions, a variety of renewable energy sources can be used in the design of the building envelope. One of the most practical energy sources is solar energy, which can be used in a variety of ways, including solar thermal collectors, daylighting, passive heating, and photovoltaic systems. The high-performance building can meet the energy efficiency requirements by employing these passive, active strategies. It is anticipated that building types like Net Zero Energy Buildings (NZEB), Buildings Integrated Photovoltaics (BIPV), Positive Energy Building (PEB), and Buildings Applied Photovoltaics (BAPV) will meet the requirements for high energy efficiency and climate change adaptation.

CHAPTER III

Algeria's energy situation, regulations and legislations

III.1. Introduction

Algeria heavily relies on fossil fuels due to its substantial oil and gas reserves. It is amongst the world's leading hydrocarbon producers and is affiliated with the Organization of Petroleum Exporting Countries (OPEC). Over 90% of hydrocarbon profits originating from Algeria are exported. The African continent's largest surface area benefits from over 3000 hours of sunshine annually, indicating substantial solar potential. Therefore, Algeria has the potential to make a considerable contribution to the field of renewable energy (Ersoy & Terrapon-Pfaff, 2021).

However, due to competing political visions, the nation is currently only utilizing a small portion of this potential and is at a turning point in the creation of a new energy system (Hochberg, 2020).

Algeria agreed to reduce its greenhouse gas emissions by 7 percent by the year 2030, in accordance with the Paris Agreement in comparison to the business-as-usual situation (INDC of Algeria, 2015). And with assistance from other nations, the Algerian country may possibly be able to cut its greenhouse gas emissions by twenty-two percent by the year 2030 (Darby, 2015).

Although Algeria has put in place a legal framework to utilise applicable technologies and has set ambitious goals for sustainable energy, the current proportion of renewable energy sources in its overall energy mix remains inadequate. The COVID-19 pandemic has exposed the country's acute vulnerability to fluctuations in oil and gas prices worldwide. Furthermore, the progress towards transitioning to clean energy has slowed down due to the pandemic.

Depending on the efforts and desires of the top political decision-makers in the country, the crisis could potentially serve as a catalyst for a significant transformation and ultimately prioritising investment in clean energy (Ersoy & Terrapon-Pfaff, 2021).

The reason for shifting to renewable energy for energy security is because traditional energy sources, which include fossil fuels, are finite and can cause damage to the environment and political instability. Renewable sources of energy, on the flip side, are plentiful and ecologically sound, and may offer a long-term reliable and economical source of energy.

The principal objective of this chapter is to provide insights on how the use of energy has changed over the past two to three decades, to determine the country's current energy situation in terms of renewable and non-renewable sources, and to demonstrate the promising potential of alternative green energies in Algeria, the viability of developing and utilizing these resources within the framework of Algeria's energy transition, as well as the attempts of the government, citizens, and the private sector.

III.2. Evaluation of the Algerian energy situation

In addition to the industrial growth, and the urbanization, Algeria's increasing energy demand is being driven by a combination of demographic change, as the (Figure III.1) shows, where the increasing of population from almost 35 million to almost 42 million, was followed by an increasing of national electricity consumption from 32 TWh to 79 TWh.

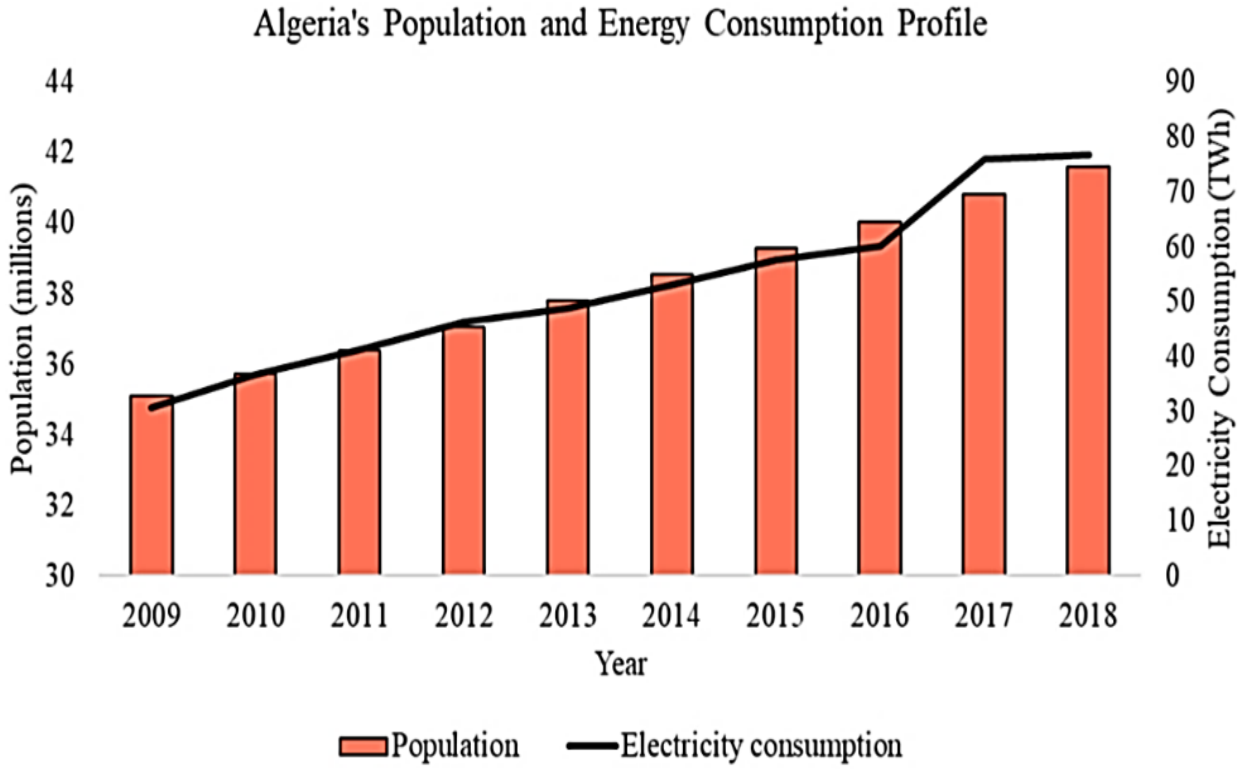


Figure III. 1. The evolution of Algerian population, as well as yearly electricity consumption, between 2009-2018.

Source: (Zahraoui et al., 2021).

The (Figure III.2) displays the distribution of the energy use by industry, in the year 2018; showing that the building industry in Algeria is the biggest consumer of fossil fuels, accounting for 46% of the overall national energy bill, of which 37% is used by residential buildings, followed by transport sector with 31.7%, and then, the industrial sector with 21.7%; knowing that the total annual energy consumption in the year 2018 was 48.1 MTep.

According to (Figure III.2) also, the residential sector's energy consumption increased significantly over the course of the previous ten years (2009-2018), rising from about 9000 KTep to greater than 17,700 KTep.

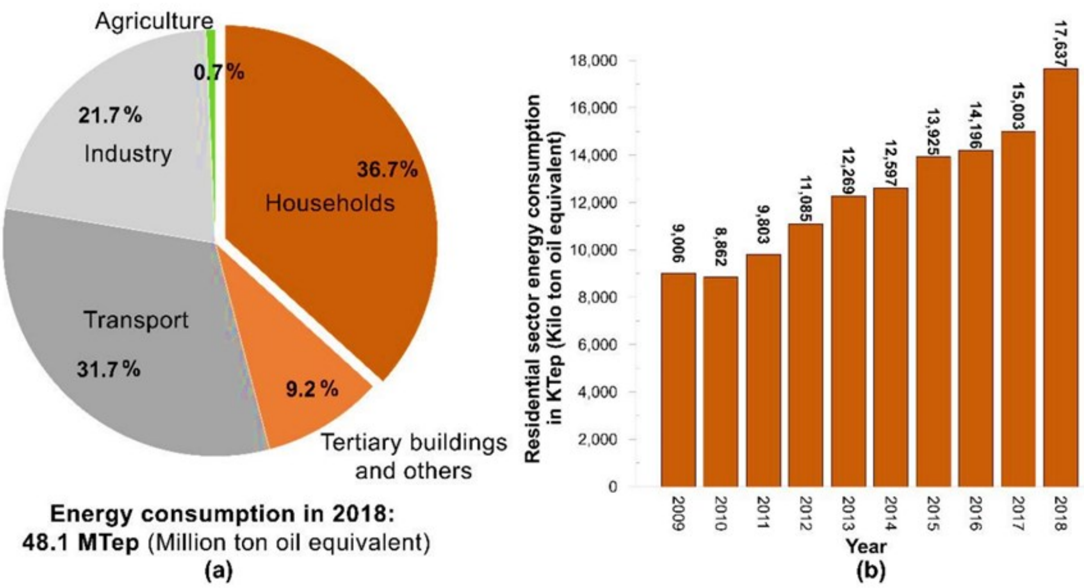


Figure III. 2. Algeria's energy use: (a) a sector-by-sector breakdown; (b) a comparison of the residential sector's energy use between 2009 and 2018.

Source: (Semahi et al., 2020).

Algeria's total energy supply was based on a number of sources (Figure III.3), including natural gas, which accounted for 63.8%, oil 35.4% and coal 0.6% of the overall energy mix in 2018, while energy from renewable sources accounted for the remaining 0.1% (IEA, 2020b).

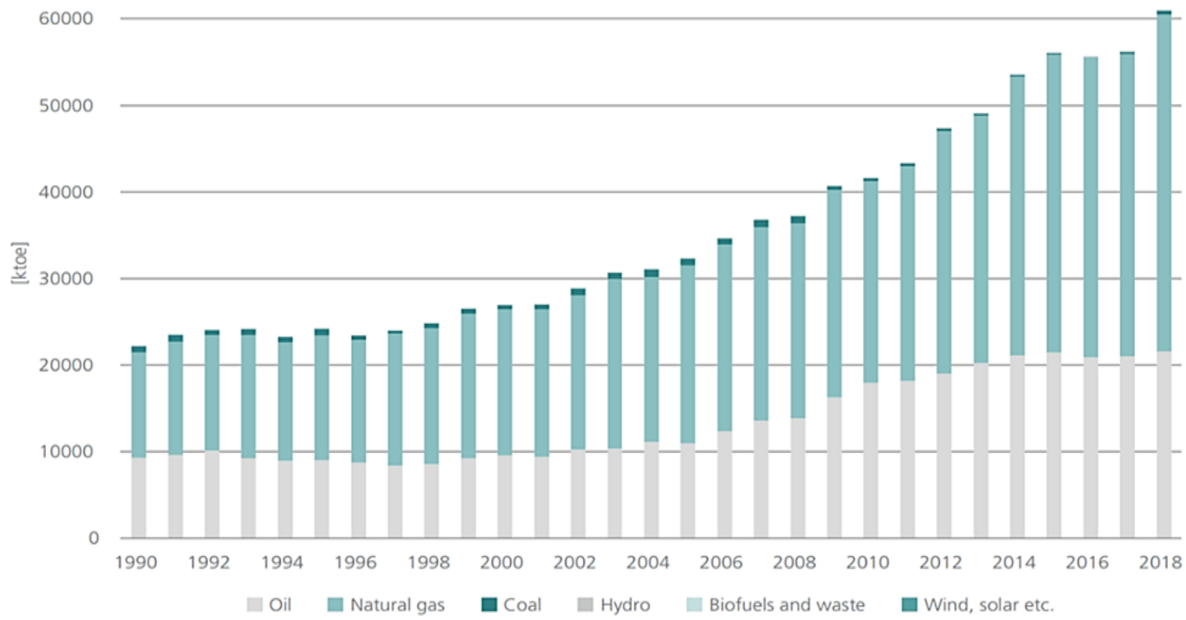


Figure III. 3. Total energy supply (by source), between 1990-2018 (in ktoe).

Source: (Ersoy & Terrapon-Pfaff, 2021).

Between the period that extends between 2000 and 2017, Algeria's energy usage increased yearly, by about 5% on average. The country had a total installed capacity of 20963 MW in 2019, of which 96% came from natural gas power plants (CEREFE, 2020). Algeria intends to boost its entire installed power capacity to 36000 MW by the year of 2028, in accordance to the CREG (Commission for Energy and Gas Regulation). Solar energy plants, alongside natural gas, are predicted to be responsible for 15% of the capacity being produced in 2028 (Hochberg, 2020). An initiative to build a nuclear power facility utilizing the country's enormous uranium deposits to address rising electricity demand could also be in progress (Xinhua Website, 2019).

The amount of electricity used in the year of 2018 was nearly 66.7 TWh (see figure III.4), almost five times the amount needed in the year of 1990. Demand rises, in summertime, between 1:00 pm and 3:00 pm, because cooling technologies are used more frequently, where the highest peak recorded for Algeria in August 2019 was measured at around 15656 megawatts at 2:30 pm (Ersoy & Terrapon-Pfaff, 2021).

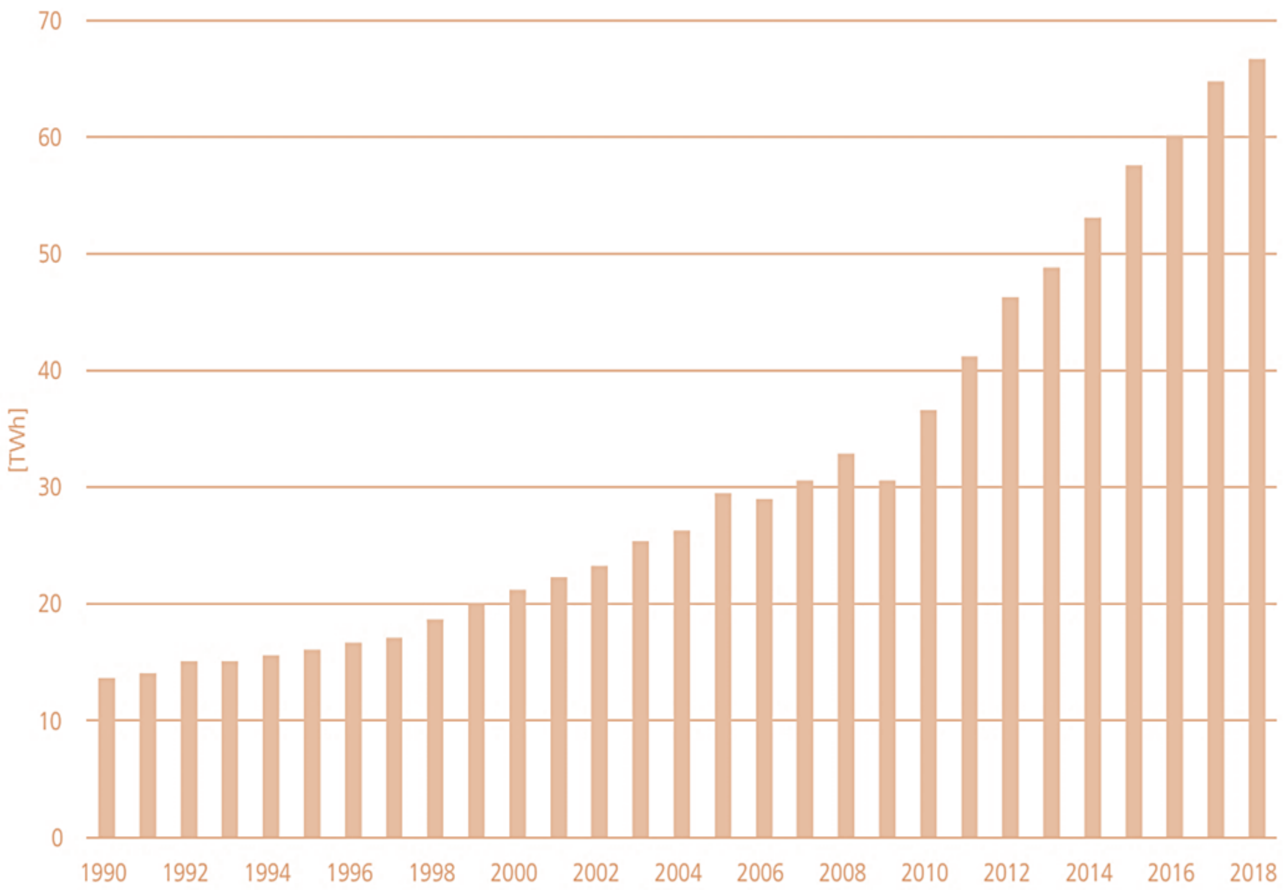


Figure III. 4.National electricity consumption, in Algeria, between 1990-2018 (TWH).
Source: (Ersoy & Terrapon-Pfaff, 2021).

Algeria's power demand is predicted by CREG to increase to 150 TWh in 2030 as well as 250 TWh in 2050 according to (Bouznit et al., 2020), who cited also that changes in consumer behaviour and industrial goods manufacturing processes are the main causes of this rising demand. Despite the fact that the potential reserve gap for 2013 had been 47 percent (The world bank website, 2013), there were frequent civil unrests in past years when the demand for energy was greater than the supply (for instance, in 2003 alongside 2012). Power outages are another major threat to the sector (AHK-Zielmarktanalyse, 2018).

Algeria has the ambition to include a considerable quantity of energy from renewable suppliers in its electricity grid in the aim to cope with increasing demand rates. This could take a while, however, as it's shown in the (figure III.5), in the year of 2018, natural gas contributed more than 98% of all energy production, while renewable sources only contributed with one percent (Ersoy & Terrapon-Pfaff, 2021).

Renewables, corresponding to the data, have only a slight effect on the energy mix and are incapable of entirely offset the usage of petroleum and natural gas in order to meet Algeria's rising energy needs.

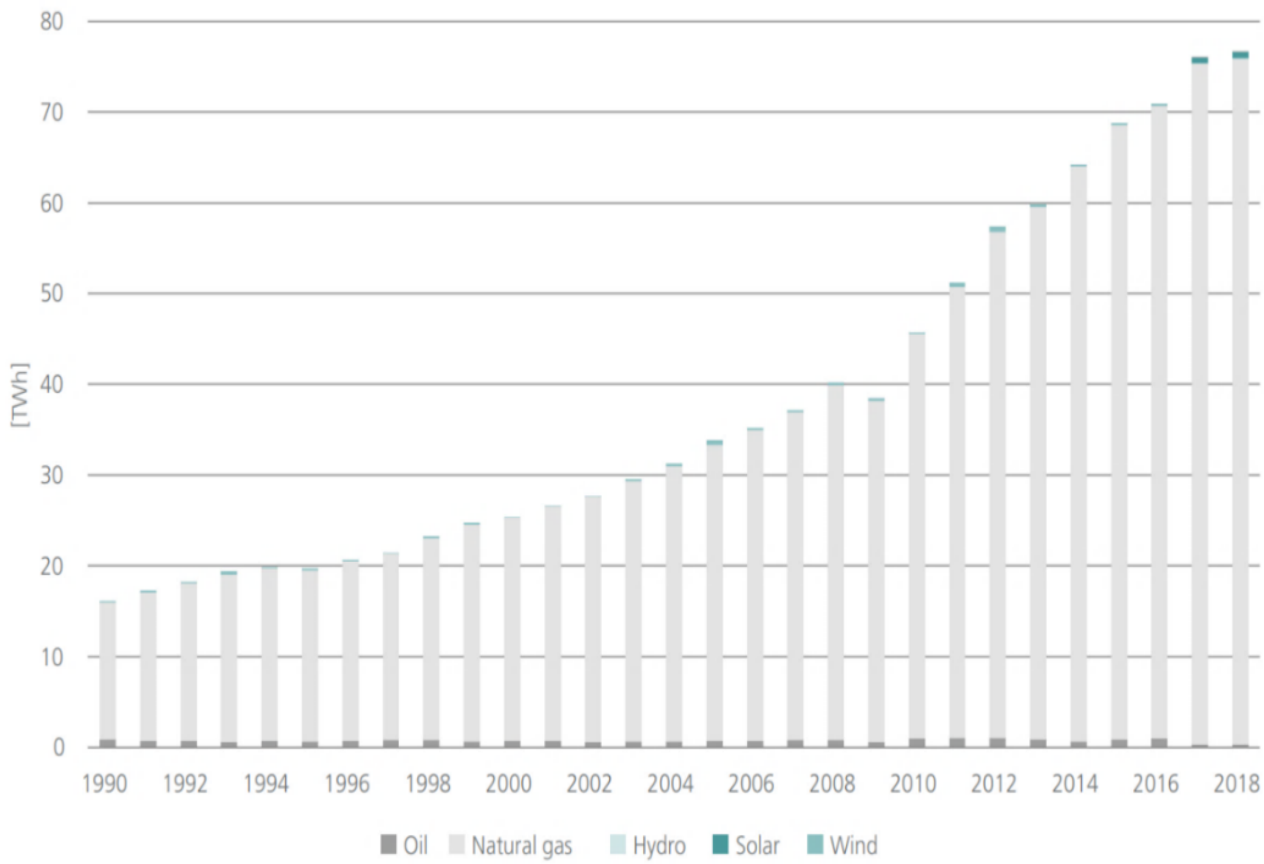


Figure III. 5. Electricity generation (by source), between 1990-2018 (in TWH).

Source: (Ersoy & Terrapon-Pfaff, 2021).

III.3. Fossil fuel energy

High petroleum deposits in Algeria support the country's economy, where the (figure III.6) shows the national infrastructures that contributed in the extraction, the transportation and the exportation of oil and gas sources. Algeria, so, is an exporting nation, ranking fourth in the world for liquefied natural gas exports, third for liquefied petroleum gas, and fifth for natural gas (DENA, 2014).

Furthermore, according to recent finds, Algeria has the third-largest amount of natural gas resources in the world (19 800 billion m3) and the most shale oil reserves (5.7 billion barrels) (Boersma et al., 2015). Although Algeria has given shale gas fracking some thought, its growth has been temporarily put on hold due to popular protests against shale gas drilling. The outbreak of COVID 19, which led to a fall in gas and oil prices on the world market, has further slowed progress in this area.

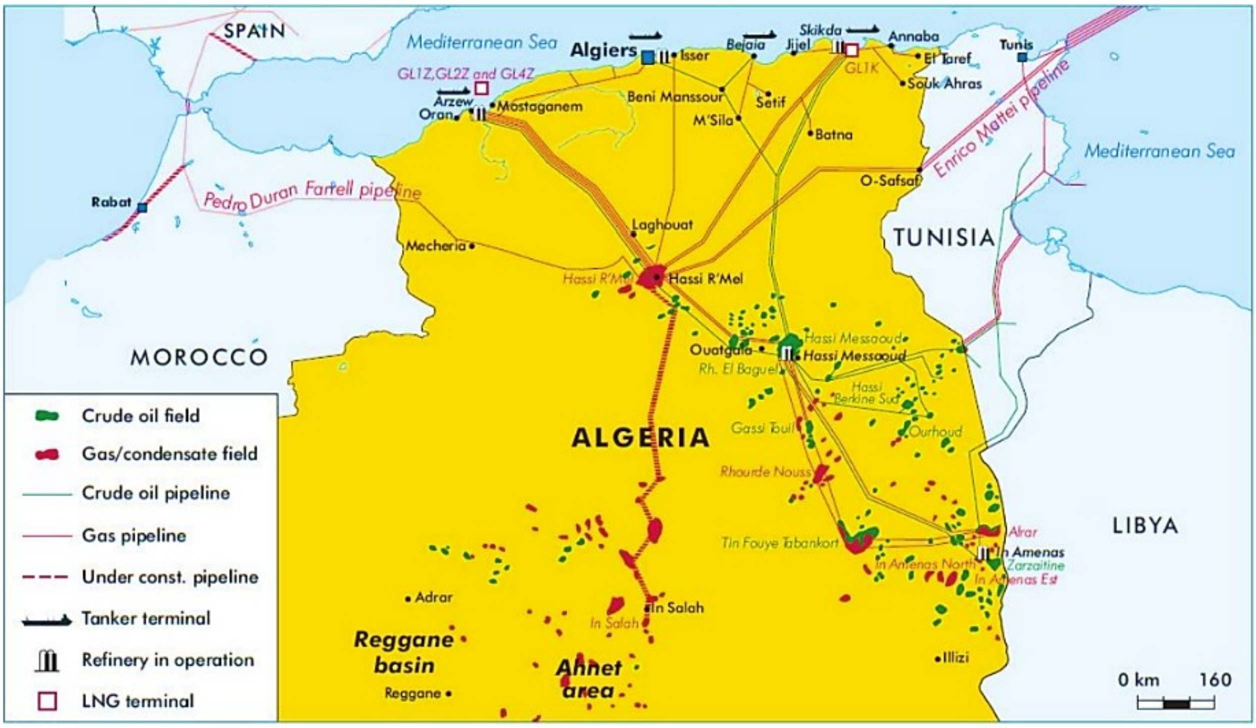


Figure III. 6. Algerian oil and gas infrastructure.

Source: (DENA, 2014).

Recent evaluations suggest that Algeria's potential for gas reserves may be greater than previously thought, with over fifty percent of known conventional gas stocks located near Hassi R'Mel in central Algeria. However, hydrocarbon extraction has decreased due to fields drying out and delays in new extraction caused by a lack of government support, infrastructure, and technological difficulties (DENA, 2014).

A new energy legislation that aims to enhance the environment for foreign investment in Algeria (via measures like reduced taxes) went into effect in January 2020 (Henle & Schmitz, 2021).

III.4. Renewable Energy potentials

As shown above, one percent of the nation's power was generated by renewable sources in 2018, according, also, to (Ersoy & Terrapon-Pfaff, 2021).

As the (figure III.7) demonstrates, solar energy provided almost 91% of all electricity from renewable energy sources during 2020, followed by hydropower with 6.9% alongside wind with 2.1%, according to (IEA, 2020a).

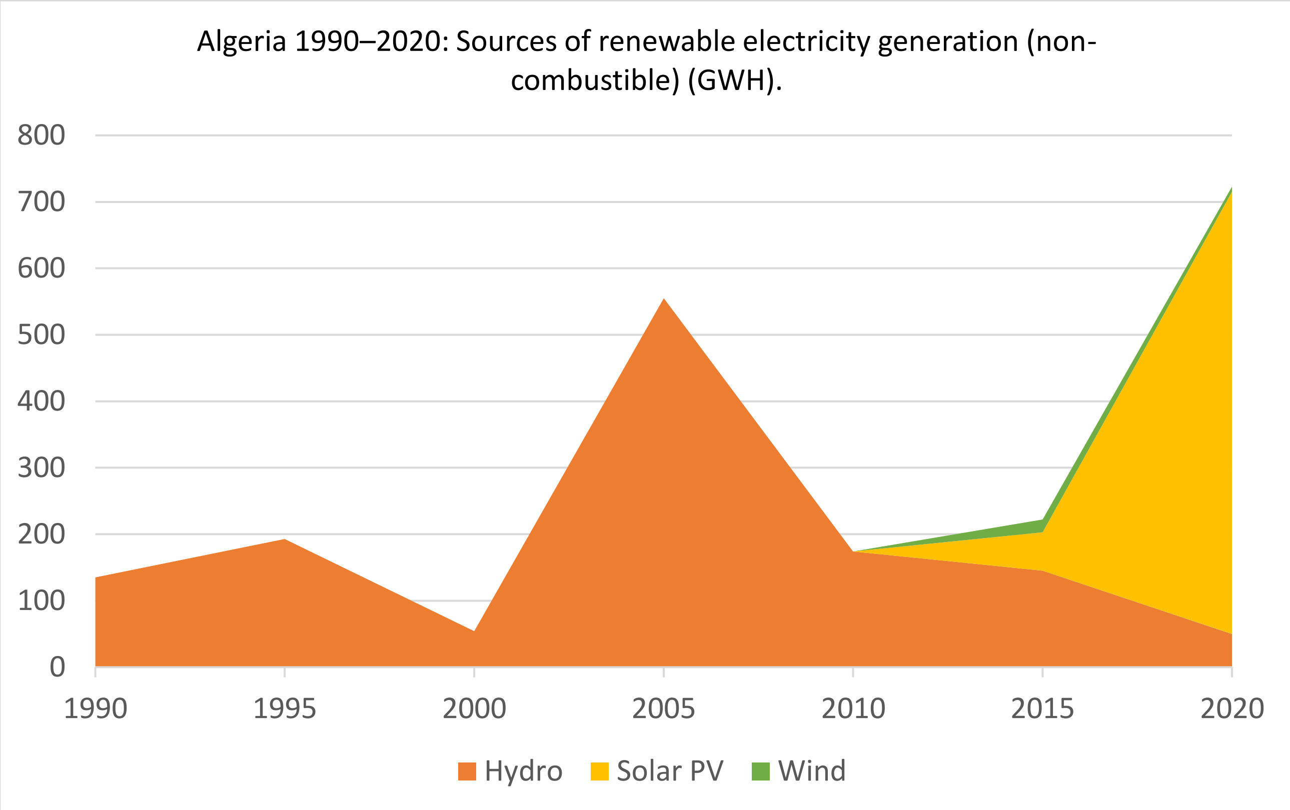


Figure III. 7. Stacked area chart for the presentation of renewable electricity generation sources, in Algeria between 1990-2020.

Source: (IEA, 2020a).

III.4.1. Solar energy

As exposed in (Figure III.8), Algeria has one of the highest solar energy potentials globally, with an average daily irradiance of 7.00 kWh/m2 and a yearly average ranging from 2000 to 2650 kWh/m2. Despite the country's slow progress in adopting renewable energy sources (DENA, 2014), its solar energy potential remains significant.

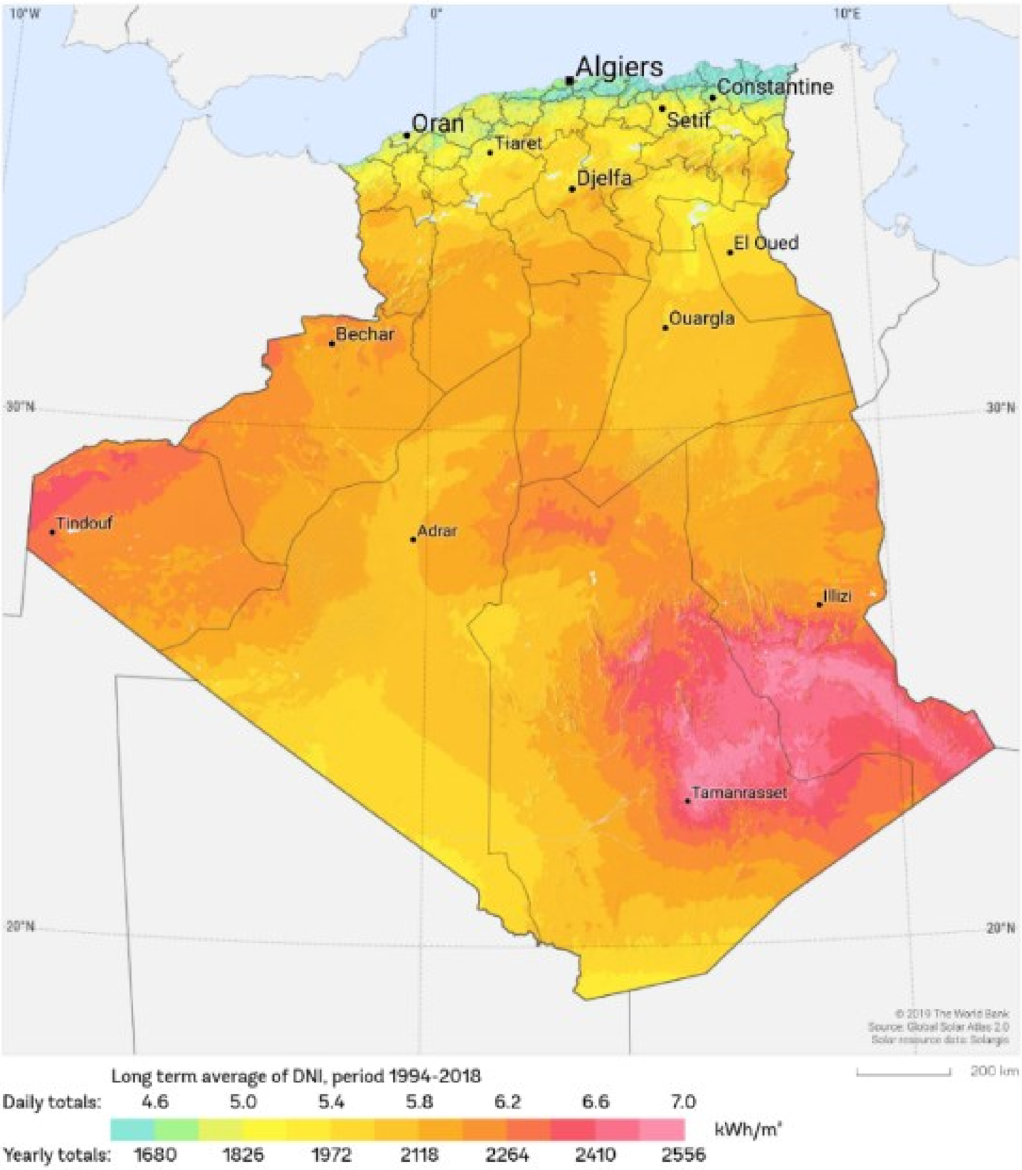


Figure III. 8. Daily and yearly long-term average of direct normal irradiation, in Algeria (between 1994-2018).

Source: (Solargis website, 2020).

Large-scale solar project execution has significant potential in Algeria because the Sahara Desert covers 86% of the country. According to (DENA, 2014), the annual thermal solar power capacity approximates 170 thousand TWh, whereas the annual solar photovoltaic potential is approximately 13.9 TWh. The southern part of the country has the most potential, whereas the northern metropolitan centres have the greatest need. Algeria's primary CSP (concentrated solar power) facility is the hybrid CSP-gas power plant located near Hassi R'Mel, as shown in (Figure III.9). The plant combines solar power with gas power to generate electricity.

Figure III. 9. CSP station of Hassi R'mel.

Source: (El Gharbi, 2011; SPG Dry Cooling Website, 2023).

The facility has a 25 MWp CSP along with 125 MW gas capacity. This facility cost approximately 313 million of euros to build, and it began running in 2011. A second photovoltaic power station having a 10 MWp potential was officially inaugurated in Bir Rebaa in 2018, after the 1.1 MWp Photovoltaic power station in Ghardaia began running in 2014.

22 photovoltaic power plants totalling 343 MWp have been constructed by SONELGAZ's subsidiary for energy from renewable sources, which is SKTM (Ersoy & Terrapon-Pfaff, 2021).

III.4.2. Wind energy

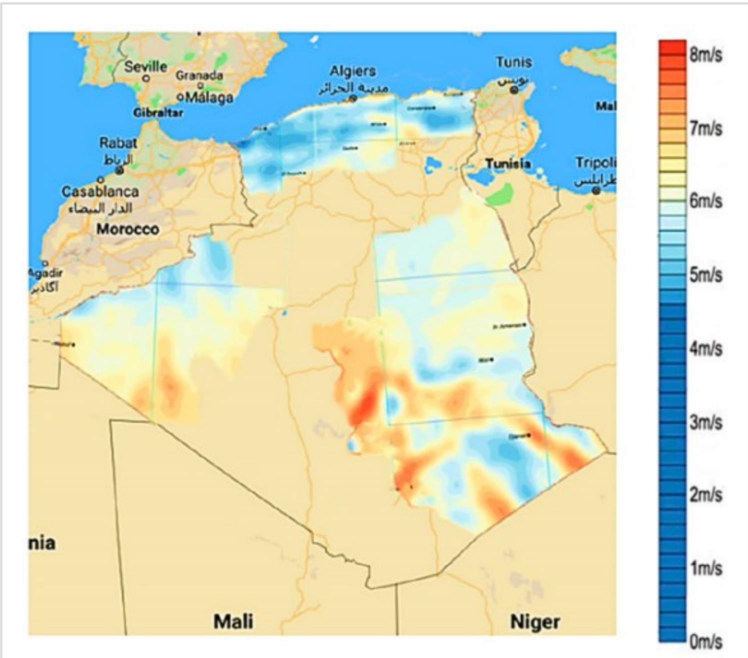


Figure III. 10. The Algerian potential in terms of wind speed.

Source: (Zahraoui et al., 2021).

Island micro networks powered by solar energy have also been built to address demand locally in the south's isolated and sparsely inhabited regions, in addition to the larger-scale deployments; These provide 1.5 GWh annually to 16 communities (DENA, 2014).

According to the (figure III.10), and considering a mean wind velocity of 7.5 m/s, central as well as western Algeria are prime areas for wind energy. It may be inferred from some studies, according to (DENA, 2014), that are currently available, that Algeria has a 35 TWh annual wind power potential. The high percentage of particles such as dust and sand in the air that circulates, which may impair the turbines' performance as a limiting issue.

Moving large wind turbines to remote desert areas, where the potential for the generation of wind power is greatest, may provide additional challenges since Algeria's desert transportation networks are not built for this kind of traffic (DENA, 2014). Kabertene (Figure III.11), which is currently operating with almost 10 MWp capacity, was the first significant wind energy facility to start up in 2014.

Figure III. 11. Kabertene wind farm (Adrar, Algeria).

Source: (Wiley Online Library, 2018).

III.4.3. Biomass and geothermal energy

The deployment strategy for renewable energy in Algeria does not incorporate the limited potential for using biomass for energy generation. Even though there is a certain potential for geothermal energy in regions with limestone as well as sandstone geological formations, geothermal capacity is not taken into account for massive implementation (DENA, 2014).

According to the investigations in (Ait Ouali et al., 2019; Saibi, 2015), the country's mountainous areas have over 240 thermal waters that are spread out from east to west and are situated at a moderate altitude. The eastern area had the greatest recorded temperature of 98 °C, the western area had the highest at 68 °C, as well as the central area had the highest at 80 °C. The median temperature in the southern region is 50 °C. (Figure III.12) displays the locations in the nation where geothermal energy can be produced.

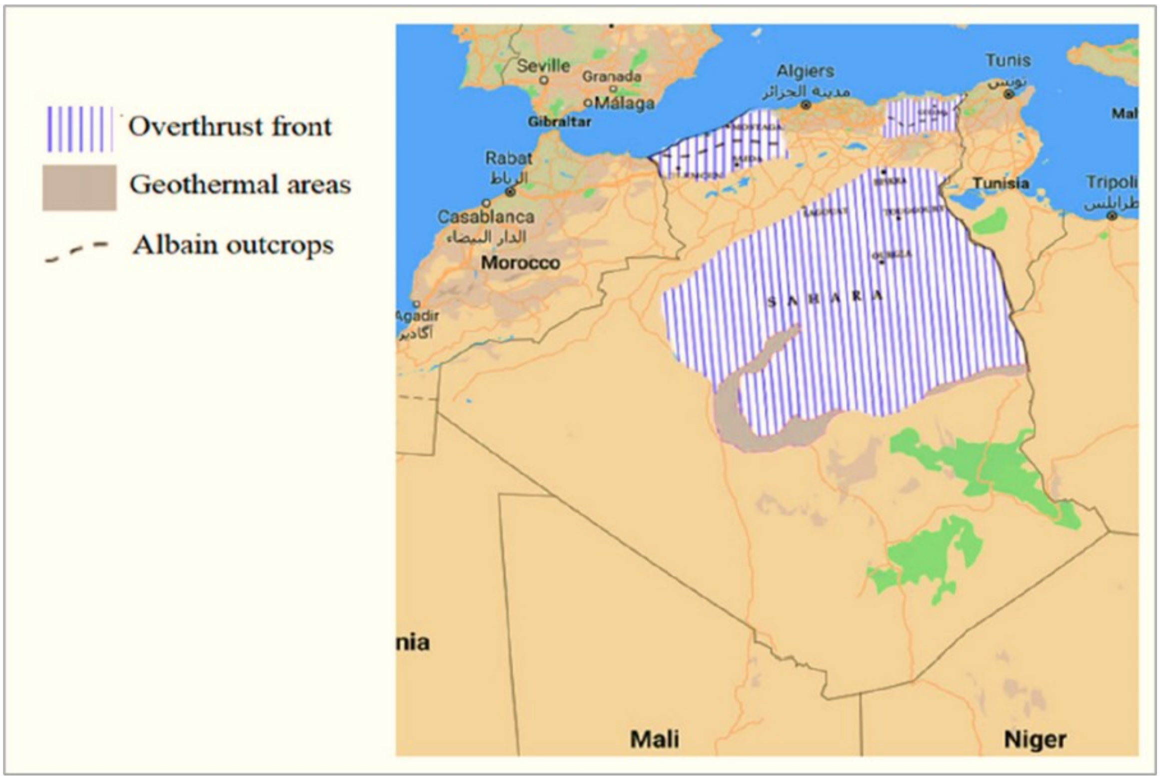


Figure III. 12. Locations of the geothermal potentials in Algeria.

Source : (Zahraoui et al., 2021).

III.4.4. Hydraulic energy

Algeria's hydroelectricity potential is likewise severely constrained due to the lack of water there. The possibilities for hydroelectricity are restricted by low precipitation rates, rapid discharge, and a very high rate of evaporation. Additionally, the majority of the river waterways are transient. Just 117 GWh electrical power was produced in Algeria in 2018, despite the country having a 313 Megawatt installed hydroelectric power plant and the ability to create up to 500 GWh annually (DENA, 2014), where the (Figure III.13) demonstrates the location of these plants across the country.

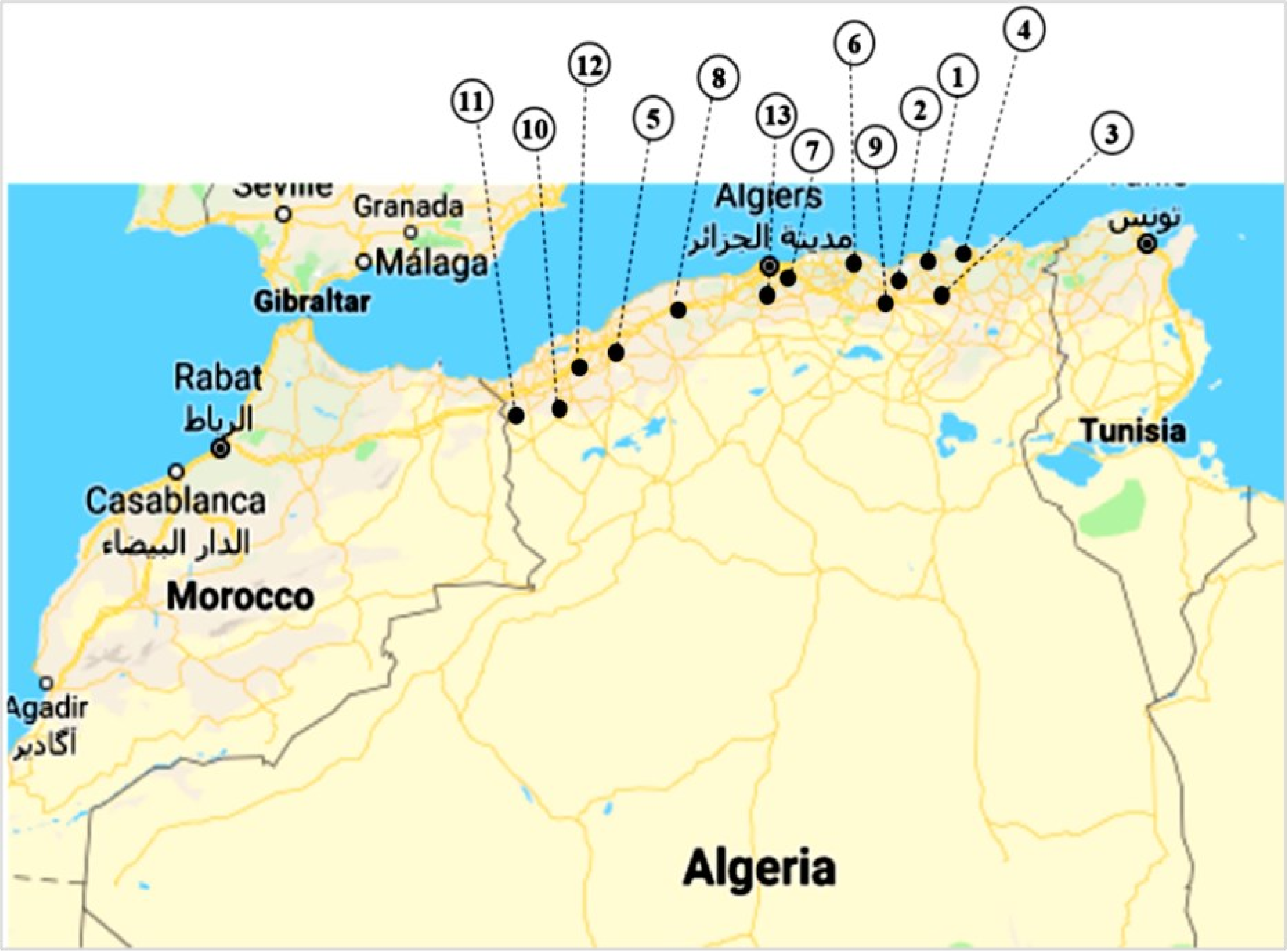


Figure III. 13. Location of hydroelectric power stations in Algeria.
Source : (Zahraoui et al., 2021).

III.5. Algeria's programs within the framework of the energy transition

Algeria has operational grid-connected clean energy plants with an overall installation power capacity of over 389 MWp. Despite the present low levels of energy from renewable sources, the authorities aim to build renewable energy projects to fight global warming and safeguard Algeria's energy supply. In 2011, the Ministry of Energy introduced the PNEREE.

The plan aims to implement 22 gigawatts of renewable energy capacity by 2030, with ten gigawatts designated for export. Algeria aims to produce 40% of its electricity from renewable sources by 2030, as shown in (Figure III.14), making renewable resources a central part of its energy and economic strategies. The country is striving to become a leader in the production of energy from photovoltaic technology and solar power, which will drive economic sustainability and promote a new growth model according to (Dib et al., 2012). To carry out this strategy, Algeria would need to spend approximately 86.55 billion euros (DENA, 2014).

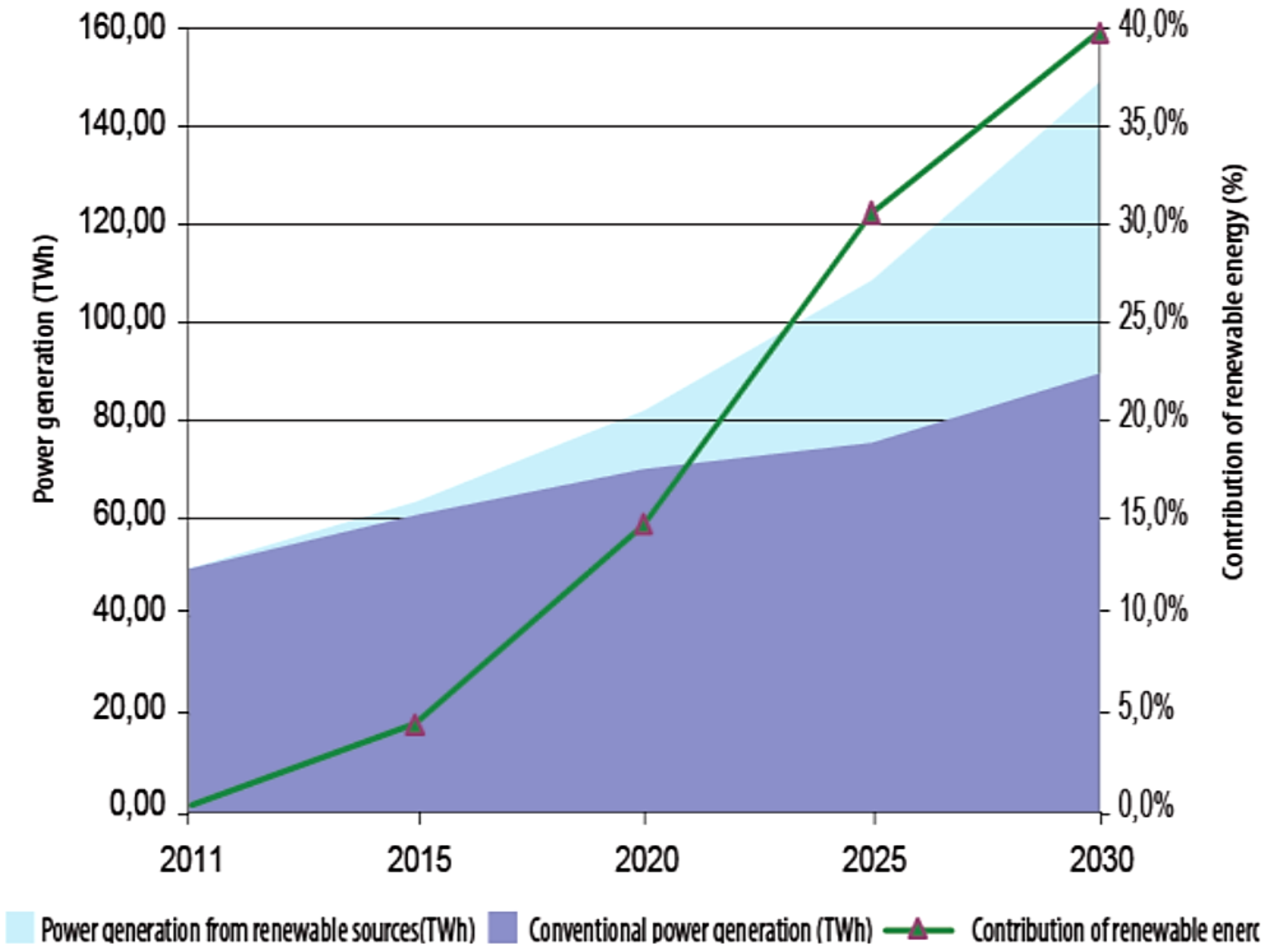


Figure III. 14. Perspectives of contribution of renewable energies for generating power.

Source: (Dib et al., 2012).

A new version of the program was released in 2015, with lofty goals to increase solar power reaching 13.5 gigawatts in 2030. The percentage of photovoltaic power capacity was raised, while CSP was dropped from the initial phase of installation. The technology of CSP was abandoned mostly because to its greater price.

However, given that energy predictions indicate that Algeria uses 80% of its energy for heating and 20% for electricity, the government's choice to deploy CSP may turn out to be nonsensical. The COVID-19 pandemic's effects, which have caused the oil price to fall globally, are anticipated to further strengthen the Algerian government's desire and political commitment to make investments in renewable sources of energy (Stahl, 2020). In light of this, the government of Algeria has lately expressed a strong interest in exploring the potential for switching out gas-fired power facilities with solar ones. Instead of being used in Algeria's gas generation facilities, the gas might be exported, saving the country money (Henle & Schmitz, 2021).

Algeria is preparing Tafouk (1), a solar project consisting of five bids of 800 Megawatts, to meet its targets. This project could boost Algeria's capacity to produce solar modules, racks, and cables, and reach its renewable energy targets (Hochberg, 2020). The demand for local creation of parts is an important element of the bidding process, which could initially be a barrier. However, these regulations could encourage the transfer of knowledge to the regional economy.

Algeria, which is located at the intersection of Europe, the Middle East and North Africa, could, in the best-case scenario, become a production and distribution centre for the renewable energy industry (Hochberg, 2020).

The agriculture industry in Algeria is a leader in the use of renewable energy. In the distant south, away from the transmission system, are the majority of the agricultural locations. As a result, several agricultural enterprises have made investments in wind or solar energy plants to provide continuous operations for irrigation, drying, along with processing. Although most agricultural producers still employ diesel generators, this has not yet become the industry norm (AHK-Zielmarktanalyse, 2018). Additionally, a number of small-scale off-grid initiatives have been put into action, such as solar kits and irrigation systems powered by the sun and the wind (CEREFE, 2020).

The Algerian state has established a quantity of finance instruments to encourage the use of renewable energy sources. These involve feed-in tariffs for wind, solar, in addition to cogeneration energy, which are ruled by the By-laws of 2014; and power purchase agreements, which are governed by Executive Decree No. 13-218. Depending on the power plant's capacity, the feed-in tariffs change.

Small wind energy facilities (under 5 Megawatts) earn almost 12 eurocents/kWh, whereas larger wind energy plants (greater than 5 Megawatts) are paid 9.5 eurocents/kWh. Small solar energy systems (under 5 Megawatts) earn 14.5 eurocents/kWh, whereas larger solar energy plants (more than 5 Megawatts) are paid 11.6 eurocents/kWh. The "feed-in tariffs" program excludes CSP projects (Energypedia website, 2020).

A one percent charge on oil tax receipts is used to contribute to the FNER (which refers to National Fund for Renewable Energy and Cogeneration), which was likewise formed by Executive Decree No. 11-423 of the year 2011 (Mahmoud & Habib, 2020).

Algeria offers legal assurance of priority grid entry for renewable energy sources, which is uncommon in the Middle East as well as North African region. This preferential access is guaranteed by Executive Decree (No. 06-428 and 06-429) from 2006 and 2008, respectively (RCREEE, 2014). (Figure III.15) displays a chronological list of some of the energy-related measures and legislation that have been adopted.

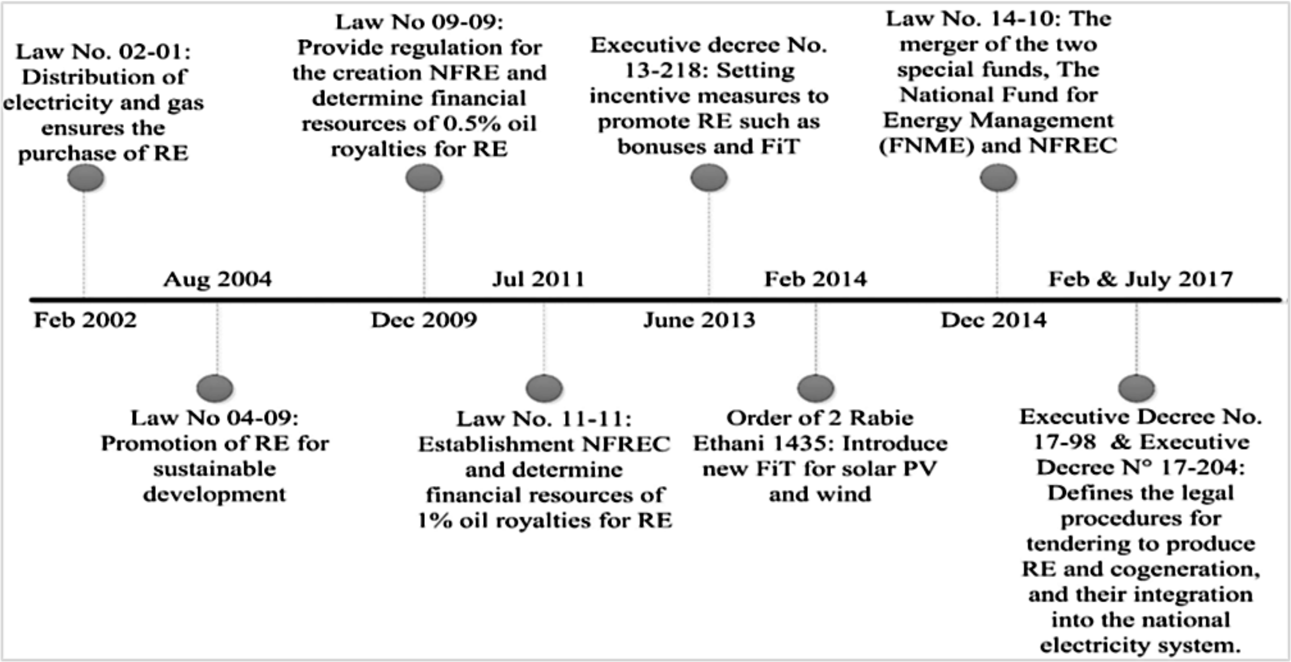


Figure III. 15. Main laws and regulations relating to renewable energy in Algeria.

Source: (Zahraoui et al., 2021).

In conclusion, it appears that the Algerian government is taking a gradual approach to renewables instead of implementing drastic large-scale reforms. The transition to energy from renewable sources is expected to be moderate as long as the state continues to subsidise energy costs and there is a robust electricity grid close to coastal demand centres. Although Algeria has the ability to host large-scale solar installations, many of the projects scheduled for 2006–2014 and 2016–2020 only exist on paper. In accordance to the phase model, Algeria has not yet fulfilled the prerequisites to be categorized as having finished the first phase (Ersoy & Terrapon-Pfaff, 2021).

III.6. Algeria's overall energy transmission networks

In Algeria, the national power transmission infrastructure serves 99% of the population. The grid is 30515 kilometres long, with 4497 kilometres of 400 kV high voltage networks. The Maghreb Interconnection connects the grid to Morocco and Tunisia. Libya is also connected to this network (The world bank website, 2013). The Maghreb countries have committed to restructuring transmission infrastructure and to working together to develop and harmonise a common electricity market. In addition, the nations expressed their intention in the 2010 Algiers Declaration to build a sustainable energy market within the Maghreb member states and to interconnect this market with the European Union, in particular the Iberian Peninsula (The world bank website, 2013). In addition, Algeria intends to build a pan-Arab electricity market, as evidenced by its agreement on memoranda of understanding with other Arab nations in 2017 (Matar, 2020). The transmission grid facilities are held by GRTE (which refers to Algerian Electricity Transmission System Management Company, and which is SONELGAZ's transmission corporation), it serves as only one buyer in the Algerian market for energy model. Another SONELGAZ business; Electrical system operator, is in charge of supply security. GRTE has created projects to extend the grids of electric transmission from 2020 until 2029, totalling 50280 kilometres (Mansour, 2020b). The distribution industry is overseen by four distribution corporations, each of which has its own system. The Algerian grid is now facing a number of issues. One-way communication, high levels of carbon emissions, lengthy transmission lines to transmit power, costly electricity, and future volatility if growing amounts of renewable energy are put into the electrical grid (Harrouz et al., 2017). At present, 389.3 MWp of energy from renewable sources is injected into the Algerian system, which gives renewables superior grid-access conditions by guaranteeing dispatch priority (Mahmoud & Habib, 2020). Having a high proportion of renewables within the electrical system will result in significant economic benefits in the long run.

Nevertheless, the grid should be able to incorporate a significant percentage of variable output, and system additions will be dependent on acceptable renewables sites (Platzer et al., 2016). Control distribution methods, like the net-metering of a grid-connected self-producers of green energy, must also be modified (Mahmoud & Habib, 2020). As a result, a comprehensive review is required for all subsequent planning initiatives (Ersoy & Terrapon-Pfaff, 2021). The time required to finish the extension and renovation will be determined by the construction of power resources as well as the motivation of the appropriate organizations (Shen et al., 2018). Algeria's transmission system is currently incapable of integrating huge amounts of renewables. Although a legislative framework is established and market liberalization has begun (Law No. 02-01 in 2002 mandates the separation of the prior vertically integrated company SONELGAZ (Algerian energy ministry, n.d.)), the grid continues to encounter both regulatory as well as technical obstacles.

Algeria's grid is still under construction, and as a result, the development of the power infrastructure for renewables integration in accordance with stage one of the process model has begun but is not yet wide-ranging.

III.7. Institutions and governance efforts in the field of energy transition

The Ministry of Energy oversees Algeria's electrical and energy industry, including the development and implementation of energy policies and plans. In response to the growing awareness of the importance of renewable energy sources, the Algerian Ministry of Energy Transition & Renewable Energy was established to promote their deployment in the country.

After the implementation of unbundling procedures in the energy markets in 2002, the sector was divided into several entities, most of which are state-owned. The Commission for Electricity and Gas Regulation (CREG) was established in the same year to protect the interests of consumers and operators in the electricity and national gas markets. CREG also oversees public energy offerings, acts as a government consultant (Energypedia website, 2020), and publishes bids for the implementation of green power technology.

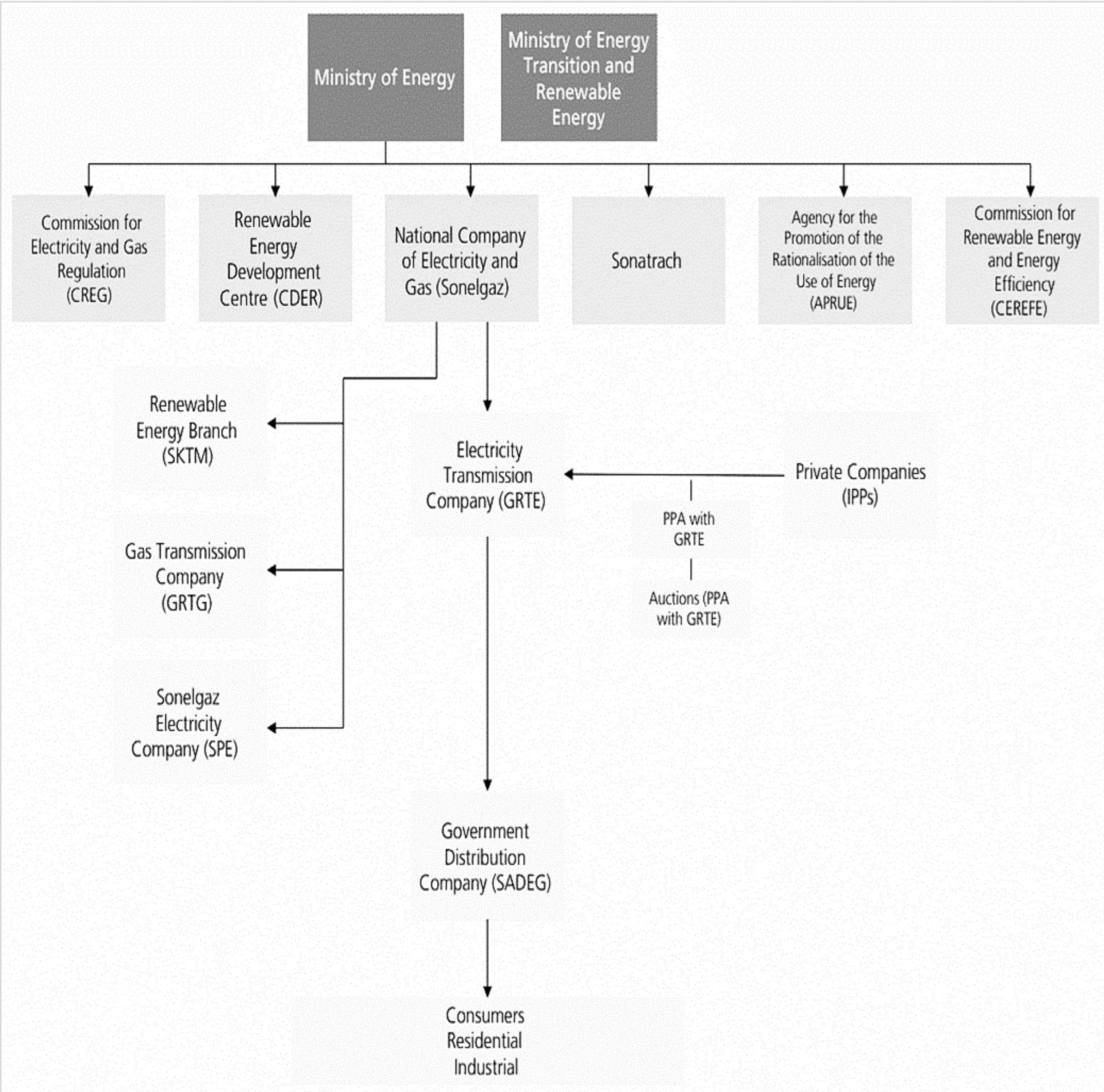


Figure III. 16. Electricity market structure, with relevant companies and authorities.

Source: (Ersoy & Terrapon-Pfaff, 2021).

On the resource extraction and production side, several national companies represented in (Figure III.16), dominate the Algerian energy sector: the SONATRACH Group of companies is in charge of petroleum products, while the SONELGAZ Group produces and markets electricity, and is also in charge of the national distribution of natural gas.

The SPE also produces electricity, while the GRTE takes care of transport. SADEG is in charge of electricity distribution, resulting from the merger of the four initial distribution entities of SONELGAZ: SDC, SDO, the SDE, as well as the SDA (Mansour, 2020a).

To promote energy efficiency measures, the Ministry of Energy established an Agency, which called APRUE (Agency for the Promotion of the Rationalization of the Use of Energy), in 1985. APRUE is in charge of educational as well as public awareness efforts on energy efficiency.

Since the year 2002, Independent Power Producers have been able to generate and sell energy within the scope of the sole buyer market (Ersoy & Terrapon-Pfaff, 2021).

A power purchase agreement must be executed with GRTE, which purchases electricity from independent Power Producers. Currently, 13% of Algeria's power is produced by the Independent Power Producer, the majority of which are involved in the field of fossil fuels (DENA, 2014).

In Algeria, a tender process is in place to encourage investment in renewables. Contracts, in the form of a power purchase agreement, are granted to firms who bid the lowest cost to produce power. The initial tender was announced in 2019, with a total capacity of 150 MW sought.

Nevertheless, since the tender rules required significant local production of solar power plants alongside additional equipment - regardless of the small number of local solar producers - offers for just 90 megawatts were made, despite the contract including an obligatory 51% ownership interest for the Algerian entity and financing via Algerian banking institutions (Bellini, 2019; Bouznit et al., 2020; Hochberg, 2020). The projects chosen in the 2019 bidding round will be built on a build-own-operate (BOO) plan with a PPA (Power Purchase Agreement) lasting 20 years. The government has announced a new tender for 50 MW of off-grid hybrid gas/diesel and solar energy plants. The bids and Feed-in tariff program are part of Algeria's goal to build 22 GW of energy from renewable sources capacity by 2030. Experts have stated that Algeria's efforts to liberalize the market have been inadequate since SONELGAZ was reformed as a holding corporation in the year 2002 (Law No. 02-01), and that the private sector continues to face significant barriers. Although the legal structure is established, the regulatory structure along with funding mechanisms have been shown insufficient (Hochberg, 2020). In accordance with (Boersma et al., 2015), energy businesses confront bureaucratic and time-consuming processes since all communications must go via SONATRACH or SONELGAZ. This causes project completion to be delayed and might cause communication issues.

As a result of the current stage of development and efficacy of the institutional framework, Algeria is at the starting point of the initial stage of transitioning to a renewable-based power system, corresponding to the Middle East and North Africa phase concept (Ersoy & Terrapon-Pfaff, 2021).

III.8. Algerian social contribution in energy transition

Algeria is seeing an increase in the total number of cultural, social, alongside environmental organizations, as well as an increase in environmental consciousness among the population (BTI Website, 2020). Several energy initiatives have also faced significant criticism, including one in the southwest of Algeria to investigate the country's shale gas deposits. Unexpected demonstrations by local communities sparked nationwide opposition, effectively suspending shale gas drilling in the Algerian nation for the time being. Regardless of the environmental as well as socioeconomic benefits that accompany sustainable energy development, social acceptability of projects related to renewable energy may not be expected (Ersoy & Terrapon-Pfaff, 2021). Several organizations have been established to study and educate about renewable energy, including IAER, APRUE, as well as CDER (Tuerk et al., 2013). APRUE organizes energy-saving awareness programs, while CDER provides crucial knowledge on renewables and routinely publishes updates on this issue on its website. The Solar Energy Cluster was founded in 2017 by Twelve energy firms to increase the network of national enterprises and value chain participants. Raw material providers, programmers, technicians, professional trainers, scholars, and designers are among them. This network currently has 34 firms as members. The cluster's goal is to create consciousness and promote the use of alternative clean energies, particularly solar energy, through offering detailed information and best practices recommendations to aid the nation in its energy transition (Haouari, 2017). The establishment of the "Solar Energy Cluster" has resulted in an innovative vision of an Algeria powered entirely by renewables; yet, the government continues to incorporate fossil fuels in its future energy system strategy. Universities have begun to encourage research and award masters and doctorate degrees in this field. The IAER provides particular capacity-building training and seminars, including as courses on engineering, security and safety, energy audits, as well as management of projects for installers along with engineers (Tuerk et al., 2013). In accordance with (CEREFE, 2020), 40 individuals received professional licenses in energy conservation and efficiency during the years 2017 and 2018; 46 in photovoltaic system implementation and upkeep, and 268 in the placing of photovoltaic panels and solar thermal power systems. Due to the banking sector's inadequate understanding of the topic of renewable energy, it is difficult to implement projects utilizing renewable energy widely in the country of Algeria. Although it is necessary, specific financial industry training has not yet become commonplace. Generally speaking, Algeria has recently established a number of institutions that support renewable energy. However, Algerian society continues to downplay the significance of environmental challenges. It will be helpful to promote awareness campaigns in this regard, but it will take a lot of effort to incorporate these elements into people's daily routines and beliefs (Ersoy & Terrapon-Pfaff, 2021).

III.9. Energy market and economy

There are six time-based tariffs in Algeria's power price structure: a fixed rate, an off-peak rate, a major consumption rate, and hours during the course of the day and night. Additionally, prices vary based on the type of customer (for example, residential compared to industrial), with the latter often paying more per kWh. As a consequence, the prices per kWh vary between 0.007 and 0.052 euros. The tariff structure is under the control of CREG (Ersoy & Terrapon-Pfaff, 2021).

Algeria is an example of a rentier state. It depends on hydrocarbons for local use along with the export process of natural oil and gas. Each of these resources are significantly subsidized. Subsidies accounted for approximately 7.6 percent of Algeria's Gross Domestic Product (GDP) in 2019: 8.8 billion USD for oil, 2.3 billion USD for gas, and 2 billion USD for electricity (IEA, 2020a). The cost of generating electricity from subsidized gas power plants determines the price of energy. One of the primary obstacles to the expansion of electricity from renewable resources in Algeria is the low electricity cost brought on by these subsidies. Additionally, the low price has unfavourable effects; not only will let energy consumption be excessive, but it's doubtful that the affordability of energy will be reflected in the cost of energy-intensive goods. Subsidy changes would relieve budgetary pressures and allow the funding to be reallocated to other desired outcomes, like green energy (Mahmoud & Habib, 2020). However, because the Algerian government still has not make a commitment or announce any subsidy changes, this scenario is unlikely to alter in the foreseeable future (DENA, 2014). In order to promote renewable energy, Algeria established the FNME, a cogeneration as well as renewable energy facility funded by taxation and penalties. The yearly funding requirements for programs promoting energy conservation as well as sustainable energy are used to determine how much taxation is needed to support the fund. The budget law includes them (AHK-Zielmarktanalyse, 2018). In the context of private sector funding, obtaining a loan from a bank for renewable power or conservation of energy projects is often challenging (AHK-Zielmarktanalyse, 2018) since the sector continues to be in its early stages in Algeria, making the risks unknown for banks. It is feasible to finance projects with private equity backing in the shape of investment funds. However, just a few Algerian private enterprises specialize in this field. Project finance plans, in which repayments are associated to future cashflow, are another alternative. However, one downside of these systems involves the fact that foreign companies can only acquire 49% of the stock (AHK-Zielmarktanalyse, 2018). Algeria's transition to renewable energy is slowed by state-subsidised energy prices, which also limit the government's support for renewable energy.

These subsidies cause market disruption and hinder the energy transition. To progress towards a renewable energy system, Algeria must reform its fossil fuel subsidies alongside diversifying its energy investments. According to Ersoy & Terrapon-Pfaff (2021), Algeria is still in the early stages of the transition phase of the framework.

III.10. National technical plans towards energy efficiency

In 2011, the Algerian government launched a national campaign to promote energy efficiency. This campaign was updated in 2015 to improve energy efficiency in the building, transport and industry sectors. The housing sector aims to save more than thirty million (toe), by 2030 through the use of LED lighting, solar thermal water heating and insulated building materials. The transport sector aims to reduce CO_2 emissions by fifteen million tonnes, mainly by switching from traditional fuels to compressed natural gas and liquefied petroleum gas. By 2030, the industrial sector is expected to save up to 34 million tonnes. The government plans to allocate 900 billion Algerian dinars to energy efficiency efforts. To achieve the objectives outlined in the strategic plan, the following actions must be carried out annually until 2030: installation of thermal insulation in 100,000 residential buildings, installation of ten million energy-efficient lights, and conversion of 1.3 million cars to run on liquid petroleum gas. These steps are estimated to generate up to 180,000 new jobs (Sahnoune & Imessad, 2017; Energypedia website, 2020). Furthermore, the government aims to reduce gas combustion in power stations by one percent by 2030. It is important to note that these labels are intended to inform consumers about the energy efficiency of the products they are purchasing. New technical devices that use electricity, gas, or other fuels are subject to energy certification and labelling. Energy efficiency law 05-16, which came into effect in 2015, requires air conditioning units, refrigerators, heaters, lights, and televisions to be labelled with energy categories. Energy-saving measures in the building industry are currently not regulated by legislation. However, technical manuals provide guidance for renovation work on thermal insulation and lighting (AHK-Zielmarktanalyse, 2018). Another objective is to concentrate on promoting a circular economy through the implementation of organic waste composting as well as methane gas valorisation in water purification facilities. Undoubtedly, the energy efficiency strategy includes first measures toward maximizing resource efficiency. An assessment of Algeria's energy efficiency efforts reveals that the government recognizes it as a critical component of transition in terms of the energy model and system. The objectives outlined in the regulatory structure show that Algeria has implemented energy efficiency initiatives at the political level. However, the objectives are still not being met, indicating that Algeria is currently undergoing the initial phase of the Middle East and North Africa phase paradigm of energy transformation. Algeria, in simple terms, has not yet finished the preliminary stage in its power saving initiatives (Ersoy & Terrapon-Pfaff, 2021).

III.11. National Greenhouse Gases emissions

Algeria is third in Africa in terms of CO2 emissions (Hochberg, 2020). Energy consumption per capita in 2014 was 1327 kilograms of oil equivalence (The world bank website, 2014), meaning that it's very high when viewed alongside the rest of the Maghreb states. According to (Ritchie et al., 2020), CO2 emissions are the result of many sources, and the main sectors responsible for these emissions between 2005 and 2018 are fugitive emissions, followed by electricity and heat, then transport, buildings, industry as well as other sectors, as shown in (Figure III.17).

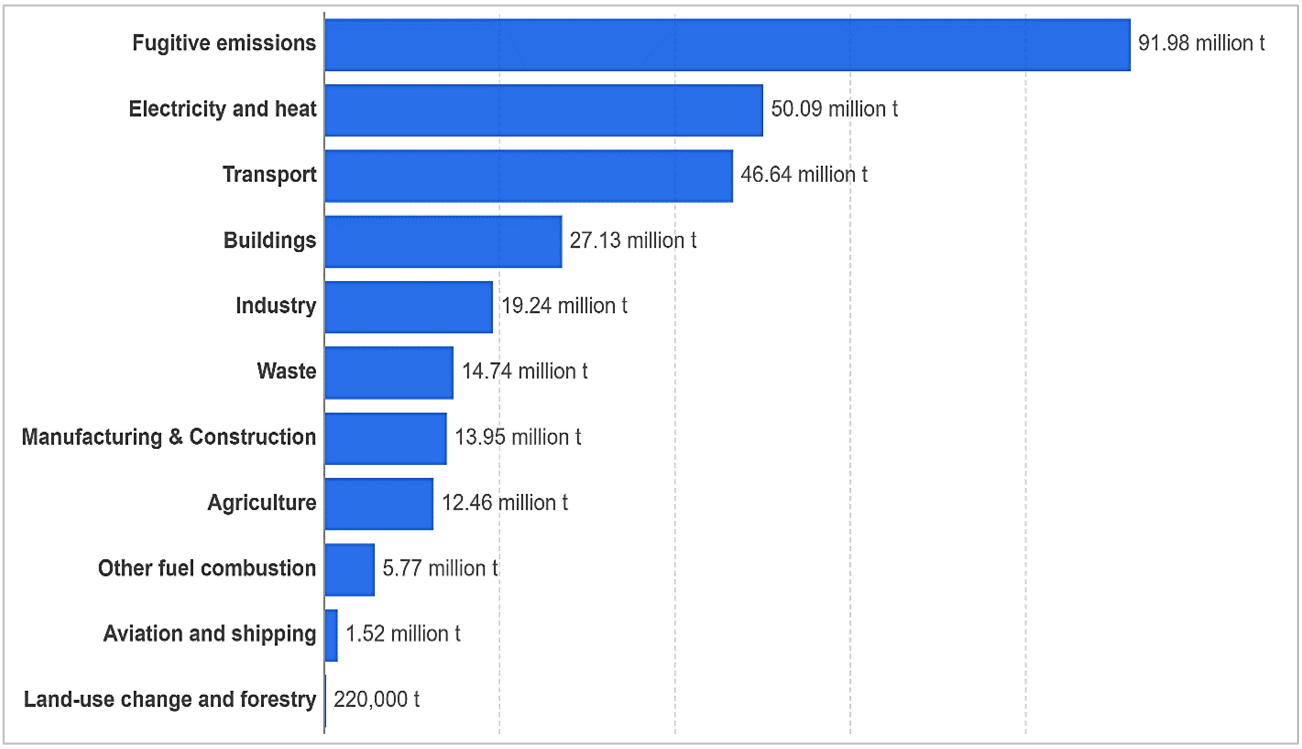


Figure III. 17. Emissions of CO2, by sector, in Algeria 2005-2018 (in Mt. CO2).

Source: (Ritchie et al., 2020).

(Figure III.18) illustrates the quantities of CO2 emitted by the various sectors, year by year, showing that the increase in quantities began in 1950 and has continued to rise, to the point where CO2 national emissions in 2018 were almost 180 million tons.

Algeria is extremely susceptible to the effects of climate change since it already has substantial shortages of water. The availability of water continues to be a serious issue. In terms of water desalination, the nation of Algeria is in second place only to Spain among Mediterranean countries. Algerian desalination relies heavily on the use of fossil fuels sources (Sahnoune & Imessad, 2017).

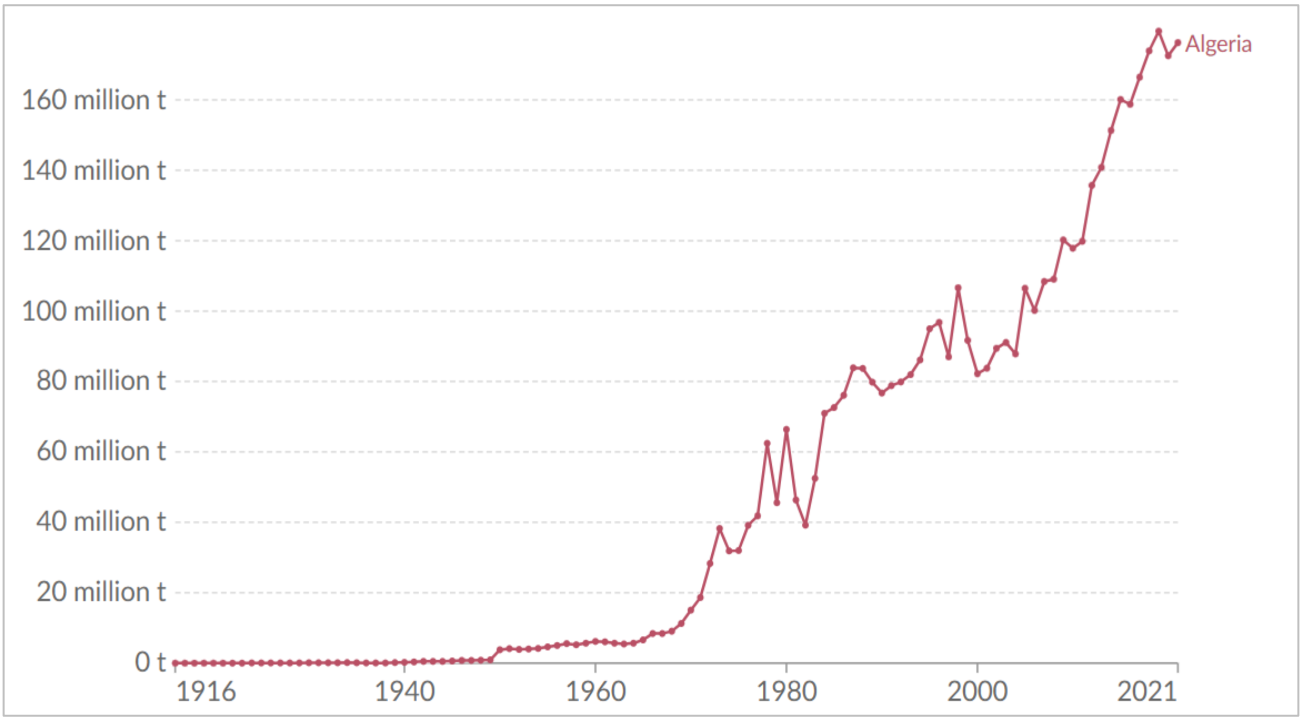


Figure III. 18. Quantity of emissions of CO2, by years, in Algeria 2005-2018 (in Mt. CO2). Source: (Ritchie et al., 2020).

As a consequence of its energy-intensive process, this industry creates large amounts of greenhouse gas emissions, with a desalination operational capacity of approximately 2.4 million cubic meter per day in the year 2015.

Despite Algeria's NDC (Nationally Determined Contributions) aim of reducing greenhouse gas emissions by seven percent by 2030, carbon dioxide emissions are growing due to industrialization. To decarbonize the transportation industry, which accounts for the majority of greenhouse gas emissions, electrification programs must be adopted. Direct electrification, on the other hand, will only succeed in lowering emission levels of greenhouse gases if the power is obtained from sources that are environmentally friendly (Ersoy & Terrapon-Pfaff, 2021).

III.12. Algerian dwellings between energy consumption and efficiency

III.12.1. Statistics about Algerian dwellings and their energy consumption

Over 3.6 million homes were constructed during the period (1999 - 2018). In Algeria, there are primarily two types of residential buildings: multifamily apartment complexes, which account for 51% of the household sector; and single-family homes, which account for 49% of the housing sector in the country. In the latter, there are two categories: self-built dwelling and housing in rural areas (see Figure III.19).

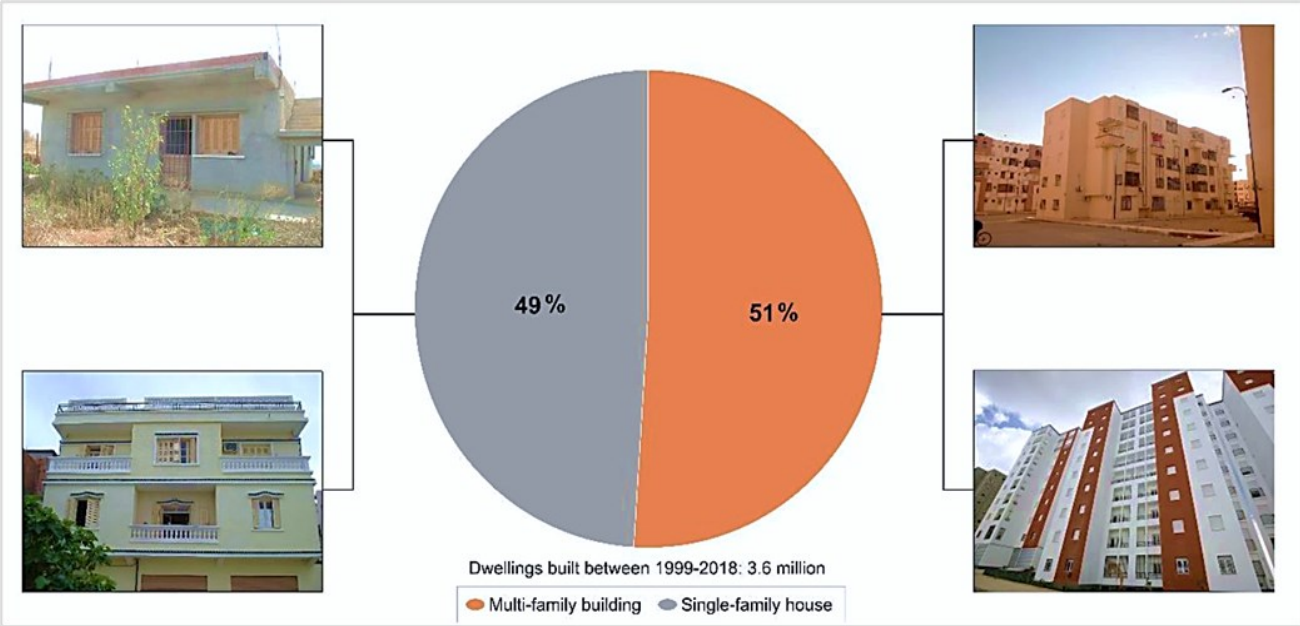


Figure III. 19. Classification of residential housing typologies in Algeria by the archetypes of dwellings.

Source: (Semahi et al., 2020).

According to the contract type that reflects the inhabitants' income, there are several subcategories of the multi-family residential building archetype, including public rental apartments, participatory public housing, rental-ownership dwellings, as well as free promotional housing (see Figure III.20). The majority (31%) of the collective building archetype is represented by the category of social residential structures (public rental housing). The low-income population of Algeria is the target audience for this category.

(Figure III.20) displays in its left half the breakdown of residential building typologies by contract type. According to the right half to the same figure, which depicts the development of built social residential units, the number of dwellings in the social housing construction category has increased annually. During 2009 and until 2014, and between 2015 and 2019, the Algerian Ministry of Housing, Urbanism, and the city began an 800,000-dwelling initiative.

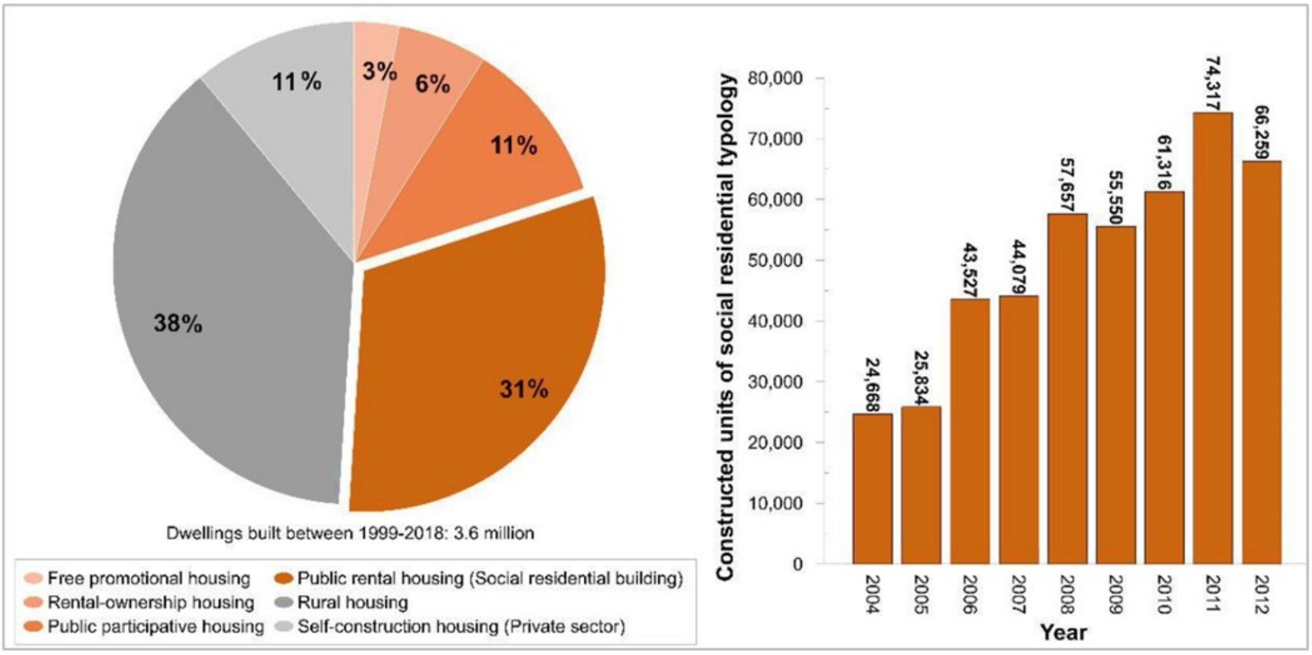


Figure III. 20. Classification of Algerian residential housing typologies based on dwelling contract forms, as well as the evolution of social housing unit building.
Source : (Semahi et al., 2020).

Semahi et al. (2020) found that the thermal and energetic characteristics of social housing in Algeria vary significantly across the territory.

The annual discomfort hours range from 3900 hours between the lowest and highest amounts, while the difference between the shortest and longest hours of cold discomfort is 4200 hours. However, the difference is 6400 hours for heat discomfort.

The results for thermal energy consumption show a large variation between the minimum and maximum, with an average of 109 kWh/m2.

The difference in cooling energy consumption between the lowest and highest values is 141 kWh/m2. However, heating energy consumption is 148 kWh/m2.

This variation is due to differences in climate zone conditions. For instance, the highlands zone has a continental climate characterized by hot, dry summers alongside cold, dry winters.

Despite this, the desert region maintains an arid climate with dry, extremely hot summers as well as frigid winters, and sunny weather throughout the year (Semahi et al., 2019).

III.12.2. Building thermal regulations in Algeria

The implementation of Law 99.09 on energy management in the construction industry was made possible by the issue of Executive Decree 2000-90 on Thermal Regulations for New Buildings on April 24, 2000.

These rules aim to make new residential and other structures, as well as parts of buildings built as additions to existing buildings, more energy efficient (HACHEMI, 2011).

A- Presentation of the DTRs (C 3-2, C 3-4, C 3-31)

The 1997 thermal standards for residential structures in Algeria aimed to cut down on heating by about 25%. There are currently plans to raise this amount of savings to around 40%. Digital simulations of typical houses were run to achieve this. According to the study, it is conceivable to accomplish this new goal while significantly lowering the summer air conditioning load by focusing just on preventing heat losses through transmission.

The 1997 standards should only be used for housing that is individually owned, and new more stringent regulatory factors should be established for dwelling in communal buildings (Hassar et al., 2002). The minimum thermal performances are specified in the regulations for estimating heat losses, DTR C 3-2 and DTR C3-4, which also include calculation procedures for the sizing of heating and cooling facilities. The calculations employed in Algerian rules are largely based on French regulations, but they are simpler. They permit, at least within certain parameters, automated calculations of heating and cooling requirements. This is a benefit since it enables you to take use of a building's thermal inertia, which is crucial given Algeria's various climatic conditions and preexisting building styles.

Regulations that concern thermal comfort are taken into account, particularly in hot weather. Given the issue of summer comfort and energy consumption brought on by the widespread use of air conditioning in Algeria (Foura & Zerouala, 2017), such regulation is of utmost relevance.

The creation of DTR C3-31 "Natural Ventilation - Residential Premises" in response to the energy management problems raised by law 99-09 of July 28, 1999, addresses the issue of energy efficiency.

The broad guidelines that govern the design of natural ventilation facilities can be defined using this DTR, together with the calculation techniques required to size them.

However, neither the smoke extraction systems (which remove smoke in the event of a fire) nor the smoke ducts for removing combustion products from gas appliances are covered by this DTR (CNERIB, 2011).

B- RETA Tool

CDER has created an application called RETA (Algerian Thermal Regulation) to make it easier to use and apply Algerian thermal rules. This software program is available for free and has a graphical user interface. It may be accessed online at (reta.cder.dz). The application gives the user a comfortable and simple-to-use interface that enables him to define the various building components and do the required thermal calculations to determine whether a project complies with thermal requirements. The program also provides the option of sizing a heating and cooling system to correspond with the needs for interior thermal comfort. The RETA application, like any software, is used to spare the user from laborious calculations that could result in mistakes and wasted time.

The project is RETA's primary component. It provides the essential information shared by all other organizations. Geographical information, such as height, latitude, longitude, wilaya, municipality, etc., is primarily at issue. The second phase will be to build the thermal volumes that comply with the DTR criteria after the project has been defined. Then, in order to establish a closed area, it is required to define the walls that make up each envelope or thermal volume (Imessad et al., 2017).

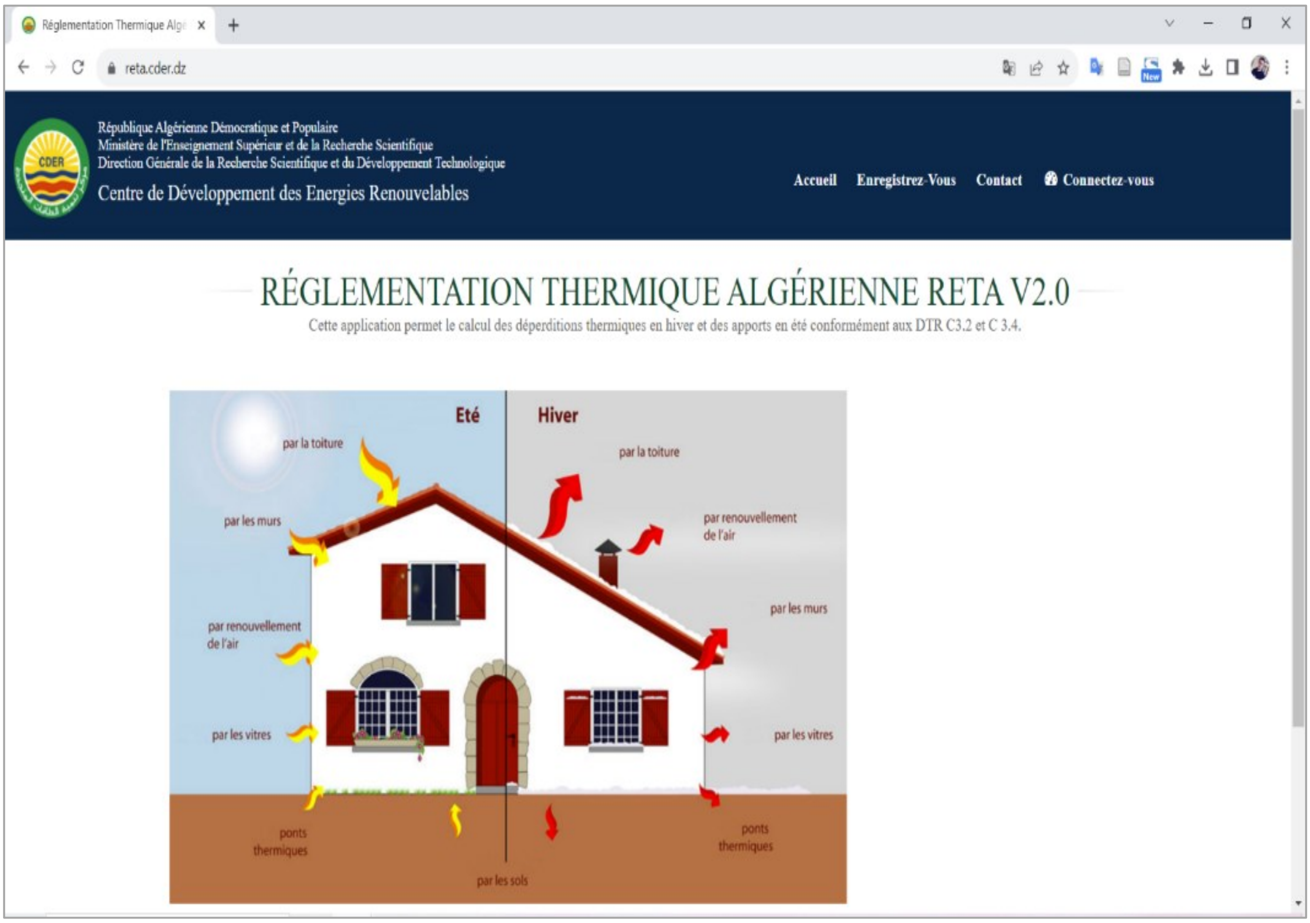


Figure III. 21. Interface of RETA (welcome page).

Source: The author, 2023.

III.12.3. Pilot projects in Algeria

The APRUE carried out a number of initiatives under the national energy policy and the national energy management program (PNME 2007-2011 and PNME 2010-2014), including the ECO BAT project (Figure III.22) in collaboration with the Ministry of Housing and Urban Planning. The goal of this project is to give the funding required to build homes that optimize indoor comfort by lowering energy use, mostly related to air conditioning and heating. APRUE began building 600 high energy efficiency dwelling units as part of the PNME 2007-2011, and it plans to develop an additional 3,000 units under the PNME 2010-2014.

The design strategy adopted for the ECO BAT project was to limit heat loss in winter through appropriate orientation and design of facades, as well as the use of suitable design strategies and materials. During the summer, architectural design can be used to control sunlight. Natural cooling techniques also can be employed. Additionally, the use of appropriate materials, depending on the climatic zone, can also be effective (Sami Mecheri et al., 2012).

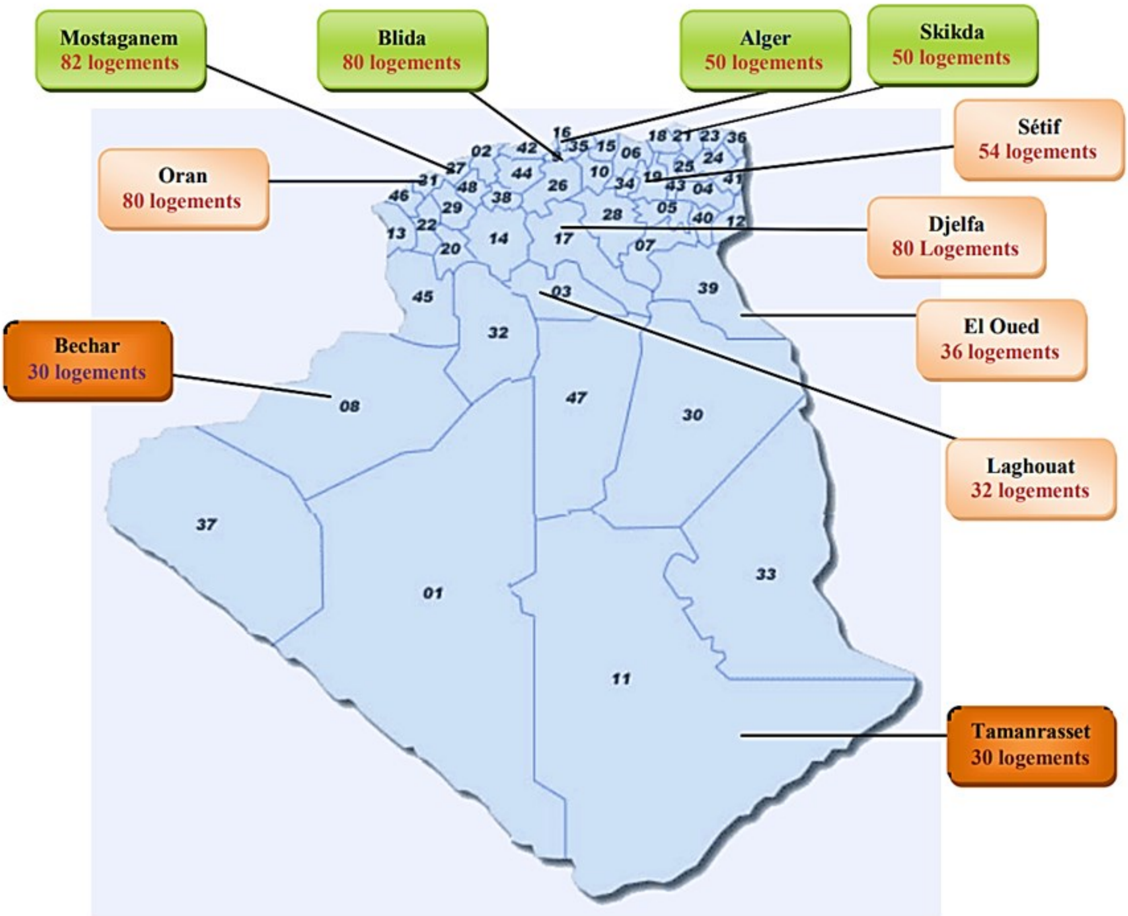


Figure III. 22. Breakdown of the housing (ECO-BAT project).

Source : (Sami Mecheri et al., 2012).

Algeria has undertaken various other energy efficiency projects, including the Med-ENEC project. The objective of this pilot project is to disseminate good practices in energy efficiency in buildings. The project targets 10 countries in the southern Mediterranean, with the aim of carrying out a pilot project in each country. The European Union finances this project with German technical cooperation (GTZ).

A pilot project has been carried out in Algeria. This pilot project aims to integrate energy efficiency and renewable energy measures in a typical 80 m² rural dwelling (Figure III.23). The project is being carried out in partnership with CNERIB and involves testing and validating the measures in preparation for large-scale replication (Sami Mecheri et al., 2012).

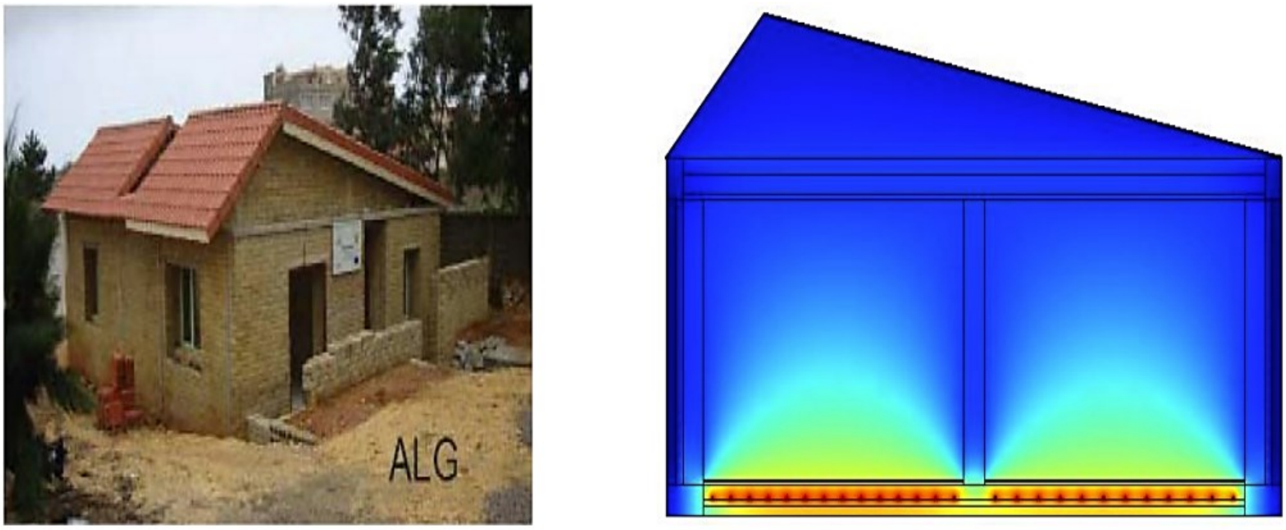


Figure III. 23. Prototype solar house built in partnership with the CNERIB, and simulation of the effect of its solar underfloor heating system.

Source : (Sami Mecheri et al., 2012).

III.13. Conclusion

Because of the rate at which energy consumption is increasing, demand must be properly managed to keep up with population expansion and household habits. Current trends in energy use risk jeopardizing the long-term supply-demand equilibrium. Given steady domestic demand growth, it is difficult to guarantee long-term expansion in the supply of fossil fuels, whose resources are, by definition, finite. Furthermore, the amount of fossil fuel output is determined not only by reserves, but also by investment, which is now insufficient to enhance the level of proved reserves. To maintain energy security and sustainable development for the nation, it is consequently vital to move to a system based on renewable energy sources.

The Algerian government seems to be taking a step-by-step approach rather than making rapid, wholesale changes. Despite Algeria's potential for large-scale solar projects, many renewable energy projects are only on paper.

When it comes to household energy performance, the body of rules and laws continues to be basic. The designated energy efficiency strategies are utilized in just a tiny number of dwellings in contrast to the vast existing buildings.

Advancement in this field of energy transition, more broadly in all energy-related fields, or more especially in the building industry, necessitates thorough planning to enable the integration of infrastructures and systems while accounting for socioeconomic structures.

To achieve Algeria's renewable energy targets, trust-building among stakeholders and decision-makers is essential. To do this, improvements and adaptations regarding investment, legislation, and behaviours will all be needed.

CHAPTER IV

Energy-efficiency renovation of buildings

IV.1. Introduction

The current energetic emergency situation demands a shift towards lower energy consumption and the establishment of a sustainable and renewable energy production system. Among the crucial sectors, buildings offer the potential for rapid progress in controlling energy consumption and greenhouse gas emissions. No technological breakthrough is necessary to initiate action, but it's the strategic tools that is needed. Additionally, the Algerian Minister for Housing, Town Planning and the City, according to (Nassima, 2019) reported that the national housing stock stood at approximately 9.6 million units in 2018. However, realistically, it will take several hundred to a thousand years to fully renew the national housing stock. There is only one way to rapidly transform energy consumption in the building sector - by renovating old structures on a large scale, seeing that failure to act in the building sector today would signify a complete lack of power to address the challenges posed by climate change and energy demands. Consequently, the renovation of buildings represents an optimal and indispensable solution to the social, energy and environmental problems, as well as the economic challenges that humans face today and tomorrow.

This chapter delves deeper into the issue of energy renovation, starting by defining what it is and what its objectives are. The framework outlines each intervention type that can be undertaken and the successive stages of their implementation, bearing in mind the condition of the built and human environment through efficient decision-making during the process. Subsequently, various previous research studies were analysed to determine the impacts of diverse improvement measures on energy and ecological issues. The chapter, afterwards, discusses advanced approaches in the frame of sustainable development and energy transition in urban areas. Firstly, it introduces the concept of Urban Building Energy Modelling (UBEM) and the tools developed on the basis on its principles, in order to help researchers to have an idea of the urban building response to different renovation interventions. Secondly, it provides an overview of an additional approach that can aid in the same objective, which involves solar simulation in the urban environment. This approach seeks to examine the impact of spatial factors that influence solar access to building surfaces, as well as identify the most suitable surfaces to implement solar panels, as part of renovation work.

IV.2. What is energy renovation?

Energy renovation is a physical intervention in which work is carried out on an existing building to improve its energy performance and make it more environmentally friendly. This procedure takes into account gas and electricity consumption reduction as well as the well-being of occupants. It is considered one of the primaries means of achieving sustainability in the built environment, that too, at a low cost, thereby improving the quality of life (Quelle energie website, 2019).

IV.3. Energy renovation objectives

IV.3.1. Energy and economic objectives

Reducing energy demand is crucial for ensuring energy security. A competitive and sustainable energy strategy prioritises achieving the highest potential for energy savings, particularly in buildings. Implementing measures to decrease energy demand preserves a significant amount of energy during periods of high usage. This benefits all electricity users by avoiding load and resultant losses in the transmission and distribution networks, leading to reduced operational expenses. When evaluating the cost-effectiveness of energy refurbishment, it is essential to consider not only the energy savings but also the benefits associated with improved comfort and reduced expenses in supporting energy usage and deployment.

The primary advantage of increased energy efficiency is the reduction of energy consumption, resulting in lower energy bills in the future. Although there are initial costs associated with implementing improvement measures, they can lead to a stronger financial position for the building owner and potentially increase the building's resale value.

Creating momentum towards more effective methods of reducing energy consumption in buildings enables the implementation of programs that promote energy renovation and home automation technologies. This statement suggests that research and development can enhance industrial competitiveness (Hamiti & Bouzadi-daoud, 2021).

IV.3.2. Environmental and health objectives

Many experts posit that the excessive use of fossil fuels is a major contributor to global warming, necessitating a reduction in our ecological footprint and impact on climate (Bardou, 2009). With conventional energy production releasing pollutants into the air, soil and water, enhancing energy consumption is crucial in mitigating air pollution. As energy production from power stations, district heating plants, and local heating production decreases, air pollution associated with them also decreases.

Consideration of optimal indoor comfort and microclimate is a priority objective in building design. This focus on user well-being is critical given the potential for energy-inefficient housing to increase the risk of exposure to excessively low indoor temperatures.

Such exposure presents a risk to occupant health, particularly the respiratory and mental health of building users (Ezratty et al., 2018). Respiratory disorders are primarily influenced by changes in temperature. Low temperatures can cause humid conditions, which increase the risk of mould growth and lead to respiratory symptoms (Wimalasena et al., 2021).

To improve the health and productivity of occupants in refurbished offices or indoor spaces, it is recommended to implement enhancements such as better insulation, improved heating efficiency, increased natural lighting, and superior ventilation. The enhancements also improve the interior microclimate, reducing the likelihood of occupants experiencing various symptoms.

IV.4. Energy renovation types

Researchers and building professionals have devoted considerable effort to the development and use of different renovation technologies and decision support tools with the aim of improving building performance. (Figure IV.1) presents the primary renovation technologies applicable to building systems. These approaches can be classified into many groups: supply management, demand management as well as changing energy consumption behaviours.

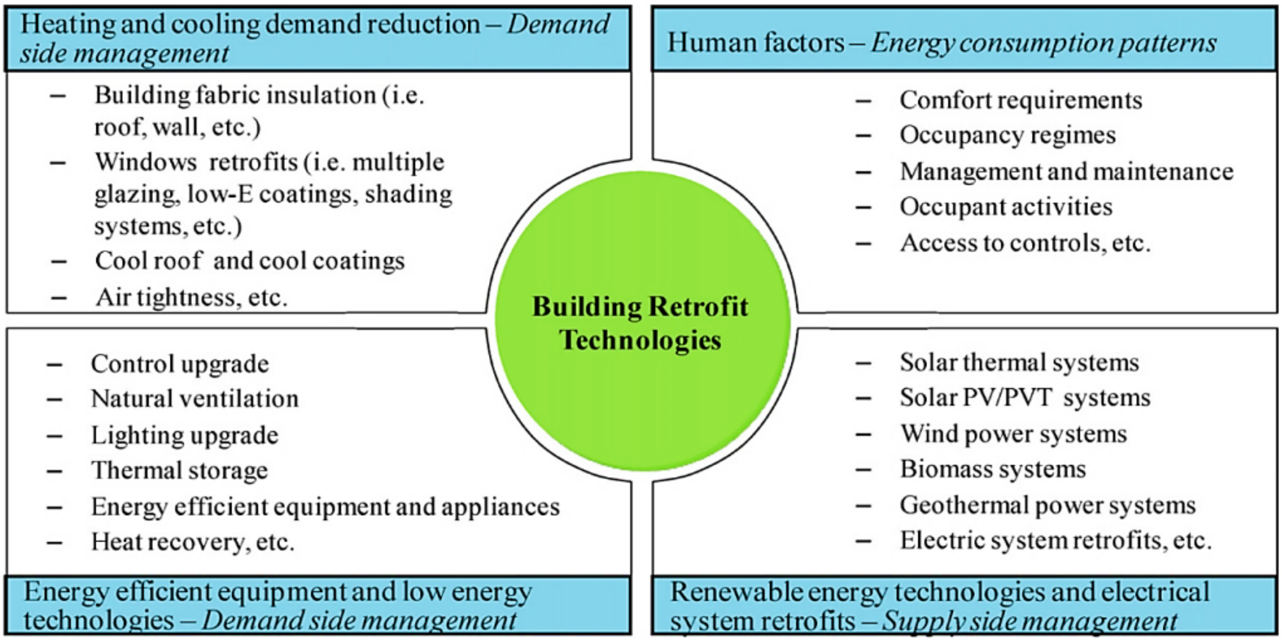


Figure IV. 1. Main types of building renovation technology.

Source : (Ma et al., 2012).

IV.4.1. Strengthening the thermal insulation of the envelope

To achieve high results in energy efficiency terms, it is necessary to optimize thermal inertia, eliminate thermal bridges and control solar access, avoiding heat loss in winter, or overheating in summer, and benefiting more effectively from the sun's rays, thus reducing the need for heating, air conditioning and artificial lighting. The (figure IV.2) schematizes the main consideration that should be taken in mind during the different interventions on building envelope.

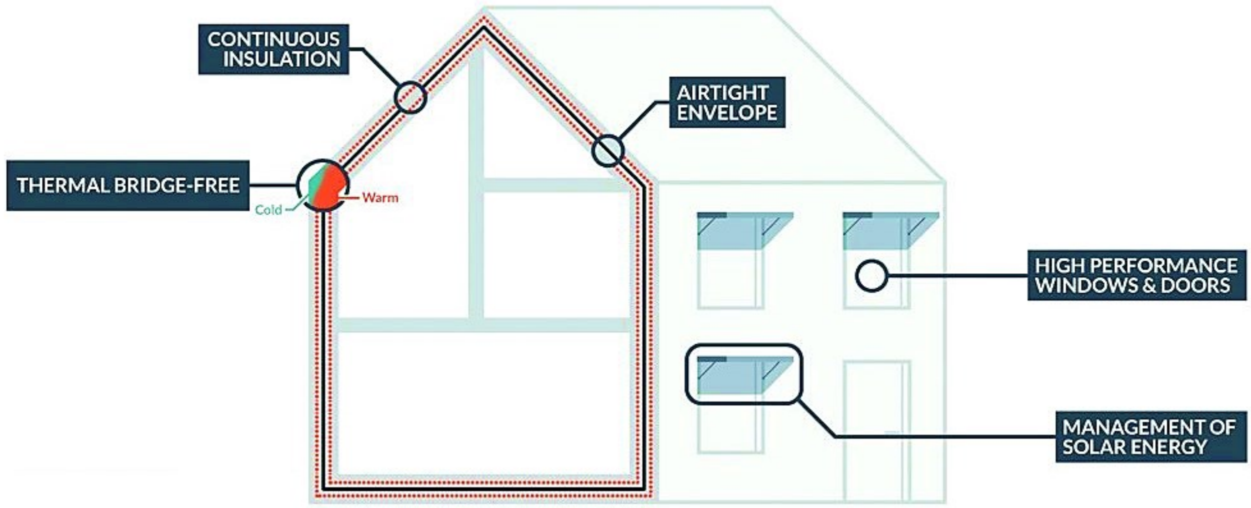


Figure IV. 2. Schematization of the different considerations that should be within envelope thermal reinforcement. Source: (Upstate House Website, 2021).

Firstly, by insulating the attic space, where the least expensive solution is to lay unrolled insulation panels under the roof structure. For greater efficiency, insulation should be laid on the ceiling of the top heated floor. Insulation can also be laid on the outside of the roof structure. In the case of unfinished attics, the work is easier and can follow the same technique. Insulation can also be blown onto the attic floor. The roof can be responsible for up to 30% of heat loss in the home, making roof insulation a priority for energy renovation. This can be done either internally, by insulating floors in the case of lost attic space, or by insulating crawl spaces in the case of converted attic space, or externally, by installing self-supporting roofing panels above the roof structure, after complete removal of the roof (Site: La prime énergie par effy, n.d.). Reinforced wall insulation is also very important, and can be applied from the outside, either by installing insulation covered by a thin plaster, or by installing insulation and then attaching cladding (wood, slate, terracotta, etc.) to the framework, or by applying a thick insulating plaster (hemp lime mortar or hemp cork). It can also be done from the inside, either by installing a lining complex incorporating insulation and plaster cladding, or by installing insulation between the wall and a metal frame, followed by plasterboard on this frame. Its importance can be seen in the fact that:

- Walls are responsible for 20 to 25% of energy loss in the home.

- The thermal performance of one cm of insulation is equivalent to that of 40 cm of concrete.
- Wall insulation can reduce a household's energy bill by up to 25% (Communauté d'agglomération Valenciennes Métropole, 2017).

Floor insulation, too, is essential for optimum thermal comfort and a well-protected envelope against external fluctuations. There are a number of techniques for insulating floors: slab insulation, added insulation, under-face insulation, surface insulation, etc.

Heat loss through windows can account for up to 15% of heat loss, which is of course significant. But it also means that 85% of heat loss has another source. If thermal insulation is not treated as a whole, the gain between double and triple glazing will be minimal. For a passive house or very low-energy home, on the other hand, triple glazing is almost mandatory, because every detail counts.

Double and triple glazing are often used in the same house: double for windows facing west and south, triple for windows facing east and north, or north only. For regions that are very hot in summer and temperate in winter, triple glazing offers few advantages (Site: La prime énergie par effy, n.d.).

It's important also to choose the right insulating materials: ecological, healthy materials such as cellulose wadding, wood fibre or cork have a high thermal capacity. They store heat and therefore provide greater comfort in summer, at a reasonable thickness.

As soon as a window or door presents a problem with airtightness or opening or closing, the replacement of windows and doors is a priority to improve the thermal quality of the home (Communauté d'agglomération Valenciennes Métropole, 2017).

IV.4.2. Integration of renewable energy systems

The environmental challenges of global warming and the foreseeable depletion of fossil fuel resources have encouraged and motivated to take steps towards energy transition, in all sectors, and especially in building sector which involves harnessing cleaner, more sustainable energies such as wind, hydro, solar, geothermal and biomass, through different systems that include: photovoltaic solar collectors - thermal solar collectors - geothermal energy - methanization - urban wind power...

In order to raise living standards, dependable energy sources, like renewable energy sources, can be extremely important (Shafiullah et al., 2012).

The most common sort of renewable energy source is solar thermal energy, which can be obtained both directly and indirectly. There are many thermal applications for solar energy, including solar water heaters (Xue, 2016; Aydin et al., 2018), rooftop solar power systems (Al-Hassan et al., 2018), air conditioners systems (Kurata et al., 2018), etc. Other thermal applications for solar energy include stoves, refrigerators, and cooling systems.

These applications can provide for a family's requirements and guarantee an environmentally friendly future (Al-Marri et al., 2018).

In a number of countries, solar thermal methods are widely used to produce hot water (Rogers et al., 2013; Tévar et al., 2019), they are designed as either closed-loop or open-loop, while extremely cold regions may use a closed-loop solar system (Veeraboina & Ratnam, 2012). In particular, the efficiency of movable heating systems, exploratory study of nanoplatelets made of graphene nanofluid-based volumetric solar collectors for domestic hot water systems, local market circulation for solar- powered water heaters in Taiwan, and hybrid renewable energy systems for residential use were all covered in the scientific literature. These uses include a new opaque roof sunlight chimney configuration for homes (DeBlois et al., 2013), a boxed hybrid solar stove created by photovoltaic alongside thermal power technologies (Joshi & Jani, 2015), a parabolic-type portable solar stove (Regattieri et al., 2016), a boxed-type solar stove using an internal reflecting device (Haileslasie et al., 2014), the development and setting up of both heating and cooling water systems (Osborne et al., 2015), and more…

Renewable energy sources technologies (solar as well as biomass) are utilized to reduce a household's power usage and meet the energy needs of a single-family detached dwelling (Enteria et al., 2015, 2016). There is a ton of material on the topic of using artificial neural networks for predicting solar radiation to create efficient solar products (Alam et al., 2009; Jiang, 2009; Qin et al., 2011). All of these appliances, involving solar-powered stoves, boiling water heaters, cooling systems, as well as dryers, have an opportunity to help developing countries conserve energy. According to a survey (REN 21 STEERING COMMITTEE, 2015), Bangladesh was the country with the highest usage of solar residential systems in 2015. The addition of a water heater powered by the sun may decrease overall home energy usage by around thirteen percent, according to a study of family energy use (Aydin et al., 2018). The research project of (Thinsurat et al., 2019) investigated the possibilities of a mix of photovoltaic-Thermal solar collectors (Hybrid PVT) combined with a thermochemical energy storage device for the heating of water with the aim to enhance the residential use of solar energy. Solar home systems, such as energy-saving multicookers as well as LED lighting, are employed to address domestic energy shortages in nations that are developing (Zubi et al., 2018). According to a different study by (Shakeri et al., 2018), house energy management systems (HEMS) batteries can be recharged using a solar photovoltaic system as a secondary source. Another reason for people to use renewable resources at home is that they are regarded as being both affordable and safe for health. Different applications of these RES are employed in home settings. For instance, solar household systems, dryers, cookers, refrigerators, heaters, cooling systems, and power generating all use renewable energy sources (i.e., the energy from sun radiations). Similar to how biomass is used for the production of heat and power, wind power is used for windmills, water pumps, and wind turbines. The (Figure IV.3) summarizes and schematizes the different used systems based on the different renewable sources, and their different modes of uses by buildings occupants.

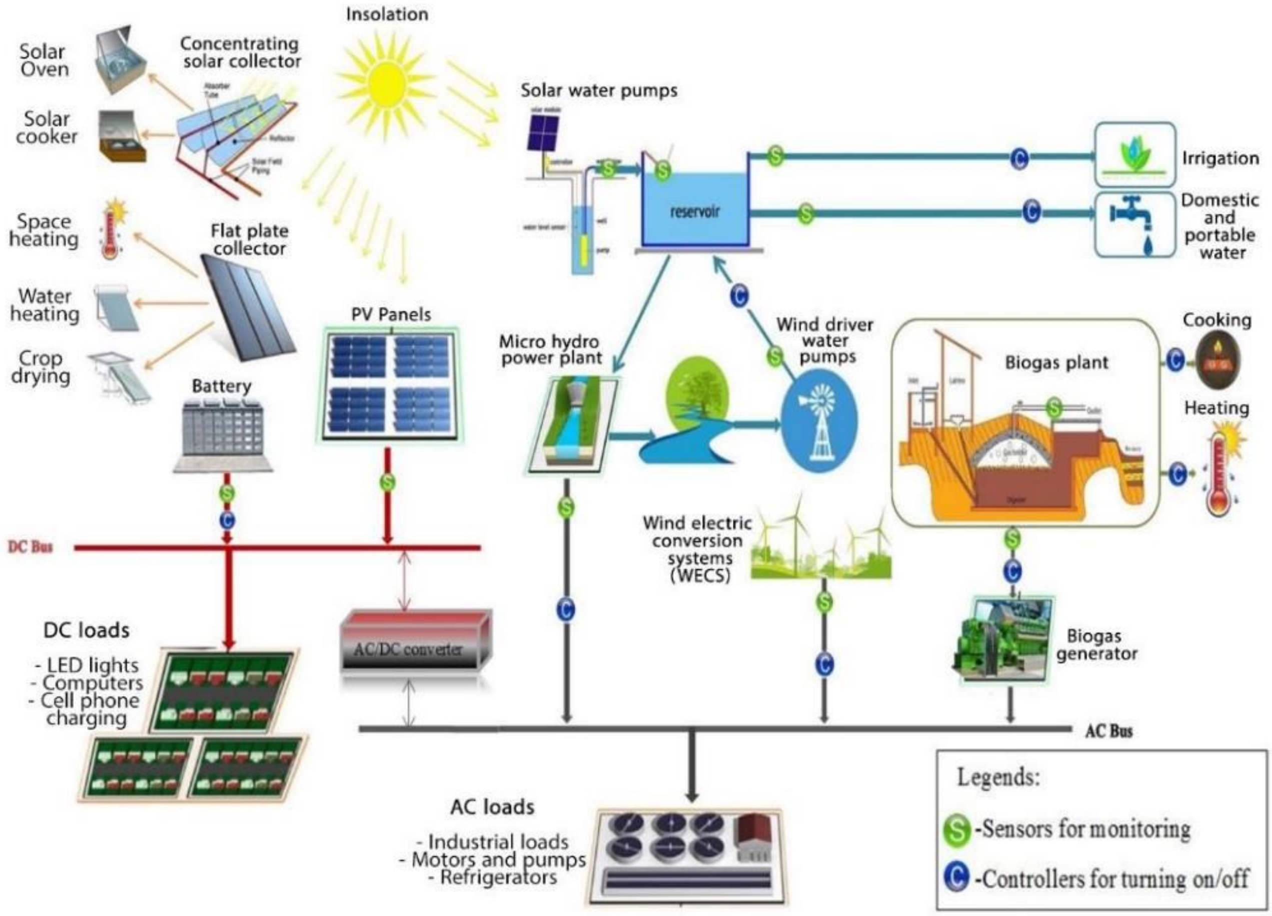


Figure IV. 3. Schematic illustration of building integrated renewable energy systems. Source: (Maheshwari & Ramakumar, 2016).

IV.4.3. Energy efficient equipment and low energy technologies

According to the study by (Jones et al., 2017), after applying the improvement measures (external wall insulation; loft insulation; low-emissivity double glazing; LED lighting; gable cavity wall insulation; gas boiler and hot water cylinder; photovoltaic systems; positive loft ventilation.) on 5 case studies, the results show a remarkable reduction in CO_2 emissions of 50 to 75%; savings of £402 to £621 per year, 56% reduction in energy consumption for heating and 84% for electricity.

The LED lighting, gas boiler, and hot water boiler were instrumental in reducing energy consumption and the carbon footprint. This was demonstrated by comparing the space heating demand in the case study abbreviated (Retrofit 1), which features integrated gas and hot water boilers, to the difference in heating demand before and after refurbishment, resulting in a significant reduction. In contrast, the energy demand remains unchanged in the case study abbreviated (Retrofit 5), knowing that the same mentioned equipment (New gas boiler with hot water tank), used in (Retrofit 1) scenario is not present in (Retrofit 5) scenario. The result is illustrated in (Figure IV.4).

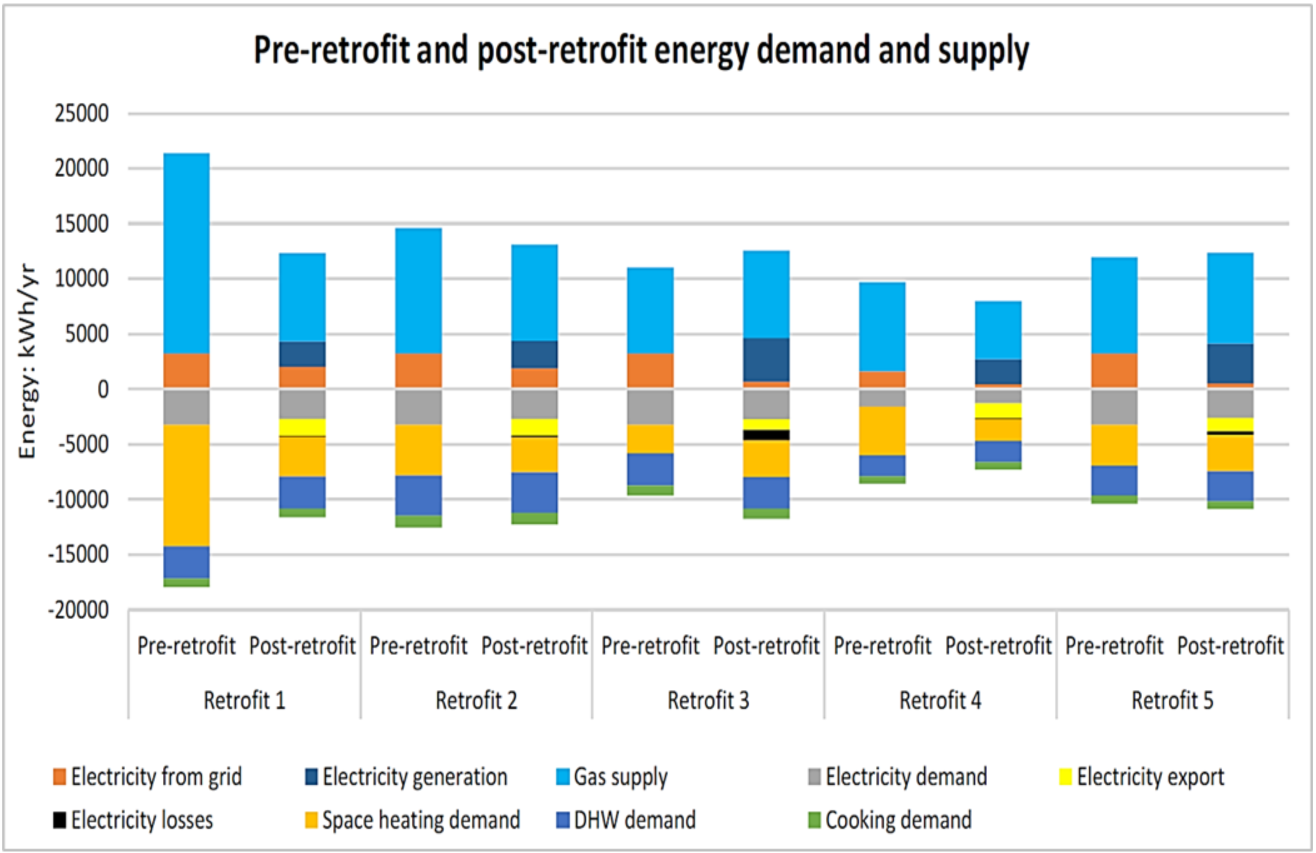


Figure IV. 4. Forecasting energy demand and supply before and after retrofit, as exemplified by research carried out by Jones et al. (2017).

Source: (Jones et al., 2017).

Other several measures can be taken within this kind of interventions, such as:

- Replacing inefficient boilers with condensing gas boilers.
- Improving mechanical ventilation, air conditioning, lighting and auxiliary systems.
- Installation of heat recovery systems.
- Improvement of emission systems and distribution of technical systems (e.g. pipe insulation).
- Installation of micro-cogeneration systems.
- The use of electrical household appliances with energy labels of A, A+ and A++, seeing that these appliances consume up to three times less energy than those labelled C, D or E, thereby reducing your energy consumption and associated costs (Communauté d'agglomération Valenciennes Métropole, 2017).

IV.4.4. Home automation technologies

To enable a building to self-regulate its energy consumption based on factors such as occupancy, climate, and energy availability, it must be equipped with home automation systems. This is what an intelligent building is all about. The building must include four essential systems:

1. A building automation system that offers amenities to occupants all around the structure, such as lighting, security, and ventilation and air conditioning (HVAC) systems.
2. An apparatus for communication.
3. Room automation systems that apply the first system's concept but speak specifically to a single room.
4. Systems of command and control that oversee the rooms' equipment (Nikolaou et al., 2004).

In order to monitor, identify abnormalities, and control equipment (such as blinds, HVAC systems, and air conditioning units), an intelligent building is simply outfitted with sensors, information, and communication systems. This is a component of intelligent building energy management.

The goal of dynamic energy management is to increase the energy efficiency of a building, achieving a better balance between cost and comfort for users.

An Energy Smart Building should have energy advisory software that manages the energy systems, considering the occupants' preferences. Communication between the software and occupants will be through suitable man-machine interfaces, such as smartphones, optical interfaces, and voice commands.

The Building Energy Management System (BEMS) is the software used to manage the Smart Energy Building. It must adapt to external weather conditions and user requirements, while ensuring that users retain control over the final decision (Badreddine, 2012).

Home automation can optimize several areas of application, including comfort, security, energy, and the management of technical packages such as divisional switchboards, lift control panels, sprinklers, and plumbing through remote management. This system can be applied to various fields, including heating and air-conditioning.

It manages, operates, and forecasts maintenance for boilers or unit heaters. It also optimizes operating times using a timer.

The system controls and regulates the temperature of each room based on occupancy using a presence detector. It differentiates between rooms located to the north or south of the building or on different floors.

Electricity can be conserved by zoning the electric convectors and implementing presence detection or time-based lighting management.

Access management can be improved through the use of badges, voice or biometric recognition, and intruder detection. In the event of an evacuation, counting people can facilitate rescue operations. Installations can be monitored for malfunctions or anomalies through alarms that alert the supervisor. The maintenance department can receive alarms via email, fax, or text message for prompt notification. Alarms can be generated for various reasons, including intrusion, lift failure, water leakage, fire, malfunction in heating or air conditioning, or if there is a mathematical difference between several meters. Usage limits can also be set (wallonie energie SPW site, n.d.).

IV.4.5. Human factors

Energy consumption in buildings depends on various physical factors. However, the actions of occupants, which are essential components of the built environment, affect the preservation and energy savings of the building and also significantly impact the ecological performance, before or after the energy renovation. Recently, the influence of building occupants and their behaviour has become increasingly important (Uddin et al., 2021).

A- Eco gestures and good practices

For heating, the best indoor temperature is 19°C. This ensures that comfort, health and savings are combined. When the occupants are away, it is advisable to reduce the temperature by 3°C to 4°C. To be able to adjust the temperature according to the presence or absence of occupancy, it is vital to have a programmable thermostat. A temperature of 16°C in the bedroom is satisfactory.

As far as lighting is concerned, it is advisable to opt for natural light as it is both the most efficient and environmentally-friendly option. To ensure the natural flow of light is not disrupted, it should be enhanced by avoiding anything that might obstruct it. Furthermore, it is important to remember to turn off lights in unoccupied rooms to conserve energy.

Simple measures, such as ensuring equipment is regularly maintained, enabling natural ventilation through openings, and increasing awareness among users, can effectively enhance comfort and health. Sufficient and continuous air renewal is crucial for improving air quality.

A high concentration of CO_2 indicates insufficient air renewal, which can result in the presence of harmful airborne pollutants, posing potential health hazards (Communauté d'agglomération Valenciennes Métropole, 2017).

These actions, in addition to choosing more efficient household appliances and reducing the use of entertainment devices such as televisions, game consoles, etc., are just a few examples of behavioural actions that can consolidate energy efficiency and reduce the ecological footprint.

B- Factors that influence homeowner renovation decisions

Individuals and their surroundings have an impact on behaviour. The elements that affect human behaviour can come from a variety of sources and are divided into four categories: personal factors, contextual factors, barriers (such as information), and motives (such as thermal comfort).
In order to pinpoint the elements influencing homeowners' renovation choices, (Wilson et al., 2015) analysed behavioural studies on energy efficiency. The way people assess information is one instance of a personal element. In order to arrive at decisions, people typically analyse data based on their own views (Gigerenzer & Selten, 2002).
The behaviour is produced by the interactions of personal and environmental elements (Stern, 2000). (Figure IV.5) displays the major categories of individual, environmental, and motivational influences.

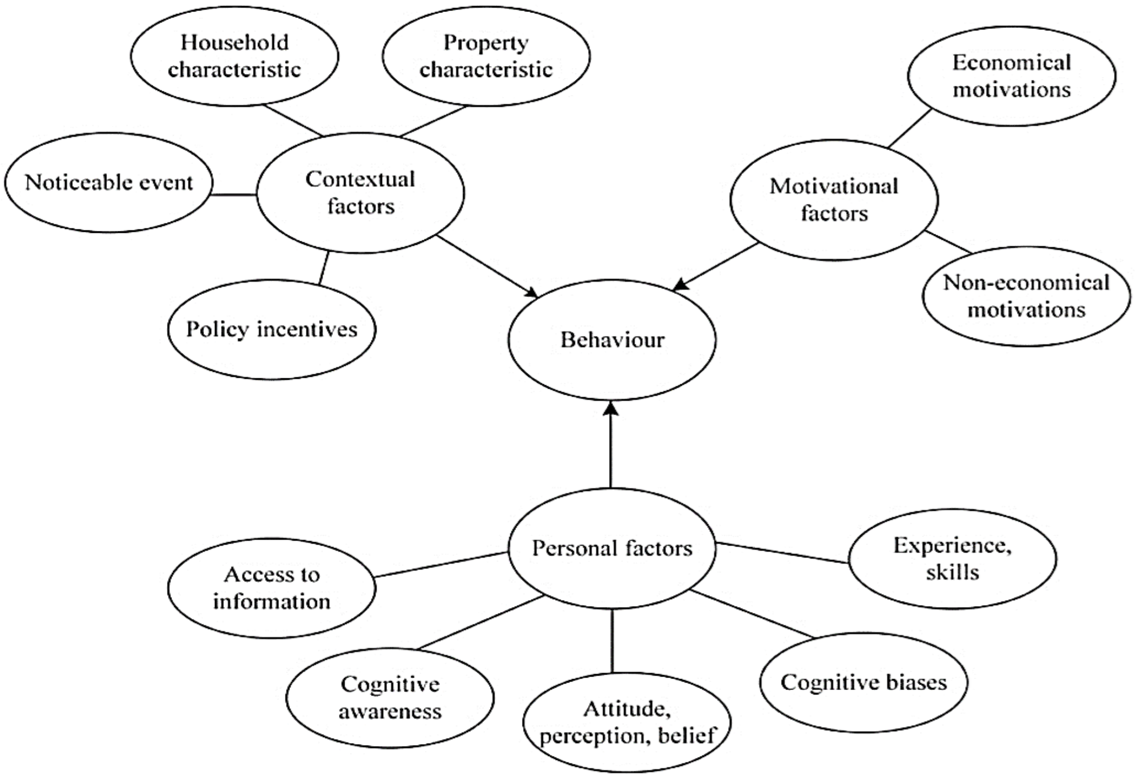


Figure IV. 5. Behaviour-influencing factors affecting the decision-making process of homeowners regarding energy efficiency renovations.
Source: (Ebrahimigharehbaghi et al., 2021).

For the housing industry in the United States, (Steemers & Yun, 2009) looked into the both the direct as well as indirect impact of several factors on home energy use. The key findings were as follows: firstly, physical characteristics, such as climate alongside heating system type, are significant factors for heating; secondly, financial status has an indirect impact on the amount of energy used for space heating or cooling; and finally, the amount of heated or cooled rooms along with the frequency of air conditioning use are the main factors influencing energy consumption for indoor cooling and heating. According to a study on the Chinese housing sector, households with senior members were more likely to have their homes retrofitted (Yang et al., 2017).

The effects of several variables, such as building characteristics, sociodemographic behaviours, and self-reported behaviours on energy usage in the housing industry in the UK were studied by (G. M. Huebner et al., 2015). They came to the conclusion that the main source of variation in energy use was due to building factors. Socio-demographic factors and attitudes have less of an effect on energy use. But, according to another research by (Vassileva et al., 2012), factors that significantly affected energy consumption were household characteristics, the kind and use of electrical devices, and attitudes regarding it. The size of the household and the types and sizes of the appliances were the two factors that had the greatest impact on energy usage in a separate investigation by (G. Huebner et al., 2016). For homeowners in both the Netherlands as well as Denmark, the effects of building along with household characteristics were assessed by (van den Boomen et al., 2019), where about 50% of the variation in heating usage was explained by household and building variables, separately.

(Risholt & Berker, 2013) conducted research on Norway's owner-occupied market. They discovered that homes that are energy conscious or have members who work in fields related to it, are more likely to have efficient energy renovations. According to research that was in Germany (Stieß & Dunkelberg, 2013), individuals were found to be most motivated to conduct efficient energy renovations when they worked together, and shared knowledge.

C- Policy interventions for the control of householders' behaviours

(Steg & Vlek, 2009) classified policy interventions which impact human behaviour as structural or informational. Financial support (e.g., subsidies, taxes) along with access to technologies that are energy-efficient are examples of structural interventions that change the conditions under which families make decisions. Informational interventions, such as providing information on energy efficiency technology alongside social norms on reducing energy consumption, as well as feedback on these topics, influence people's motives (Sanguinetti et al., 2018; Abrahamse & Schuitema, 2020). Most typically, information is provided to encourage households to minimize their energy consumption. This type of intervention can be divided into two types: preceding and following interventions. The latter, such as labelling, primarily influences behavioural determinants such as knowledge and motivation. The former tries to deliver information after the behaviour has been performed, such as feedback (Hu et al., 2020). There are numerous examples of structural improvements in the Dutch nation's approach. In the Netherlands, natural gas is used in 95% of homes for heating, boiling water, along with cooking. Despite this significant contribution, the Dutch state has set aside specific budgets to phase out natural gas as an energy source by 2050. Financial assistance, loans, as well as taxes are instances of market supply side strategies. Low interest rates, third-party financing, reimbursement on energy bills, energy efficiency mortgages, and crowdfunding are examples of similar help provided by other countries (Kerr & Winskel, 2020; Bertoldi et al., 2020; Bergman & Foxon, 2020). Belgium, France, Italy, the UK, and Poland all have energy efficiency obligation programs in place that require energy suppliers to demonstrate that they are contributing to energy savings through encouraging energy efficiency operations or providing financial assistance to inhabitants (Kerr & Winskel, 2020; Bertoldi et al., 2020). The UK's Green Deal is an example of third-party finance and repayment through energy bills. However, it has not been effective in increasing the number of energy efficiency renovations, despite aiming to reach one million households. The process was complicated and administrative, with interest rates higher than those on mortgages. The primary goal was financial savings rather than improving the comfort and well-being of households (Bergman & Foxon, 2020). These factors contributed to the lack of assurance on energy savings.

In addition to these regulations, the national environment centre uses informational interventions to affect householders' intentions. This resource centre offers details on all the options for an eco-friendly and sustainable home, the availability of grants and loans, the stages to going gas-free, finding a professional or business, etc. Because people frequently rely their decisions on psychological shortcuts and routines, access to information does not always lead to a change in behaviour (Lehner et al., 2016).

IV.5. Energy renovation steps

The analysis directed by (Tupenaite et al., 2010) indicates that renovation is treated in different scientific models. These models focus on various renovation processes, decision-making, sustainable renovation strategies, and both macro and occasionally micro environmental factors.

Furthermore, these models are tailored towards specific processes or objects like housing, hotels, and commercial properties. No model has been presented that evaluates the renovation of the built and human environment as a totality, taking into account all the elements of the renovation process of the built and human environment, the needs of the stakeholders and the impact of macro, meso as well as micro level factors.

Whole-system design is crucial after presenting renovation strategies that may potentially be applied to all built along with human environments based on categories. None of the categories and strategies

are independent, and decisions made in one area may affect performance in the other. A single enhancement in building design has the potential to advance multiple systems' performance.
Careful consideration of prevailing wind and sun angles when deciding on building shape and window placement can improve not only a building's thermal capabilities but also its daylighting.

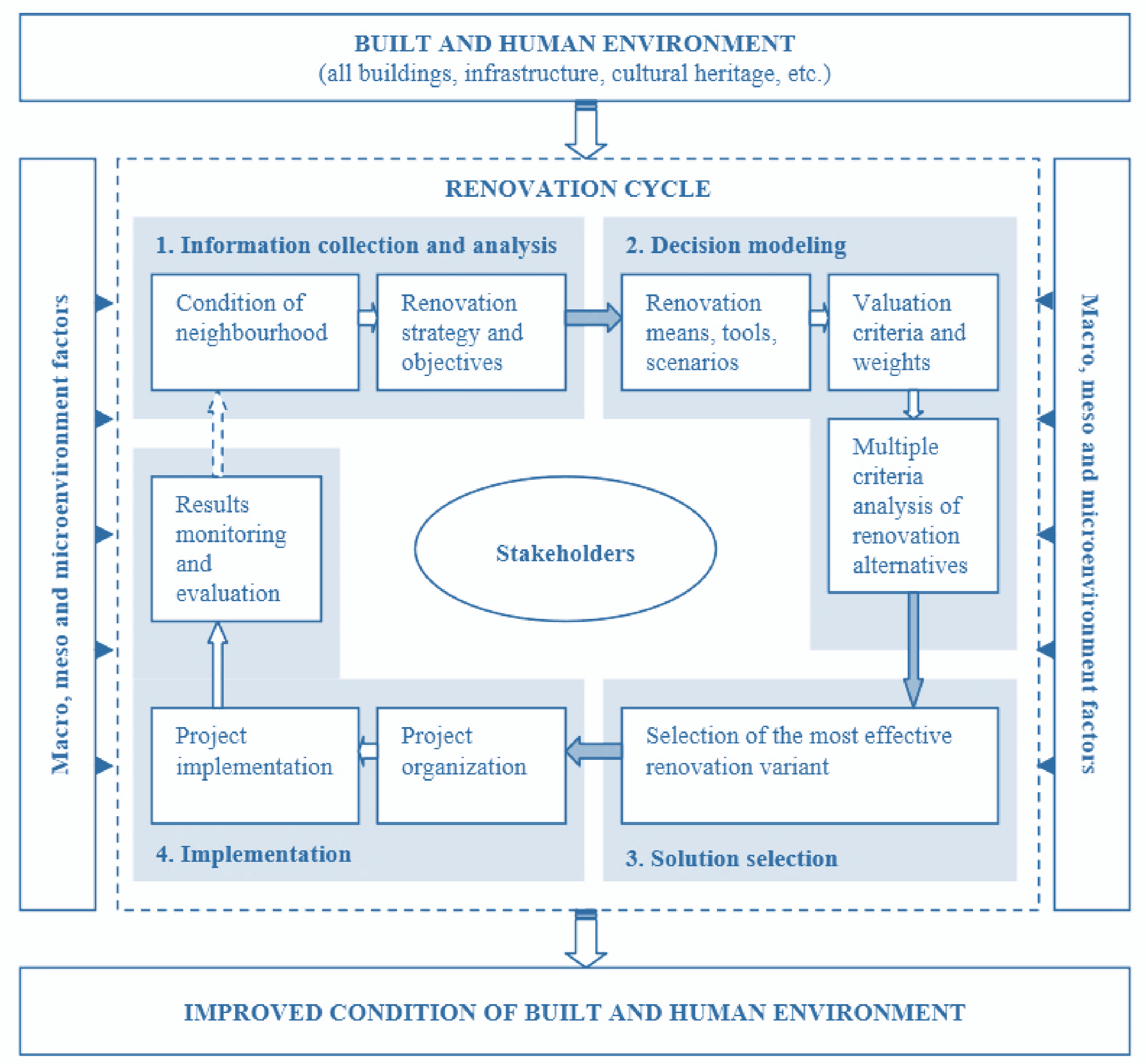


Figure IV. 6. Integrated study of a built and living environment rehabilitation conceptual model. Source: (Tupenaite et al., 2010).

Alternatively, overlooking other structures while solely evaluating a single building can lead to suboptimal outcomes in the built environment. For instance, improving a building without addressing accompanying infrastructure issues may only marginally enhance the living standards in the area, failing to reap the full benefits of the renovation. Any conflicts between categories must be resolved through an integrated design approach. Careful consideration should be given to the types of designs that can generate multiple savings or other outcomes. It is essential for all stakeholders to collaborate and take into account all sustainability categories to understand the impact of their decisions on the whole sustainability performance of the building in each category.

With these principles in mind, the authors have developed the Conceptual Model for the Integrated Analysis of a Built, and Human Environment Renovation (IABHER) presented in (Figure IV.6). The primary aim of this created model is to enhance the state of the built as well as human environment via efficient decision-making during renovation, backed by multiple criteria evaluation techniques. It considers all the relevant factors associated with the macro, meso, alongside micro environment and takes into account the requirements of stakeholders.

Renovating a house is not as straightforward as it might seem. Whether it's a partial or total renovation, all the right questions need to be asked. In all cases, professional help is needed, because it requires real expertise, whatever the type of work, and must be carried out in the following essential stages:

Stage 1: Survey the existing buildings, i.e., they are most often under occupation and use, and each of them has its own specific constraints.

As a result, technical solutions need to be adapted to the current state of the premises, to meet the expectations of the occupants, and to take into account the emotional impact of the property.

Step 2: The list of needs: The first step is to list what needs to be renovated in the house in relation to the current state of the property and the householder's needs.

Step 3: Take stock of the existing situation: The next step is to take stock of the existing situation to avoid unpleasant surprises during the works.

Once the householder's needs have been listed, it's time to:

- Draw up technical and architectural recommendations tailored to the work planned.
- Take stock of the constraints linked to the existing building: technical and administrative constraints, etc.
- Draw up a list of work to be carried out during the renovation and propose solutions tailored to the householder's needs.

Step 4: Estimates and duration of the work: this step's aim is to put a figure on the cost and duration of the work:

- Provide the householder with detailed estimates for each type of work so that they can assess the cost and see if it fits into their budget, and estimate how long the work will take.

Step 5: Acceptance of quotes by the householder:

Have the various estimates approved by the owner before starting the work, and propose a timetable.

Step 6: Start of work - structural work: The first stage of the renovation work will be the structural work, if there is any: facades, framework, roofing, drainage system, external joinery.

Step 7: Continuation of the work with the finishing touches: Once the major works have been completed, the next stage is the finishing and embellishment work with the finishing touches. This second part of the work will make the house or flat habitable.

Examples of finishing work include thermal insulation, floor coverings, wall coverings, painting, electricity, plumbing, the heating system, interior partitions and interior joinery (Batiweb, 2018).

IV.6. Analysis of earlier energy renovation studies

To learn more about the impact of passive and active renovation strategies on a building's energy consumption and environmental impact, an analysis of previous studies in the same research field was conducted, and presented in (Table IV.1). These studies were selected on the basis of the geographical and climatic context of the buildings and the types of interventions applied.

Table IV. 1. Renovation improvement measures and its results according to different previous studies. Source: The author, 2022.

References	Building type	Improvement measures	Major results
(Stovall et al., 2007.)	Typical houses in several places, the United States.	Wall renovations, counting replacing cladding, adding insulation under siding, and air sealing methods for replacement windows.	Additional energy alongside cost savings were possible over the adoption of low-emissivity storm windows or the replacement of vinyl-framed double-glazed windows.
(Kneifel, 2010)	Commercial buildings, the United States.	HVAC system (heating, ventilation and air conditioning), different types of thermal insulation of the building envelope, low-emissivity windows, LEC (low Energy Case) design.	The proposed measures decrease energy consumption by 20 to 30%; the (LEC) system is cost effective; carbon emissions will decrease by 32% in 10 years.
(Fluhrer et al., 2010)	The Empire State Building - Skyscraper in New York, United States.	Levelling windows; Insulated reflective barriers; Daylighting, tenant lighting and sockets; Modernization of the cooling plant; Use of a new air handling unit; Ventilation on demand; Balance of direct digital controls; Tenant energy management.	Can achieve 38% reduction in power consumption, save 105,000 metric tons of CO_2 over the next 15 years.
(Nabinger & Persily, 2011)	An unoccupied prefab house built in 2002; United States	Install a house wrap on exterior walls, seal leak sites in the living space floor and leaks in the air distribution system, and tighten the insulated belly layer.	The renovations reduced building envelope leaks by 18% and duct leaks by 80%, resulting in energy savings of 10%.

(Ascione et al., 2011)	A historic building hosting presidential offices and some classrooms, Italy	Modifying the indoor temperature set point; Reduction of infiltration; Increased thermal insulation of the vertical wall; Replacement of the old boiler with a condensing gas heater.	Could achieve 22% primary energy savings.
(Chidiac et al., 2011)	Canadian office building in Edmonton, Ottawa and Vancouver, Canada	Heat recovery; natural lighting; boiler efficiency saver; improved preheating; reduction in lighting load.	The use of five improvement options could reduce electricity consumption by 20% in Edmonton, Ottawa and Vancouver, and natural gas consumption by 30%, 32% and 19% for each of the respective cities.
(Bin & Parker, 2012)	A two-storey brick detached house built in 1910, Waterloo, Belgium	High-level insulation of the roof, walls, foundations and basement floor; Airtightness and replacement of windows and doors; Adopting renewable energy and energy-efficient appliances.	Improving energy performance through renovation is an environmentally friendly action for houses with a lifespan of several decades. This result remains valid for more recent houses as well as for century-old houses which can easily achieve reductions in energy consumption through renovation.
(Rysanek & Choudhary, 2013)	5 storey office building in Cambridge, UK	Thermal insulation of the roof and facade; improvement of exterior glazing; condensing boilers; improved lighting control; electronic thermostatic radiator valves.	Demand-side measures are the most cost-effective and offer a greenhouse gas (GHG) mitigation potential of around 10-40%; demand-side measures with a condensing boiler and a mini-CHP system are the most cost-effective solutions to maximize the reduction of GHG emissions.
(Ferrara et al., 2014)	Two-story high-yield single-family home, France	Different thicknesses of building envelope insulation; low-e windows; mechanical ventilation unit with heat recovery, reversible cycle air-air heat pump; cooling fans; condensing gas boiler; wood pellet boiler; electric heaters.	The lightweight wooden envelope is the best choice to achieve good energy performance at limited costs; the pellet boiler is the best solution in terms of costs; a high-performance all-in-one system achieves superior performance with a low increase in cost; cost-optimal design options are tied to poorly performing envelope systems.
(Corrado et al., 2014)	Apartment building, Italy	Wall insulation; insulation of upper and lower floors; low emittance windows; solar protection devices; solar thermal system ; PV system.	The optimal level of cost obtained implies a primary energy consumption for cooling, heating and hot water production equal to 115 kWh/m2.
(Akande et al., 2014)	Public heritage buildings, Brussels, Belgium	Passively improved building (insulation, double glazing). Photovoltaic panels, biomass and geothermal heat pump have been installed as well as ventilation with heat recovery.	The results show that there is 50% energy savings compared to the reference and 100% of the heating and cooling produced by renewable energy sources.
(DeAngelis et al., 2014)	A social housing building located in Brescia (northern Italy)	Wall insulation techniques; insulation of roofs and floors; replacement of windows or panes; condensing heat generator; thermostatic valve; heat pumps; photovoltaic panels.	The energy savings for classes B and A are approximately 70% and 80%, respectively. When heating systems are taken into account, heat pumps are the most cost-effective option.

(Santamouris, 2014)	A nativity scene in Athens, Greece	Green roofing	The results reveal that the application of a green roof system substantially enhances the energy efficiency of the structure. This translates to impressive energy savings, as the cooling load during the summer period was reduced by up to 49% following the green roof system installation.
(Ascione et al., 2015)	Educational building in the old centre of Benevento, Italy	Adequate management regime, Reduction of infiltrations, replacement of windows, increase of thermal inertia	24% reduction in annual electricity demand.
(Mauri, 2016)	Seat of the Province of Agrigento in Italy	Installation of PV alongside geothermal heat pump.	According to the simulation, the goal of reaching the NZEB " near zero energy building" is completed.
(Jones et al., 2017)	5-unit houses in Wales	Insulation of exterior walls; attic insulation; low-emissivity double glazing; LED lighting; insulation of the cavity walls of the gables; gas boiler and hot water tank; photovoltaic systems; positive attic ventilation.	Reduction of CO2 emissions by 50 to 75%; savings of £402-621 per year, 56% reduction in energy consumption for heating and 84% for electricity.
(Zangheri et al., 2018)	Single family Home; apartment building; office building; school, Italy	Building envelope, space heating, domestic hot water system, ventilation systems, cooling system, solar systems, lighting.	The cost-optimal measures allow a reduction in primary energy consumption that varies between 36 and 88%; for buildings that meet NZEB targets, the overall costs are lower than for a retrofit to meet minimum energy requirements.
(Fregonara, 2017)	Two-storey family residential building, Italy	The insulation of opaque walls; low-emissivity, high-insulation windows; decentralized mechanical ventilation units; double flow system with heat recovery; solar panels; photovoltaic panels.	The renovation measures make it possible to obtain a class A energy classification; building envelope renovation interventions are the most cost effective compared to others (no maintenance costs and no decrease in performance level over time).
(Gremmelspacher et al., 2021)	Historic buildings, Sweden	Two ventilation strategies, two glazing systems and five wall insulation configurations were tested, as well as interior insulation measures for the roof and floor slab, Photovoltaic panels on the roof.	The study shows that with a thorough renovation strategy and PV adaptation, NetZEB could be realized for a historic building in southern Sweden.
(AlFaris et al., 2017)	Individual habitat in Saudi Arabia.	Integration of the Intelligent Home Energy Management System (IHEMS) along with photovoltaic panels.	The results show that these technologies improve energy performance by 37% compared to the ASHRAE standard for single-family homes. Therefore, these techniques provide a solid foundation for adopting renewable energy systems, and for building low or zero-energy homes with high energy efficiency design.
(Morón et al., 2016)	A residence in the city of Galapagar, Madrid, Spain.	Installation of home automation systems (HBAS) including sensors, actuators, alarms, etc.	The implemented system in this dwelling has numerous objective advantages, primarily energy efficiency and reduced CO2 emissions, which are highly valued in today's world. Additionally, the system provides increased comfort and safety for the user.

(Ippolito et al., 2014)	A mid-sized Italian house in Rome, Italy.	The presence of building automation control systems (BACS) and technical building management systems (TBM).	The case study demonstrates that installing a BACS or TBM system is particularly practical when a building has high energy consumption (both electrical and thermal) and a low initial energy class. Such a system could enhance a building's energy performance.
(Martirano et al., 2017)	Residential building in Campobasso, Italy	A microgrid architecture, with a BEMS that manages both electrical and thermal loads.	Simulations on a case study building located in central Italy, equipped with a heating system and smart devices, have shown that on a reference day in March, a 12% reduction in peak power and a 23% reduction in average power can be achieved even if not all users fully cooperate. Additionally, load control improves self-consumption of PV-generated energy.

The literature indicates that different technological, physical and energy-based renovation methods have demonstrated varying degrees of accomplishment in improving energy efficiency and environmental sustainability. Such findings are derived from previous research works that involve examining case studies that were either undertaken in the field (In situ) or were simulated via computer software, and encompass several building types, combinations of different renovation measures, as well as diverse geographical contexts and climatic zones.

IV.7. UBEM approaches

Over the last three decades, a range of energy and environmental labels, as already discussed, has arisen for the construction and urban development sectors. These labels aim to enhance energy and environmental efficiency and are implemented in accordance with public technical standards on a voluntary basis. They function as quality indicators and are linked to programming, design, construction, refurbishment, operation, and city development processes.

In recent years, several techniques and approaches have emerged to attain the same objective in academic research field. Among these, computational energy models have been used to evaluate and enhance various design choices for energy-efficient buildings. Several energy simulation models have been developed to serve various energy-related functions, including planning, estimating energy needs and potentials, analysing retrofits, predicting outcomes, appraising the impact of green energy, and reducing greenhouse gas emissions (Torabi Moghadam et al., 2017; Jebaraj & Iniyan, 2006). Energy modelling can be conducted at either the architectural (BEM) or urban (UBEM) level, depending on the scale of the study. It is noteworthy that there has been a consistent increase in BEM and UBEM articles from 2011 to 2019, as depicted in (figure IV.7). Additionally, it should be mentioned that UBEM studies have only recently emerged and in smaller amounts than BEM studies, but both have been steadily increasing because of the great necessity and attention paid to improving energy quality and environmental performance in buildings, or even urban agglomerations.

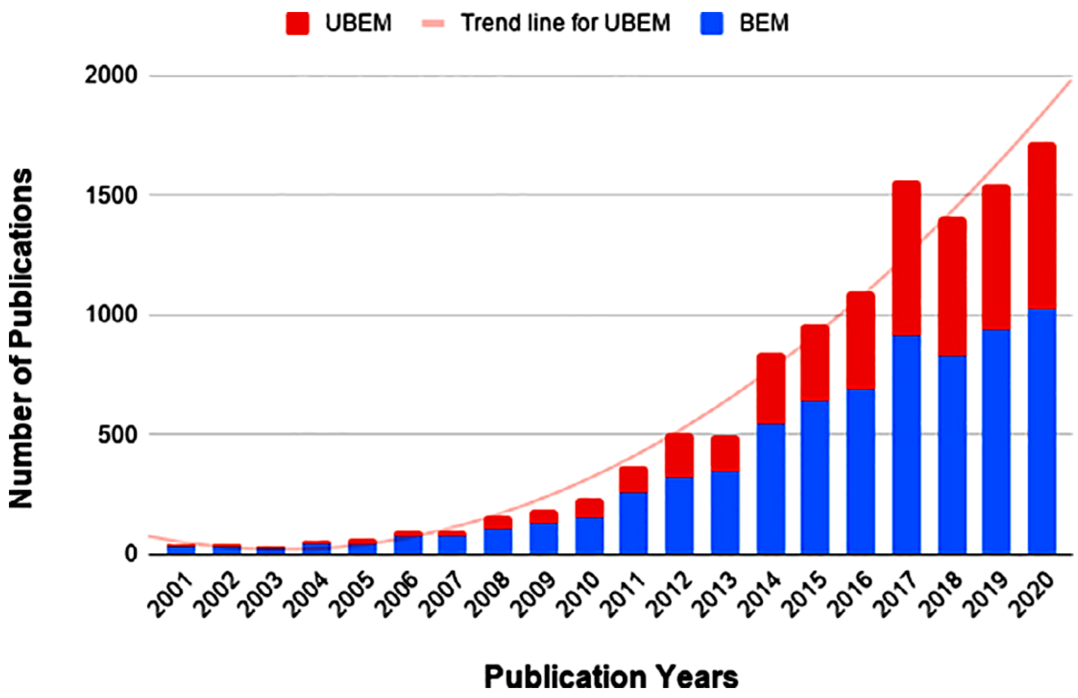


Figure IV. 7. From the academic search platform World of Science, the number of BEM and UBEM publications is increasing.

Source: (Ali et al., 2021).

UBEM therefore requires even more consideration, as it is a relatively new field, covering large geographical scales, as well as vast scenarios and improvement systems.

IV.7.1. The main categories of UBEM approaches and tools

As shown in (Figure IV.8), UBEM includes numerous approaches such as top-down and bottom-up modelling approaches, which in turn contain other types of approach.

Top-down methods use large-scale aggregated data to estimate energy consumption in buildings. They analyse the long-term links between energy consumption in a metropolitan area and specific factors. This classification distinguishes three types of models: socio-econometric, technological and physical. The majority of models belong to the first category, which concerns social, economic and market-related factors (Bentzen & Engsted, 2001). Technical aspects of buildings, including systems and envelope, act as drivers in technical models for a detailed examination of buildings (Huo et al., 2019). Environmental factors, such as weather conditions, are identified as major influencing factors by the third group (Kavgic et al., 2010).

These models require little input data to characterise the buildings, which is generally readily available aggregate data. In addition, the model can take into account long-term socio-economic factors. However, this creates a limitation as they attempt to anticipate future energy use based on past links between the energy and economic sectors. An additional disadvantage is the lack of technical information (Ferrando et al., 2020).

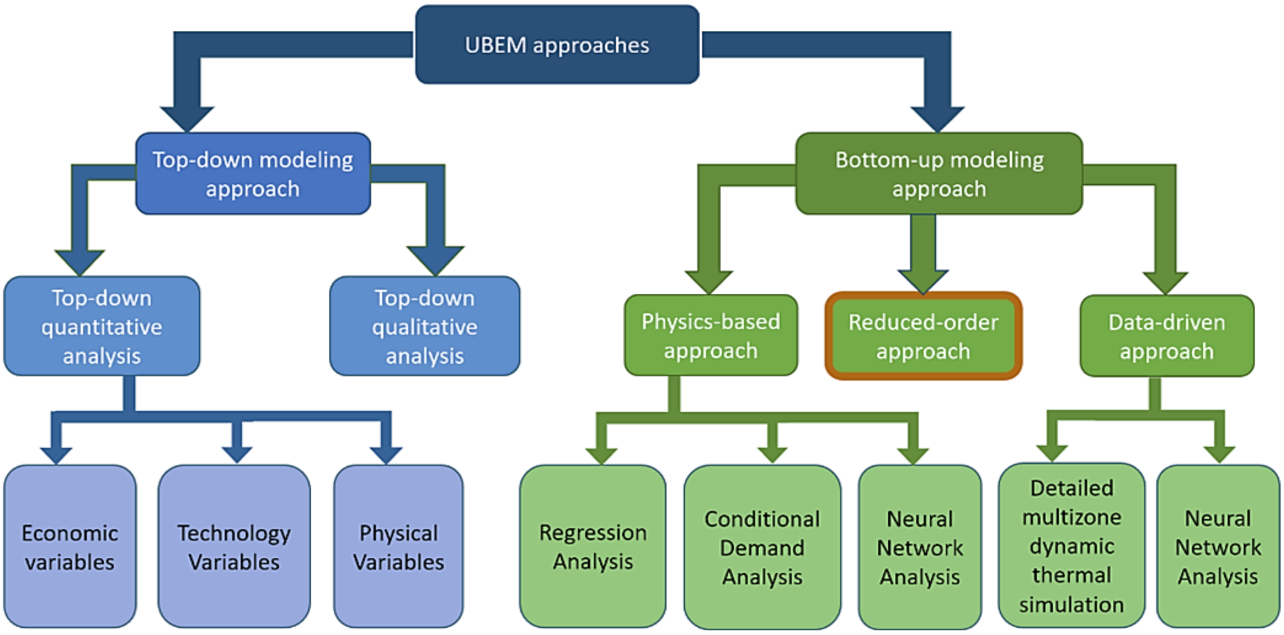


Figure IV. 8. Representation of the UBEM approaches.

Source: The author, 2023.

Bottom-up models examine energy usage for a building with a specific geometry, and then collect data at various levels within an integrated framework. For effective operation, these models need ample data, which can be impacted by confidentiality and other issues.

Additionally, a classification between statistical (data driven) and physics-based models is conceivable within this typology of models. This classification is based on the energy demand calculation procedure. Statistical (data driven) models utilise data mining and machine learning approaches to assess the energy consumption of buildings. The most frequently adopted methodologies include regression analysis, conditional demand analysis, and neural network analysis. The regression approaches establish links between building energy consumption and various characteristics, which are hypothesised to impact energy demand directly (Capozzoli et al., 2015; Mostafavi et al., 2017). Conditional demand analysis techniques estimate energy consumption by integrating survey, consumption, and meteorological data (Parti & Parti, 1980). The most recent techniques utilise neural network methods for the assessment of building energy usage (Nutkiewicz et al., 2021; Talebi et al., 2017). UrbanFootprint and CoBAM are amongst the data-driven tools available.

The physics-based method, also known as the engineering or simulation method, uses simulation techniques to calculate end-user energy consumption. This method takes into account building characteristics, construction, climate, and system data. Bottom-up models based on building physics provide useful information for policymakers to improve the efficiency of end-user buildings. Tools that work on the basis of this method include Citysim, UMI, CityBES, UrbanOPT, and SEMANCO.

To expedite analysis of the energy efficiency of buildings, reduced-order approaches are frequently used, requiring minimal input data compared to physics-based and data-driven options (Hong et al., 2020). One procedure particular to this technique is determining model parameter values, which can be approximated with different calculation standards published by the European Committee for Standardisation (CEN) and the International Organisation for Standardisation (ISO).

These standardised procedures delineate the calculation process via a set of normative statements that contain the physical parameters of the building and related systems for various building types. In the EU, various mathematical methods have been utilised to gauge the energy performance assessment (Lee et al., 2013).

The primary thermal network model formulated by ASHRAE elucidates the heat transfer and thermal dynamics across the building envelope, impacting the indoor temperature (ASHRAE, 2021). CEA, TEASER, SimStadt, and OpenIdeas are some of the tools operating under this scheme.

(Figure IV.9) illustrates a chronological overview of main bottom-up UBEM tools.

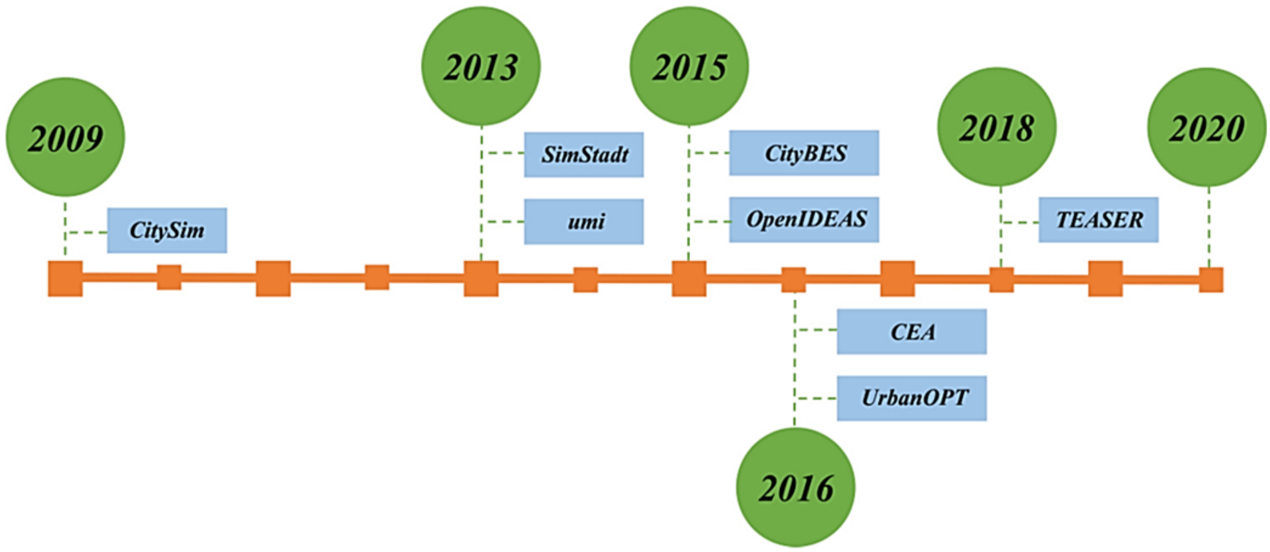


Figure IV. 9. Evolution of bottom-up UBEM tools.

Source : (Ferrando et al., 2020).

IV.7.2. UBEM Tools workflow

The (Figure IV.10) illustrates the steps involved in urban modelling and simulation, from inputs to outputs along with post-processing of the final result. Generally, UBEM tools have a similar procedure, where the method is mainly divided into five main stages: inputs (1), model (2), simulation (3), outputs (4), as well as post-processing (5).

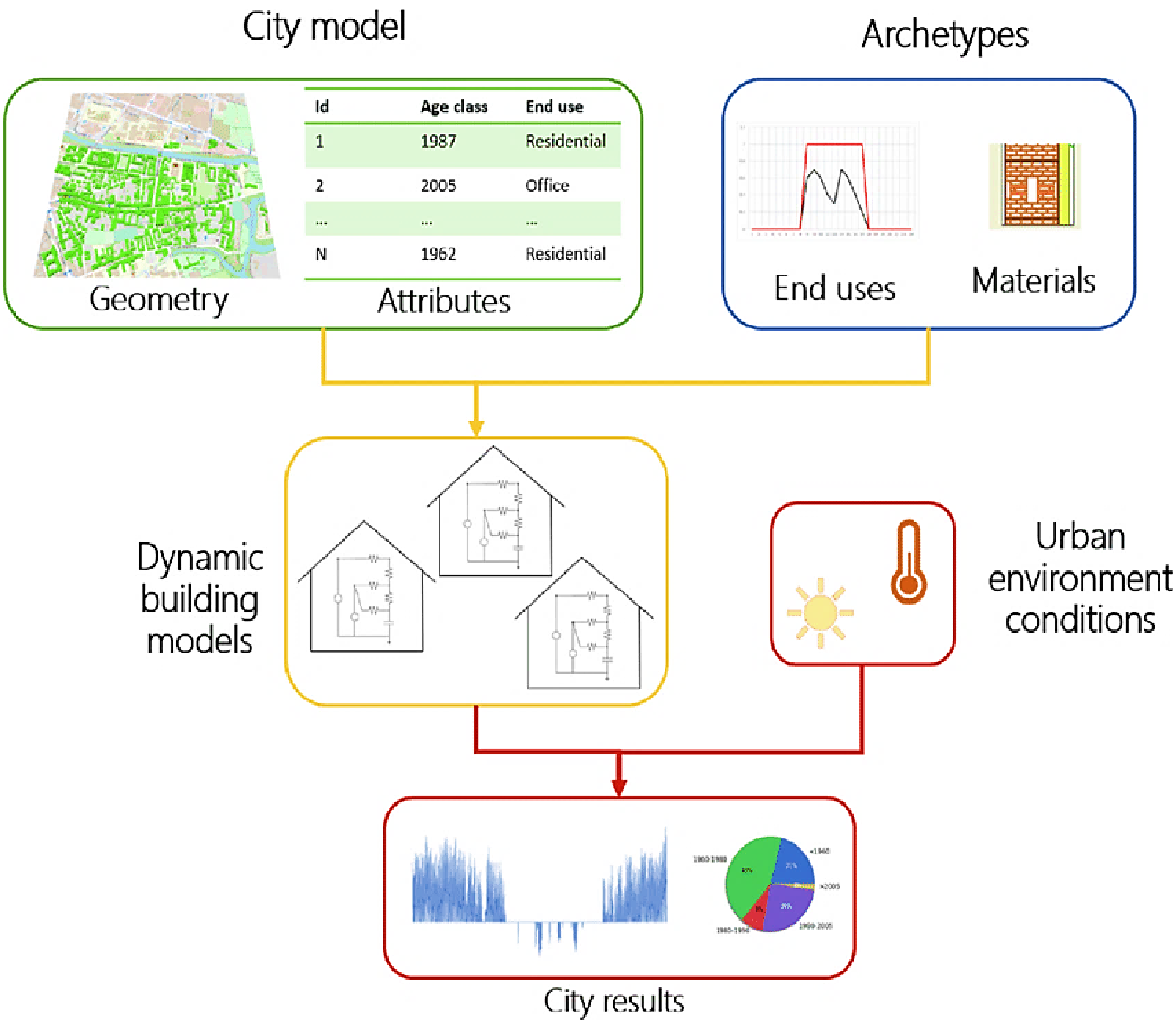


Figure IV. 10. UBEM tools workflow.

Source: (Prataviera et al., 2022).

The input stage comprises four categories: utility rates (which may be used for evaluation analysis or as part of the calibration as well as validation procedure), building-related information (which incorporates geometry together with characterization information, either unprocessed or already arranged as archetypes in conjunction with 3D models or even GIS files), and, if required, data about the district systems. Specifically, geometry and building-related data may already be merged in formats like CityGML or GeoJSON.

Combining geometry with the data from district systems and the building stock is the modelling process. The building system features and thermophysical qualities of each segment of the geometry characterize it. When feasible, CityGML files in conjunction with Energy ADE files may be used for this purpose. The topography and area attributes are connected to system-related data in the district network model. During the simulation phase, the meteorological dataset is merged with the building as well as district systems models. Simulation outcomes are created and practical analyses are carried out in the next step. The use of automated or manual validation and calibration may be one of the three main stages. During the postprocessing stage, the findings are altered so they may be downloaded as spreadsheet forms or visualized using graphs or geometry (Ferrando et al., 2020).

IV.7.3. In-depth overview of the UBEM reduced order approach

SimStadt, CEA, TEASER, and OpenIDEAS are all commonly utilized applications that are based on reduced-order methodologies.

(Table IV.2) summarizes information about each tool, along with its supported inputs and outputs, based on a variety of sources, including (Baetens et al., 2015; Ferrando et al., 2020; NOUVEL et al., 2015; Remmen et al., 2018).

These different tools have many things in common as well as many things that set them apart. Initial observations from the data presented in the table indicate that the majority of the tools used for this approach are developed by German universities.

However, there is one exception: the recent CEA tool was developed in Switzerland, at ETH Zurich University, in collaboration with its Singapore centre. This demonstrates a significant interest in the development of this field in the region of Germany and its neighbouring country, Switzerland.

The emergence of this type of tool occurred in the last decade, illustrating its novelty. Furthermore, its development is ongoing, with increasing support for inputs and outputs which may enhance precision and yield more results. Consequently, this provides greater ease of analysis and more opportunities for examining the subject from different perspectives.

Over time, these tools have expanded beyond simply analysing the energy use of a building or group of buildings, and can now also facilitate life-cycle analysis, solar analysis, and the consideration of economic factors. This includes the needs of the construction phase and the ongoing operation of the building, over varying time periods.

In addition to passive and active architectural systems, UBEM's latest tools feature reduced-order tools that incorporate urban energy systems, including district heating and cooling, the power grid, and energy storage.

Table IV. 2. Comparison of the most important tools of the reduced order approach. Sources : (Author, 2023), on the basis of (Baetens et al., 2015 ; Ferrando et al., 2020 ; NOUVEL et al., 2015 ; Remmen et al., 2018).

Tool	**SimStadt**	**OpenIDEAS**	**City energy analyst**	**TEASER**
Year	2013	2015	2016	2018
Developer	University of Stuttgart, Germany.	Katholieke Universiteit Leuven, Germany.	ETH Zürich (Switzerland) and Singapore.	RWTH Aachen University, Germany.
Availability	No public release	Available for free	Available for free	Available for free
Structure	Energy analysis is conducted in accordance with ISO 13,790, and the solar potential is estimated through internet databases such as PVGIS or weather data like METEONORM.	The first two components comprise of Systems from the MODELICA IDEAS library, stochastic modelling of dwelling occupancy (Python StROBe), and building modelling (Modelica FastBuildings library in addition to GreyBox).	There are six components (Demand, Resource Potential, Network Technology, Supply Infrastructure, Decision alongside Evaluation) and seven data sets (Weather, Urban Environment, Energy Suppliers, Conversion, Distribution, Systems, also Targets).	There are three main packages, consisting of the data package, which allows the input and output of data to be read, the logic package, which supports the processing of data, and the graphical user interface package.
Inputs				
Supported data format	Geographic Information System + CityGML.	Modelica + Python.	Geographic Information System + CityGML.	CityGML+ Modelica + Python.
Archetype supported properties	Systems, envelope, energy consumption, and deterministic occupation.	Envelop, systems, energy use.	Systems, building type, energy usage, deterministic use, intended use, envelope, and stochastic as well as deterministic occupancy schedules.	systems, volume, building type, year of construction, deterministic as well as stochastic occupancy schedules, envelope, and intended use.
Outputs				
Output display	Spreadsheet, and Graphic visualization.	Spreadsheet.	Spreadsheet, and Graphic visualization.	Spreadsheet.
Building energy use	HVAC, hot water, electricity.	HVAC, hot water, electricity.	HVAC, hot water, electricity.	HVAC, hot water, electricity.
Solar potential estimation	Only on roofs.	No solar potential estimation.	On roofs and walls.	No solar potential estimation.
Urban energy systems	No urban energy systems.	District Heating and Cooling, Power Grids, Power Storage.	District Heating and Cooling, Power Grids, Power Storage.	District Heating and Cooling, Power Grids, Power Storage.
Large scale general evaluations	Scenarios, life cycle analysis.	No large-scale evaluations.	Scenarios, lifecycle, benchmark, foodstuff, CBA (cost benefit analysis), transport.	No large-scale evaluations.
Time resolution	Yearly.	Minute/Hours/Day/ Month/Year.	Hours/Day/Month/Year.	Hours/Day/Month/Year .
Spatial resolution	Single building.	Building or grouping of buildings.	Building or grouping of buildings.	Building or grouping of buildings.

IV.7.4. The contribution of the UBEM reduced-order tools in energy and ecological field

To get a clearer idea of the use of these tools in the energy and environmental analysis, in addition to improvement scenarios of buildings and urban areas, (Table IV.3) summarizes the analysis of some articles together with their main conclusions.

Table IV. 3. Summary of research work which has used the reduced-order approach and tools of UBEM.

Source: Author, 2023.

Researches	Used tool	Study objectives	Main findings
(Baetens et al., 2015)	OpenIDEAS	IDEAS, StROBe, FastBuildings, and GreyBox1 make up the OpenIDEAS structure, which was designed for integrated energy simulations in districts. This framework allows for rapid prototype development in design and operation of district energy systems. The research has established the key criteria for creating this structure and also explained the software design standards, library architecture, and sample research results using the provided framework.	Thanks to the innovative methodology of OpenIDEAS, it is possible to examine the interdependence of electrical and thermal (building and district energy) models in a single simulation model. The stochastic behaviour of building occupants is used to estimate the aleatory unknown parameters in the proposed approach for all considered commodities, while the computer simulation of both centralised and decentralised algorithmic controls in district energy systems is achieved through the use of a large single model.
(Mosteiro-Romero et al., 2017)	CEA	This study looks into how architectural features, heat properties, operating standards (temperature settings and airflow rates), and internal heat gain (from people, devices and lighting) are impacted by the ratio of windows to walls, the quantity of occupants, and how airtight the building is. The study uses Saltelli's method of Sobol adjustments, the CEA, and a two-step sensitivity analysis. The case study region, situated in the centre of Zurich, Switzerland, comprises 284 buildings primarily used for educational, medical, and residential purposes.	The research approach illuminates the vital variables in CEA models based on different building typologies and occupancy types, with regards to heating and cooling requirements. The results demonstrate the most sensitive features of the scale and provide essential inputs for model calibration, guaranteeing accurate urban demand predictions. Seasonal variations, types of occupancy, sizes and shapes of buildings, and geographical distribution were all considered throughout the study.
(Happle et al., 2017)	CEA	This study contrasts a model that incorporates wind pressure and air temperature together with a constant air exchange rate model to see the comparative impact of each technique on the cooling and heating needs of a neighbourhood. A case study is conducted using the CEA urban energy simulation tool on a Swiss area with 24 buildings serving various functions.	The findings indicate that a tried and tested infiltration rate model could be appropriate for initial design explorations of district energy management systems, even with the substantial deviations observed for individual constructions, as the impact on system scale remains relatively insignificant. This analysis serves to advance the development of precise and efficient computer models for urban energy.
(Monien et al., 2017)	SimStadt	As part of the WeBest project investigation, the authors analysed six building styles that represent significant architectural periods. For this case study, authors chose Essen, a German city. Using the SimStadt urban simulation program, which relies on three-dimensional city geometry. They computed the heat demand for individual buildings and entire city districts. The results of each type of building are compared to those produced by the dynamic building simulation software TRNSYS, which is commonly utilized in the industry.	The results indicate that much time was required for the preparation of building models and transfer to TRNSYS, while the SimStadt method is entirely automated. The SimStadt results were compared with the district-level data on overall consumption. The analysis suggests that using SimStadt urban simulation platform, which is founded on three-dimensional city algorithms and construction databases, as an indicator of building type and construction period is suitable for predicting heat demand. This applies to both single buildings and entire districts.

(Pajot et al., 2018)	TEASER	The aim of this study is to estimate the potential for flexibility in electricity consumption of a structure. As part of the European City-Zen project, research has been carried out in a residential neighbourhood to develop efficient load shedding strategies. This area, comprising of 23 buildings, is distinct as it is heated by heat pumps. The findings of the GreenLys project and the research carried out by the electricity transmission network, RTE, were utilised to establish typical heat consumption patterns for load shedding scenarios in the initial case study. This method was then contrasted with research that adopts dynamic energetic simulation to factor in the building's physical characteristics.	This method achieves a satisfactory equilibrium between the enriched model's precision and its lengthier setup time relative to the simpler model. Dynamic thermal modelling is exceptionally fascinating in this scenario since it enables the monitoring of temperature variations during operation while also considering the physical response of structures and their rapidity of response. The selection of appropriate indicators, including the rate of delay by time period, energy savings achieved by 11 p.m., operational temperature and reduction in CO_2 emissions, enables a comprehensive evaluation of the outcomes of load-shedding performance, including peak reduction, energy savings, thermal comfort, and carbon dioxide footprint.
(Remmen et al., 2018)	TEASER	To generate dynamic models for simulating the thermal demand changes of individual buildings within large stocks, this paper presents TEASER's approach and structure. It then explains crucial design choices by discussing the structure and organisation of real Python packages. Lastly, the article showcases the tool's capabilities with three use cases of different scales.	By demonstrating TEASER's potential through three use cases, the high-data-density scale of buildings, the necessary-building-parameter scale of neighbourhoods (including construction period, geometry, and function), and the very-little-data scale of cities (only geometry), the results clearly indicate that TEASER is a fully scalable and adaptive UEM solution. The TEASER concept serves as a foundation for tackling concerns with diverse, evolving construction models and urban-scale simulation. It provides a framework and strategy for producing distinct and dynamic simulation models of building performance for several buildings within an urban context. In future development, the TEASER data enrichment will be merged with stochastic user behaviour tools for constructing physics capabilities.
(Steingrube et al., 2021)	SimStadt	The outlined methodology merges KomMod, an energy system optimization tool, with SimStadt, a program that enables researchers to assess heating requirements of buildings using 3D models. By incorporating these models with a revolutionary heat disaggregation algorithm, exploring optimal approaches for heating urban areas, and designing the appropriate heating grid, as well as determining the central heat distribution that works ideally, becomes achievable. In addition to evaluating the central heating function, a cost-optimal energy system may also consider other demand sectors, including cooling. The new framework was tested in both a high-density metropolitan area and a low-density rural community.	The suggested concept provides an effective means of organising the development of district heating systems in urban areas. Its main advantage is that it enhances all sectors while configuring the district heating grid. This is done by using a system model that considers all demand sectors and proposes solutions that meet each sector's energy needs at the lowest cost. One of them is created for heating grid layouts, while the other utilizes heuristics for linear point-like energy systems. Two quick optimization algorithms are used in this study. The algorithms produce two intersecting solution curves that have distinctive features. This method can be applied to a wider area, including the entire city, with enough computing time and is not restricted to small building models.

(Orozco-Messana et al., 2021)	CEA	This study proposes a methodological approach for a performance-based life cycle assessment (LCA) of urban regeneration options on a neighbourhood scale, based on building construction techniques aimed at achieving energy-efficient building performance. The proposed framework includes specific architectural alternatives and plans for a designated building infrastructure. The proposed methodology is evaluated using the LCA results to compare the anticipated results of two building certification programmes, LEED and BREEAM.	The study demonstrates a technique for creating an accurate digital representation of a neighbourhood to evaluate its life cycle assessment (LCA) in an environmentally friendly manner. This is achieved by assessing its carbon emissions. This approach may be linked to commercial tools for financing. However, generating a database that contains comprehensive information on construction solutions related to building classifications and subsystems requires extensive knowledge of materials and practices specific to the region and period.
(Gorzalka et al., 2021)	TEASER	The purpose of this study is to provide information for specific retrofits through the use of UBEM data collection and simulation tools on a single building. This study employs precise geometry data obtained through unmanned drone aerial vehicles, demonstrates how the entire process can be fully automated, and avoids several simplifications that are often used in automated district and city-scale modelling to create the energy simulation model. Using this method, it is possible to create a dynamic energy simulation model with minimal user input. This study includes a case study as the first step towards validation.	The model accurately depicts indoor air temperatures during artificial heating and cooling. A sensitivity analysis emphasizes the importance of accurate window characterisations, and simplicity in interior geometry. The method is nearly ready for practical use, allowing for quick estimation of financial potential and energy savings following refurbishment. The use of typical U-values involves uncertainties that can be determined by comparing different classifications. Comparisons between best and worst-case scenarios reveal a variance of approximately twenty percent in the energy demand of heat consumers prior to retrofit, compared to the average value.
(Weiler et al., 2021)	SimStadt	The research evaluates SimStadt's capability to size centralized and decentralized heat supply solutions for a neighbourhood of 65 buildings in Mainz, Germany. The study compares a decentralized system that employs air-water heat pump technology with a biomass-fired boiler, an oil-fired auxiliary boiler, and a heating network using technical and financial metrics.	The study proves that, although input information is limited during early project stages, simulations for a district's heating demand and heat supply alternatives can be performed with sufficient precision. Nevertheless, obtaining precise data on building renovations' condition is essential since existing structures' heat requirements significantly affect the heat supply network's size and functionality. Depending on national regulations, economic factors, primary energy sources and carbon dioxide emissions can be calculated using this data.
(Santhanavanich et al., 2022)	SimStadt	This study assesses and contrasts different methodologies, including the utilization of SimStadt internet applications, databases, as well as the OGC SensorThings API standard, to maintain the dynamic simulation outputs of the 3D city model and to present these data on the 3D web-based Smart City platform.	For optimal utilization of the energy analysis data storage and visualization in the smart city applications, it is advisable to integrate the SimStadt API service for real-time simulation and the SensorThings API for managing pre-simulated results.

The table summary indicates that these tools have widespread use in researching energy and thermal comfort whilst considering ecological and economic aspects. It demonstrates their capabilities and high performance across various methodologies, either independently or in combination with other software packages, depending on the study's requirements. These are recommended principles for building renovation planning. They can help with preliminary urban design to maximize affordable on-site renewable solar energy techniques while taking into account operational and embodied greenhouse gas emissions, ultimately evaluating and improving urban and building performance.

UBEM reduced-order tools could analyse various building types and forms such as collective housing, individual housing, commercial buildings, hospitals, and offices. The tools can be used at the architectural, urban, or city scale, and in various geographical and climate contexts.

These tools could be applied to smart technologies and parametric studies concerning the building envelope or energy supply systems. Additionally, this simulation software conduct research on energy consumption and how it relates to HVAC needs and solar penetration, and also carry out sociological investigations on users' behaviour and occupancy rates.

IV.8. Approaches of solar analysis in the urban environment

Solar panels can generate sustainable electricity and heat in urban areas, providing local renewable energy systems for urban contexts. Building-integrated photovoltaics, as example, represent a promising way to support the transition to sustainable energy in the buildings sector (Shukla et al., 2017). They allow for the use of existing urban areas without requiring extra land or infrastructure, and can generate energy wherever it is needed. This is particularly significant given the increasing demand for electricity in the buildings sector (Enerdata website, 2019). These systems can be used for a variety of purposes, including generating electrical and thermal energy for cooling or heating, as well as for other household needs such as lighting, cooking, powering appliances, etc.

To address the need for energy conservation in buildings and generate electricity and heat from local solar energy systems in urban areas, cities and urban neighbourhoods can combine the renovation of buildings' roofs and facades with photovoltaic and thermal systems. (Martinez & Choi, 2017; Wu et al., 2017) have shown that this practical method reduces energy usage in buildings.

Numerous techniques for enhancing the energy efficiency of the building envelope, increasing the thermal comfort for occupants, and enhancing the architectural appearance of the external surface, are available to the architects. The nature of these methodologies is dependent on various factors, including the original qualities of the building envelope prior to renovation, regional weather conditions, financial and technical constraints, as well as regulatory standards (Ma et al., 2012).

In order to guarantee the efficient incorporation of solar photovoltaic and thermal technologies in urban regions, where a substantial proportion of energy requirement is focused, it's essential to evaluate the local solar potential (Abu Qadourah et al., 2022).

The potential of building facades to integrate photovoltaic and thermal systems is closely linked to local solar radiation, which can vary significantly in urban areas. The amount of irradiation that a specific location receives is affected by various global, local, geographical, temporal, and climatic factors (Li, 2013).

Numerous methods have been developed and employed in several studies to evaluate the integrated photovoltaic and thermal potential of building facades.

According to the research of (Saretta et al., 2019), just 14 of the 85 studies that were gathered from the prior literature research are concerned with the economic, technical, and geographic building integrated photovoltaics potential of facades at the urban level. Although some of them evaluate the potential of the roofs as well, the analysis only focuses on factors associated with estimating the solar energy potential.

At the district and city levels, a total of 14 studies offered techniques for forecasting the building-integrated Photovoltaics potential of the current facades. However, the majority only consider generated energy (technical potential) and received irradiation (geographical potential) when evaluating the building-integrated photovoltaics potential; only the studies by (Brito et al., 2017; Fath et al., 2015) consider the potential economic benefits as well (techno-economic potential).

In correspondence with (Saretta et al., 2019) also, the approaches established or utilized in the reviewed studies for calculating the solar energy potential on facades are bottom-up and can be classified into three major categories, as shown in (Figure IV.11):

1) Approaches that incorporate real/statistical construction surface data sources: Methods for this type of approach usually depend on real/statistical building surface data and adjustment variables based on facade/envelope types, as in the Dias et al. (2015) study.

2) 3D model-based approaches: with exposure to sunlight simulations, the urban environment may be modelled via three-dimensional characteristics (e.g., beginning with CAD as well as CityGML data) and, with the help of specific software (e.g., Radiance), the solar irradiation may be calculated while taking into account building obstructions via comprehensive models or using adjustment factors that reduce the entire roof/facade area in order to get the appropriate area for solar energy systems. (Lobaccaro et al., 2012; Caamaño-Martin et al., 2012) studies, are instances that demonstrate this type of study.

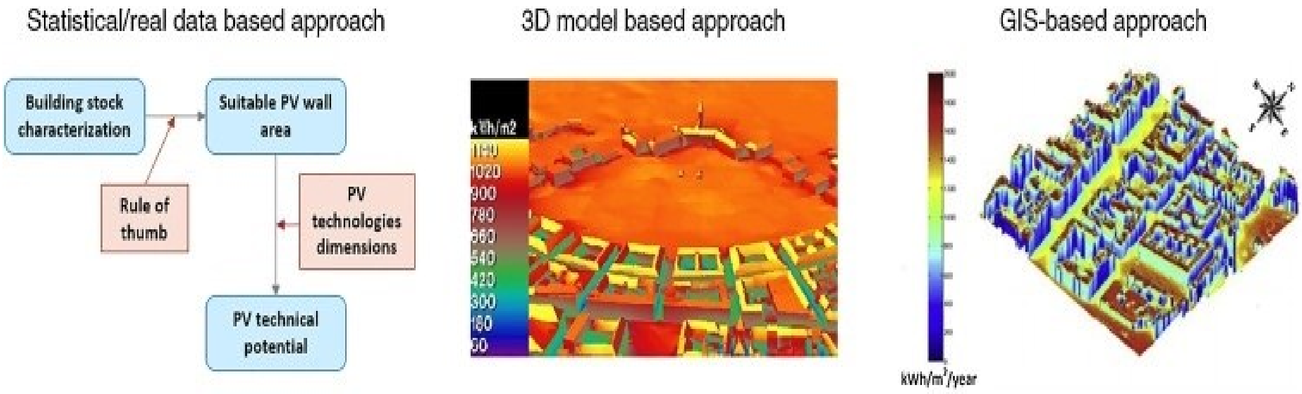


Figure IV. 11. Examples of the 3 approaches to assessing the solar energy potential of facades in urban areas. Note that the 3D model-based approach produces a similar image to the GIS-based approach, but the process of obtaining the city model varies.
Source: (Saretta et al., 2019).

3) GIS-based Approaches: The GIS approach is widely used, and permits the use of 2.5D and 3D urban area algorithms as data sources to indicate the output of the irradiation algorithm applied to building areas. (Freitas et al., 2015) offer a comprehensive study of radiation prototypes and tools.
The calculation of solar radiation commonly utilizes tools such as "SolarAnalyst" by (Fu & Rich, 1999), "r.sun" (Šúri & Hofierka, 2004), alongside the "SOL" algorithm (Redweik et al., 2013), or specific computational methods developed by researchers, including (Bremer et al., 2016; Catita et al., 2014; Karteris et al., 2014).
Regardless of the chosen method, solar irradiation is subject to weather and time. Thus, a critical factor is the fluctuation of energy production over time, which has been examined by (Brito et al., 2017; Catita et al., 2014; Redweik et al., 2013). Although hourly data on electricity generation may vary depending on the calculation technique, it is valuable for gauging the energy independence of buildings. This is particularly applicable to smaller districts, while larger urban areas may face challenges managing hourly data on energy generation and demand. It is worth noting that the large proportion of studies based on 2.5D or also 3D urban models are required to assess the geometric dimensions and orientation of facades, in order to calculate the solar energy potential with a view to integrating thermal and photovoltaic panels.
Nevertheless, urban models often omit the architectural details of facades (such as openings, balconies, cornices, etc.). However, after applying reduction factors in a second phase, their effect on the real potential of the solar system is taken into account, as shown in studies such as (Amado & Poggi, 2014; Vulkan et al., 2018; Brito et al., 2017; Fath et al., 2015). Most of assessments within the different studies of the building solar system potential consider the shadows cast by nearby buildings.

However, only one study examines reciprocal reflections, and only a small number of studies incorporate the effect of vegetation (Bremer et al., 2016; Brito et al., 2017; Redweik et al., 2013).

IV.9. Conclusion

Building renovation is not just about making physical changes to reduce energy consumption. Rather, it serves as a means to ensure a specific level of comfort and well-being for the residents, allowing them to carry out their daily tasks in a good, healthy and pleasant physical alongside psychological state.

This concept which is in the frame of energy transition ambitions, is a viable solution towards attaining sustainable development which will guarantee a liveable planet with equitable living conditions for future generations.

This chapter explored energy renovation, showcasing its success in various contexts and the energy and ecological benefits resulting from the integration of different improvement measures, whether through upgrading the building envelope or incorporating renewable energies. It also detailed the UBEM approach and its range of innovative tools, used for assessing and renovating the built environment at various scales.

The analysis of this approach led to the intriguing idea of using one of these tools in our research, thanks to their capacities for considering diverse factors linked to the building and its surrounding environment.

CEA, specifically, is a useful tool that has many features. It has a higher number of inputs and outputs, and presents results, in an interesting way. It also proved its credibility and reliability through many previous scientific works, and that's why it could be a key choice.

Finally, it's important to ensure that solar panels are integrated into a building in a way that will provide the best performance, taking in account that panels location is one important factor to consider. To guarantee the best outcome, it's necessary to conduct a solar analysis based on approaches developed specifically for this purpose.

CHAPTER V

Multifaceted exploration of the study context

V.1. Introduction

This chapter outlines the characterisation of Skikda's environment, which serves as the context for this study from multiple angles. The analysis is structured into many sections to facilitate a logical flow of information. First, Skikda's history is briefly introduced to highlight its appeal. Subsequently, the city underwent a comprehensive contextual localisation within both global and Algerian frameworks, followed by an examination of its unique climatic traits. Epistemological research and classification have been conducted in this chapter, which includes an examination of the various habitats found within the city of Skikda.

Additionally, the discussion has been expanded to include the presentation of four urban collective housing archetypes, chosen as targeted case studies for the purpose of multiscale energy and environmental study.

V.2. Presentation and historical overview of the city of Skikda

Skikda, which dates back to the "Neolian" era in the year 20,000 B.C., is said to be the earliest city in eastern Algeria in terms of human presence. This marked the start of the subsequent existence of various civilizations (Hamdaoui, 2017).

Skikda was founded by the Phoenician civilization between 11 and 12 B.C. During this era, the city was known as Thapsus or Thapsa, named with reference to nearby river that flowed between the hills of Beni Melek and Skikda. At that time, Thapsus was the only outlet of the Cirta region. This information is based on volume XIV of the Dictionary of Christian Archeology and Liturgy from 1939. In ancient Punic times, "Russicada" succeeded Thapsus, who was alternately known as Ras Skikda and Russicada and who kept this name for the indigenous element throughout the years (R. Hadef & Labii, 2017); and this name means "head of the lighthouse," since they used to light a fire atop the mountain to direct ships to the port of "Astora." which is situated in the city's westernmost region (Hamdaoui, 2017). Following Carthage's defeat in the Second Punic War (218–202 BC), Masinissa, King of Numidia, took possession of Russicada and Astora.

As a result, the city had significant growth throughout the Numidian period and contributed to the development of economic ties between Numidia and Rome by supplying meat, olives, and fruits to the Romans and all of their colonies.

The Romans, who sought to expand their empire, were drawn to the area by its location and richness, and they took control of it around the year of 45 B.C.

Along with Chullu (Collo), Milev (Mila), and Cirta (Constantine), also Russicada (Skikda) was a member of the confederation of the four Roman Colonies (Soltane, 2022).

The Roman domination, which abused the wealth of the area, sparked an uprising and rebellion among the Berbers.

The vandals attempted to overrun the area after the fall of Rome but were met with fierce resistance, which led to the destruction of a significant portion of Russicada, which lasted until the end of the fifth century. The Byzantines settled on the Phoenician counters after the vandals with the goal of commerce. Byzantine rule was short-lived, and it was followed by the Arabo-Muslim civilisation's conquest.

This city would see an “Islamization” under the leadership of Omeyyade Abu al-Muhajir Dinar, starting from 681, and as Islam spread, the Arabic language was introduced and quickly assimilated because native speakers had already mastered the use of the Semitic language, in contrast to other languages like Berber and Latin (Bakri, 1859).

It is important to remember that the earliest Arab chroniclers, including one of the first to write about Arab conquests, lbn Abd El Hakam, attribute the name to Taskikdit.

Since the arrival of the Ottomans, who ruled over Constantine and Collo; mountainous areas have largely escaped Turkish rule; Among these regions, Skikda and Stora should be also noted.

Following Ahmed Bey's defeat at Constantine in 1838, the French took control of the area to the east and used the port of Skikda to foster trade along the Mediterranean Sea. In honour of the French king Louis Philippe, they gave him the names of Port of France and Philippeville. The expansion in the French colonial period is pointed in the direction of Jebel Mouader and Bouyala, two mountains that surround the original Roman settlement. It encounters resistance from the terrain, which features sharp cliffs. The gates of Stora and Constantine encircle the historic core, which is situated in the middle of two mountains (Djebel Mouader and Bouyala). The expansion to the South on the entrance of Constantine designates the time between 1849 and 1910; New suburbs like the Esperance and Beni Malek districts were created gradually. Due to the site's terrain, the city's expansion saw a multidirectional development rather than adhering to the Romans' checkerboard pattern.

Between 1911 and Algeria’s independence in 1962, the city's population increased from 20,000 to 50,000, and new sites were urbanized. The “Bab Constantine”, for example, gave rise to a crossroads where people could travel to other parts of the city, which maintained its Roman centre during the colonial era and expanded in a number of ways despite the challenging relief of the city.

Following Algeria's independence, the city's name is changed to Skikda, its population increased, and the city occupied new territories in all directions, but without prior planning (Bendjemila, 2018).

With the establishment of the industrial zone in 1973, it became industrialized, even before becoming the main town of the wilaya, which led to a number of spatial, economic, and social distortions as a result of a disconnect between decision-making functions and the power of the industrial complex (Boukerzaza, 1991).

The urban environment became, then, more complex, leading local officials to implement emergency measures such as constructing additional buildings and extending road networks. This complexity has also contributed to the decision to expand the colony's periphery throughout the launch of the program of the ZHUNs. The urbanization fronts that emerged between 1971 and the late 1990s were not meant to reduce the attractiveness of the historic centre, which saw an increase in both commercial activity and rural inhabitants.

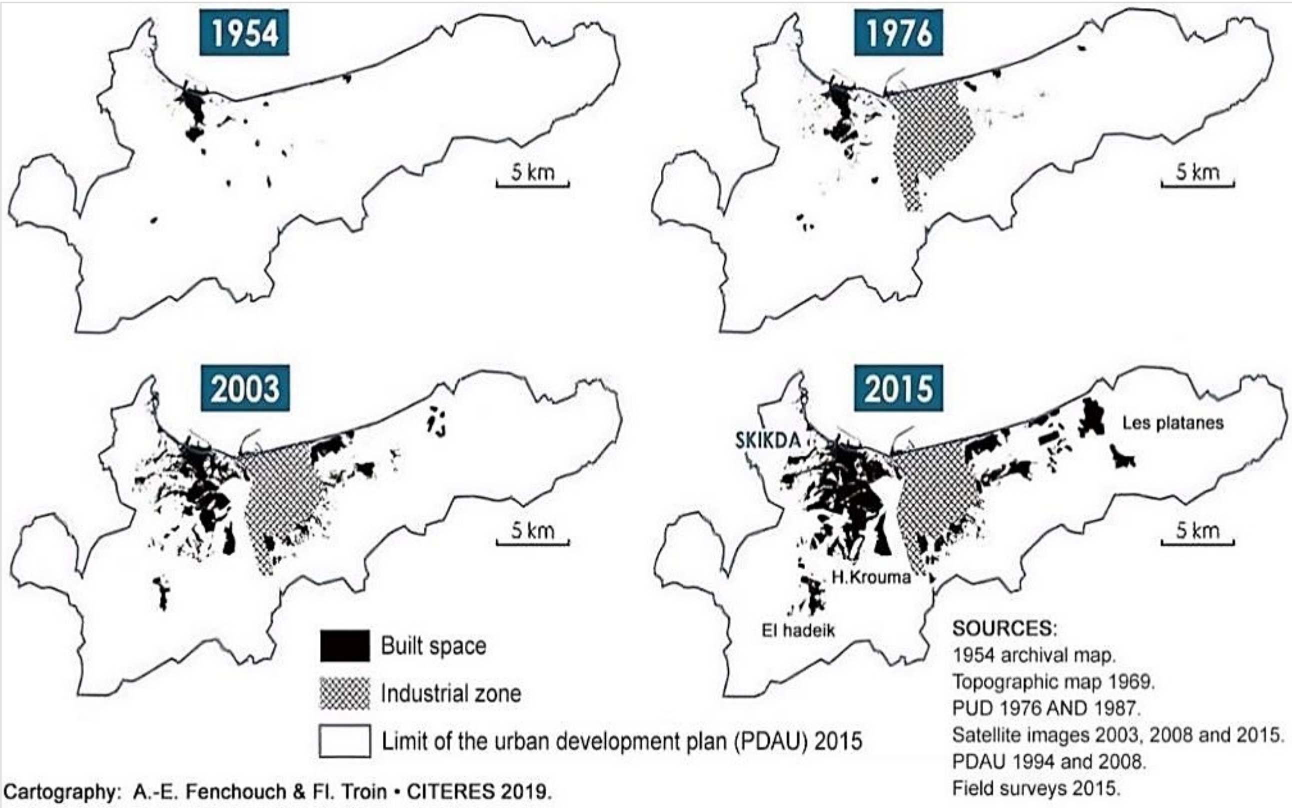


Figure V. 1. Skikda: evolution of the urban area 1954-2015.

Source: (Fenchouche & Tamine, 2019).

The past two decades have marked the initiation of a new process that has loosened the driving forces responsible for urban dynamics, ultimately leading to the emergence of a new aspect of urban centrality. Starting in the 2000s, the spatial dominance of the city centre began to recede. This process has become even more marked since 2005, with the advancement of urban growth and a corresponding dedication from both public and private players (A.-E. Fenchouch & Tamine, 2019).

The (Figure V.1) illustrates the evolution of Skikda urban areas during all these years, and especially in the period between 1954 and 2015.

On the other hand, the recent extensions built on the outskirts of Skikda - Messioune and Zef-Zef - have had no major impact on the centrality of the city, since they were developed without complying with the initial requirements of the POS. In fact, these extensions were built as part of a national initiative to rehouse disadvantaged populations and not as part of a desire to extend the city (A.-E. Fenchouch & Tamine, 2019).

V.3. Climate study

V.3.1. Global and Algerian climate

Weather refers to the specific conditions of the atmosphere, including heat, cloud cover, dryness, sunshine, wind and precipitation, at a particular place and time, while the climate refers to the prevailing weather conditions in a given area over an extended period, generally. There are several dissimilar classes of climates around the world, and numerous kinds of studies, especially those pertaining to the earth's energy, must initially fix the type of climate.

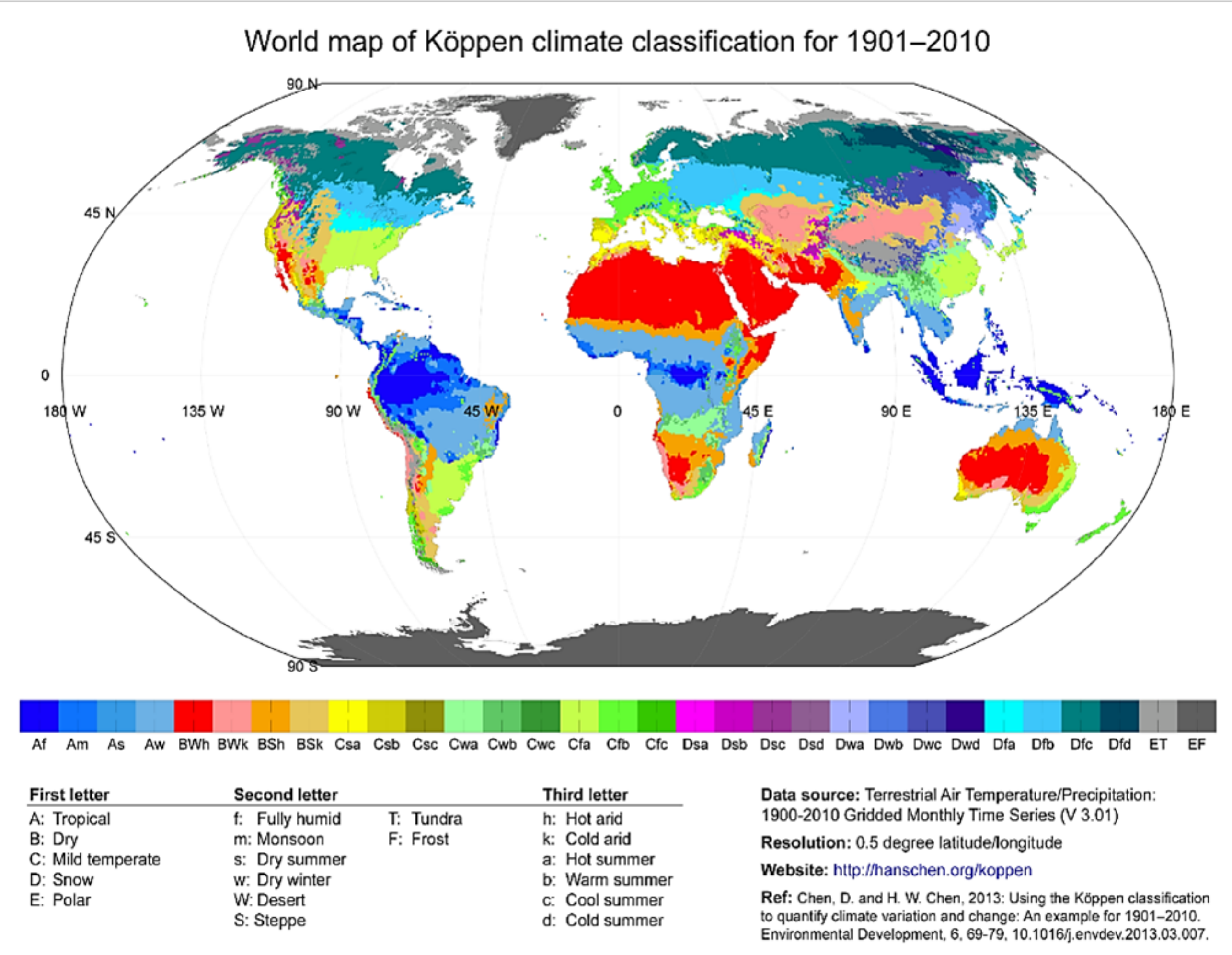


Figure V. 2. World map of Köppen climate classification for 1901-2010.

Source: (Chen, 2023).

To define the climate of a location, Wladimir Koppen created a categorization system for the earth's climate about 1900 (Kottek et al., 2006).

The climates are split into five main climatic groups (tropical, dry, temperate, continental, and polar) on the world map of Köppen-Geiger climate classification, as it appeared in the (Figure V.2); each group is then further separated depending on seasonal patterns of temperature and precipitation. Algeria, north African country, located south of the Mediterranean Sea and containing a portion of the Sahara, has exceptionally bright, hot, and dry summers. It has a Mediterranean climate over a large coastal strip with well-watered winters, while the rest of the country is desert or semi-arid.

In terms of relief (particularly in the north, northwest, and southeast of the nation), the temperature reduces by around 0.6°C every 100 meters of height.

The climate in the extreme north of the country - where Skikda is located - is Mediterranean. Summers are dry and quite hot, while winters are warm, although morning frosts are possible. Nights during summers are pleasant to warm. Spring and fall serve as a transition to a fairly dry summer, with winter being the wettest season. The climate in the rest of the country is generally dry and desert-like, with temperatures typically being hot. The far north experiences a Mediterranean climate and is generally less hot. Tamanrasset, located in the southwestern part of the Hoggar massif in southern Algeria, experiences particularly dry conditions throughout the year. Winter evenings are fairly cool, and morning frosts are possible, while the days are moderate. Summer nights are hot and humid, and the days are scorching (Quand partir Website, n.d.).

V.3.2. Climate study of the city of Skikda

a. Location

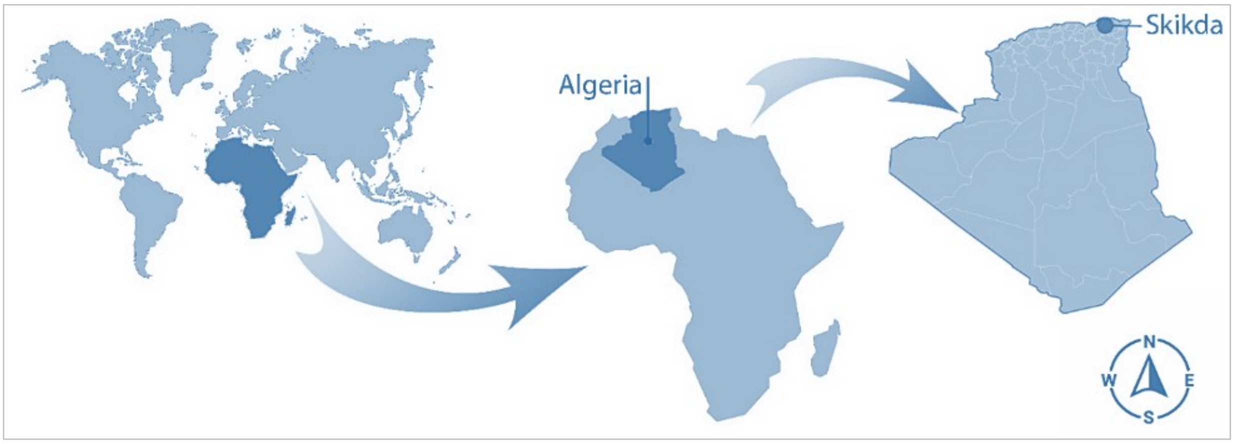


Figure V. 3. Location of the city of Skikda, in relation to national, continental and international scale.

Source: Author, 2023.

As shown in (Figure V.3), Skikda is a city in the north African country of Algeria, located on the Mediterranean Sea's coast in the northeast. It is situated in the coordinates 36° 52′ 00″ north, 6° 54′ 00″ east. Skikda is 345 kilometres east of Algiers (the capital), 105 kilometres east of Jijel, 65 kilometres northeast of Constantine, and 72 kilometres west of Annaba.

The city is bounded to the north by the Mediterranean Sea and to the east by Filfila, to the south by El Hadaiek and Hamadi Krouma, and to the west and south-west by Ain Zouit (Gifex Website, 2023).

b. Air temperature

The city of Skikda, located on the Mediterranean coast in north-east Algeria, has a Mediterranean climate, with hot, sunny summers and warm, wet winters.

Despite the mild winters, there may occasionally be irruptions of chilly air from the north. It can even snow on occasion, as it did in January 2005 and February 2012, knowing that snowfall is more frequent on the hills behind the city.

When the wind comes in from the desert, the temperature can suddenly rise at any time of the year.

Between 1991 and 2020, the average temperature in the city was 12.9°C in the coldest months and 26.3°C in the hottest month (Site Climats et voyages, 2020).

The following are the monthly maximum, minimum and average temperatures (Figure V.4).

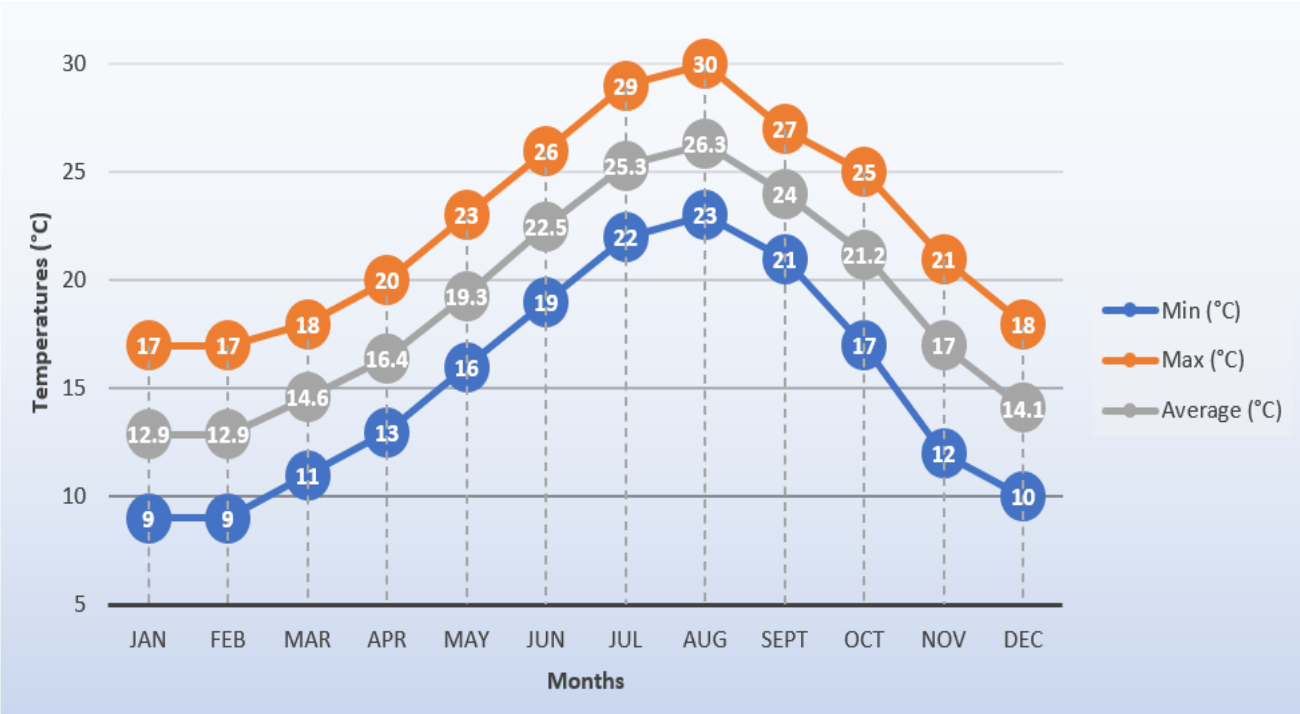


Figure V. 4. Monthly maximum, minimum and average temperatures, in Skikda for the years between 1991-2020.

Source : (Site Climats et voyages, 2020).

c. Precipitation

A day with precipitation is one with at least one millimetre of accumulation of water, as measured in water. In Skikda, the likelihood of precipitation days varies throughout the year.

The (Figure V.5) show the percentage of days on which various types of precipitation are observed. For a period of more than 8 months from the 6th of September to the beginning of the last third of the month of May has the highest precipitation, with a daily likelihood of precipitation of more than 14%. December is the month with the most days with precipitation, with an average of almost 8 days having at least 1 millimetre; Conversely, the period from the 19th of May until the end of first week of September, which is approximately 3 months and a half, is the driest season.

With an average of almost 1 day with at least 1 millimetre of precipitation, July has the city's fewest number of precipitation days.

By extracting only rainy days, snow only, or both of the two for days with precipitation. December has an average of almost 8 days more rain-only days than any other month in Skikda. According to this ranking, rain alone is the most frequent type of precipitation throughout the year, with a chance peaking at 26% on February 7th (Weather Spark Website, 2023).

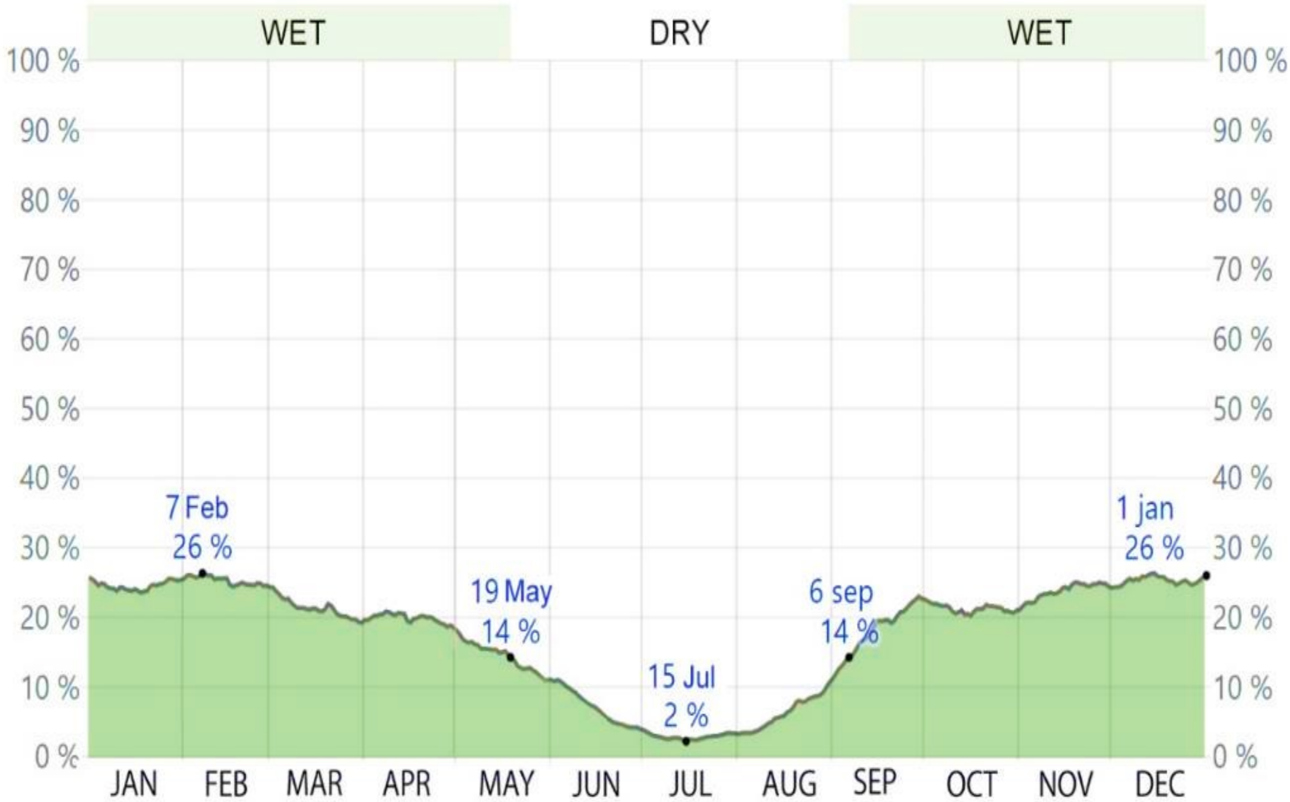


Figure V. 5. The percentage of days on which various types of precipitation are observed, except for trace amounts: rain only, snow only and mixed (rain and snow fell on the same day).

Source: (Weather Spark Website, 2023).

d. Relative humidity

The humidity on the dew point is used to estimate the level of comfort since it influences whether sweat evaporates from the skin, causing the body to cool. Lower dew points indicate a drier climate, whereas higher dew points indicate a more humid environment. Dew points move more slowly than temperature, which often swings substantially between day and night. As a result, even if the temperature drops at night, a humid day is frequently followed by a muggy night.

Skikda has substantial seasonal changes in perceived humidity, with the heaviest period of year lasting more than four months, from the 6th of June until the mid-month of October, with at least 18% of the time feeling heavy, oppressive, or stuffy. Whereas, August has the most humid days in Skikda, with almost 22 or more muggy days.

But as it concerns February, it has the fewest humid days in Skikda, with 0.0 or more muggy days (Weather Spark Website, 2023).

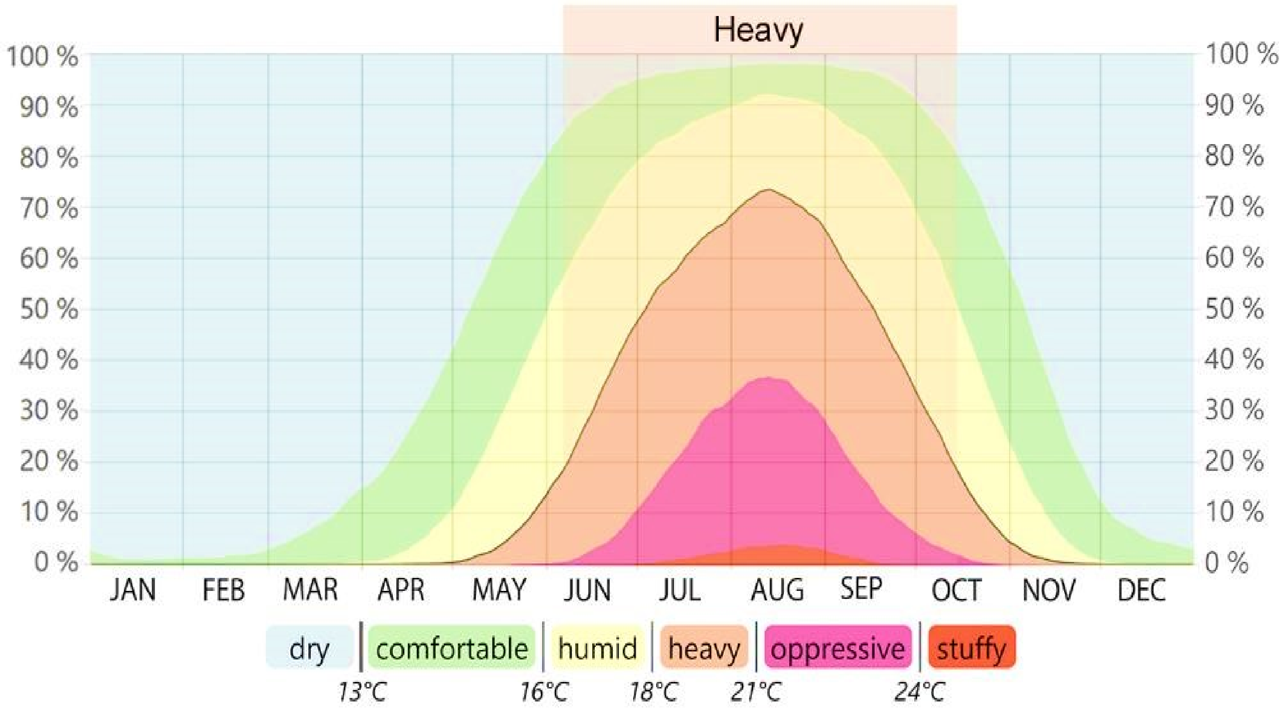


Figure V. 6. The percentage of time spent in various humidity comfort levels, classified by dew point.

Source: (Weather Spark Website, 2023).

e. Wind

The Skikda diagram, in (Figure V.7) displays the frequency of days per month when the wind reaches a particular speed. It illustrates that the monsoon is characterised by strong and constant winds between December and April, and calm winds from June to October.

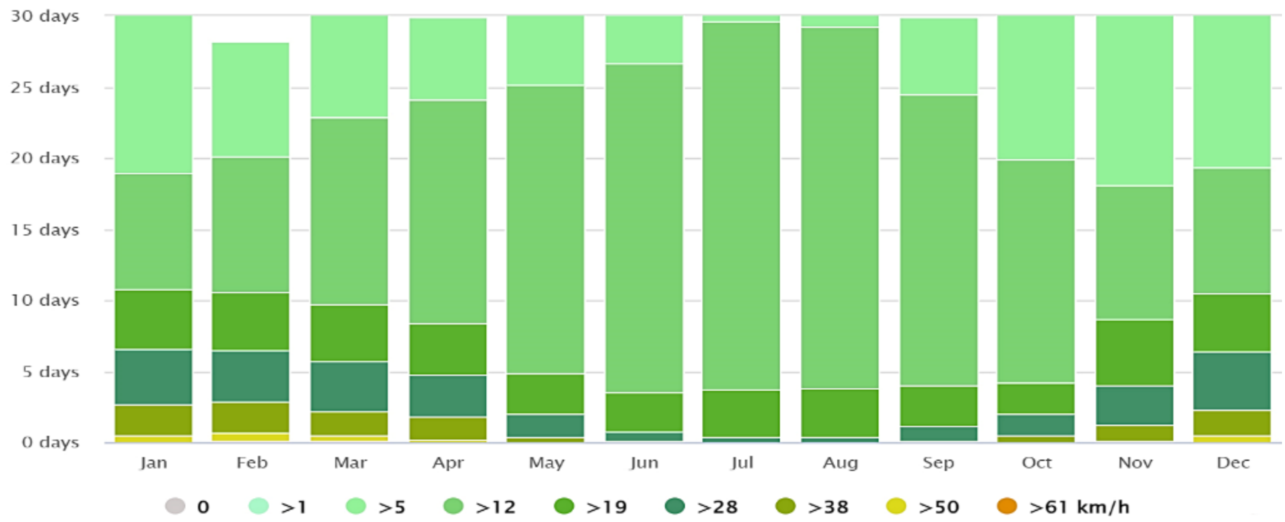


Figure V. 7. Monthly Wind Speed Data in Skikda, illustrated in a diagram displaying the number of days per month where the wind speed reaches a certain level (2021).

Source:(meteoblue, 2023).

The Wind Rose of Skikda (Figure V.8) shows how many hours per year the wind blows in the indicated direction.

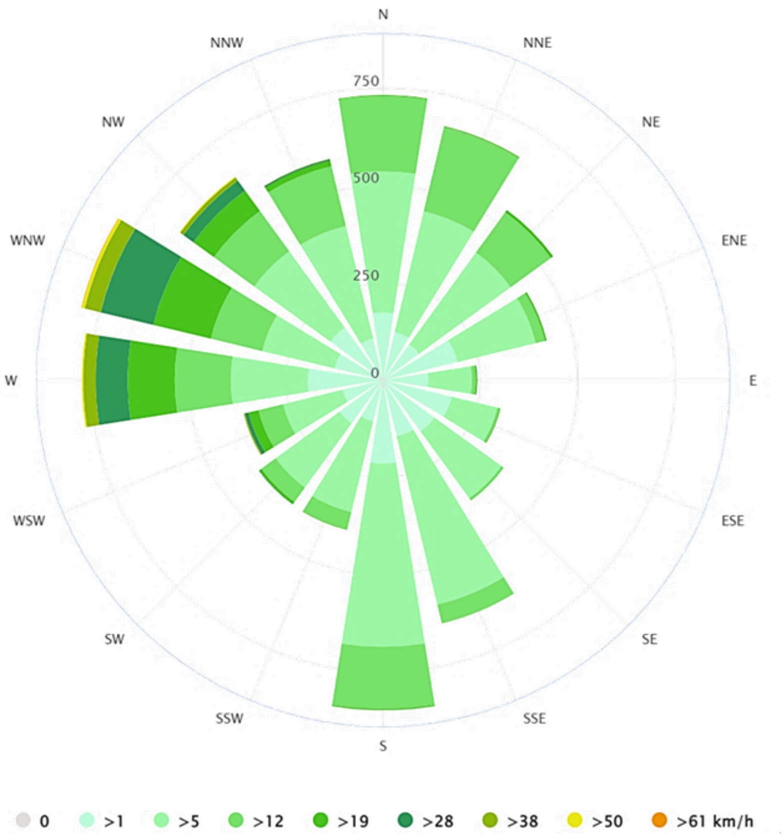


Figure V. 8. The Rose of Winds for Skikda.

Source:(meteoblue, 2023).

In the winter, there are two main types of winds in the region, relatively strong fresh winds from the West and West-North West directions that are frequently the cause of major disturbances. These directions of winds have a range of speeds between 1 and 50 km/h for more than 750 hours for each of the two close directions. In contrast to the first category, there are also dominant summer breezes from the South that are relatively moderate strength and have less influence.

f. Insolation

The energy that comes from the solar source in the form of light, and which has several properties such as intensity and duration of illumination each day, is known as solar irradiance or insolation, this insolation involves direct sunlight that is not obscured by clouds, especially over a large area or surfaces on earth. It includes the light as well as the direct rays and heat of the sun's rays (aquaportail, 2023). In Skikda, there is an average of 2675 hours of sunshine per year, according to (Site Climats et voyages, 2020). The (Figure V.9) shows the number of hours during which the sun is visible, and indicates also: the full daylight, the twilight (civil, nautical, and astronomical), as well as the full night. The duration of daylight in Skikda varies considerably throughout the year. Generally, the shortest day is December 22, knowing that, for example, its duration is about 9 hours and 38 minutes of daylight, while the longest day is June 21, with 14 hours and 42 minutes of daylight. According to Capderou Michel in his book (the solar atlas of Algeria), in 1985; In Skikda, an incident energy spreads up to 8010w/m² on a horizontal plane during July, while, during December, this incident energy spreads around 2928w/m² on a horizontal plane (Mansouri et al., 2018).

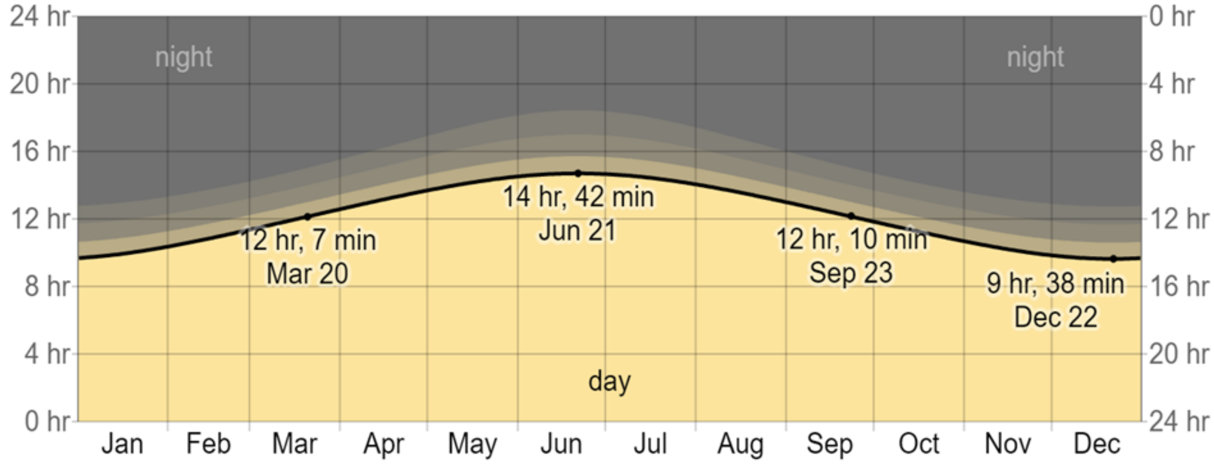


Figure V. 9. The number of hours during which the sun is visible (black line). From bottom (most yellow) to top (most grey), the colour bands indicate: full daylight, twilight (civil, nautical, and astronomical), and full night.

Source: (Weather Spark Website, 2023).

g. Cloudiness

As shown in the (Figure V.10), in Skikda, the percentage of clouds varies greatly throughout the year; the clearest season starts around mid-June and lasts for about two and a half months, ending around the 5th of September.

The sky is often clear, mostly clear, or partially cloudy in more than 90% of the time in July, the month with the clearest skies. While the cloudiest month is December, when the sky is typically gloomy or overcast for 43% of the time. The year's cloudiest phase starts around the beginning of September and lasts for more than 9 months, ending around mid-June (Weather Spark Website, 2023).

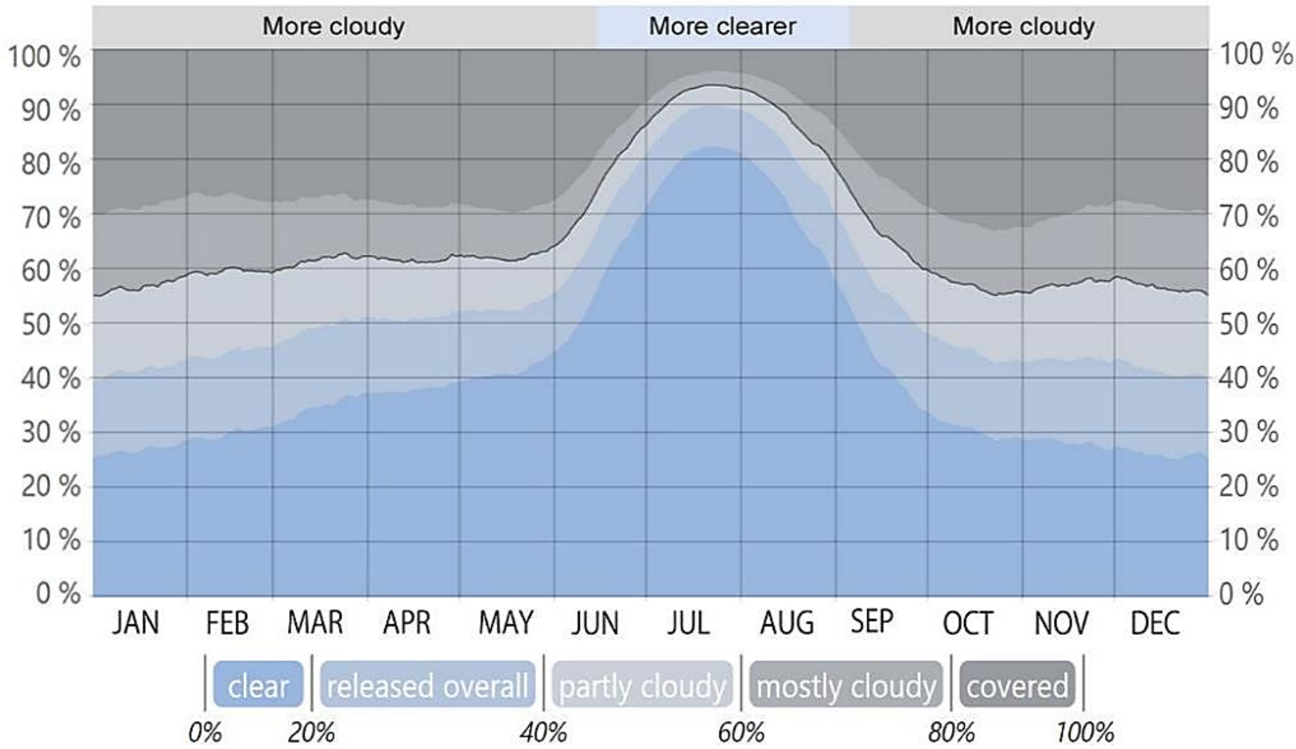


Figure V. 10. The percentage of time spent in each cloud cover band, classified by the amount of cloud cover in the sky.

Source: (Weather Spark Website, 2023).

V.4. Urban housing study in the city of Skikda

In Skikda city, different types of houses can be recognized in chronological order: the traditional style, the colonial style, the post-colonial style, and the modern style. (Figure V.11) displays a map depicting the different types of housing found in the city of Skikda.

According to (Bendjemila, 2018) and the map below, the urban layout of Skikda city showcases both the historical architecture and town planning in the colonial centre, as well as the apartment buildings built during the post-independence period. Moreover, individual dwellings have also been established

without control. One in four houses show signs of disrepair, and according to PDAU (2010), "the situation in the Stora agglomeration and sparse areas is especially worrisome where the rates of precariousness are 73% and 56% respectively".
The following part of this section will give an overview about the different existent typologies.

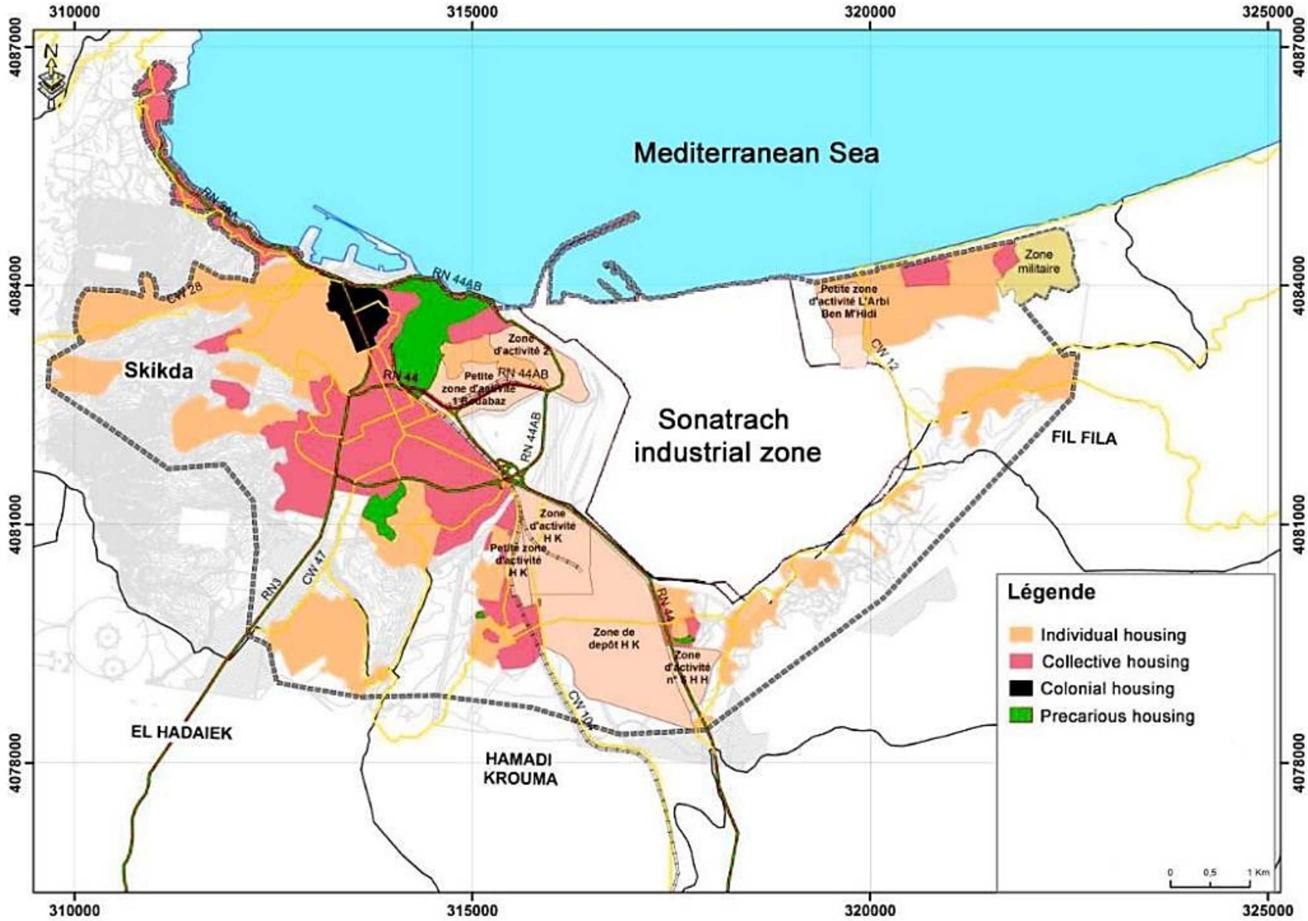


Figure V. 11. Housing typologies in the city of Skikda.
Source: (Bendjemila, 2018) + modifications by the author.

V.4.1. Colonial urban social housing

The city was built by the French on the sloping terrain of Béni-Melek and Bouabbaz in 1838. Although the development towards the plain was foreseen by the military authority in the 1840s, the decision to construct the city in that location was made initially for defensive purposes.
According to (Solal & Prigent, 1957), the Philippeville region comprises two mountainous slopes that enclose a north-south trending ravine to the east and west. Towards the southern entrance to the ravine, there is an alluvial plain located outside the fortified enclosure, and at the outlet of the ravine, a small alluvial cone. As illustrated in the map, in the (Figure V.12), the road network is distinguished by its

geometry, which is made up of blocks with an orthogonal layout and a mainly rectangular form. These roads typically include stairs that are there because of an extremely high slope.

The ground became increasingly important as the city expanded, the population increased, and the streets grew narrower, especially on the western side.

Nearly the whole area is taken up by the buildings, which are arranged in a courtyard within and along the roadways. Whether on the level of the military district or the civil district, these buildings take up the entire block.

The plots are adjacent to one another and are constrained by access roads. They range in shape from square to rectangle and are relatively regular.

Each parcel is made up of a unit of construction, regardless of its intended use (housing or equipment).

Figure V. 12. Colonial urban social housing in Skikda (Didouche Mourad avenue).

Source: Google map (treatment by the author) + The picture from Facebook page.

The civic district is located to the west on the djebel Bouyala and consists of tiny blocks; at the end of this district is the Quartier “Napolitain”, which is aligned with the major road (rue de Clemenceau) that divides the military district from the civil district. The residential block is divided into plots to produce dwelling lots.

As shown in the photographic shot in the (Figure V.12) also, all buildings stretch the ways of the city while observing architectural standards, particularly those that lengthen the city's main street, which necessitated the establishment of arcades on the bottom floor " of the homes. The height of buildings is limited to four levels, and the technique of construction is mostly based on stone masonry for foundations and load-bearing walls, iron beams allow for the construction of several storeys, and the roofs are generally double-pitched and tiled (Lebied, 2012).

V.4.2. Autochthone population housing

From the 1940s until independence, the socio-spatial division of the city grew as the urban area expanded and extramural extension occurred. In fact, a new neighbourhood which is displayed in the (Figure V.13), for the autochthone population called "El Koubia" was created just a few meters from the national road. The latter is set up using a layout that is somewhat based on the Arab city.
Undoubtedly, the goal of this decision was to suppress the Muslim community in order to better control it. The neighbourhood's location on the outskirts of the city has exacerbated the social and spatial marginalisation of the Muslim population (A. Fenchouch, 2019).

Figure V. 13. Old picture, and aerial view, of the Koubia neighbourhood.
Source: The picture from Facebook page + Google map (treatment by the author).

Its architecture is evocative of Andalusian homes under the Muslim occupation.
This complex is semicircular in shape, and the dwellings are relatively near to one another, with little openings and arched entrances. The name "Koubia" relates to the many tiny domes that adorn the houses in this neighbourhood. The dwellings lead to a pretty large space in the centre of which sits a fountain; this place is utilized as a which is known as "Wast Dar." (R. Hadef & Labii, 2017).

V.4.3. Low-cost housing H.B.M (Habitat Bon Marché)

The HBM housing building took over this form of house for two primary reasons. The first is the emergence of concrete, which was widely employed in Paris by August Perret. The second cause was the significant growth in Algerian and French communities. These structures are distinguished by two urban forms: a linear layout, with blocks grouped side by side on both sides of the road, and a height ranging from three to four stories. The other urban form is a collection of blocks with heights ranging from seven to eight floors, as well as building site circumstances.

The two forms have a relatively similar structure and construction method, which is primarily distinguished by the use of reinforced concrete (RC) for the foundations, the slabs, the beams, the stairs, and the retaining walls also (Selougha & Wilkinson, 1984). This kind of construction can be seen in Skikda (Figure V.14), where it has been since 1938. It is situated on Madjid Lazrak Street, in the heart of the city, a few meters to the east of the Neapolitan neighbourhood.

Figure V. 14. Aerial view, and old photographic shot of HBM in Skikda.

Source: Google map (treatment by the author) + old photographic shot from Facebook page.

V.4.4. Collective dwellings HLM during the colonial period

The European population turned its attention to creating the collective dwellings with the end of colonization, importing the European model in the process. Big number of these ensembles were constructed on great agricultural land. To meet the country's housing needs, France sought to build quickly, widely, and cheaply. However, colonization brought with it a new vision of the city and a new form of construction. It is the implementation of large group collective housing (HLM).

This type of construction exists in Skikda, where it has launched for the first time since 1953. It is situated on Arsenal Street (Figure V.15), in the heart of the city, a few meters also the Neapolitan neighbourhood, and from the massive HBM building. Likewise, a neighbourhood with 1200 collective dwelling units would be built in the south of the city in 1957, as R+4 structures with accessible cellars. The housing is separated into sizes F2, F3, F4, and F5 (Brighet, 2018), concurrently with the

Constantine plan, with help from the Skikda municipal government and the Algerian real estate company (C.I.A) (Lebied, 2012).

Figure V. 15. Aerial view, and photographic shot of HLM construction in Arsenal Street, Skikda. Source: Google map (treatment by the author) + photographic shot by the author.

The new urbanization has therefore developed on flat land, giving rise to the emergence of two new low-income neighbourhoods, intended for the middle-class colonial community and, to a lesser extent, for the Muslim community of the "Arab Quarter": Camus-Rossi and the CIA (Figure V.16), which were constructed in the colonial pericentre, a few dozen meters from the neighbourhood of “les Allées du 20 Août” (A. Fenchouch, 2019).

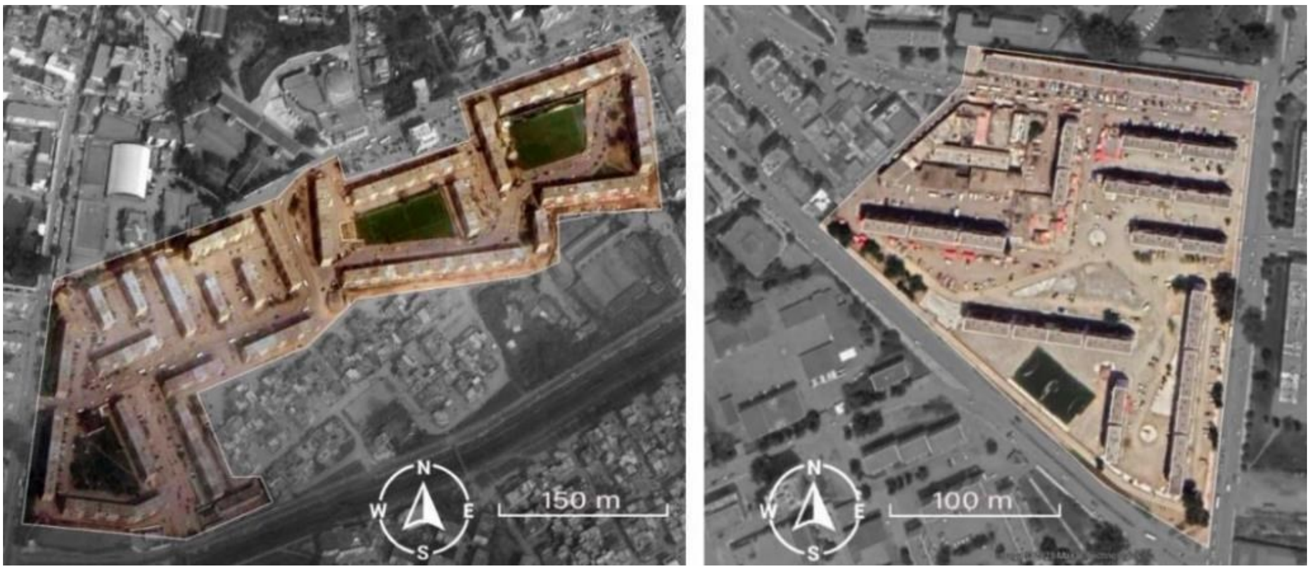


Figure V. 16. Aerial view, and photographic shot of HLM construction in Camus Rossi (left), and CIA (right). Source: Google map (treatment by the author).

These complexes are distinguished by the fact that they occupy huge blocks of land, some of which are larger than the original Skikda city centre.

The horizontal frameworks might be massive, consisting of hundreds or even thousands of standardized dwelling units.

Following the concept that the most essential purpose is residential; they request relatively large quantities of land (Lebied, 2012).

V.4.5. ZHUNs and multi-family buildings

During the years (1975-1976), two urbanistic instruments, which were widely used in Algeria, were created: the ZHUN (New Urban Settlement Areas) and the ZI (Industrial Zones).

The ZHUN strategy has accelerated the growth of certain cities, doubling their surface area in fewer than thirty years. The ZHUNs (New Urban Settlement Areas) in Skikda were developed without the involvement of urban planners or politicians. According to agricultural services, all of the land allotted to these projects is of high agricultural value. Thus, the ZHUN of Merdj eddib, 20 Aout 1955 (Figure V.17), in addition to Salah Boulkeroua, Bouyaala, neighbourhood, and others...

Figure V. 17. Aerial illustrations of multi-family buildings, in Merdj eddib neighbourhood (in the left) and 20 Aout 1955 neighbourhood (in the right).

Source: Google map (treatment by the author).

A topological analysis of the living areas in the ZHUNs indicates that the spatial configurations associated with the inhabitation modes prescribed by the designer are severely lacking in terms of shape, area, and aesthetic (Lazri, 2007). The domain services are in charge of managing State property. The Public Property Management Office (OPGI), the Algerian Family Housing Promotion Company (EPLF), and private developers who purchase state-owned land to build collective housing programs intended primarily for rental are now in charge of housing production as the State is no longer able to handle this task.

The law of supply and demand determines the pricing of the land that the domains sell to various companies (OPGI, EPLF, private developers, etc.). They vary from location to location, especially between the city core and the surrounding districts.

Without the agreement of the Directorate of Agricultural Services (DSA), which is the principal controller of agricultural land, the selected lots of land are frequently found in the fertile plain of Skikda, knowing that the DSA's operational duty is to prevent the nibbling of agricultural land, which is becoming increasingly scarce than ever (Nemouchi, 2008).

V.4.6. Unplanned self-built individual housing

Excessive urbanization in the form of Z.H.U.N and housing estates has been accompanied by urbanization in the form of illegal and informal housing estates. These operations have been carried out in the centre and on the urban periphery on virgin sites, often on uneven terrain. These excessive urban extensions have had negative effects on the urbanization of old centres, as in the case of Boulkeroua and Bouabbaz (Djema, 2013).

The construction of this private area, composed of individual houses, is random (as shown in the aerial view in (Figure V.18). Its realization lacks an overall vision. The layout of the houses is devoid of urban cohesion due to the illogical, even opportunistic, distribution of plots.

The acquisition of urban land in this region often has diverse origins: regularization of a former illegal occupant, sales of family property, transfers of communal plots, sales through real estate development companies, or resales from private individuals.

Because of the inequality of the surface areas of the blocks and the cost per square meter, these different modes of appropriation result in diversified parcels. Not to mention the diversity of socio-economic classes represented among the users of the aforementioned places. The great social variety of purchasers results from the diversity of land supply circuits (Nemouchi, 2008).

These operations were established on the immediate outskirts of urban centres on poor land or land with low agricultural yields.

This form of urbanization has created veritable dormitory towns lacking all the accompanying facilities and remaining dependent on the nearest urban centres (Djema, 2013).

Figure V. 18. Aerial view of examples of unplanned self-built individual housing in Skikda. Source: Google map (treatment by the author).

V.4.7. Illegal and informal constructions: sets of Gourbis and precarious housing

Obtaining a building permit and a plot of land may be particularly difficult for the poor, which has significantly contributed to the growth of unlawful operations. The Bouabaz site, the Boulkeroua site, the Briqueterie site, the Stora site, and the Mechtet Laghouat site are the main five places where spontaneous settlements have occurred, in addition to Zefzef and Messiouene (Figure V.19).

Figure V. 19. Aerial illustrations of informal housing (Gourbis), in Messiouene neighbourhood (in the left) and Zefzef neighbourhood (in the right). Source: Google map (treatment by the author).

Frequently, the land occupied is public property. The emergence and growth of shantytowns provide a dilemma for the government and raise concerns about its housing strategy, which is seen to be unable to accommodate the requirements of the community (Nemouchi, 2008). A gourbi (precarious dwelling), according to the Department of Urban Planning of the wilaya of Skikda, takes up roughly 120 m2. The location is absolutely devoid of tools, a road network, technological networks (water, gas, electricity, etc.), and hygienic conditions.

Since it has been occupied for more than twenty-five years, the majority of the population is from the nearby rural areas, which moved in large numbers to the city in search of employment. In the slum, there are disturbing social tensions. Delinquency, insecurity and violence, are extremely high there, as well as some form of precariousness in the quality of life, deterioration in education, health services (Toumi, 2018). There are emerging unregistered and tax-exempt informal economic operations like tiny food businesses (Nemouchi, 2008).

V.4.8. Planned self-build housing

During the colonial period in the early 1940s, land subdivisions were developed in Algeria for the construction of this type of housing and other French colonial infrastructure (Picard, 1989; Alkama, 1995), as example, Timgad neighbourhood, in Skikda (Figure V.20).

Figure V. 20. Aerial view of example of planned self-build housing in colonial period in Skikda: Timgad neighbourhood.

Source: Google map (treatment by the author).

The urban tissue for this type of housing is planned ahead of time through an urban planning procedure, in accordance with the concepts of zoning and subdividing. The subdivision is defined by the process of creating an area of land, which is typically a set of cells of regular blocks (as shown in Figure V.21), so that each block is divided into plots whose construction heights are limited to three stories, and a subdivision permit that has been granted by the relevant services (DUAC) is necessary for development intervention on dwelling developments (Boukhabla, 2015).

The post and beam building technique, hollow body floors, compression slabs, masonry, and hollow brick are the defining features of this type of constructions.

Figure V. 21. Aerial illustration of planned individual housing, in Merdj eddib (Left), and Zefzef (Right).

Source: Google map (treatment by the author).

V.4.9. Collective housing after 1990 (Period of the State Regulator)

This period named also by the new policy of the habitat (after 1990) of which the sector of the habitat is characterized by enormous politico-economic upheavals democracy, liberalism: the opening on the investments, the opening of the field of the production of the habitat notably the collective habitat and the demonopolization, for the participation of various national public (OPGI, Land Agency) and private (real estate developers) and even foreign actors-promoters and the appearance of the new procedures of acquisition of collective -formulas- (social rental housing " LSL ", social participative housing " LSP ", currently " LPA ", renting-selling, promotional, cooperative real estate)

(Harkat, 2014). There have been many projects of this type in Skikda, of which the (Figure V.22) show aerial views of examples in Oued el wahch district.

Figure V. 22. Aerial view of examples of promotional collective housing in Skikda: in Oued el wahch.

Source: Google map (treatment by the author) + picture obtained from Facebook site page.

V.4.10. Prefabricated chalets

Ben M'hidi's ZET (Tourist Expansion Zones) is provided in the form of a linear strip. The Wilaya road that connects the Filfila region to the city of Skikda separates the beach from the remainder of the ZET, which is located east of Skikda and restricts the platform of the SONATRACH petrochemical complex on the sea side.

In the 1970s, political decisions prioritised industrialisation over other sectors. This had a negative impact on the management of the ZET area, which was originally intended for tourism due to its natural beauty. The original plan was to build chalets (as shown in Figure V.23 left) as a living base for foreign employees.

After the cooperators left, the deteriorated prefabricated houses, which were already in an anarchic state, were assigned to Algerians.

The environment has degraded over time due to its location on an old dune belt, and sanitation issues have increased. The existence of septic tanks poses a risk of polluting the water table. Currently, the site remains desirable, and new individual constructions are being built in Oued Righa, despite laws on coastal protection and enhancement that prohibit the extension of two adjacent settlements unless they are separated by at least 5 kilometres (Meghzili, 2015).

Figure V. 23. photographic shots of prefabricated chalets
in Ben Mhidi's ZET and "La grande plage", Skikda.
Source:(Meghzili, 2015).

The beach, known as "La Grande plage" (Figure V.23 right) features private buildings situated beyond the back beach. A section of around twenty chalets is present, most of which are recently constructed, occupying a part of the back beach. Sanitation is maintained by septic tanks. No evidence of pollution has been recorded at Grande Plage ZET.

To the west, there lies a wooded mountain range. Tourism at La Grande Plage can combine the advantages of the mountains and the seaside.

V.5. Skikda's current state from different angles

As a scaled-down representation of Algeria, Skikda replicates that country's realities and deals with similar environmental and energy problems (H. Hadef, 2020).

Previous studies indicate that most of Skikda's dwellings are vulnerable in terms of energy efficiency and indoor comfort due to their age, outdated bioclimatic design and inability to withstand meteorological factors. Rapid urbanisation has intensified the problem (Brighet, 2018), and the buildings do not meet contemporary energy-saving requirements or ensure occupant comfort (Kassis, 2012). Also, according to a study which was by (Boulkenafet, 2014), these structures of urban parc of Skikda were ill-equipped to adapt to daily and seasonal variations in climate and relied on artificial industrial methods, leading to excessive energy consumption and pollution.

The issues that prevent horizontal urban development—such as the city's challenging topography, a lack of land suitable for habitation, the presence of agricultural land that cuts through the city and prevents its expansion, and the presence of the industrial zone, particularly the refining zone, with the risks it entails—impose the verticality of the buildings (Bendjemila, 2018).

However, due to its enormous economic potential based primarily on agriculture and industry, this city is thought to be one of the important and the wealthiest cities in Algeria, with its capital commune ranking fourth nationally out of 1541 existing communes (Aït Saïd, 2013; Benali, 2018), taking into account the wilaya of Skikda's designation as an intensive vegetable, fruit, industrial, and fodder production zone. In addition to SONATRACH's petrochemical hub for refining and upgrading hydrocarbons in the Hamrouche Hamoudi industrial zone, the city has an industrial fabric comprised of units for processing useful materials and substances (wood, leather), agri-food, and textile production (ANIREF, 2020), not to mention summer beach tourism as an important exploitable source, despite its low contribution to local income (Sehab, 2013).

Skikda's seaport is considered the country's second largest (Eurisles, 2021), and one of only three industrial ports in Algeria (Setti et al., 2011). It enables the transport of goods, notably hydrocarbons with a capacity of 25 million tons, as well as passengers, with a capacity of 1,200 passengers according to Skikda's State Programming and Budget Monitoring Department, in 2012 (Sehab, 2013).

All of this demonstrates the city of Skikda's economic importance to Algeria, as well as its capacity to engage in energy transition initiatives, but it also establishes its terrible ecological status, as well as the unstable energy as well as lack of thermal comfort on the inside of its buildings.

V.6. Choice and overview of the urban case studies

The residential urban samples were selected after a typo-morphological analysis of 103 typologies of collective habitats according to:

- The building's height.
- The age of the building.
- The complexity of the building’s envelope.
- The height of nearby buildings.
- The distance between buildings.
- The topography of the site and the surrounding area.

The reasons for these choices are explained in the next chapter, which is related to methodology workflow.

And as results of this classification; the four selected case studies, were:

- The neighbourhood of Khaldi brothers (Case Study A).
- The neighbourhood of Messiouene (Case Study B).
- The neighbourhood of Merdj eddib (Case Study C).
- The neighbourhood of Saadi brothers (Case Study D).

The locations of these study cases are shown on (Figure V.24).

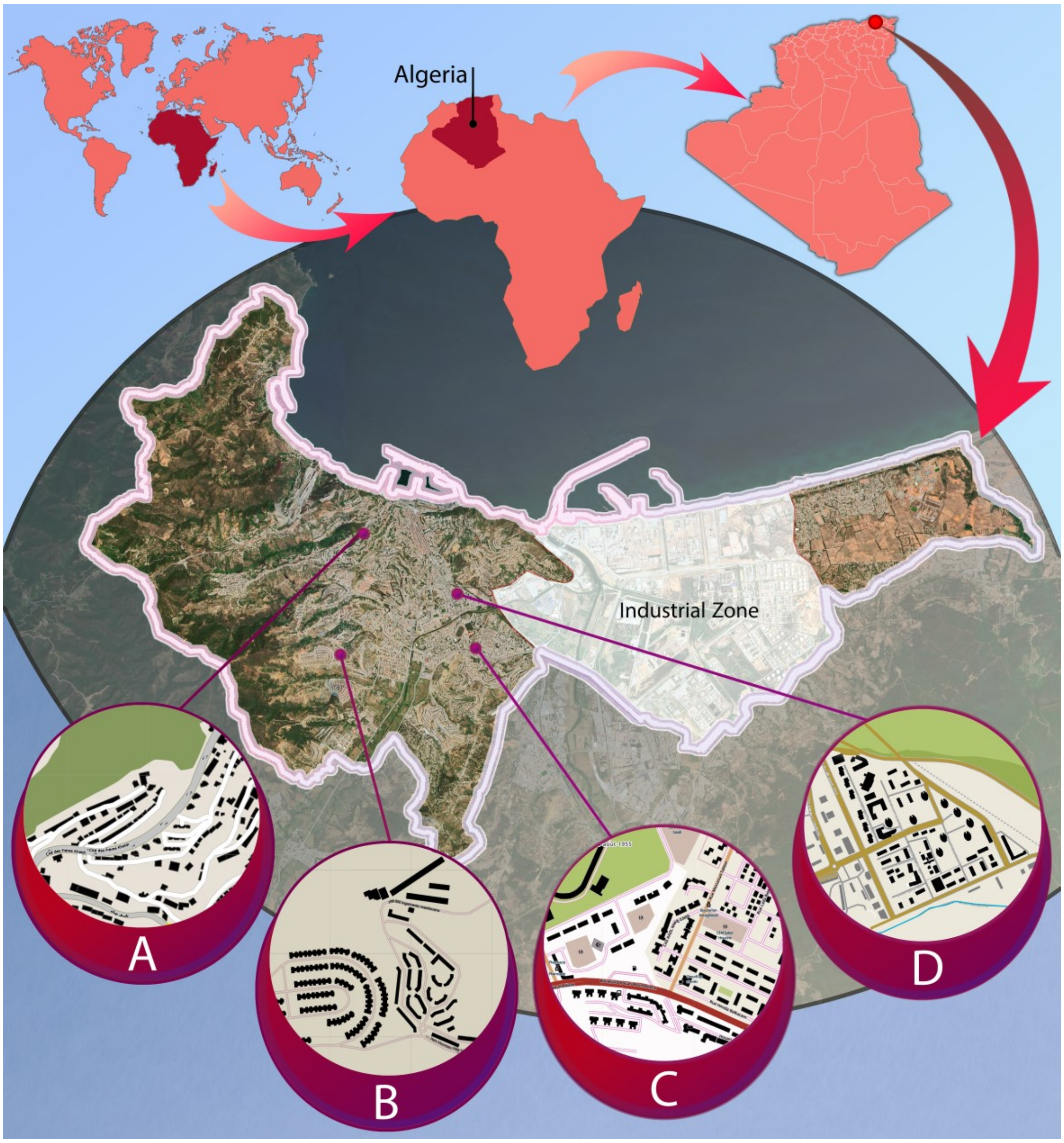


Figure V. 24. Designation of study case locations at different scales.

Source: the author, 2023.

The (Table V.1) shows more details from the actual photographic shots of typologies, footprints, and heights of each of the buildings studied.

Table V. 1. More details about the studied cases.

Source: The author, 2023.

Study Cases	Case A	Case B	Case C	Case D
Real photographic shots of the typologies				
Typologies footprint				
Altitude	83 m	84 m	8 m	11 m
Number of floors	10	6	16	15
Surface area	323.7 m²	208.1 m²	573.8 m²	519.4 m²

V.7. Conclusion

The North African and Algerian city of Skikda belongs to the temperate Mediterranean climate zone, which is generally humid, with summers that can be hot, but winters that are generally mild. Moreover, the city has had a unique and fascinating historical growth in the construction industry, particularly in the residential sector. According to the above epistemological work, the city has a range of housing categories based on many factors over the generations. This variety in weather over the year, natural context and built environment gives the city a unique and appealing location for multidisciplinary research. The final section of this chapter gave an outstanding demonstration and also overview of the different typologies of collective housing available in the city; this section has been expanded to point out the choice of the most fascinating archetypes for collective housing as case studies, in different neighbourhoods, which have different urban and natural characteristics.

CHAPTER VI

Methods and Materials

VI.1. Introduction

To link the state of art as well as the first theorical part of the study that is showed, it is necessary to define the methodology that will conduct the research practical part.

This chapter provides a thorough review of the instruments and procedures utilized to carry out the investigation. It aims also to provide a more detailed description of the typo-morphological characteristics of the case studies related-archetypes, as well as of the neighbourhoods in which they exist, at different scales, including the mesoscale, the neighbourhood, the local shading, and the architectural scales. These characteristics are significant elements of this study, and their elucidation will foster an enhanced understanding of the different multiscale factors that impact the energy performance of buildings. Following this, data will be presented on the current energy demand, its description, and supply sources across various apartments. The upcoming section will present an account of the varied tools used, including ArcGIS, Autodesk Revit, Insight 360, as well as the main tool used, which is based on the urban building energy modelling approach, and known as City Energy Analyst (CEA). The criteria used for choosing specific tools will be also explicated. This chapter also consists of the explanation of the workflow of topographical, urban and solar analysis of the existing surrounding context, established with the aim of extracting factors that influence solar access to the external facades of the archetype. Furthermore, the procedure for collecting actual energy data for all archetypes will be clarified. Subsequently, the energy simulation stage, encompassing calibration and validation, have to be also described. Moreover, the work process of analysing the annual greenhouse gas emissions and energy consumption will be presented in comparison with European benchmarks, which are then used to evaluate the different improvement scenarios following different types of active and passive strategies in the context of building energy renovation, which will be also well enlightened.

VI.2. Research workflow

After a thorough reading of documents and prior researches, the workflow of this research was organized as the schematic description in (Figure VI.1) recapitalizes.

The choice of four different study cases in the city of Skikda was made after a morpho-typological analysis of all 103 existing and occupied collective housing typologies (Appendix 1). Measured energy consumption data for the four study cases were obtained from local commercial agencies of (SONELGAZ) in the city of Skikda (Appendix 2).

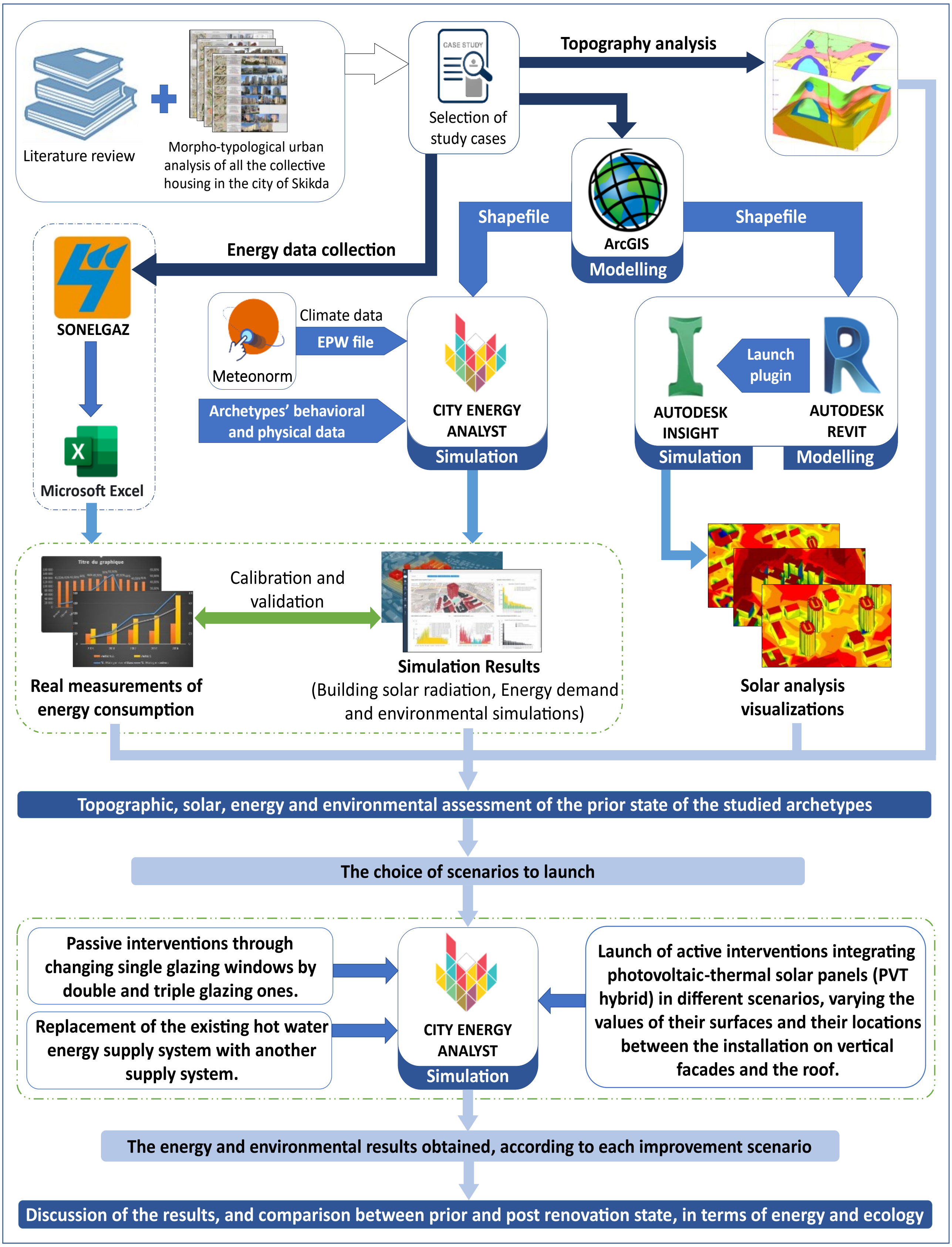


Figure VI. 1. Schematic description of the work methodology.

Source: The author, 2023.

Geometric modelling was carried out using ArcGIS via ArcMap, by creating "Shapefiles" that were then imported into Revit Autodesk, where they were ready to come out solar analyses and visualizations that show the variance in the amount of cumulative incident solar energy, over the entire 2021 year, according to one-hour recording intervals, for each urban model using the Autodesk Insight 360 plugin. In addition, the same "Shapefile" files for the 4 cases were integrated into the CEA simulation tool, which also uses climate data for the city of Skikda based on the EPW file which was produced by the METEONORM 8.0 meteorological tool. The simulation results produced by CEA were calibrated using measured energy consumption data, which they were also analysed and compared with each other. Other studies and topographical visualizations were also performed to show the altitude of the various places investigated in relation to the surrounding topography. All of the data obtained, including numerical findings and visualizations, was presented in order to show the relationships between the numerous characteristics relating to site conditions, energy consumption, solar energy quantities received, and greenhouse gas emissions. The results were analysed and discussed according to a multi-scale approach, in which reflection is based on the consideration of several levels of scale, and on the interdependence between these levels, depending on (Fusco, s. d.); which also mentioned that, according to (Lacoste, 1982), each level of observation reveals only certain phenomena, which necessitates combining or articulating different levels of spatial analysis to study the same phenomenon and grasp its different facets; which then postulates that each geographical level enables us to study part of a phenomenon, but also that there are interactions between scales.

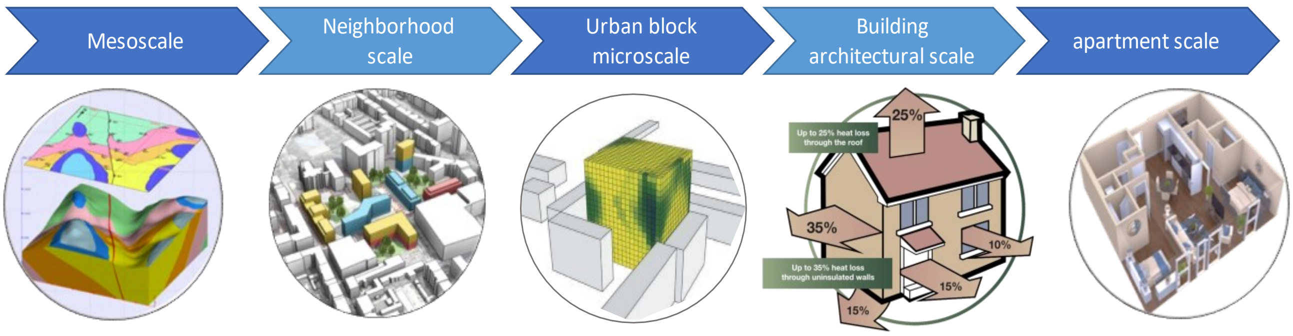


Figure VI. 2. Workflow of the analysis using a multiscale approach.

Source: The author, 2023.

This research, then, began at the mesoscale, through a topographical analysis before moved on to a solar analysis at the neighbourhood scale. After that, it took the archetype under study, from an urban standpoint, analysing the extent to which surrounding spaces affect the amount of energy received on its surfaces, as shown in (Figure VI.2).

The study was then moved to an architectural scale, with an energy and environmental analysis of the complete archetype analysed. Next, an energy analysis also based on comparisons between the measured energy data of particular sampling apartments was carried out. Finally, an energy and environmental assessment were done, in comparison with benchmarks of some European countries (France, Spain, Italy). Furthermore, a similar assessment of post-renovation scenarios will be conducted after implementing new measures, including the use of double, triple glazing, and, in some cases, a photovoltaic-thermal system with variations in the quantity and position of the latter in different scenarios, in addition to the changing of the supply system for the hot water needs, by the use of hot water boilers based on electric supply system. The aim is to understand the effectiveness of these improvements. Energy simulations for various energy renovation scenarios were also launched using the CEA tool, extracting energy and ecological changes after each scenario.

The annual energy consumption and operational greenhouse gas emissions for each scenario are compared to the same mentioned European benchmarks. The integration of photovoltaic-thermal solar panels on roofs and south-faced surfaces is based on 3D solar visualizations generated by Insight 360. The findings can aid the good planning of building renovations, allowing for the most optimal decisions to be made with regard to energy and ecological impact. This can be achieved by developing an understanding of the impact of hybrid measures, determining the most suitable placement of hybrid PVT panels, and identifying the most effective combination of a range of interventions.

VI.3. Identification of the four Skikda’s study cases

Residential urban samples were chosen after investigating the typo-morphology of collective housing buildings. Criteria such as building height, architectural envelope complexity, height heterogeneity, spacing between urban buildings, and the topography of the site and its surroundings were taken into account, seeing that the first phase of practical research begins with the focus on analysing how building morphology and surroundings impact the annual cumulative insolation.

The site's altitude, topography, geometrical and thermal characteristics, along with the year of construction and apartment orientation were considered when assessing the impact of surrounding factors, as well as the building's thermal and geospatial state, on energy requirements and carbon emissions in relation to the supply system used. The selection of these criteria resulted also from the software's assembly capabilities and provided inputs and outputs. Hence, appropriate renovation scenarios and locations for incorporating PVT hybrid panels have to be studied, relating to these mentioned spatial factors. The following section will describe each case study, illustrated in (Figure VI.3), involving archetypes and their environment.

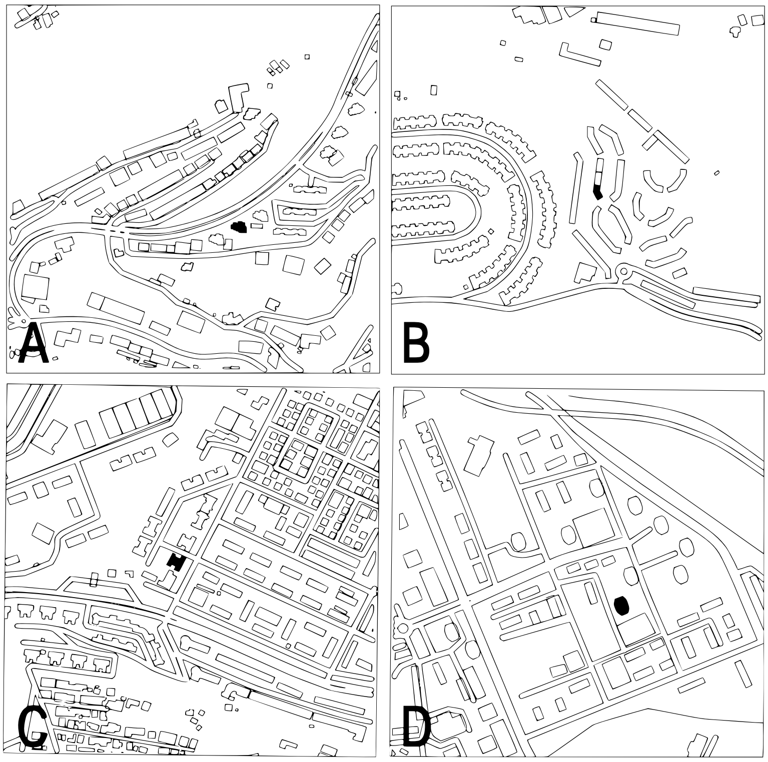


Figure VI. 3. Urban context of the study cases.

Source: The author, 2023.

VI.3.1. Case study A

The archetype belongs to a housing unit built under the ZHUN (New Urban Housing Zones) program, implemented from 1970 to 1980 in the Khaldi brothers' neighbourhood, as extension of the old city of Skikda, after independence. The district is comprised of collective housing buildings of the same archetype type, although varying in their footprints and heights, ranging from 6 to 10 floors. The site also includes newer individual residences of 2 to 4 storeys. There are further amenities available on-site, including educational and recreational facilities.

VI.3.2. Case study B

The archetype, situated in Messiouene extension zone, is being built, along with the other houses in the neighbourhood, under the new LPA's social housing program, formerly known as the LSP program, which is a new house built by a property developer according to defined technical specifications and financial conditions. The dwelling is designed for applicants who meet the eligibility requirements for state assistance. This section targets individuals earning an average income; eligibility for this form of accommodation is contingent on a financial package that accounts for personal contributions, a subsidised loan, and direct front-end assistance (Logement-Algerie

Website, n.d.). The neighbourhood, which comprises also social buildings and promotional public housing, is entirely residential, with a few commercial establishments and educational facilities. Almost all buildings have the same height, with five storeys and a continuous typology that leans towards horizontality.

VI.3.3. Case study C

The studied prototype resides in the Merdj eddib estate, a complex of promotional collective housing units erected under the AADL program in the early 21st century. The buildings range between six and sixteen floors in height.

The location is situated in the southern extension of the city and is adjacent to the national highway. The neighbourhood includes collective housing units constructed under the ZHUNs programme in the form of bars, with heights of 4 and 5 floors. Additionally, the neighbourhood features individual homes with a maximum of 4 floors. The site accommodates commercial activities, administrative facilities, and educational amenities.

VI.3.4. Case study D

The archetype is located in the Saadi brothers' housing estate, which stands at the core of Skikda's new town centre, on the extension of the Boulevard des Allées du 20 Août 1955, which is one of the main thoroughfares of the town. This housing estate is distinct from others in Skikda owing to its nine residential towers (R+14), which function as vertical neighbourhoods. The towers comprise 13 shops on the ground floor and 56 homes on the upper floors. The residential area comprises 14 towers, 6 mini-towers (R+7), and 27 buildings/barrels (R+4) that together form a cohesive and diverse architectural landscape. The " Saadi Brothers" estate houses 1112 dwellings, which accommodate 7804 inhabitants across 1324 households.

The estate also incorporates 10 structural facilities. Most of these public facilities offer a broad range of services that extend beyond the housing estate's boundaries to cater for the entire population residing in the southern part of the town. The ZHUN project oversaw the estate's construction between 1978 and 1981, and it has been operational since 1982 (Kassis, 2012).

The technical and administrative data relating to the four case studies were obtained from various departments affiliated with the Wilaya of Skikda, such as the Skikda municipality, the Office for the Promotion and Management of Real Estate (OPGI), and certain master builders' offices.

(Table VI.1) displays data pertaining to construction year, geometry, and thermal properties.

Table VI. 1. Main properties and data for each archetype.

Source: The author, 2023.

Study cases	**Year of occupancy**	**Geometry**		**Construction system**	**Exterior wall**		**Glazing**		**Roofing**	
		Number of floors (Height)	Surface area (3 apartments/ floor).		Components	U-value [W·m−2 K−1]	Windows glazing type	U-value [W·m−2 K−1]	Components	U-value [W·m−2 K−1]
A	1983	10 (30 m)	323.7 m² (3 apartments / floor).	« PASCAL» heavy prefabrication process	Prefabricated reinforced concrete sandwich panels + plaster + paint	2.30	Simple glazing	6.00	Prefabricated reinforced concrete sandwich panels + multi-layer bituminous waterproofing (felt + bitumen + polystyrene + screed + gravel)	1.20
B	2017	6 (18 m)	208.1 m² (2 apartments / floor).	Column-beam system	15 cm hollow brick + 5 cm air gap + 10 cm hollow brick + exterior and interior rendering + interior and exterior painting	1.50	Simple glazing	6.00	Hollow-body floor (Hourdis + joists + reinforced concrete slab) + multi-layer bituminous waterproofing (felt + bitumen + polystyrene + screed + gravel)	1.08
C	2008	16 (48 m)	573.8 m² (4 apartments / floor).	Column-beam system + load-bearing walls	**Wall type 1:** 20 cm thick reinforced concrete load-bearing wall + exterior and interior rendering + interior and exterior paintwork	2.30	Simple glazing	6.00	Hollow-body floor (Hourdis + joists + reinforced concrete slab) + multi-layer bituminous waterproofing (felt + bitumen + polystyrene + screed + gravel)	1.08
					Wall type 2: 15 cm thick hollow brick + 5 cm thick air space + 10 cm thick hollow brick + external and internal rendering + internal and external paintwork	1.50				
D	1982	15 (45 m)	519.4 m² (4 apartments / floor).	« PASCAL» heavy prefabrication process	Prefabricated reinforced concrete sandwich panels + plaster + paint	2.30	Simple glazing	6.00	Prefabricated reinforced concrete sandwich panels + multi-layer bituminous waterproofing (felt + bitumen + polystyrene + screed + gravel)	1.20

Also, the (Figure VI.4), gives an overview on the height of the four archetypes, in addition to the heights of the other surrounding buildings in their neighbourhoods.

Figure VI. 4. Designation of buildings' heights in the four case study neighbourhoods.

Source: The author, 2023.

VI.4. Energy demand data

The energy consumption data for the period between October 2020 and July 2022 was collected quarterly. This data was necessary to calibrate the building energy simulation models for 2021. It was also used to compare the energy consumption of apartments on different floors and orientations of each of the four buildings studied, as well as with European benchmarks. The energy consumption data for this study were collected from three agencies affiliated with the national electricity and gas distribution company (SONELGAZ): Skikda's East regional agency on Bachir Boukadoum avenue, and two commercial agencies on Benhouria street and Zighoud Youcef street. The energy consumption values of the samples studied will be presented in the following stages of this research. The energy consumption of the entire building was estimated by sampling the quarterly electricity and gas consumption of multiple apartments situated on different floors and orientations relating to each archetype, as well as other ground floor business and administrative premises. In Skikda, as well as other parts of the country, gas is mainly used for heating, domestic hot water, and cooking, while electricity is primarily used for lighting, air conditioning, and household appliances.

VI.5. Tools

VI.5.1. ArcMap 10.7 (ArcGIS)

ArcGIS is a geographic information system (GIS) that allows users to view, edit, manage, and analyse geographic data. It was created thanks to Esri (Environmental Systems Research Institute), in Redlands, California-based company that is a pioneer in the development of GIS, geolocation, and mapping. ArcMap is the cornerstone of Esri's GIS software package. This is the method through which users may generate maps from scratch. They can find location patterns as well as trends in ArcMap by studying the data (GISGeography, 2015).

A shapefile is a vector data storage format designed by Esri that captures the position, shape, and properties of geographic features. It is saved as a series of interlinked files and provides a set of features. Form files have consistently been an essential component of most specialist applications due to their richness of information (ArcGIS Online, n.d.).

This present study utilised the tool to create a model of the archetype in its respective urban and geographical context. The model includes all necessary geospatial data for integration into the CEA tool and Revit. The imported data for other simulation tools was in “Shapefile” format.

The (figure VI.5), below, shows how to model the example of the case study (D) using ArcMap tool. Firstly, by creating a 2D model of building footprints on the ground and the geographical location, and then by adding data about their heights.

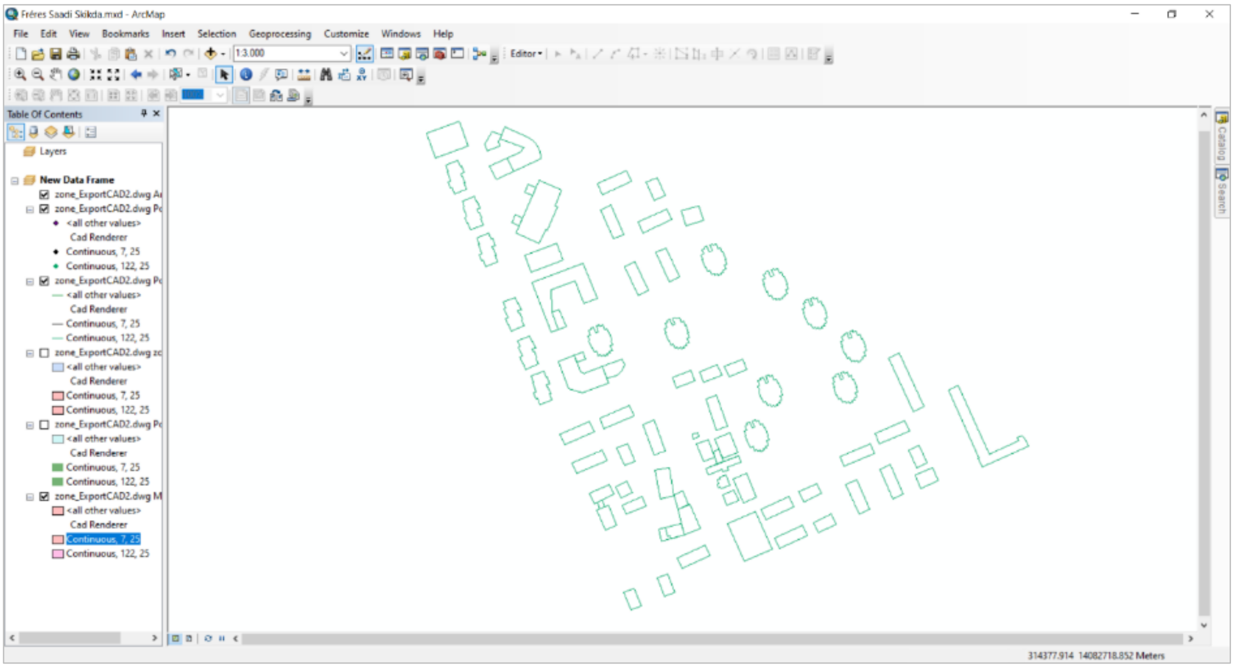


Figure VI. 5. Example of the use of ArcMap to model the urban context of the case study (D). Source: The author, 2023.

VI.5.2. REVIT and INSIGHT 360 AUTODESK 2020

Autodesk Revit is a building information modelling application. The most popular users are architects, structural engineers, electrical, mechanical, as well as plumbing engineers, designers, and contractors. Users using Autodesk Revit may create, change, and update 3D models in excessive details (Microsol Resources, 2021).

Users get consolidated accessibility to performance data in addition to powerful analytical engines with Insight 360. Because of its tight interaction with Revit and direct access to advice and suggestions from trustworthy simulation engines and industry references, this plugin allows users to approach the design process by integrating features that contribute towards improved building performance throughout its lifespan. Insight 360 combines and extends several existing procedures, which include lighting alongside solar analysis, to give a comprehensive approach to building performance (Grimm, 2016).

The information was imported and adjusted in Revit to allow the simulation of outdoor spaces for getting the annual cumulative insolation.

The Revit software interface, depicted in the (figure VI.6), displays the command icons of the Insight add-on tool which is located at the far right of the main work panel above.

The locations' geographical coordinates and simulation period for the whole of 2021 have been entered into the sun settings panel, where solar simulations were run every hour.

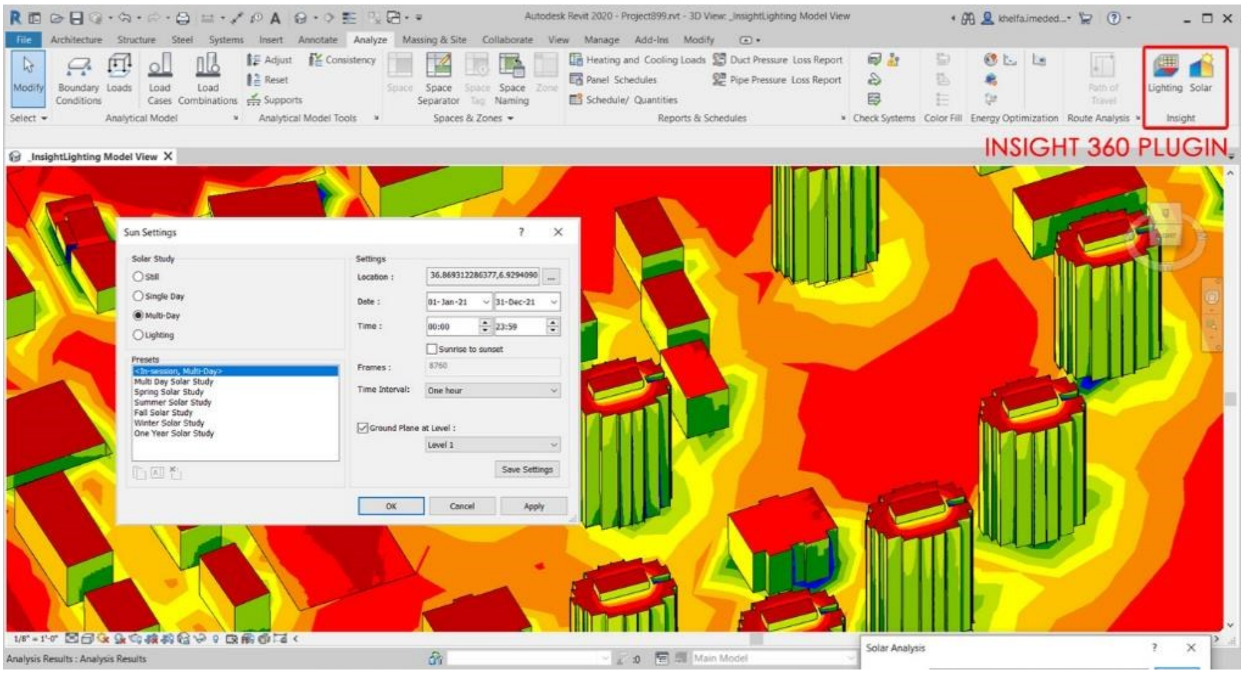


Figure VI. 6. Example of the use of Revit and Insight 360 plugin to run the annual cumulative insolation of the case study (D).

Source: The author, 2023.

VI.5.3. City energy analyst 3.32.0

City Energy Analyst (CEA) is an urban building simulation platform which was one of the first open-source simulation tool initiatives, established in 2016 by the Swiss university of ETH Zurich, alongside its scientific centre based in Singapore, both together with EPFL; for constructing energy-efficient, low-carbon cities (Ferrando et al., 2020). In an integrated simulation platform, it incorporates expertise from urban planning and energy systems engineering. Researchers may now investigate the consequences, trade-offs, and synergies of alternative urban design options and energy infrastructure plans (CEA official website, n.d.; S. Li & Aydt, 2020). The Python-based model operates as an ArcGIS extension. This integrated model includes demand, resources potential, systems technology, systems optimization, decision-making, in addition to spatio-temporal analysis (Sola et al., 2020). CEA supplies default datasets on occupancy schedules, internal energy loads, interior comfort parameters, building systems, envelope systems, and emission systems based on archetypal building stock data. To link archetypal data to the specific building, just generic data on building geometry (including the number of storeys and height), year of construction as well as year(s) of refurbishment, building system typology, and principal building purpose are required (Willmann et al., 2019; Jepsen et al., 2022). The meteorological database holds time series data from the METEONORM program on ambient temperature, relative humidity, and solar transmissivity

(Fonseca, 2020). CEA, like several other programs such as SimStadt (NOUVEL et al., 2015), OpenIDEAS (Baetens et al., 2015), followed by TEASER (Remmen et al., 2018), operates according to the reduced-order UBEM (Urban building energy modelling) paradigm, which is extensively used to undertake fast assessments of building energy performance.

This CEA based-method requires less inputs than physical and data-driven methods (Hong et al., 2020). The estimation of model parameter values is one of the procedures involved in this technique, which may be approximated using various calculation standards published by the European Committee for Standardization (CEN) along with the International Organization for Standardization (ISO). These standards describe the calculating procedure via a collection of guidelines which involve the physical characteristics of the building as well as the systems connected with various building types (Ali et al., 2021). Several previous studies have used this tool to obtain results, including (Sreepathi et al., 2017; Happle et al., 2017; Maiullari et al., 2018; Mosteiro-Romero et al., 2019; Bello Acosta, 2020, 2020; Happle et al., 2020; Mosteiro-Romero et al., 2020; Johari et al., 2020; Dalla Mora et al., 2021; Shi et al., 2021).

The CEA makes it possible to cover several spatial and temporal scales, and facilitate the representation of the results through graphs. For this, it is favourable in this part to take CEA as a sample to explain the working method of UBEM reduced-order tools. It is one of the earliest open-source attempts of computing tools for the construction of low-carbon as well as highly efficient cities, a platform for urban building simulation.

In a single simulation platform, the CEA integrates expertise in energy systems engineering and urban planning. This allows the impacts, trade-offs and synergies of various urban design concepts and energy infrastructure ideas to be analysed. The CEA allows professionals and academics to ideally design future low-carbon cities (Official CEA website, n.d.).

The (figure VI.7), which recapitulate the method of use of this tool, showed that the database and various inputs, including zone, district, topography, and weather, must be picked when a new project is started since these are crucial for the commencement and requesting of geospatial data.

The application only provides a limited choice of weather files, for only some locations, but there is an option to import weather files which can be entered in EPW format. The user can import these files that contain climate data from other specialized software, like METEONORM, for example.

There is also a map that gives the option to pick the district to be looked at is then displayed. Buildings in this region can be automatically identified by CEA, using its built-in identification capabilities, at which point they are prepared for editing (Jepsen et al., 2022).

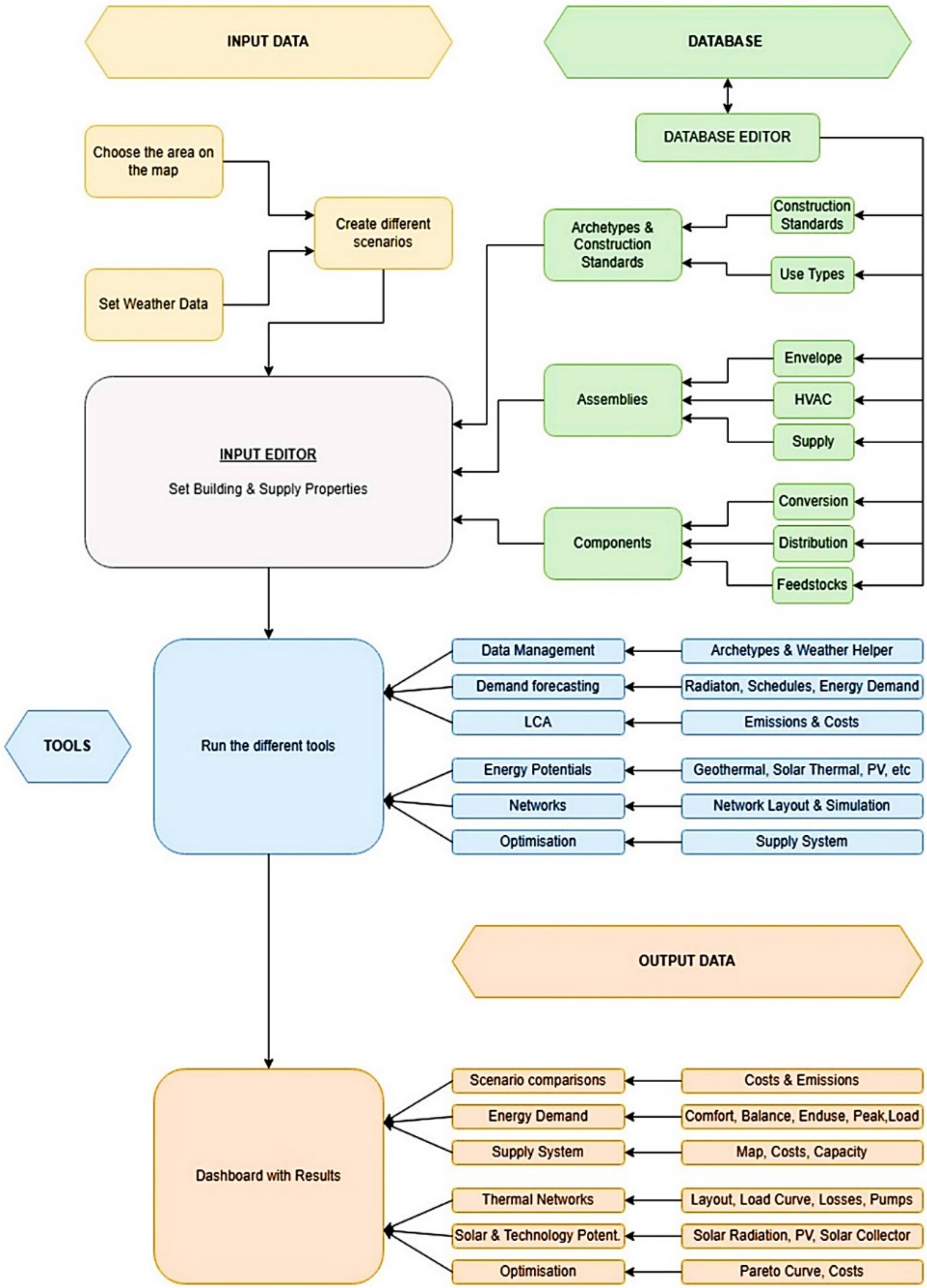


Figure VI. 7. Schematic representation of the mode of use of the CEA tool.

Source: (Jepsen et al., 2022).

The CEA provides standard databases on occupation schedules, loads of internal energy, indoor comfort variables, structure systems, envelope construction systems, as well as supply systems depending on building stock archetype data that offer energy demand predictions for simply unknown town quarters with no need of accessibility to specific construction or building detailed plans, as well as building system properties.

The following screenshot (figure VI.8) shows the integration of case study (D) into the CEA tool as an example, and also illustrates the interface of this tool which were used to trigger the solar, energy alongside environmental simulations for the case shown, as well as for the remaining three cases.

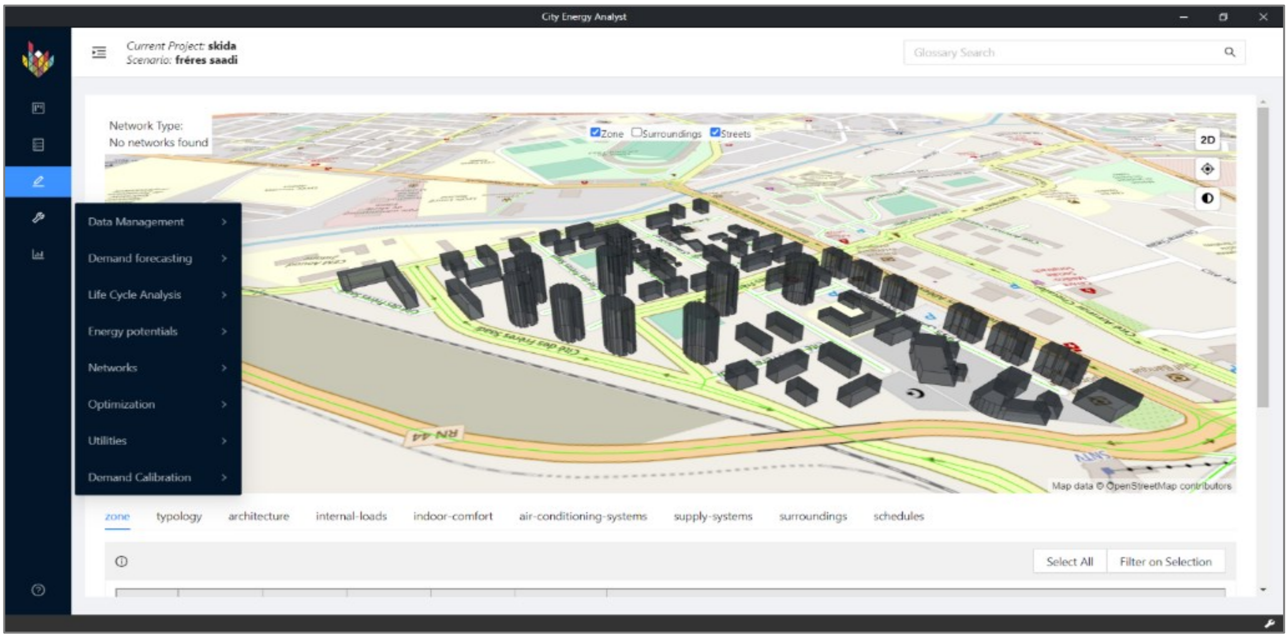


Figure VI. 8. Interface of the CEA tool, involving the urban context of case study (D), to perform solar, energy and environmental simulations.

Source: The author, 2023.

VI.5.4. Excel Microsoft

Excel is a component of Microsoft's Office suite that allows to generate tables, automated computations, schedules, charts, and databases. Excel makes it simple to build and combine many types of tables and computations. The table values are then automatically updated in accordance with the entries and calculations. Excel may also be used to create graphs (bar charts, pie charts, and so on) to aid in the visualization and interpretation of data. It is an extremely effective mathematical visualization tool (Xyoos Website, n.d.). It was utilized in this study to organize the quarterly energy data obtained, as well as create various graphs. It also revealed linear regression to study correlation between urban factors and energy consumption, or even polynomial regressions of occupant behaviours regarding their use of heating and cooling equipment.

VI.6. Calibration and validation of energy models

To ensure more credibility and accuracy, CEA model for each of the four case studies was calibrated by comparing the simulation's resulting energy demand to measured consumption data, like other previous studies did (Chong et al., 2021; Coakley et al., 2014; Trucano et al., 2006).

A variety of important factors influence building energy demand, including the thermal characteristics of the building envelope, the age of the building in addition to its type of use, local climatic conditions, the type of energy systems installed, temperature setpoints, operating schedules, occupant behaviour and activities (Jones et al., 2015; Salmon, 2016; Chong & Menberg, 2018; Y. Chen et al., 2020; L. Li et al., 2021).

In particular, in the four case studies selected, the value of certain factors is defined in advance, but the value of other factors is indefinite beforehand, such as temperature setpoints, and operating schedules.

So, for the calibration of the energy models, this present study used the Bayesian inference approach, similarly to several previous studies, such as (Sokol et al., 2017; Wang, 2018; Fonseca, 2020; Artiges et al., 2021), in which the prior factors (noted θ) are treated as random variables, and a prior probability distribution noted P (θ), is assigned to each unknown distribution. This distribution reflects knowledge about the potential values of θ (Ben Touhami, 2014).

The prior distributions are then updated, and adjusted depending on experimental or measured data (Gallagher & Doherty, 2007), to finally obtain a posterior probability distribution, including the information contained in the observations (Van Oijen et al., 2005), on the basis of Bayes' theorem (Bayes, 1763), using Monte Carlo (MC) simulation, a method which is based on prediction, probability and repetition, starting with a prior random variable (Team Wallstreetmojo, 2021).

After performing countless simulations, the energy models' accuracy was checked against the measured data. Gas and electricity consumption were divided into consumption linked to permanent use and consumption related to specific usage during a period of the year (cold and hot periods).

Permanent gas consumption is represented by cooking and domestic hot water needs, but usage linked to a specific period of the year is represented by heating needs; while electricity consumption is associated with the use of electrical appliances, electric ventilation and artificial lighting, while energy demands related to a specific period are represented by cooling needs.

The big importance in this calibration was given to cooling and heating use because of their significant impact on energy fluctuations along the year.

Validation of energy models is the process of determining the extent to which a model is an accurate representation of the real world in terms of the model's intended use (Chong et al., 2021).

For validation on an annual basis, the quantity of measured gas and electricity consumption in kilowatt-hours per square meter of floor area, during a year must compare with the simulated annual results according to equation (1) (Sokol et al., 2017).

$$\text{PE} = \frac{\text{EUImeas} - \text{EUIsim}}{\text{EUImeas}} \times 100\% \quad \textbf{(1)}$$

$$\text{CV(RMSE)} = \frac{\sqrt{\frac{\Sigma(\hat{Yi} - Yi)^2}{n - P - 1}}}{\bar{Y}} \times 100 \quad \textbf{(2)}$$

$$NMBE = \frac{\Sigma(\hat{Y}i - Yi)}{\bar{Y} \times (n - p)} \times 100 \quad \textbf{(3)}$$

Where:

$EUImeas$: Energy use intensity (Measured);

$EUIsim$: Energy use intensity (Simulated);

yi: Measured energy use for time interval i,

$\hat{yi}$: Simulated energy use;

$\bar{y}$: Mean of measured values;

N: Number of time intervals;

P: 1 as the number of model parameters.

For validation on a monthly basis, the coefficient of variation of root mean square permissible error (CVRMSE), according to equation (2) was limited to ⩽15% as an acceptable value (Meng & Mourshed, 2017; Sokol et al., 2017), while the value of the coefficient of normalized mean bias error (NMBE), following equation (3) is to be between -5 and +5 (Meng & Mourshed, 2017), where the calibration error limits have been determined in accordance with the recommendations of ASHRAE Guideline 14-2002 to meet the need for a standard body of methods for the calculation of energy demand and savings. The aim of the directive 14-2002 is to ensure that energy as well as demand savings resulting from energy-efficient projects in residential, commercial, or industrial buildings are measured to a satisfactory standard (Haberl et al., 2005).

VI.7. Polynomial regression for heating and cooling use behaviours

Polynomial regression is a method that uses statistics to model the non-linear connection between the response variable (y) and one or more explanatory factors (x) (DellaData, 2020). In this research, it was employed to comprehend the values of two independent undefined variables, represented by the setpoint temperature and the number of hours per week in which the heating or cooling system is used only during the cold or hot season, which have an impact on the defined dependent variable, represented by the amount of energy used for heating and cooling needs.

VI.8. Solar analysis

Based on the 3D model-based approach with solar irradiance simulations mentioned in (Saretta et al., 2019) review, and which was used in previous researches, like (Amado & Poggi, 2014; Fath et al., 2015; Desthieux et al., 2018; Lobaccaro et al., 2019; Brito et al., 2019), several observations were made from the three-dimensional visualizations of the annual solar map that were produced using the Insight Autodesk plugin associated with the Revit Autodesk tool.

The visualizations produced disclosed the various elements which affect solar access to building exteriors as well as the accumulation of incident solar energy, enabling the choice of the best places for solar panels.

In order to demonstrate the variation in the amounts of total incident solar energy and its distribution on vertical and horizontal surfaces throughout the year, a solar study was also performed using CEA.

VI.9. Topography analysis

The study and comprehension of the earth's natural characteristics, which are utilized to create terrain, land forms, and architectural constructions, is known as topography; this latter could have an impact on the building and its energy consumption.

It is therefore important to analyse the topography of a site before planning the construction of a new building (Spatialpost website, 2021), or even carrying out a renovation, which has led to an analysis using contrasted colour maps through (topographic-map, n.d.) website, and via topographical profiles which were generated using Google Earth Pro application.

VI.10. Prior state energy and environmental analysis and assessment

An analysis of measured and simulated energy data has been done through CEA tool, to have an idea about the impact of the multiscale indicators and the changes of energy needs according to the characteristics of time and place, and their ecological footprint also.

The greenhouse gases are split into two types: the first type is the embodied carbon emissions, and the second is the operational greenhouse gas emissions. The embodied carbon emissions, which are defined by (Langston & Langston, 2008; Ibn-Mohammed et al., 2013; Jang et al., 2015) as the energy required to deliver structures through all upstream processes, such as raw material extraction, production, transportation, and construction, where this production processes emit CO2. However, the operational carbon emissions, according (Ibn-Mohammed et al., 2013), represent the volume of CO2 emissions caused by the combustion and production of operational energies used in the operating phase for processes including heating, cooling, lighting, ventilation. The CEA tool was used to run the environmental simulations of embodied and operational carbon emissions on the basis of the energy simulations results and the data collected. Due to the absence of an Algerian energy and environmental benchmark, the assessment of annual operational emission rates of the 4 whole buildings were compared with two benchmarks, the first being the French benchmark (Batiactu, 2022; Vlad, 2022), and the second being the Spanish one (Premierinmobiliaria, 2022). While energy assessments were conducted by comparing four archetypes and 21 apartment samples belonging to those four archetypes, with the French (Batiactu, 2022; Vlad, 2022), Italian (Calvi et al., 2016) and Spanish (Premierinmobiliaria, 2022) energy benchmarks. The ranges of both energy and environmental classes are shown in (Figure VI.9).

	Energy consumption	CO2 Emissions
A	≤70 Kwh/m²/year	≤6 Kg. Co²/m²/year
B	71 to 110 Kwh/m²/year	7 to 11 Kg. Co²/m²/year
C	110 to 180 Kwh/m²/year	12 to 30 Kg. Co²/m²/year
D	181 to 250 Kwh/m²/year	31 to 50 Kg. Co²/m²/year
E	251 to 330 Kwh/m²/year	51 to 70 Kg. Co²/m²/year
F	331 to 420 Kwh/m²/year	71 to 100 Kg. Co²/m²/year
G	≥ 420 Kwh/m²/year	≥101 Kg. Co²/m²/year

French referentiel for energy and environmental classification of buildings

	Energy consumption
A+	< 25 Kwh/m²/year
A	25 to 40 Kwh/m²/year
B	40 to 80 Kwh/m²/year
C	80 to 130 Kwh/m²/year
D	130 to 170 Kwh/m²/year
E	170 to 250 Kwh/m²/year
F	250 to 400 Kwh/m²/year
G	≥ 400 Kwh/m²/year

Italian Adopted energy classification system, for buildings

	Energy consumption	CO2 Emissions
A	≤37.10 Kwh/m²/year	≤8.40 Kg. Co²/m²/year
B	37.10 to 60.10 Kwh/m²/year	8.40 to 13.60 Kg. Co²/m²/year
C	60.10 to 93.20 Kwh/m²/year	13.60 to 21.10 Kg. Co²/m²/year
D	93.20 to 143.30 Kwh/m²/year	21.10 to 32.40 Kg. Co²/m²/year
E	143.30 to 298.10 Kwh/m²/year	32.40 to 66.30 Kg. Co²/m²/year
F	298.10 to 336.80 Kwh/m²/year	66.30 to 79.60 Kg. Co²/m²/year
G	≥ 336.80 Kwh/m²/year	≥79.60 Kg. Co²/m²/year

Spanish referentiel for energy and environmental classification of buildings

Figure VI. 9. Benchmarks used in the energy and environmental assessment of the archetypes studied (French, Italian, and Spanish benchmarks).

Sources : (Batiactu, 2022 ; Calvi et al., 2016 ; Premierinmobiliaria, 2022).

The European standards were selected because they share a similar climate to Skikda, which belongs to the hot-temperate Mediterranean climate zone. The decision was based on the Koppen-Geiger climate classification world map and included countries such as France, Italy, and Spain. The climate of the Algerian coastline is deeply comparable to the climatic zones present in Italy and Spain, as it experiences primarily dry summers and warm to hot temperatures. However, the only difference with the French climate region is in the summers, which tend to be wetter in this latter (H. Chen, 2023).

VI.11. Launch of hybrid renovation scenarios

After conducting solar, energy, and environmental analyses of the building's initial state, several other scenarios for energy renovation were launched based on various passive and active strategies. Due to the ease of changing window types compared to other physical interventions, and to compare the energy savings between double-glazed and triple-glazed windows, the improvement measures in various scenarios involved replacing single glazing with one of these two options in two different scenarios. The study aimed to examine the effects of shifting the orientation and quantity of solar photovoltaic-thermal panels. Specifically, three scenarios were explored: panels placed on the roof, panels on the southern facade, and a larger area of panels on the roof and southern facade. The objective was to gain insight into the impact of changing panel placement and quantity.

The objective of integrating PVT panels across the entire space available on a building's roof was to assess whether consistent opportunities to benefit from energy production can be obtained across differing building morphologies whilst maintaining the same level of activity.

Finally, the natural gas-based hot water supply system was replaced with an electric one to demonstrate the significant impact on environmental footprint from a well-coordinated combination of measures. Furthermore, this case emphasises the importance of selecting appropriate appliances for minimizing negative environmental impacts. Some scenarios included only one technical improvement, while others employed multiple strategies to capture their synergies in improving building energy efficiency and ecological state. The solar panels positioned on the roof are horizontally oriented and directly fastened to the roof surface. Contrarily, the solar panels integrated onto the south facade are oriented in a vertical direction and directly secured to the surface of the south facade.

The integration of solar panels on the south-facing facades of the buildings was determined through solar analysis and 3D mapping.

Locations were selected based on the surfaces that received the highest annual cumulative energy on the facades, and then on surfaces with lower levels of cumulative insolation where space was limited. Consequently, the panels were installed on the surfaces most receptive to solar energy throughout the year, with a gradual decrease in receptiveness.

Additionally, both scenarios underwent an analysis and evaluation considering the aspects of energy and environment.

The following (Table VI.2) summarises the different intervention techniques used for each scenario, knowing that the (Baseline) scenario is the one related to the buildings' initial state, while the scenarios abbreviated by (P.R.1) to (P.R.9) are related to the post renovation states.

Table VI. 2. Presentation of interventions related to each energy renovation scenario. Source: The author, 2023.

Interventions	Baseline	P.R.1	P.R.2	P.R.3	P.R.4	P.R.5	P.R.6	P.R.7	P.R.8	P.R.9
Double glazing windows		X								
Triple glazing windows			X			X	X	X	X	X
PVT System (panels on roof) – 6 m² per apartment				X				X	X	
PVT System (panels on south facade) – 6 m² per apartment					X				X	
PVT System (panels on south facade) – 12 m² per apartment						X	X			
PVT System (roof panels) - Use as much roof surface as possible										X
Replacement of the existing hot water energy supply system with an another based on electricity supply system.							X			

After the PVT hybrid setup is fitted, it will replace the natural gas needed for heating and hot water using its thermal energy, which will then be transferred through PVT solar-powered boilers and radiators. Moreover, its power production will substitute electricity from the town's central power grid. However, for P.R.6, hybrid PVT will provide hot water necessities via electric boilers, which is a distinct arrangement. The various interventions employed in this study have been elucidated and identified in the following section.

VI.11.1. Double and triple glazed windows

Every house is unique in deciding between double or triple glazed windows, with each option, or a combination, providing distinct benefits for the property.

Both materials serve various purposes, such as providing thermal insulation, lighting, soundproofing, environmental protection, and even building security.

This study utilized both technologies to get an idea of their impact on the archetypes studied, in terms of energy efficiency and environmental footprint.

A. **Double glazing windows**

As shown in (figure VI.10), a layer of air separates the two transparent glass layers—one on the inside and one on the outside—that make up typical clear double glazing. Double glazing reduces heat loss by half when compared to single glazing because of an insulating air space among the glass layers. Double glazing with transparent glass reduces heat flow while maintaining high levels of solar heat gain as well as visible light transmission (Efficient Windows Collaborative website, 2023a).

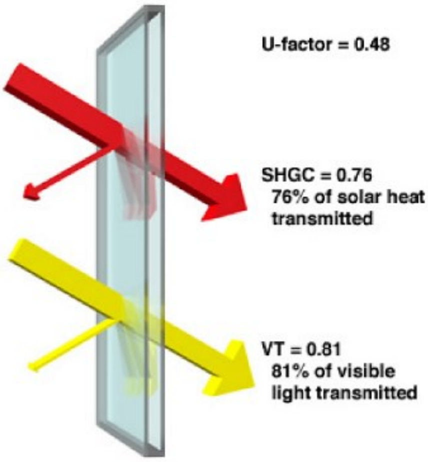


Figure VI. 10. Schematic illustration of a double-glazed unit and its characteristics.
Source: (Efficient Windows Collaborative website, 2023a).

B. **Triple glazing windows**

As double glazing, the same concepts are applied in triple glazing, but in order to retain heat even more, an additional pane of glass as well as additional sealed area are added (Figure VI.11). In order to further prevent heat loss in addition to reflect warmth back into the space, two of the glazing layers are Low E while the other is Low Iron.

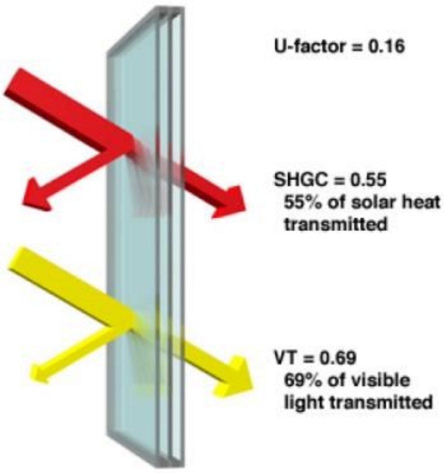


Figure VI. 11. Schematic illustration of a triple-glazed unit and its characteristics.
Source: (Efficient Windows Collaborative website, 2023b).

Each sealed unit has a spacer bar around the borders to prevent heat from escaping, and argon gas is injected into the gaps to give the primary insulating effect. Together, these elements produce a very energy-efficient design that lowers heating costs and helps keeping warmth in the house (Angelian home website, 2023).

VI.11.2. Hybrid PVT system

A system that combines multiple power sources to increase overall efficiency is called a hybrid energy system. The photovoltaic-thermal (PVT) system in the construction is an example of a hybrid system. Traditional photovoltaic systems only use light's photons to create electricity, therefore heat from the sun's rays tends to raise the temperature and decrease the efficiency of photovoltaic modules. In contrast, PVT systems use the thermal energy produced by solar radiation in addition to light.

By extracting energy through a heat transfer fluid, they may also refresh the photovoltaic panels as well as boost production by heating the area (Khelifa et al., 2015). The photovoltaic module, charging controller, the battery, convertor, as well as inverter for both AC (alternating current) and DC (direct current) voltage utilization made up the electrical system. Aluminium plates, heatsinks, thermal containers, heat exchanger, thermal transfer fluid, a thermal storage tank, alongside pump made up the thermal system. On the basis of the temperature differential between the water in the heat storage tank as well as the thermal fluid within the thermal container, the control unit adjusts the pump's speed and operations (Hajibeigy et al., 2018). (Figure VI.12) shows the planned overall structure of the hybrid PVT systems.

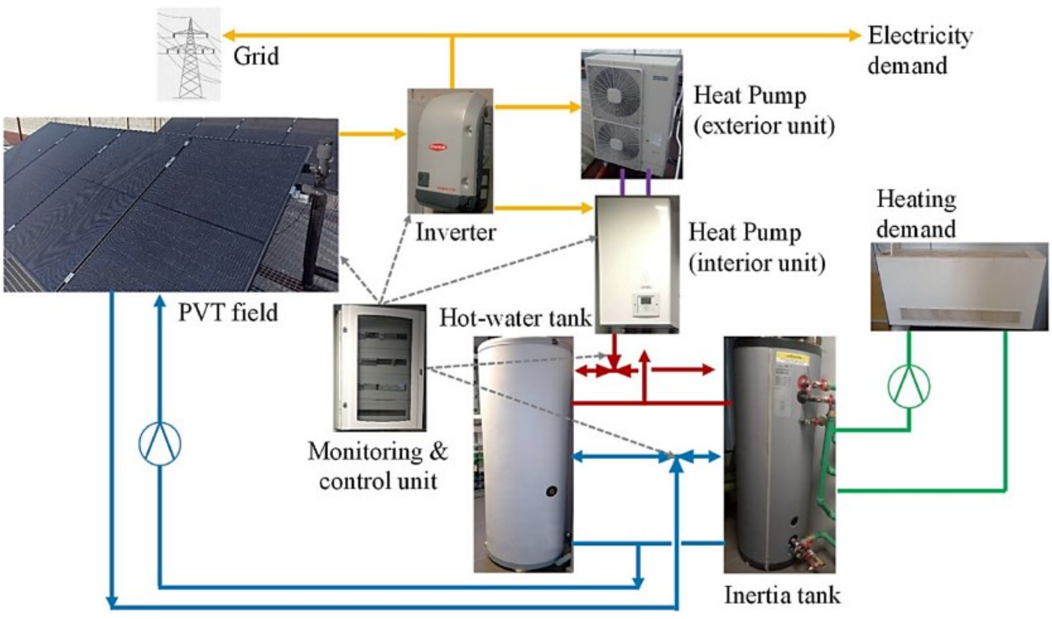
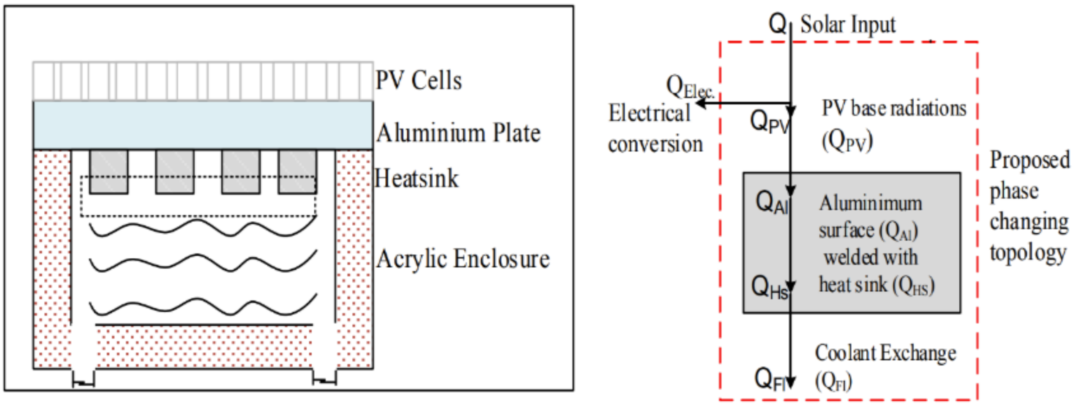


Figure VI. 12. Schematic illustration of PVT hybrid thermal photovoltaic systems.

Source: (Bellini, 2023).

The intended hybrid PVT system consists of an aluminium plate, heatsinks, a thermal container, and a PV module. The aluminium plate is affixed directly beneath the PV module using thermal glue to capture the heat it generates. Heatsinks are welded to the bottom surface of the plate to further dissipate heat. The acrylic thermal container contains the coolant, which serves as the transfer medium. The unit is built and positioned within the thermal container, with the unit sitting on top of it. Additionally, the heatsinks fit inside the coolant-filled container. (Figure VI.13) illustrates every single layer that constitutes hybrid PVT systems (Hajibeigy et al., 2018).



(a) Phase layered system setup (b) Stage changing topology

Figure VI. 13. The different layers that constitute the PVT hybrid panel.

Source: (Hajibeigy et al., 2018).

The illustration (Figure VI.14) and table (Table VI.3) below show more details about components, and general characteristics of the appearance and the electrical, thermal and mechanical specifications of the hybrid pvt model.

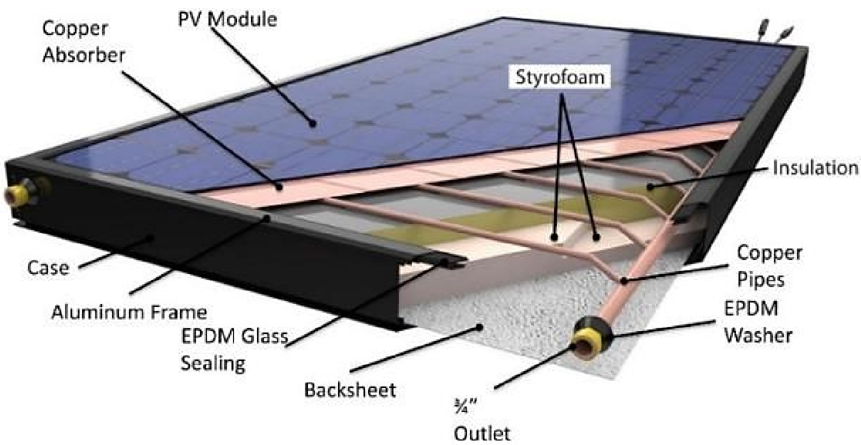


Figure VI. 14. 3D detailed demonstration of Hybrid PVT panel and its different components.

Source: (Solar Choice Staff, 2013).

Table VI. 3. Electrical, thermal and mechanical specifications of hybrid PVT model. Source: (Pikcell solar power group, 2019).

Electrical Specifications	Module Type		PiK280P (60)
	Nominal Power	P.m.p.p (W)	280.00
	Open Circuit Voltage	V.o.c (V)	38.40
	Short Circuit Current	I.s.c (A)	9.45
	Module efficiency	ŋ.m% (%)	18.66
	Solar Cell Efficiency	ŋ.c (%)	19.10
	MPP Voltage	V.m.p.p (V)	31.61
	MPP Current	I.m.p.p (A)	8.85
	Maximum System Voltage		1,000 V (Application Class A)
	Maximum Reverse Current		18A
	Power Output Tolerance		~3%
Thermal Specifications	Current temperature Coefficient		+0.1%/°C
	Power Temperature Coefficient		-0.44 %/°C
	Voltage Temperature Coefficient		- 0.34 %/°C
	Nominal operating temperature of cell		44,4±2°C
	Temperature Range		-40 °C to + 85 °C
	Nominal operating cell temperature		44 °C
	Average thermal energy produced (kWh / m2 / year)		633 (kWh/m2/year)
	Highest thermal power		910W
	Input and output of thermal part		Copper pipes F18 mm
	Absorbent sheet metal		Aluminium
	Type and quantity of fluid		Propylene glycol - 1.5 l
	Isolation		Knauf stone wool 25 mm
	Registry		Copper pipes F8 mm
Mechanical Specifications	Junction Box / Connectors		Five bypass diodes / MC4 compatible / IP 67
	Solar Cells		60 poly c-Si in series / 156 mm x 156 mm (6+”)
	Glass		3.2 mm glass with anti-reflective coating / tempered / high –transparency / low-iron content
	Frame		Anodized AL with drainage holes / rigid anchored corners
	Packaging		26 modules per pallet / stackable 2 pallets high
	Impact resistance		Hailstone / ϕ 25 mm / 83 km/h (51 mph)
	Certified Nominal Load (snow/wind)		5,400 Pa / 2,400 Pa

VI.11.3. Hot water electric boilers

Electric boilers operate on the same concept as conventional gas boilers; the only difference is that an electric boiler uses electric power to heat the water, whilst a standard gas boiler heats the water using gas. All the advantages of wet heating systems are still available with electric system boilers, which do not require a gas connection. Because of this, electric boilers are the best choice for residences without access to the main gas supply or with restrictions on gas boilers, like bed flats or listed structures. The (Figure VI.15), below, gives an overview on this kind of boilers and their different components.

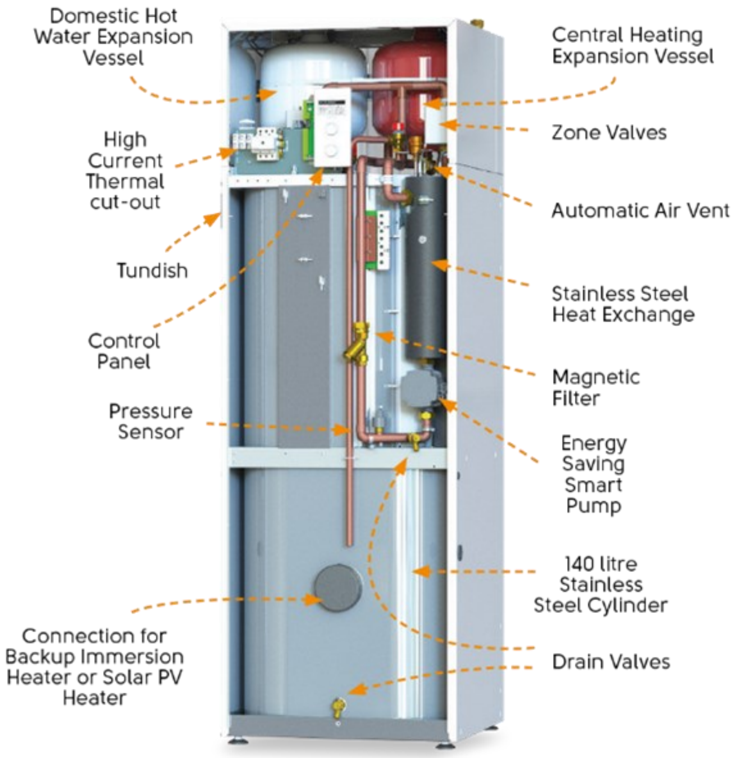


Figure VI. 15. Demonstration of hot water electric boiler and its different components. Source: (The electric heating company website, 2020).

Due of their lower installation and maintenance costs, electric boilers are frequently installed in newly constructed residences. Additionally, many people consider electric boilers to be a more environmentally responsible option because they emit no carbon dioxide during operation, in contrast to gas, oil, or LPG boilers. Hot water for heating systems and home use can be produced with the installation of an electric boiler. But the amount of instantaneous household hot water that electric boilers can provide is limited, which is why indirect cylinders are frequently used—especially in homes with bathtubs (Kelly, 2021).

Cold water coming from the principal water supply is fed into an electric boiler, just way it is in a conventional gas combination boiler. Boilers function similarly to large kettles, utilizing a metal element and power to heat water. The boiler receives its electricity from the main electrical supply.

As demonstrated in (Figure VI.16), hot water can be delivered to the taps as well as radiators on request or by means of a hot water storing cylinder by passing cold water through the metal heating component and transferring heat. Depending on the kind of electric boiler or heater being utilized, the boiler's precise method of heating as well as storing water will vary (The electric heating company website, 2021).

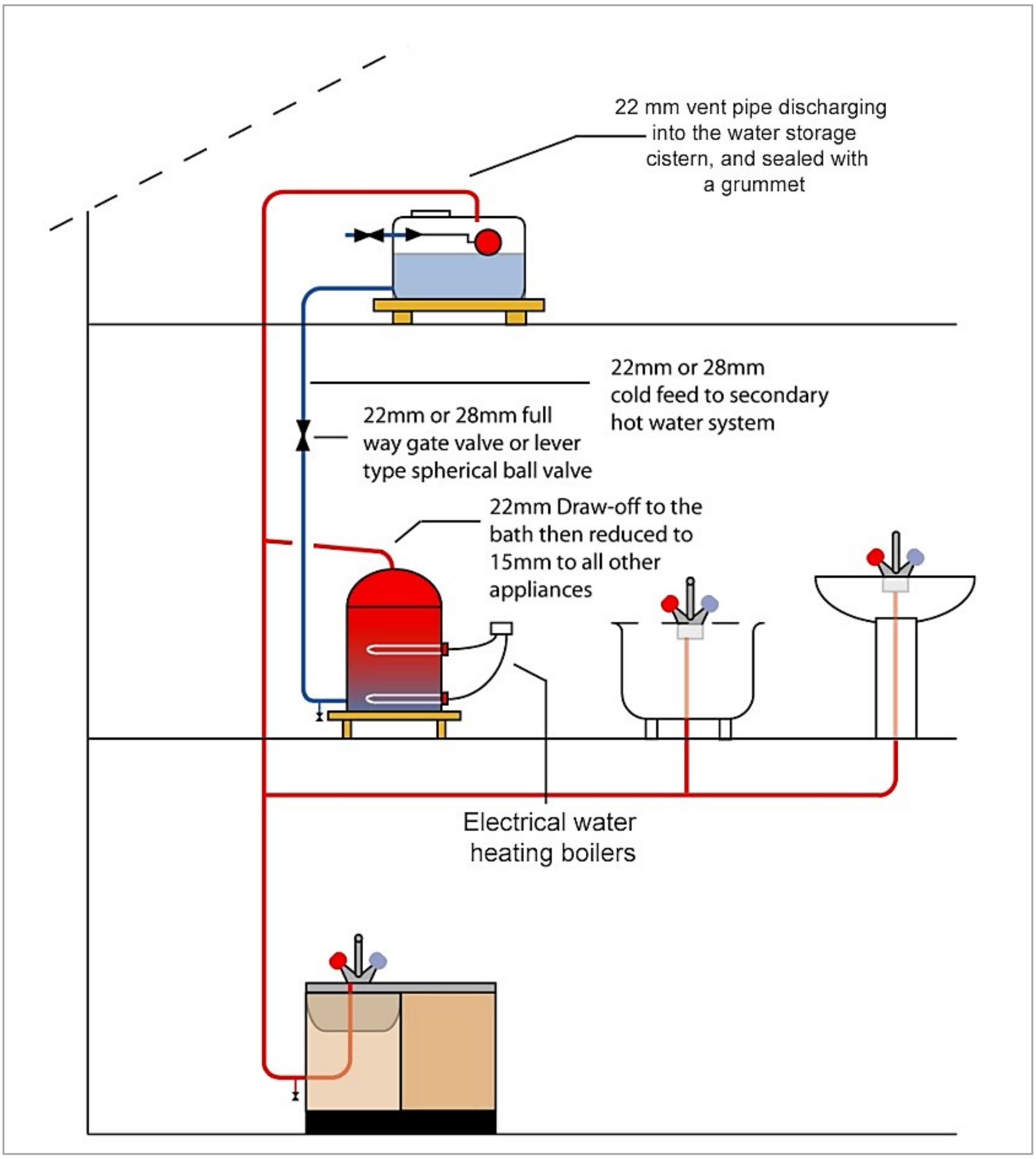


Figure VI. 16. Schematic of the system of use of the electric hot water boiler. Source: (BPEC Ltd, 2020).

VI.12. Post-renovation energy and environmental performance assessment

The outcomes of the various renovation scenarios, which pertained to the annual energy consumption of gas and electricity buildings as well as the electrical and thermal energy production of photovoltaic-thermal hybrid systems, were contrasted with each other and with the initial scenario for each case study. Furthermore, a comparison was conducted between the 4 case studies for each scenario.

Subsequently, the total annual energy consumption and the annual operational carbon emissions of each archetype in each scenario were compared with the previously identified European benchmarks.

VI.13. Conclusion

This chapter has provided a general explanation of the methodology of the whole study, presenting the approaches, methods and tools used at each stage in order to understand and accurately interpret the results obtained in the following chapter.

The whole process consists of justifying the choice of the case study and examining the characteristics of each archetype, as well as its topographical and urban surroundings, in order to analyse their influences on the energy behaviour and solar access on the different external surfaces of the buildings, as well as explaining how the energy data used were obtained and on which energy source the collective housing buildings studied are based. In addition, a hierarchical representation of the interventions associated with each of the 9 energy renovation scenarios has been drawn up. These interventions belong to passive and active strategies, which have been technically identified and explained.

CHAPTER VII

Results and discussions

VII.1. Introduction

On a worldwide scale, the reduction of energy consumption and greenhouse gas emissions in the building sector, as well as the integration and use of renewable energies in a sophisticated and studied way, as part of the ambitions linked to the energy transition and sustainable development, are of interest to scientists and researchers today.

In this context, this chapter focuses on the presentation of results and their interpretation according to the methodology and research workflow as explained in the previous chapter.

This chapter will be divided into two main parts, the first being the analysis of the existing scenario of the study cases, where the work will proceed from the largest to the smallest scale, starting at the mesoscale, where a topographical analysis was carried out, before a solar analysis, which was undertaken at the neighbourhood scale, and then at a local shading scale, in order to obtain more details on the influence of the building morphology and surroundings on the reception of solar rays.

Next, at the building scale as whole, an energy analysis was conducted. This involved comparing the measured data from the four case studies, then analysing and evaluating the energy and environmental results of the simulations after calibration and validation, and finally carrying out a polynomial regression analysis on the energy behaviour of the occupants.

Finally, a comparative analysis and evaluation against European benchmarks was carried out at the level of the apartments.

The topographical, solar, energetic and environmental analyses at different scales were discussed in such a way as to highlight the interactions between them.

The second part of this chapter was devoted to presenting the different results obtained from the simulation of the different energy renovation scenarios, before carrying out an energy and environmental analysis, assessing the state of the four archetypes after each scenario, using European standards, in order to get an idea of the extent to which these interventions contribute to energy and environmental improvements, taking into account the specificities of each archetype and its environment.

VII.2. Prior state analysis according to multiscale workflow

The various sections associated with the various analyses concerning the pre-renovation state have been structured so as to proceed from the largest scale to the smallest one, and are presented below.

VII.2.1. Mesoscale level

a. Topographical analysis

The topographical map (Figure VII.1) presents the graphic representations generated through the website (topographic-map, n.d.), depicting the fluctuations in elevations and terrains across the entirety of Skikda town, encompassing the sites of the four study specimens.

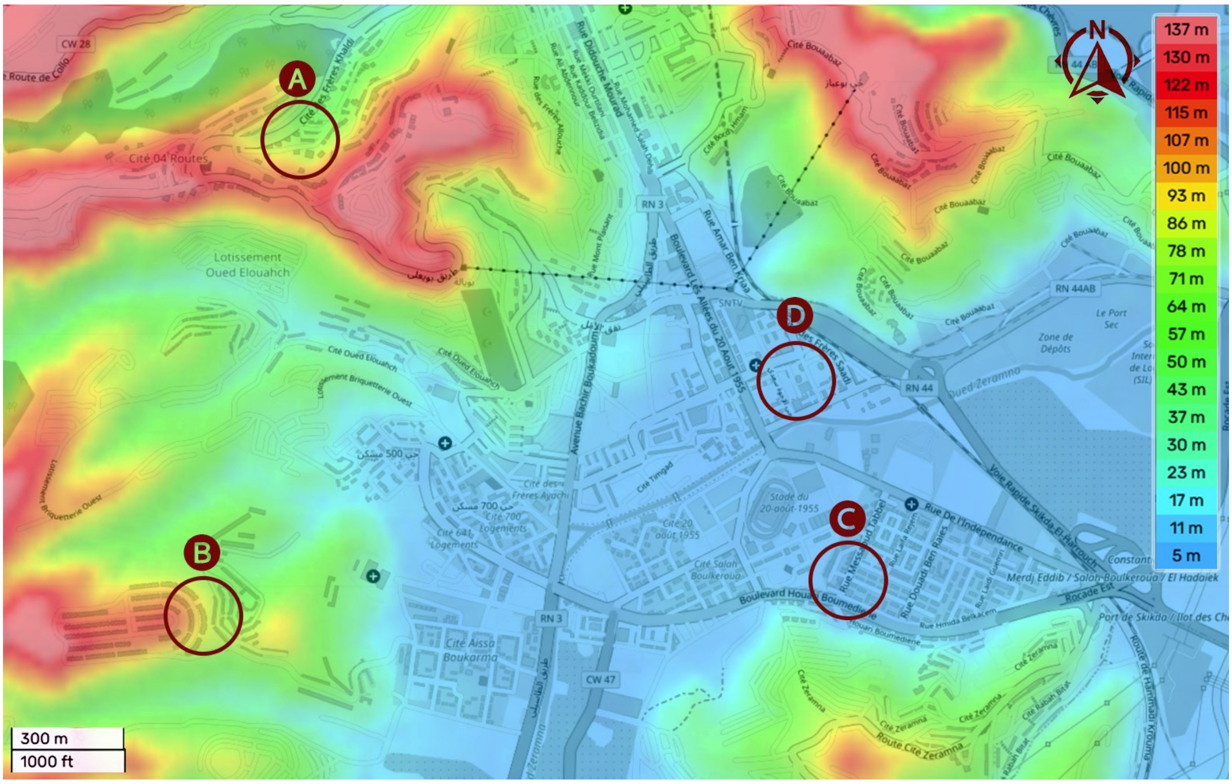


Figure VII. 1. Topographical map of the city of Skikda, including study cases.

Source: (topographic-map, n.d.).

Topography involves studying and understanding the earth's natural features which characterise landforms, terrain and architectural infrastructures; the latter can have an impact on the structure and its energy consumption. As a result, it is necessary to assess the topography of a building site carefully before initiating construction or renovation projects.

The examination was based on the topographical map (Figure VII.1), in conjunction with north-south and east-west topographic profiles, which are shown in (Figure VII.2 and Figure VII.3), in order to give more details about the relief of the case study area, and surroundings.

Except for the northeastern side, the archetype in case study (A) sits on a sloping terrain and is at a lower level than the surrounding sites. Conversely, the archetype in case study (B) is also on a sloping site but situated higher than surrounding sites, with the exception of the western part, which extends uninterruptedly towards the summit of Messiouene mountain.

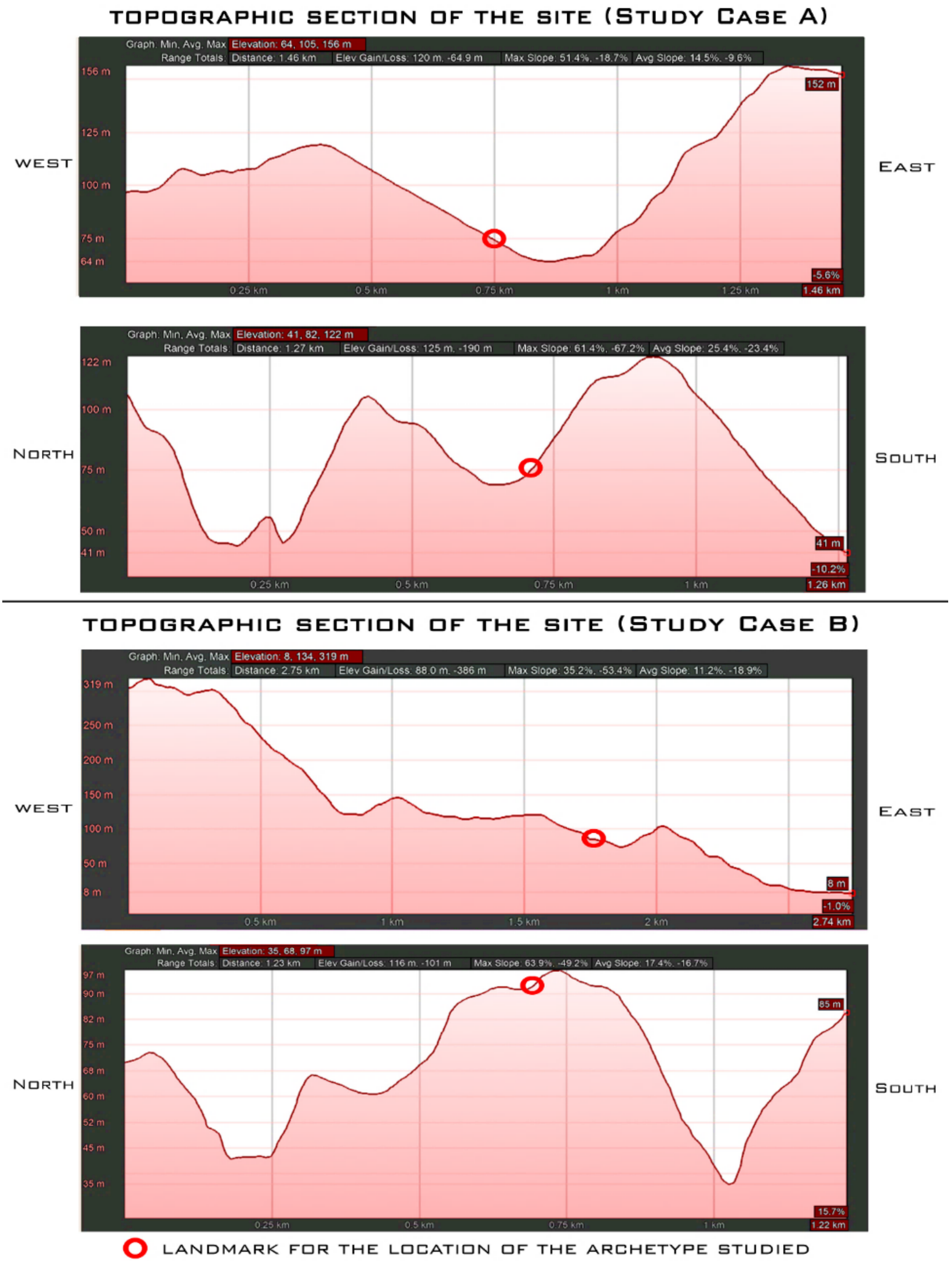


Figure VII. 2. Representation of topographic sections in the north-south and east-west directions for the area surrounding the case study A and B.

Source: Google Earth + Editing by the author.

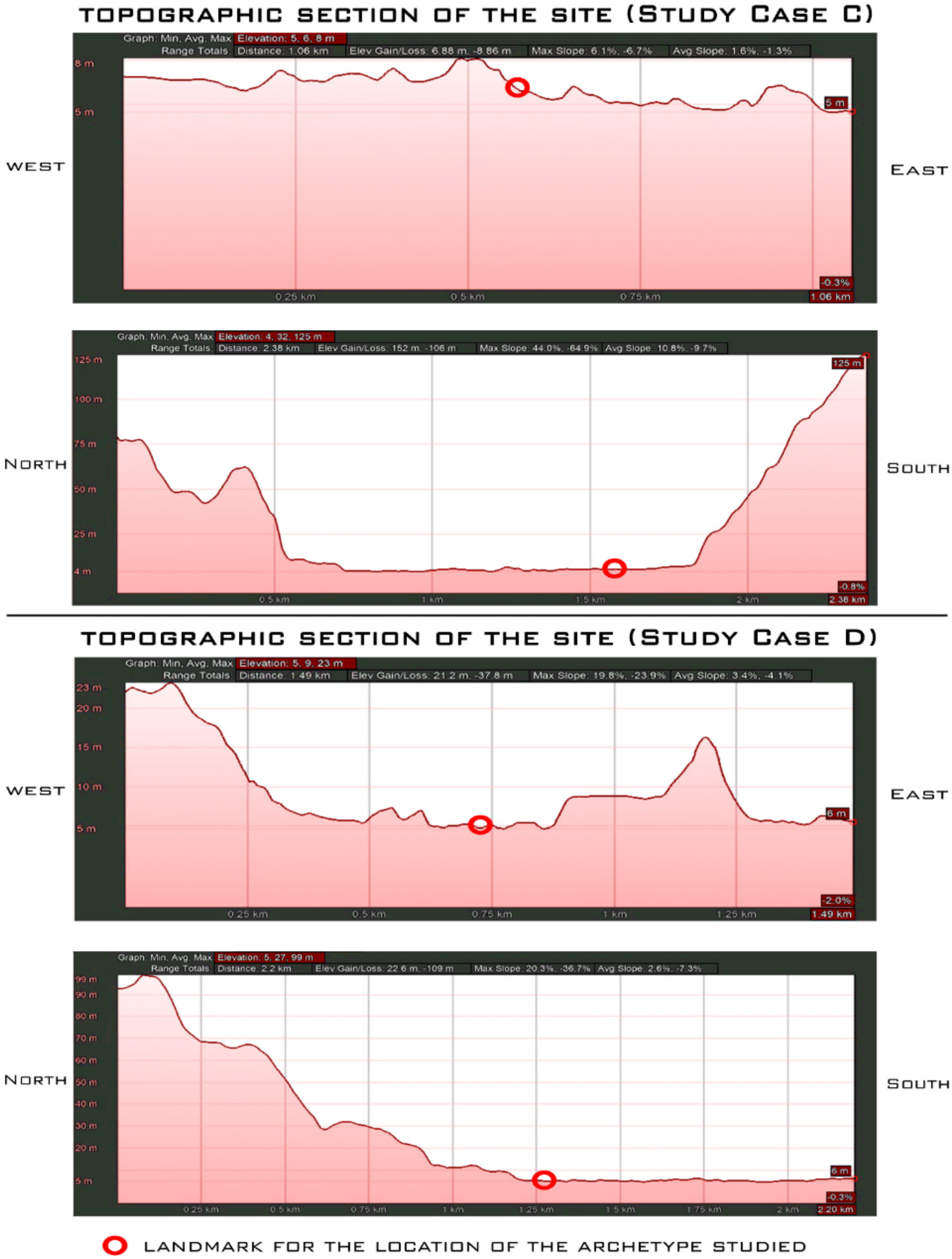


Figure VII. 3. Representation of topographic sections in the north-south and east-west directions for the area surrounding the case study C and D.

Source: Google Earth + Editing by the author.

At a local scale, particularly in scenario (C), the model exists in a low-altitude location with varying relief ranging from flat to slightly sloping, encircled by urban areas with altitudes matching those of the archetype examined, until the southern boundary where the plateaus ascend to an elevation of nearly 137 metres.

If considering case study (D), the model also resides in a region where the terrain varies between flat to slightly sloping, at a low altitude. The area is confined to the south by urban zones at equivalent altitudes yet restricted by higher terrain up to 150 meters in height to the east and west.

Case studies (D) and (C) are situated on a larger scale in neighbouring locations that are enclosed by elevated terrain in all directions, except for the east.

Study cases (A, C and D) are more protected from the prevailing cold winter winds than study case (B), which is more exposed to these winds that come from limited directions between North and West, where the strongest are determined to be from west-northwest, according to (meteoblue, 2023), as the wind rose shown in (Figure V.8), in the chapter V.

In addition, study case (B) is more exposed to prevailing summer winds than the other study cases, despite the fact that these winds come from the south and are significantly less important than those in winter (meteoblue, 2023).

VII.2.2. Neighbourhood scale level

a. Solar analysis

It should be borne in mind that in the northern hemisphere, where Skikda is located, the sun is directly overhead in the southern sky throughout the autumn and winter season; whereas during summer and spring, the sun rises and sets at a wider angle, reaching some northern corners, but spends most of the day in the southern sky, according to (Sullivan & Meyer, 2014), and as shown in (Figure VII.4).

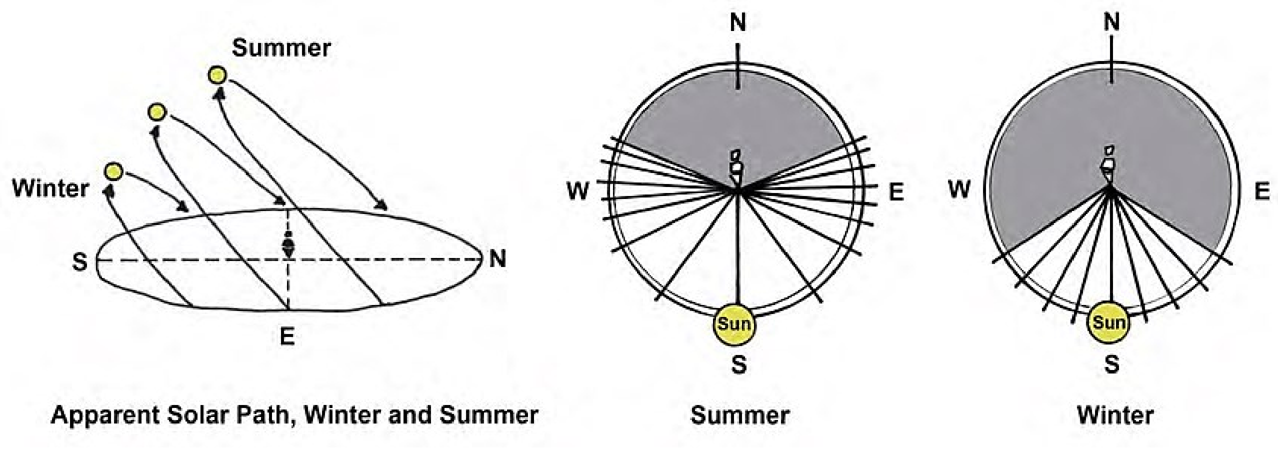


Figure VII. 4. Solar paths in the hemisphere's northern part.

Source: (Sullivan & Meyer, 2014).

The solar maps, displayed in (Figure VII.5) and (Figure VII. 6), demonstrate that solar radiation levels differ between locations within the same town. These variations occur at a neighbourhood scale and show that the maximum amount of radiation fluctuates. Study case (D) had the highest cumulative annual solar radiation, followed by study case (B), with values of 1753 to 1731 kilowatt-hours per square metre per year, respectively. Meanwhile, study cases (A) and (C) had amounts of 1708 and 1567 kilowatt-hours per square metre per year, respectively.

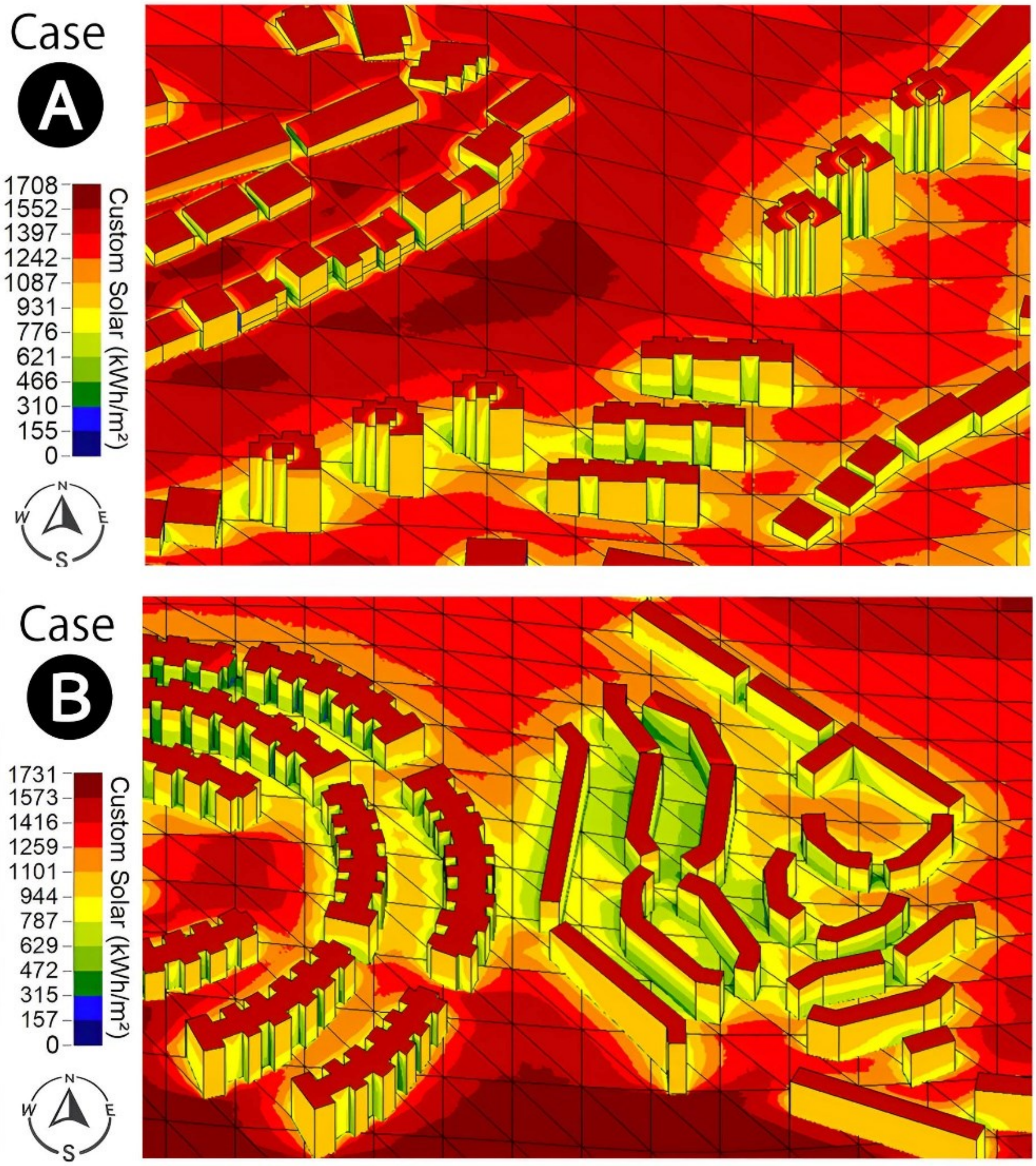


Figure VII. 5. Three-dimensional visualizations of the annual solar map for the existing situation of the study cases (A and B), at neighbourhood scale (south view).

Source: The author, 2023.

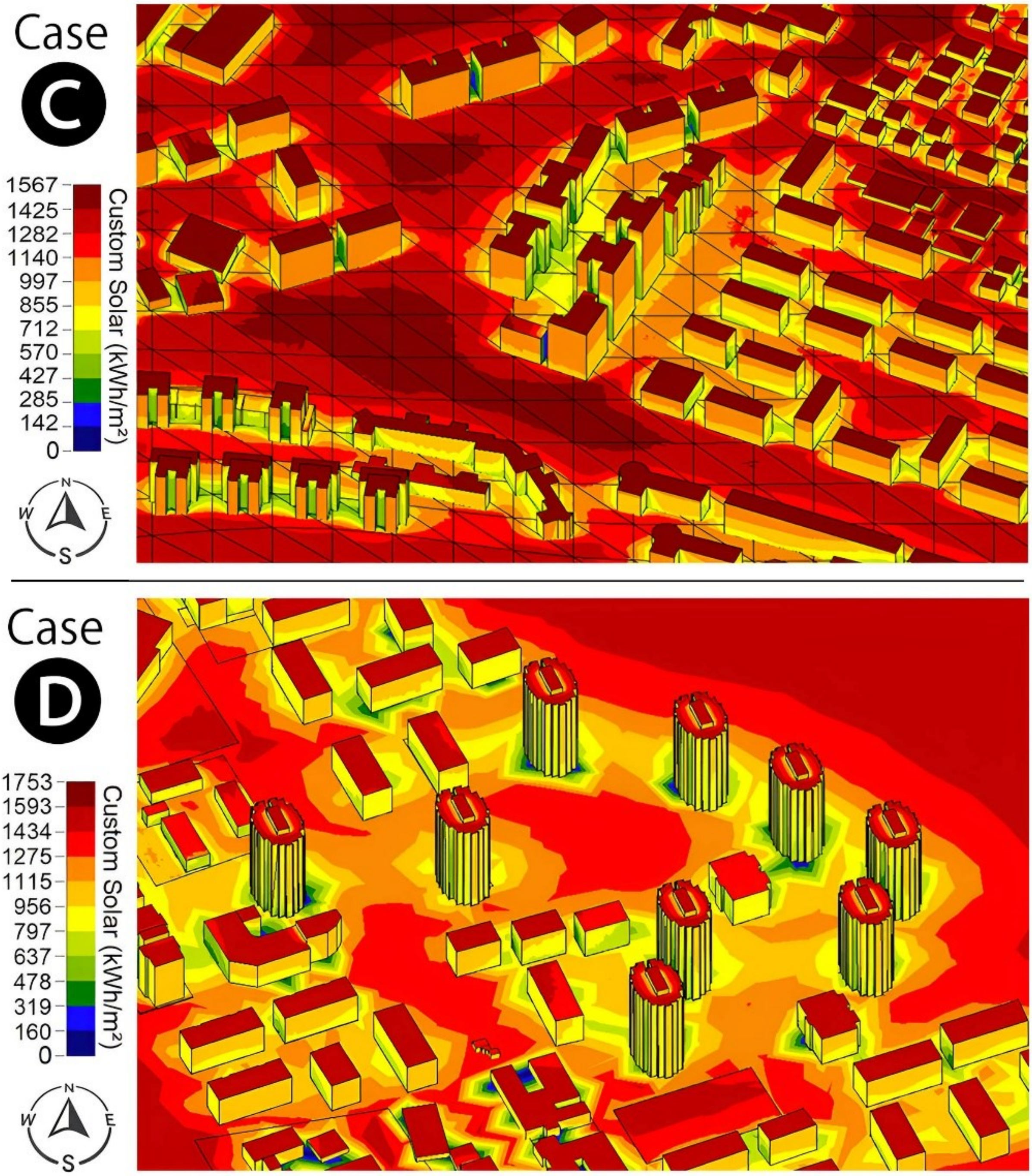


Figure VII. 6. Three-dimensional visualizations of the annual solar map for the existing situation of the study cases (C and D), at neighbourhood scale (south view).

Source: The author, 2023.

In case study (D), where the highest annual solar radiation was calculated, the location is well-exposed to solar radiation due to its altitude, which roughly corresponds with that of nearby sites. The only exception is the northern limitations, which do not affect the direct sunlight irradiation. Case study (C) had almost terrain with smooth relief and was situated at a comparable altitude to the surrounding areas.

Nonetheless, the site's high-altitude southern perimeters led to a decrease in cumulative solar radiation levels. Cases (A) and (B), situated at significantly higher altitudes than the study case (C), received less solar radiation due to their rugged terrain which hinders access to sunlight. This implies that terrain regularity has a more significant influence on solar radiation than altitude, particularly in the absence of significant natural or urban obstacles along the sun's path.

The largest amounts of solar energy were gathered on roofs and undeveloped land in all four cases. This was found to be so when the areas were far from any form of shading caused by natural or man-made sources. It was estimated that there was between 1397 and 1753 KWH/m² of solar energy per year in these areas.

It was also found that roofs that were not impacted by urban or natural obstructions still received less annual solar energy accumulation than locations on empty land and not blocked by any form of barriers. This could be because of the reduced height of the sun during sunrise and sunset, which restricts its rays from reaching the roofs of high buildings, although they can reach lower areas such as vacant land.

South-facing facade surfaces receive the maximum solar energy, amounting to between 931 and 1140 KWh/m² annually for the four case studies, making them the third-highest receivers of solar irradiance after roofs and empty lands.

In order to gain a more comprehensive understanding of how site topography affects the cumulative insolation of building surfaces, Case Study (B) was subjected to a simulation wherein its mountainous topography was changed to a flat topography (B2), as previously mentioned. The results of this solar simulation are presented in (Figure VII.7).

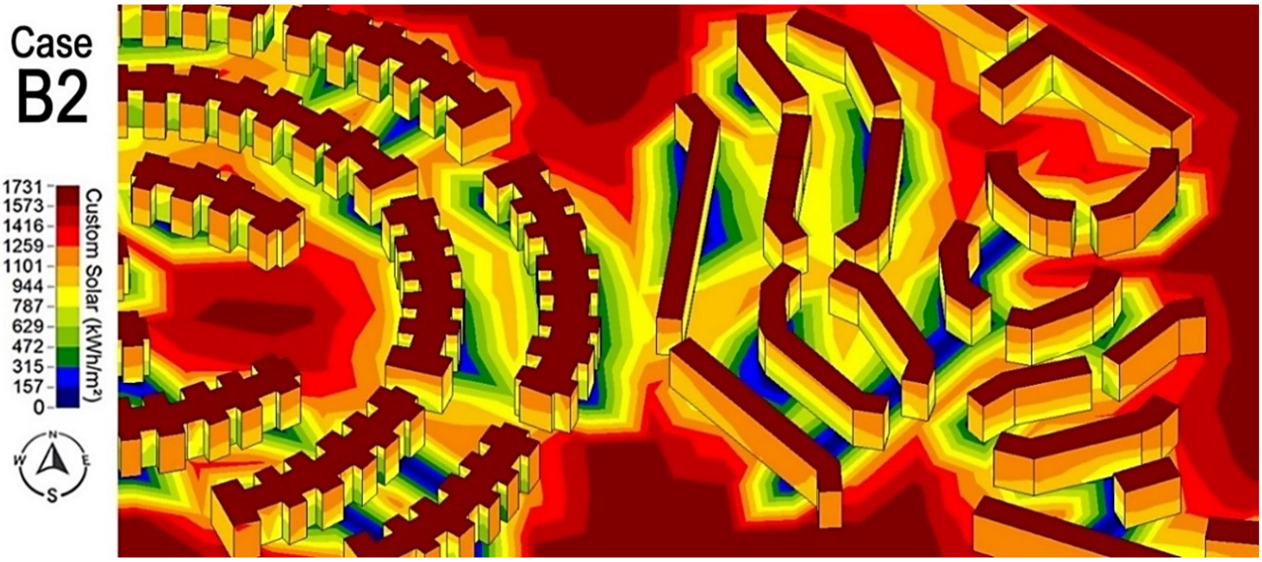


Figure VII. 7. Annual solar map in 3D for a simulated scenario (B2) of the case study (B), at the neighbourhood scale (southern view).

Source: The author 2023.

The comparison of the real (B) and simulated (B2) scenarios revealed that in the case of flat terrain, roofs and vertical surfaces receive a greater annual accumulation of solar energy, with more uniformity and larger surfaces, than in the case where sites are with varied topography such as slopes or mountains.

VII.2.3. Local shading scale level

a. Solar analysis

The yearly solar representation of the different orientations for each of the case studies' current situation at the local shading dimension is visualised in three dimensions in (Figure VII.8), it brought additional insight into the envelope, form, orientation, levels of complexity as well as the immediate environment of each model at this scale.

The simulations revealed that urban masks affect buildings, splitting them into two sections: the upper portion that remains unaffected by the urban mask and the lower portion that is influenced by external factors.

Additionally, as buildings become taller, they provide more surface area, resulting in the accumulation of a considerable amount of incident energy. For instance, a comparison between case studies (B) and (C), the shortest alongside longest archetypes, respectively, illustrated this phenomenon. On the other hand, when the distance between buildings increases and the height of neighbouring buildings decreases, the amount of incident energy received may be more evenly distributed across all building heights. This was observed in the southern perspective of study case (A), for example.

Both the neighbourhood as well as local shading measurements demonstrate that, in certain lower sections of south-facing facades in the presence of an urban obstruction, there is a significant reduction in solar energy reception compared to upper sections. For instance, in archetype (B), the annual accumulation in the lower section of the southern facade was less than 315 KWh/m² per year, while the maximum cumulative insolation was ranging between 944 and 1101 KWh/m² per year. Between 997 and 1140 kWh/m² per year were recorded on the upper, south-facing external surface of archetype (C), whereas the lower part received only around 427 kWh/m² per year.

In cases where buildings are absent or widely spaced, incident energy accumulation may be more evenly spread across all surfaces of the building, as demonstrated by 3D solar maps throughout the four case studies.

Although the east and west facing facades have smaller receiving surfaces or less accumulated energy compared to south-facing facades, they still receive significant amounts of energy each year. The north building exterior facades received the least amount of solar energy, ranging from zero to 319 KWh/m2.

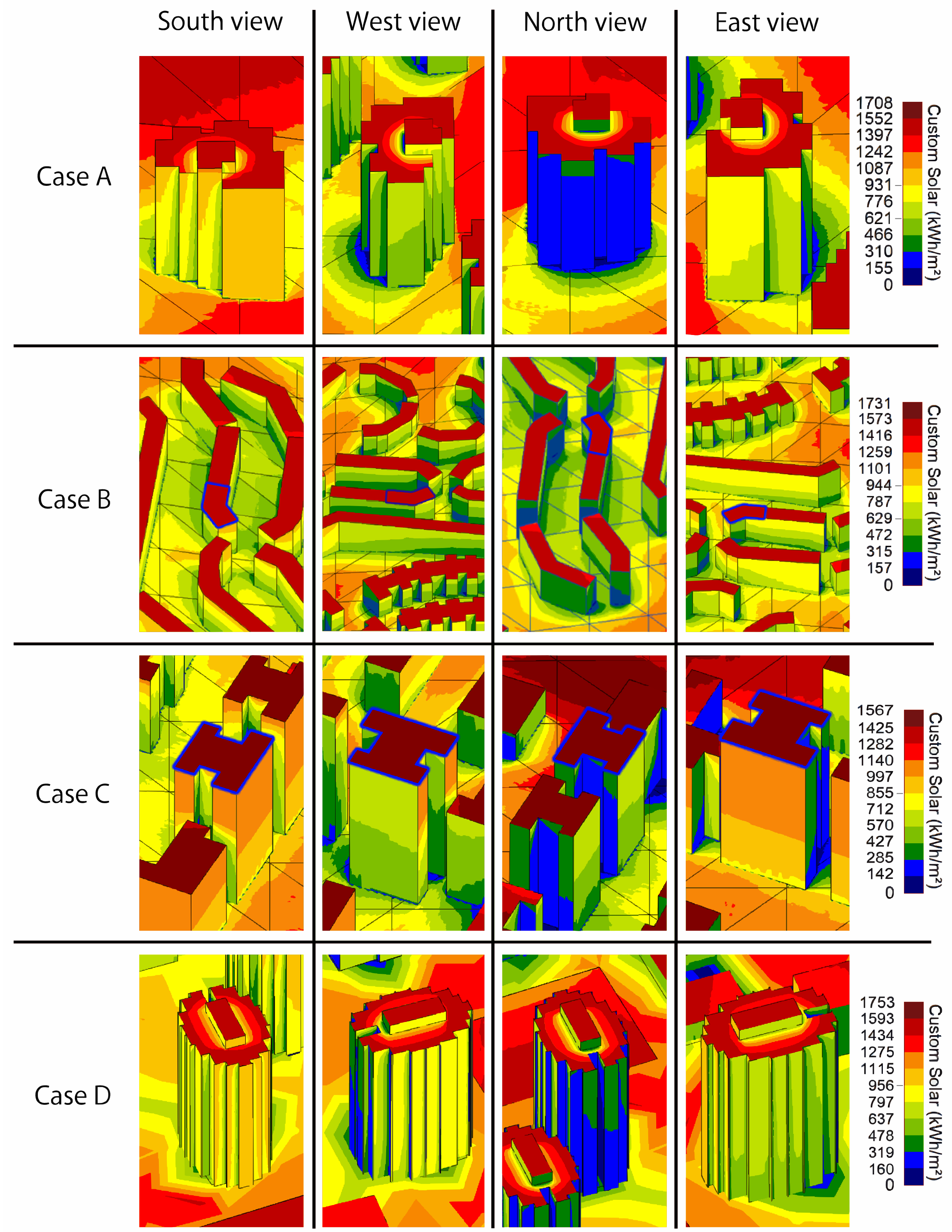


Figure VII. 8. Three-dimensional visualizations of the annual solar map for the existing situation of each of the study cases, at the local shading scale.

Source: The author, 2023.

The total amount of sunlight exposure on the south-facing facade is restricted to a lower limit compared to the vacant zones and roofs. However, at the same time, it surpassed the values of the cumulative sun exposure received on the east and west facades. Furthermore, those values were higher as compared to the exposure values on the north-facing facade.

This could be interpreted based on the amount of time this facade is exposed to the sun, taking into account the sun's daily cycle. The sun rises in the east with a low elevation, then moves across the south in higher elevations, where it spends most of the day at angles that are close to this orientation, before finally decreases in elevation until it sets in the west. The sun does not pass over the north direction during all this time, receiving only diffuse rays (Sullivan & Meyer, 2014).

In terms of building orientation related to the archetype being studied, it was found that the southern facades receive the highest amount of accumulated energy, with the exception of the case study (C), which has fewer surfaces that receive a large amount of energy, that was between 997 to 1140 KWh/m2/year, compared to the eastern facade, because of the presence of a very close neighbouring building, 30 m high.

In cases (A), (B) and (C), the archetype buildings received a greater amount of energy from their eastern facades than their western facades. However, in case study (D), the west facade received more cumulative energy per year than the east facade; it should be noted that the eastern facades of the archetypes (A), (B) alongside (C) are less affected by the various obstacles that obstruct the reception of the sun's rays, compared to the western facades; on the contrary, in case (D), the facade faces an adjoining building of identical height.

The 3D visualisations reveal that the complexity of the building envelope significantly affects the gathering of solar energy. For instance, prototype cases (A) and (D) possess perpendicular roof extensions that curtail solar energy accumulation on neighbouring surfaces. Conversely, cases (B) and (C) possess even and maximal collection of solar energy throughout the roof. The principle holds true for facades: the greater the complexity of a facade, the lower its annual energy yield and the less uniformly it distributes this energy across all receiving surfaces of the facade.

The aforementioned suggests that the best locations for solar panel installation may be empty sites at higher elevations than the surrounding area, away from urban areas, through structures such as solar power plants that supply electricity to buildings under refurbishment, or even to the public grid, according to the scale of the energy transition project.

Then, the roof is a favourable site for installing solar systems, when there are no facade extensions that block access to the sun's rays, or surrounding high-rise buildings that create urban or natural masks. Additionally, the upper sections of south-facing facades can offer ample surfaces for solar panel installations, especially when they receive high levels of cumulative solar energy annually. These areas expand automatically with increasing building height.

The east and west-facing facades, particularly their upper parts, also receive significant cumulative annual solar energy. These facades can be useful, particularly when technical challenges arise in installing solar panels on roofs or south-facing facades. However, the integration of solar systems on the north-facing facade is completely unsuitable. The integration of this type of panel offers the maximum potential for energy efficiency, particularly when incorporated into uncomplicated architectural designs free from excessive extensions or offsets.

Furthermore, a monthly calculation of energy amounts on the different vertical and horizontal surfaces was carried out using the CEA tool and is shown in (Figure VII.9).

The bar charts showed that the importance of the amount of solar energy received on roofs decreases, while it increases on vertical surfaces in relation to the total amount of solar energy received, with the increasing of building height, by observing that the percentage of maximum solar energy received on roofs in case (B), where the archetype which has the lowest height, reaching up to 37.4% of the amount of energy over the whole envelope during the month of July, unlike case study (C), where the archetype has the biggest height, the percentage of maximum solar energy received on the roofs does not exceed 23.4% in the same month (July).

The quantity of solar energy received on roofs and facades is also relevant to time of year, as in the summer months, and in general, the amount of solar energy received on the entire envelope increases, but there is a significant decline in the winter period. In addition, the percentage of solar energy received on the same roof increases in the summer and falls in the winter in relation to the overall quantity of solar energy received in the four archetypes investigated.

During the hottest months (May, June, July, and August) in the 4 case studies, the roof receives the highest percentage of radiation, while the south-faced surface of the cases (A, C and D) and the west-faced facade of the case study (B) receive the greatest percentage throughout the rest of the year. This could be due to the sun's height angle being raised in summer and reduced during winter, as the study of (Alberto, 2021) showed.

The building in case study (B) has a west-facing wall that gets a lot of sun all year, comparing to south-facing ones, especially in winter. This happens because the building is bar-shaped, resulting in a predominantly horizontal design, with the area of the south-facing facade being much smaller than that of the west-facing facade.

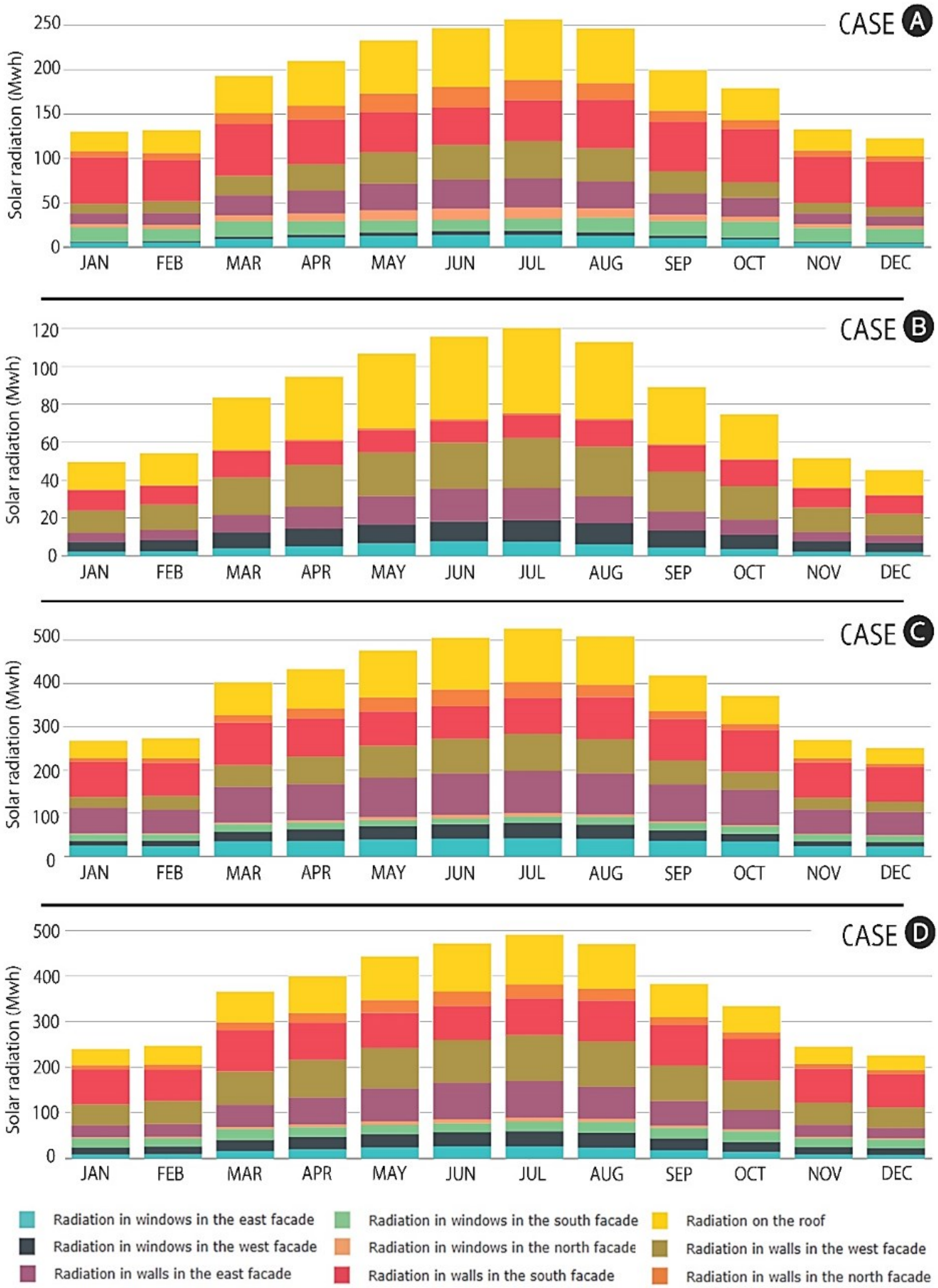


Figure VII. 9. Graphical presentation of monthly incident energy on the different surfaces of the 4 archetypes, simulated through CEA.

Source: The author, 2023.

VII.2.4. Architectural scale analysis (whole building)

a. Energy analysis of measured data

(Figure VII.10) as well as (Figure VII.11) display graphical curves depicting changes in quarterly electricity and gas consumption per unit area in the four case studies across eight quarters (between October 2020 and July 2022), based on SONELGAZ measured energy data. The first obvious finding is that gas consumption far outnumbers electricity consumption in all four archetypes investigated. In the four buildings, electricity usage is higher in the warmer months and lower in the winter months, whereas gas consumption is higher in the winter months and lower in the summer months. Archetype (C) has the lowest gas and electricity consumption per unit area in most quarters, although, according to the data in (Table VI.1) and previous solar and topographic analyses, this archetype, which is the tallest and has the largest surface area, is well protected from the prevailing cold winds because it is located in the middle of a site at a low altitude and is surrounded on all sides by higher terrain at close or relatively long distances, and it is also a better insulated archetype than archetypes (A) and (B) and the second most recently built between the 4 cases.

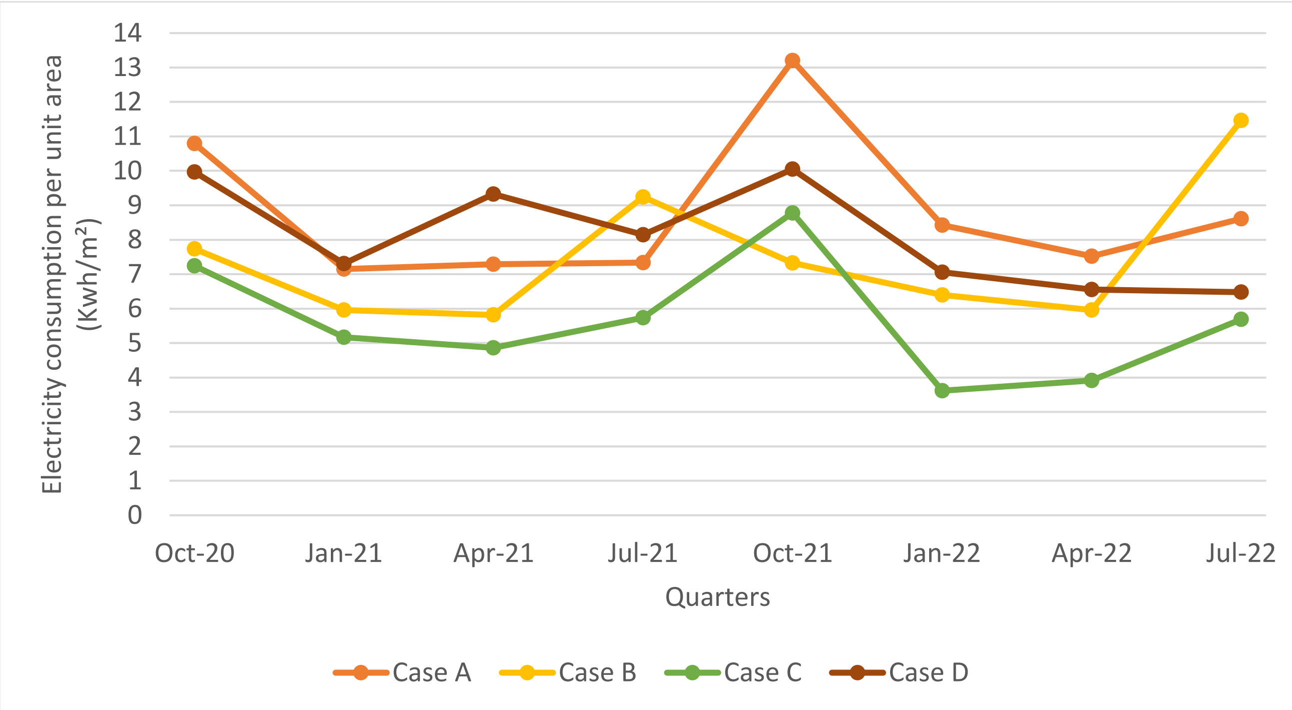


Figure VII. 10. Quarterly electricity consumption per unit area for the four case studies.

Source: The author, 2023.

Archetypes (A) and (D) consume the highest amounts of electricity per unit area in most quarters, and they are by the way, the oldest archetypes, with envelops that have the highest thermal transmittance coefficients.

And despite the fact that the two archetypes (A) and (D), the oldest archetypes, with envelops that have the highest thermal transmittance coefficients, they consume less amounts of gas than archetype (B) per unit area during the coldest months, in contrast to the other periods of the year, bearing in mind that, although this last one is the most recent archetype and its envelope has a lower thermal transmittance than that of archetypes (A) and (D). The archetype (B), as topographic sections show, is located in a context that is in a high altitude, and exposed to the north prevailing cold winds and is less exposed to solar rays than these two archetypes (A and D), which means that the impact of the geographical context was more significant than the impact of the physical state and the thermal properties of the envelope.

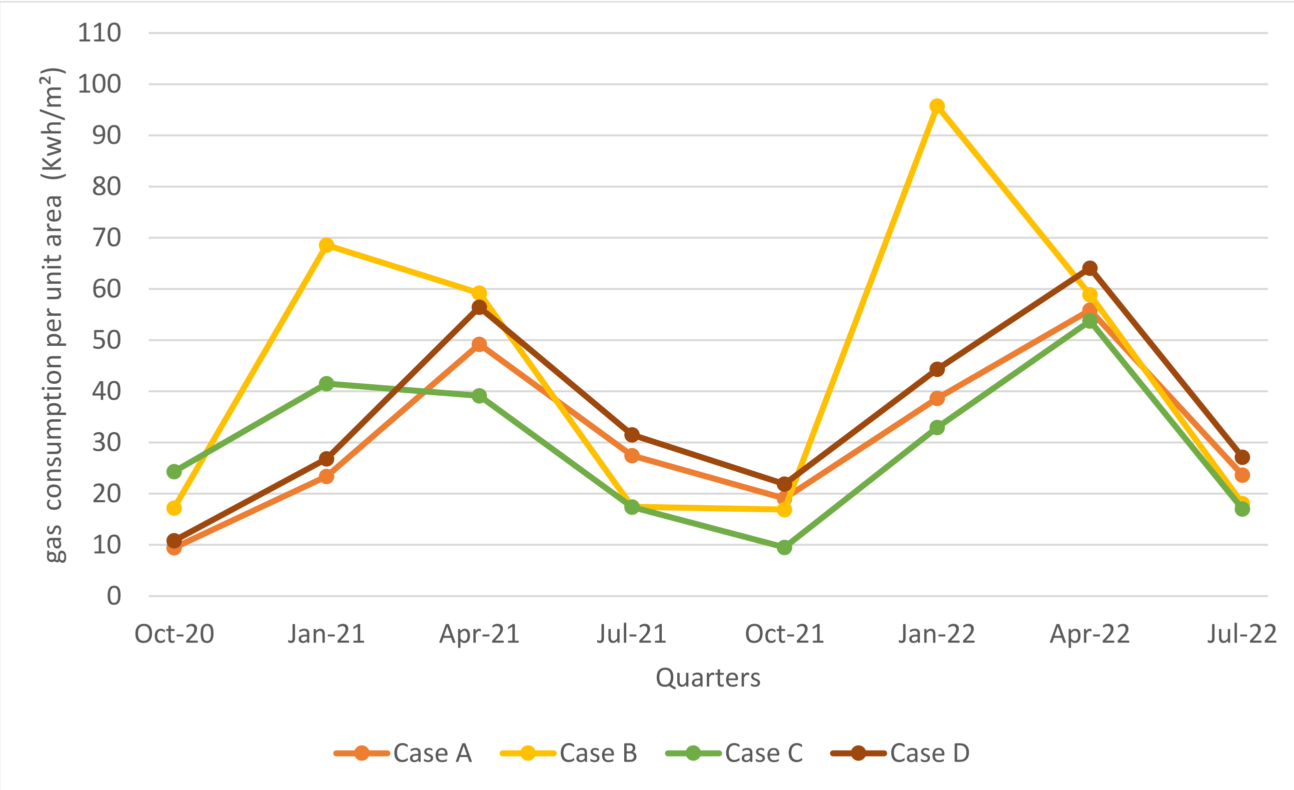


Figure VII. 11. Quarterly gas consumption per unit area for the four case studies.

Source: The author, 2023.

Based on the solar analysis conducted above, the morphology of the selected buildings and their urban surroundings played a significant role in the reception and accumulation of solar radiation on external surfaces. To get an idea about the impact of the morphology of the building and its surroundings, especially urban ones, on annual energy consumption, a linear regression was used to study the correlation between the simulated annual solar irradiation received on all the horizontal and vertical exterior surfaces, including the windows (by CEA), and the measured annual energy consumption.

The study considered the annual irradiation on the whole of the building which is controlled by the shading caused by the building's shape and surrounding urban environment, as well as topographical shading effects (which has a lesser impact). (Figure VII.12) presents the findings.

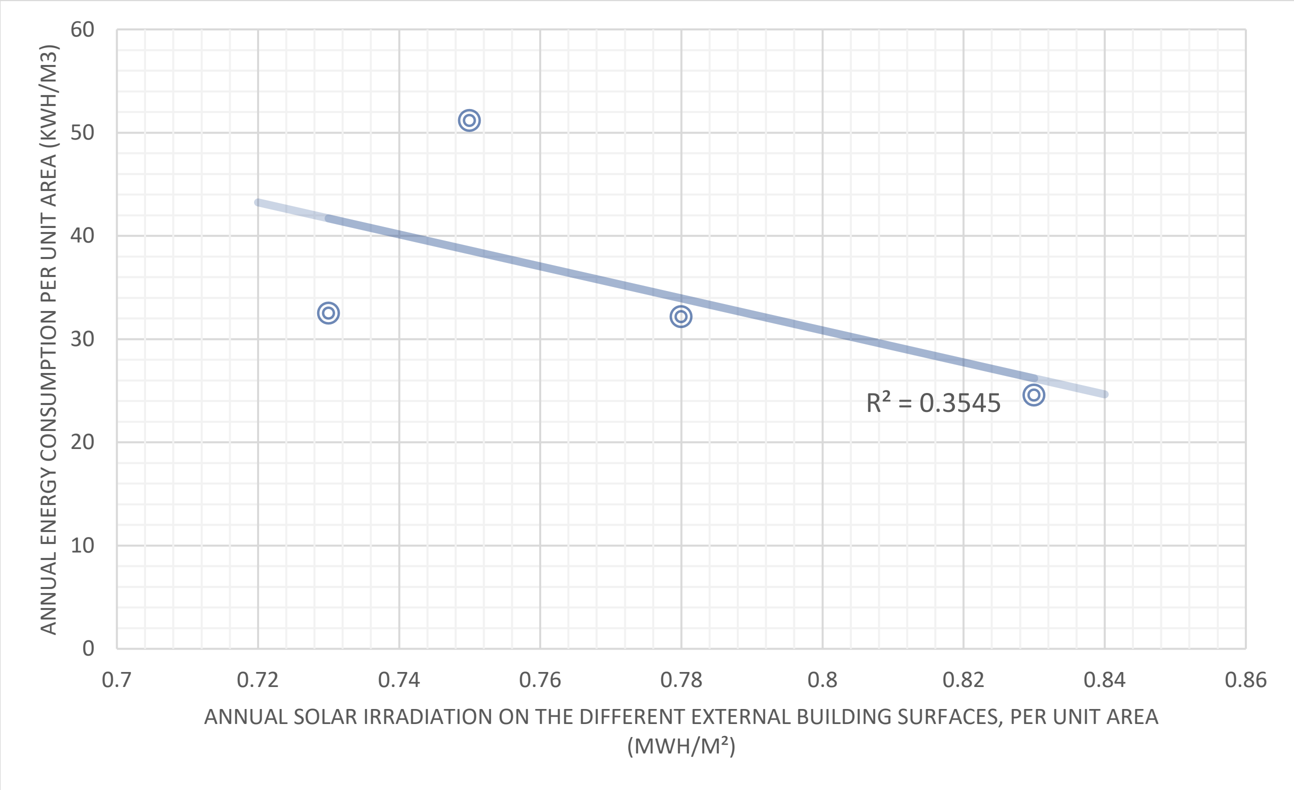


Figure VII. 12. Correlation between annual solar irradiation and energy consumption per unit area. Source: The author, 2023.

This linear regression generated an R^2=0.3545, and a descending line which means that there is a weak negative correlation between solar irradiation and energy consumption. This result leads to deduce that the impact of the morphology of the building as well as its surrounding environment morphology was weak, and did not have much effect compared to the other factors discussed above.

b. Energy analysis of simulation results

Based on the existing measured data collected concerning energy consumption, and the various data about the envelope of the archetypes, their known urban, geographical and meteorological contexts, as well as the heating and cooling supply systems used; a simulation, besides definition of posterior distributions, and ranges of values for unknown factors that have more impact on energy consumption fluctuations has done after calibration alongside validation, and before generation of polynomial regression related to occupants' behaviours.

b.1. Calibration and validation of energy models

By comparing predicted and measured total energy-use, the calibration findings, after numerous attempts, were validated annually and monthly, as shown in (Table VII.1) for all the studied archetypes, the CV(RMSE) coefficient values are limited between 0 and 15, the NMBE values are limited between -5 and +5. Whereas, the percentage error in the annual validation is close to 0. All of this indicates that the error percentages are acceptable and that the energy models have been validated in accordance with the guidelines of ASHRAE guideline 14-2002.

Table VII. 1. Annual and monthly validation of simulated energy models. Source: The author, 2023.

The study cases	**Total real annual demand measurements (MWH/year)**	**Simulated total energy demand (MWH/year)**	**Validation of simulated energy demand**		
			Percent error for total annual energy demand (%)	CV(RMSE) values for total energy demand (%)	NMBE values for total energy demand (%)
Case A	312.43	312.40	0.01	0.19	0.17
Case B	191.83	191.67	0.08	0.30	0.31
Case C	676.91	676.62	0.04	0.83	-0.36
Case D	761.36	760.17	0.19	2.5	0.44

This tiny percentage of error is to be expected, and is due to factors linked to the behaviour of the buildings' occupants, and to the difference between the simulated climate data from the METEONORM tool and real-time weather fluctuations.

b.2. Interpretation of simulated monthly energy consumption graphs

After calibration and validation, bar graphs of the simulated monthly energy use were presented and plotted (Figure VII.13), demonstrating that the total monthly energy use for all four archetypes is highest in the coldest months, peaks in January and December, and is typically lowest from May to October. Most of the energy is used for heating, which shows how vulnerable the building envelope is to cold weather, whereas housing and domestic hot water are the most energy-intensive uses during the rest of the year, but always come in second place during the coldest months. The bar charts show that the energy used for cooling grew mostly between July and August, whereas it decreased in May, June, and September. The other uses stated, artificial lighting, electric ventilation, and the usage of electrical equipment are all utilized relatively little energy.

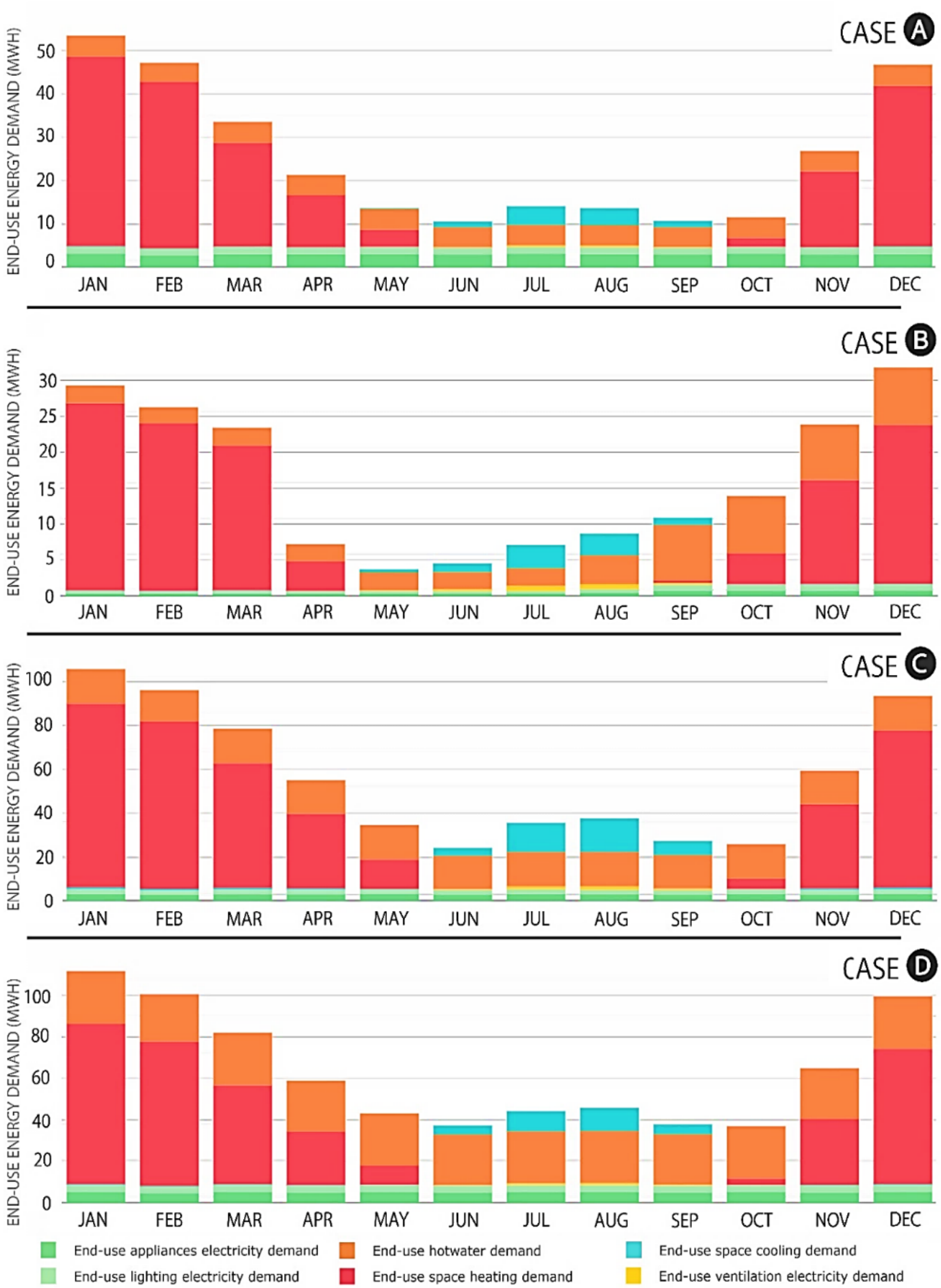


Figure VII. 13. Simulated monthly energy consumption bar charts, after calibration and validation. Source: The author, 2023.

b.3. Polynomial regression analysis

To obtain the graphical curves shown in (Figure VII.14), hundreds of random simulations in the CEA tool were carried out for each study case, followed by a selection of the different correlated values of the independent variables relative to the previously defined dependent variable; during which, the R^2 coefficient of correlation is almost equal to 1 in all the graphical curves, meaning that there is a strong correlation between the selected meeting points of the values of the independent variables represented by the setpoint temperatures and the weekly hours of use which resulted the obtention of the value of the beforehand defined dependent variable represented by the quantity of energy consumed for heating needs in the cold period only, and the amount of energy consumed for cooling needs in the hot period only. Considering the temperature range of 18 to 24°C, which is recognised as the optimal indoor thermal comfort range by the World Health Organization (2018), it is recommended that the temperature be maintained between 19°C and 24°C for summer thermal comfort and between 18°C and 22°C for winter thermal comfort, as per the OSAHS standard for sedentary activities applicable in all climate zones (Emmanuella & Alibaba, 2018; Esther, 2014).

It can be seen that the number of hours of weekly heating use is very high in relation to the total number of hours in the week in all 4 cases, with the average number of hours of heating use in archetype (C) being between 118 and 168 out of 168 hours per week, in the case of a setpoint temperature setting between 22 and 21. 5°C respectively. While, concerning archetype (D), heaters must be used for 168 out of 168 hours per week, in the case of a set-point temperature setting close to 22°C, meaning that use is permanent even when not needed, or that the set-point is at a higher temperature than the recommended range; this second assumption appears clearly in the case of archetypes (A and B), where it is found that the setpoint temperature is close to 23°C (higher than the recommended indoor comfort temperature) when the number of hours of use is at its maximum (168 hours per week), and that the lower the time of use, the higher the setpoint temperature, meaning that there is significant extravagance of heating use, and irresponsible energy consumption by occupants, together with inadequate thermal insulation capacity of the buildings' envelope. Concerning cooling, the maximum number of hours of use of the cooling system - represented by mini-split air conditioners - was limited to 19 hours per week in case (B), and to around 5 and 7 hours per week in cases (D) and (C), respectively, for setpoint temperatures limited to the OSAHS's optimal summer indoor thermal comfort range; whereas this optimum indoor temperature range has not been reached in case (A), and hours of use were also very minimal. The absence of a high cooling requirement may reflect the mildness of the summer climate and even on the behaviour of occupants, which inevitably differs from their behaviours during the rest of the year, as the case studies belong to a seaside town, which reduce their times of being inside their homes. This phenomenon can also be attributed to economic factors, given that, according to the quarterly energy bills issued by SONELGAZ (Appendix 3), the unit price of electricity is significantly higher than that of gas. As a result, users have adopted behaviours that encourage them to manage and control their electricity consumption.

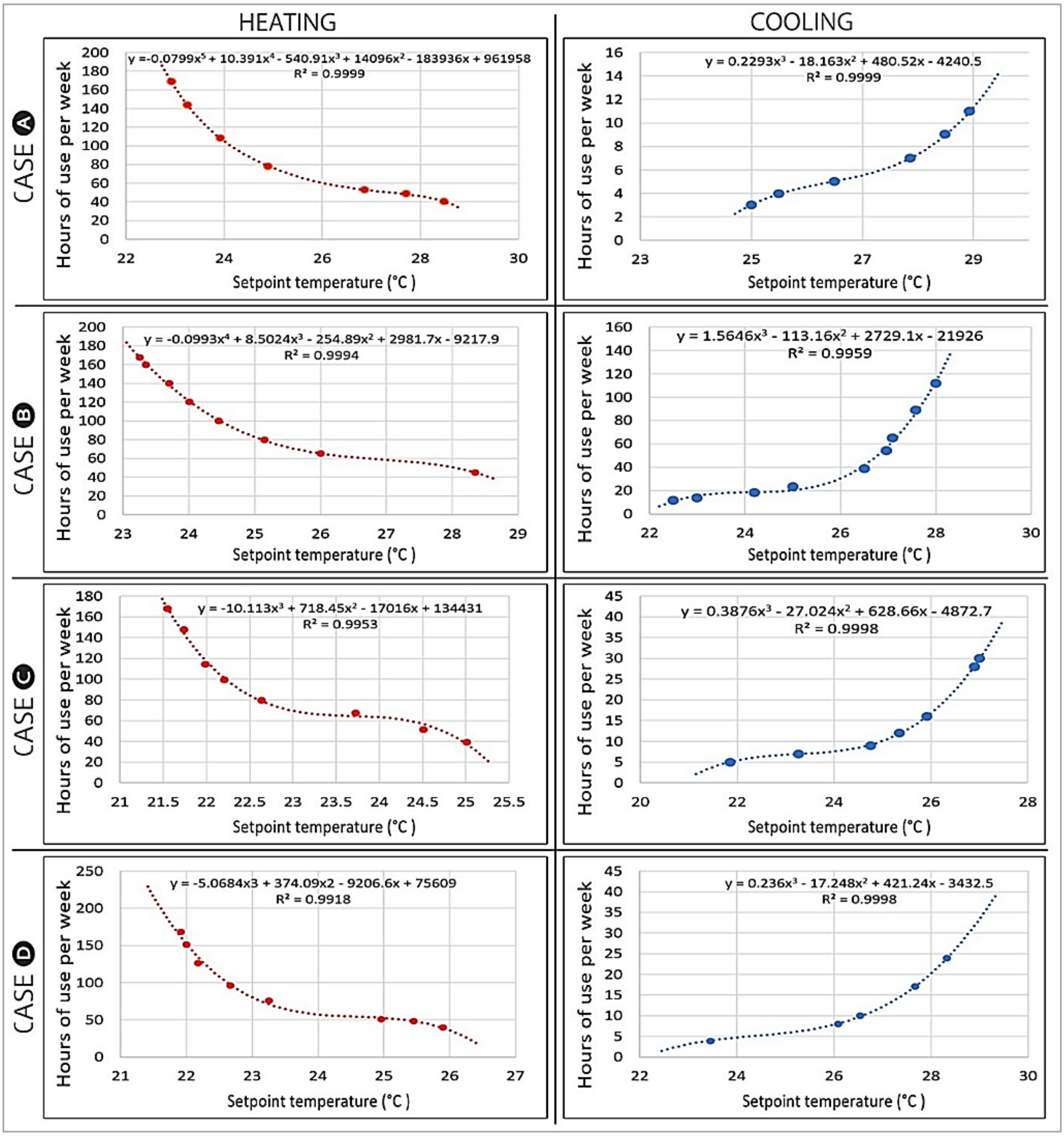


Figure VII. 14. Correlation plots of the variances of independent variables (setpoint temperatures and weekly hours of use) relating to energy consumption for heating and cooling, using polynomial regression.

Source: The author, 2023.

c. Environmental analysis

The results of the simulation are presented in (Table VII.2), and reveal that the amount of operational carbon emissions for the year (2021) is significantly higher than the intrinsic carbon emissions in all four study cases, that operational emissions are a continuous phenomenon. Therefore, it is crucial to accord them a high level of priority in order to achieve future reduction of carbon emissions, even though alterations to physical or behavioural factors. The results showed also that the quantity of intrinsic emissions per floor area in the 4 cases was convergent, and that the amount of total intrinsic emissions increases with the increasing of gross floor area, unlike the quantity of intrinsic emissions per floor area, which decreases with the increasing of the gross floor area, which implies that the increase in the volume of buildings has led to the marginalisation of certain carbon emission factors linked to the construction phase.

Table VII. 2. Intrinsic and operational greenhouse gas emissions for the four case studies.

The study cases	Gross floor area (m^2)	Embodied emissions		Operational emissions (Year 2021)	
		Total intrinsic emissions (ton of CO2)	Intrinsic emissions per floor area (Kg of CO2/m2)	Total annual operational GHG emissions (ton of CO2)	Total annual operational emissions per unit of floor area (Kg of CO2/m2)
Case A	**3237.63**	18.29	5.65	68.72	21.23
Case B	**1248.52**	7.47	5.99	47.65	38.16
Case C	**9180.38**	48.8	5.32	161.09	17.74
Case D	**7791.10**	42.19	5.42	178.62	22.93

Case study (D) has the highest annual operational emissions in (2021) with 178.62 tons of CO2, followed by case study (C) with 161.09 tons of CO2 and the largest gross floor area, and archetype (B) with 47.65 tons of CO2 and the smallest gross floor area of the four case studies. At the same time, the quantity of operational emissions per floor area was highest in case study (B) with 38.16 kg CO2/m2, then in case study (D) with 22. 93 kg CO2/m2; but this amount was lowest in case study (C) with 17.74 kg CO2/m2, confirming the direct correlation between greenhouse gas emissions and energy consumption, particularly gas, given that, during the coldest period, case study (B) recorded the highest annual gas energy consumption per unit area, followed by archetypes (A) and (D), which had converged values and are considered to be the oldest; unlike the archetype (C), where the emission of greenhouse gases per unit of floor area was the lowest, given that, according to previous data and analyses, this last one was considered new, and generally the best protected in terms of geographical and urban context, as well as envelope insulation.

Depending on French and Spanish environmental benchmarks which are shown in the (Figure VI.9), the comparison with the new French benchmark for energy performance diagnosis (DPE) of dwellings in 2021 (Batiactu, 2022; Vlad, 2022); showed that the operational emission quantities of the archetypes (A, C and D) in the year (2021), belong to environmental class C, while that of the archetype (B) belongs to environmental class D. In a further comparison with the Spanish environmental benchmark launched in 2013 (Premierinmobiliaria, 2022), the quantity of operational emissions of archetype (C) in the year 2021, belongs to environmental class C, while those of archetypes (A, B and D) belong to environmental class D. Greenhouse gas emissions for the 4 archetypes, according to the two benchmarks, were more than 3 to 6 times those of environmental class A, and were within the intermediate ranges of emissions, indicating that the audited archetypes are neither over-performing, nor over-emitting carbon (medium ecological performance).

VII.2.5. Apartment scale level

21 samples from each of the four archetypes under study, at the apartment level were chosen on the basis of their height and orientation in respect to the envelope as a whole.

(Table VII.3) shows the direction of apartment facade orientation, as well as the yearly gas, electricity, and overall energy consumption per unit area. A first observation is that in the 21 apartments, gas consumption was much higher than electricity consumption in all the apartments.

To examine how the apartment's height relates to the energy consumption of the entire building, refer to the graphical representation shown in (Figure VII.15), which categorises the 21 apartments into three levels: top, intermediate, and bottom floors, in order to perform a comparison between the apartments of each building in terms of their floors' heights.

The analysis revealed that annual energy usage was highest on the lower floors compared to the intermediate and higher floors in nearly all cases. Furthermore, in the frame of comparison between amount of energy consumption in the intermediate and top floors only, the annual energy usage in the samples was sometimes on the upper floors (4/7 or 57.14% of the cases) and sometimes on the intermediate floors (3/7 or 42.85% of the cases). By projecting the previous solar and energy analyses on these archetypes, it can be seen that the apartments on the lower floors consume more energy annually than those on the upper floors, because at the same time the annual accumulative solar radiation is lower in the bottom parts of the buildings compared to the upper surfaces, because of the urban mask resulted of surrounding buildings, which means that the effect of the incident solar energy factor on the exterior and interior surfaces of the building is significant at this scale, in terms of energy needs, remembering also that the greatest percentage of energy consumption was for heating needs.

Facades orientation	North and East	North and South	East and West	North-west	South-East	North and North-East	South and South-West
	Case A		**Case B**	**Case C**		**Case D**	
R+15				**116.26** 93.83 22.43	**127.99** 105.34 22.65		
R+14						**215.50** 174.44 41.06	**176.79** 154.49 22.31
R+13							
R+12							
R+11							
R+10							
R+9	**108.89** 84.98 23.91	**114.28** 73.02 41.26				**260.60** 206.32 54.28	**86.19** 73.29 12.90
R+8				**113.19** 96.81 16.38	**96.83** 75.15 21.68		
R+7							
R+6							
R+5	**177.41** 131.45 45.96	**124.81** 104.73 20.08	**220.86** 191.80 29.06				
R+4							
R+3			**141.28** 121.61 19.67				
R+2				**222.05** 191.36 30.69	**150.63** 131.15 19.48		
R+1	**257.31** 209.77 47.54	**159.32** 129.12 30.20				**314.97** 255.53 59.44	**88.14** 75.24 12.89
RDC			**249.33** 209.59 40.24				

Total annual energy consumption (kwh/m²/year) — Annual gas energy consumption (kwh/m²/year) — Annual electricity consumption (kwh/m²/year)

Table VII. 3. Samples of total annual energy, gas and electricity consumption in selected apartments belonging to the archetypes studied.

By including also the solar energy analyses, the results of the comparison between the energy consumption of the apartments in the intermediate and upper floors can be interpreted by the small difference between the cumulative insolation surfaces on the upper floors of the buildings, and on the intermediate surfaces of the building, taking into account the behavioural aspect related to the habits of each family, which plays an obvious role in this case, by comparison with the apartments in the bottom floor, where heating needs were much more significant.

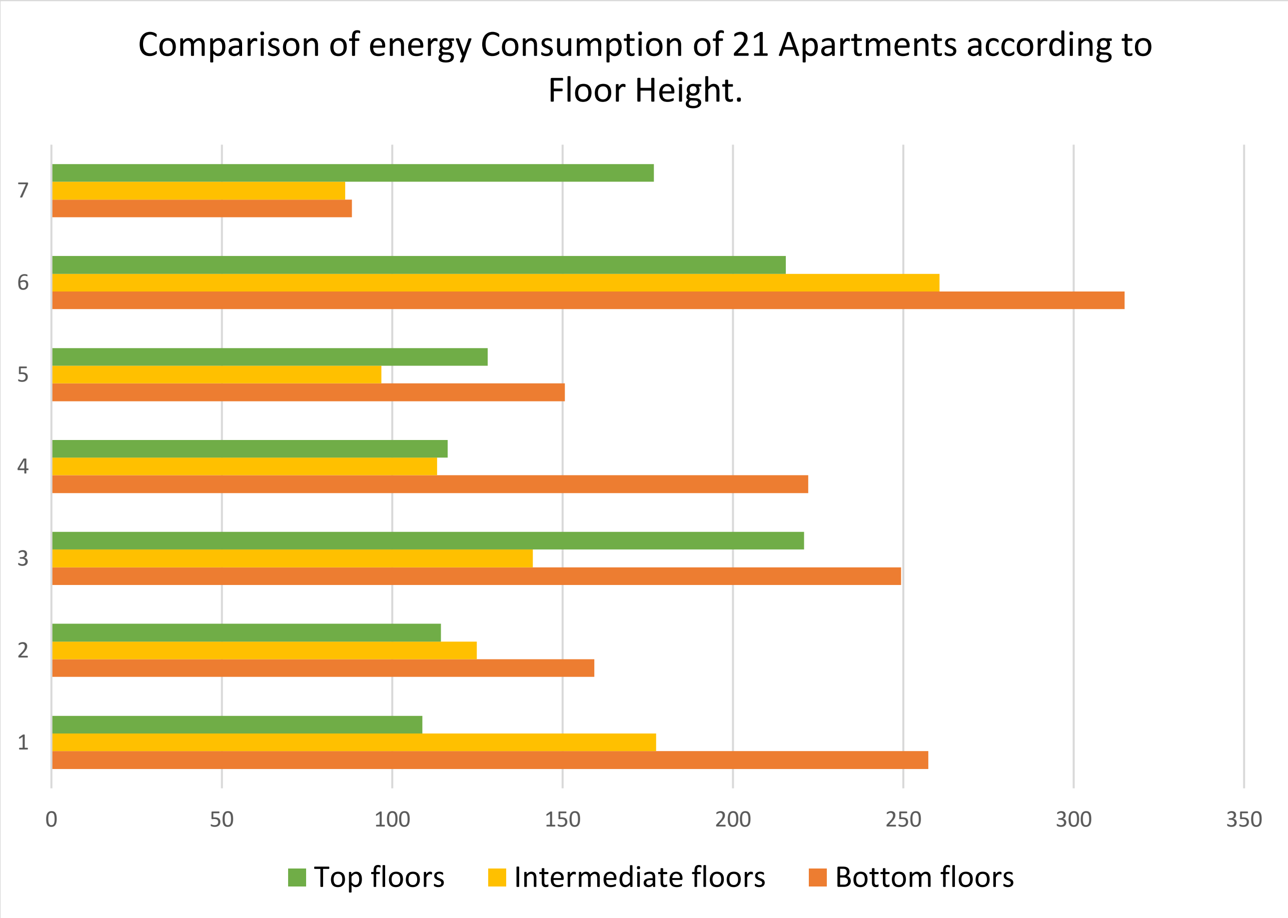


Figure VII. 15. Comparison of annual energy consumption per unit area of 21 apartments according to floor height.

Source: The author, 2023.

To determine the effect of orientation on the investigated apartments belonging to the archetypes (A, C and D), they were divided into two sections, as shown in (Figure VII.16): the first is related to the apartments that have a north orientation in addition to its near angles, and the second is related to the apartments that have a south orientation in addition to its near angles.

The comparison of the annual energy consumption of apartments in each single building based on their orientation reveals that, overwhelmingly, apartments with north-facing facades and near-north directions had the highest annual energy consumption, comparing to apartments with south-facing facades and near-south directions which had the lowest annual energy consumption. These findings demonstrate and confirm the negative correlation between energy consumption and solar availability. The north-facing facades only receive diffuse radiation, leading to an increase in heating requirements. In contrast, the south-facing facades have a high potential for solar gain, leading to a relative reduction in heating requirements.

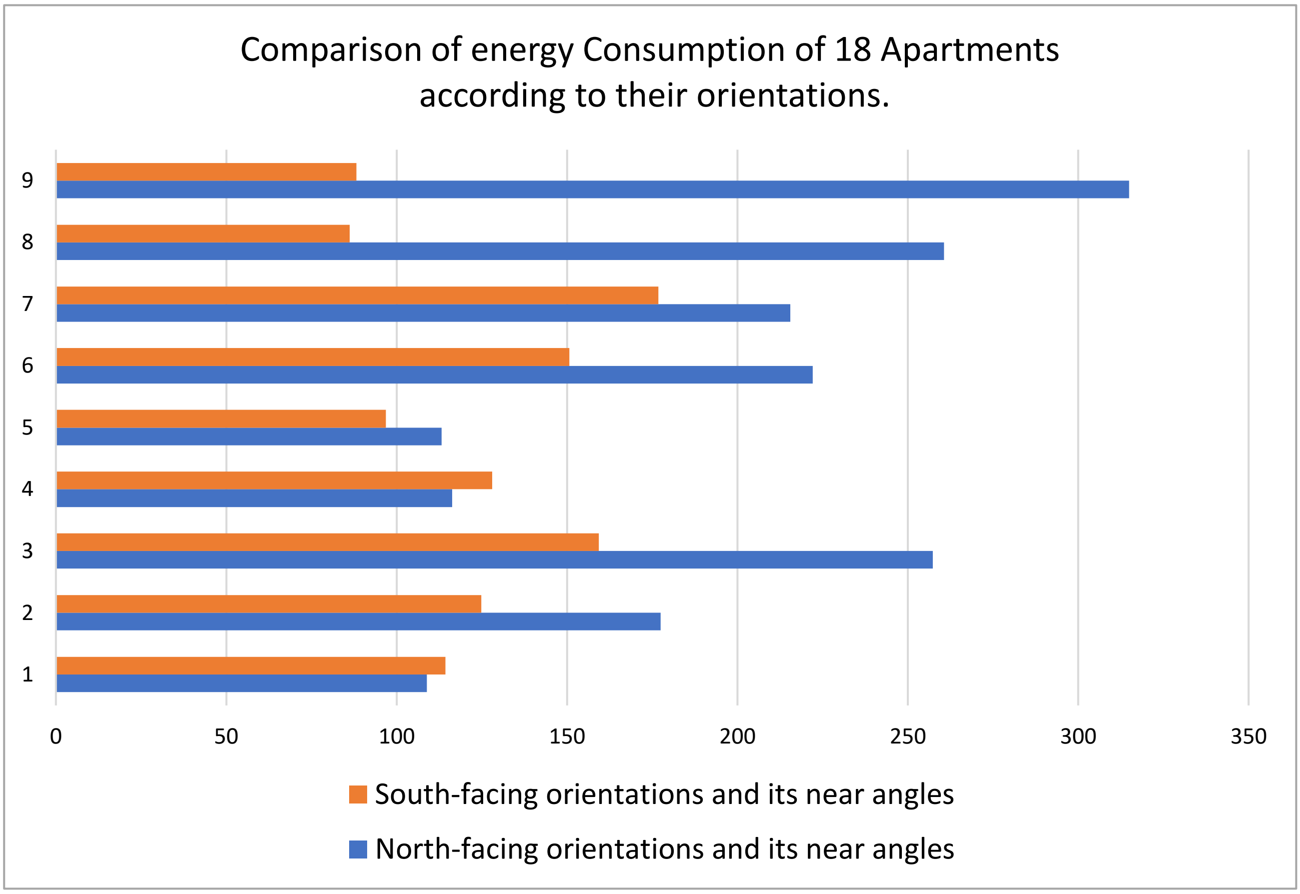


Figure VII. 16. Comparison of annual energy consumption per unit area, of 18 Apartments according to their orientations.

Source: The author, 2023.

Then, the 21 apartments were categorized into 5 categories, of equal ranges, and the results of the building categorization have been graphically represented in (Figure VII.17), which shows that 43% of the apartments belong to the first category, while 24% belong to the second category, based on their annual energy consumption, according to 5 categories that represent equal intervals, delimited by the smallest and largest values of the 21 values studied. These two categories, which account for two-thirds of apartments, represent the lowest consumption categories of all, with consumptions between

86.19 and 177.71 (kwh/m²/year). The 3rd and 4th categories have the same percentage of apartments with 14%, while the 5th category comprises 5%, in which all three of these, which represent the categories with the highest consumption among all categories, comprise only a third of the apartments, with consumptions between 177.71 and 314.97 (kwh/m²/year).

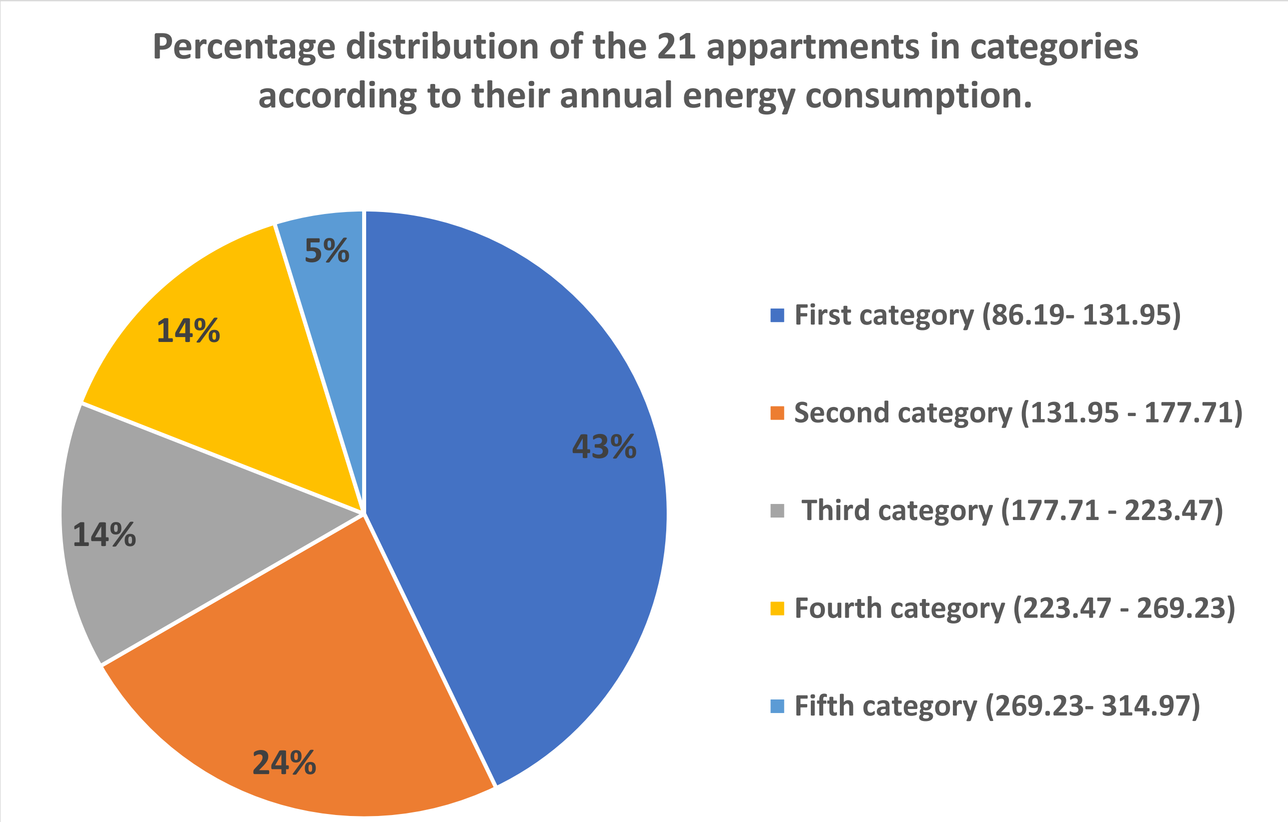


Figure VII. 17. Percentage distribution of the 21 apartments in the categories based on their annual energy consumption quantities per unit area.

Source: The author, 2023.

The comparisons with energy benchmarks which are illustrated in (Figure VI.9), showed that the French energy benchmark set two-thirds of apartments are in energy classes B and C, while the rest are in energy classes D and E. While according to the Italian energy standard, four-fifths of apartments (1st, 2nd, and 3rd categories) are in energy classes C, D and E; the rest are in energy classes F. Whereas the Spanish energy benchmark, showed that 95% of apartments were classified in energy classes C, D and E, with the rest in energy class F. The distribution of buildings' energy consumption in energy classes differs from one benchmark to another, due to the difference between these benchmarks themselves, but generally speaking, the large majority belong to the range between good to medium energy performance classes (neither too efficient nor too energy-intensive); while the rest belongs to energy-intensive building classes.

VII.3. Analysis and evaluation of post-renovation scenarios

VII.3.1. Energy analysis

The tables (VII.4), (VII.5), (VII.6) and (VII.7) present the yearly energy consumption of gas and electricity in each intervention scenario, according to each one of the 4 study cases, at whole building scale, along with the yearly renewable-based production of thermal and electrical energy following the implementation of a hybrid PVT system.

Table VII. 4. Annual energy consumption as well as production for each scenario launched, in the case study (A).

Case A Scenarios	**Annual energy consumption (Year 2021) (MWH/year)**		**Annual renewable energy production (Year 2021) (MWH/year)**	
	Gaz	Electricity	Thermal production	Electricity
Baseline scenario	240.29	72.11	-	-
(P.R.1)	209.4	78.90	-	-
(P.R.2)	180.09	87.67	-	-
(P.R.3)	240.29	72.11	140.42	31.32
(P.R.4)	240.29	72.11	7.48	24.89
(P.R.5)	180.09	87.67	14.29	48.04
(P.R.6)	116.02	151.74	14.29	48.04
(P.R.7)	180.09	87.67	140.42	31.32
(P.R.8)	180.09	87.67	147.90	56.41
(P.R.9)	180.09	87.67	159,48	35,59

Table VII. 5. Annual energy consumption as well as production for each scenario launched, in the case study (B).

Case B Scenarios	**Annual energy consumption (Year 2021) (MWH/year)**		**Annual renewable energy production (Year 2021) (MWH/year)**	
	Gaz	Electricity	Thermal production	Electricity
Baseline scenario	167.10	24.57	-	-
(P.R.1)	134.88	24.61	-	-
(P.R.2)	117.29	25.10	-	-
(P.R.3)	167.10	24.57	55,94	12,42
(P.R.4)	167.10	24.57	2.02	9,02
(P.R.5)	117.29	25.10	3,43	14,83
(P.R.6)	69.74	72.65	3,43	14,83
(P.R.7)	117.29	25.10	55,94	12,42
(P.R.8)	117.29	25.10	57.96	21.44
(P.R.9)	117.29	25.10	105,36	23,46

Table VII. 6. Annual energy consumption as well as production for each scenario launched, in the case study (C).

Case C Scenarios	Annual energy consumption (Year 2021) (MWH/year)		Annual renewable energy production (Year 2021) (MWH/year)	
	Gaz	Electricity	Thermal production	Electricity
Baseline scenario	568.90	107.72	-	-
(P.R.1)	497.92	111.69	-	-
(P.R.2)	435.24	117.32	-	-
(P.R.3)	568.90	107.72	263.49	58.57
(P.R.4)	568.90	107.72	16.90	48.79
(P.R.5)	435.24	117.32	29.89	91.437
(P.R.6)	254.24	298.32	29.89	91.437
(P.R.7)	435.24	117.32	263.49	58.57
(P.R.8)	435.24	117.32	280.39	107.36
(P.R.9)	435.24	117.32	289.47	64.37

Table VII. 7. Annual energy consumption as well as production for each scenario launched, in the case study (D).

Case D Scenarios	Annual energy consumption (Year 2021) (MWH/year)		Annual renewable energy production (Year 2021) (MWH/year)	
	Gaz	Electricity	Thermal production	Electricity
Baseline scenario	626.70	133.47	-	-
(P.R.1)	554.11	135.42	-	-
(P.R.2)	494.97	137.98	-	-
(P.R.3)	626.70	133.60	254.97	56.88
(P.R.4)	626.70	133.60	14.47	45.66
(P.R.5)	494.97	137.98	28.39	89.42
(P.R.6)	197.97	434.98	28.39	89.42
(P.R.7)	494.97	137.98	254.97	56.88
(P.R.8)	494.97	137.98	269.44	102.54
(P.R.9)	494.97	137.98	254.97	56.88

After reviewing the aforementioned tables on the annual energy consumption, it was observed that replacing single glazing with double glazing (P.R.1) resulted in a decrease in gas consumption. This reduction was even more significant with the use of triple glazing (P.R.2) compared to the use of the other two types (simple and double glazing). Conversely, the use of double glazing (P.R.1) led to an increase in electricity consumption, which increased further with the use of triple glazing (P.R.2).

These reductions in gas consumption demonstrate the high performance of double and triple glazed windows in terms of thermal insulation. This has led to greater protection against external weather fluctuations being offered to building envelopes.

The rise in electrical energy consumption can be attributed to the need for increased artificial lighting. This is due to the reduced light transmission of double and triple-glazed windows in comparison to single-glazed windows, as highlighted by a study (Ha-Nhi, 2023). The study indicates that the additional layers of glass as well as air between the panes limit the amount of light that enters the building's interior. This glazing not only reduces the quantity but also the quality of natural light, making the building's indoor visual state appears darker, and also gloomier.

In scenario (P.R.6), where the supply system was changed from one based on natural gas to one based on an electrical power system, the consumption of gas was logically reduced to a large extent, while the consumption of electricity became much higher.

The tables demonstrate variances in thermal and electrical energy production across different case studies and their respective use scenarios, owing to the integration of PVT.

Further details are provided about thermal energy production in the accompanying (Figure VII.18).

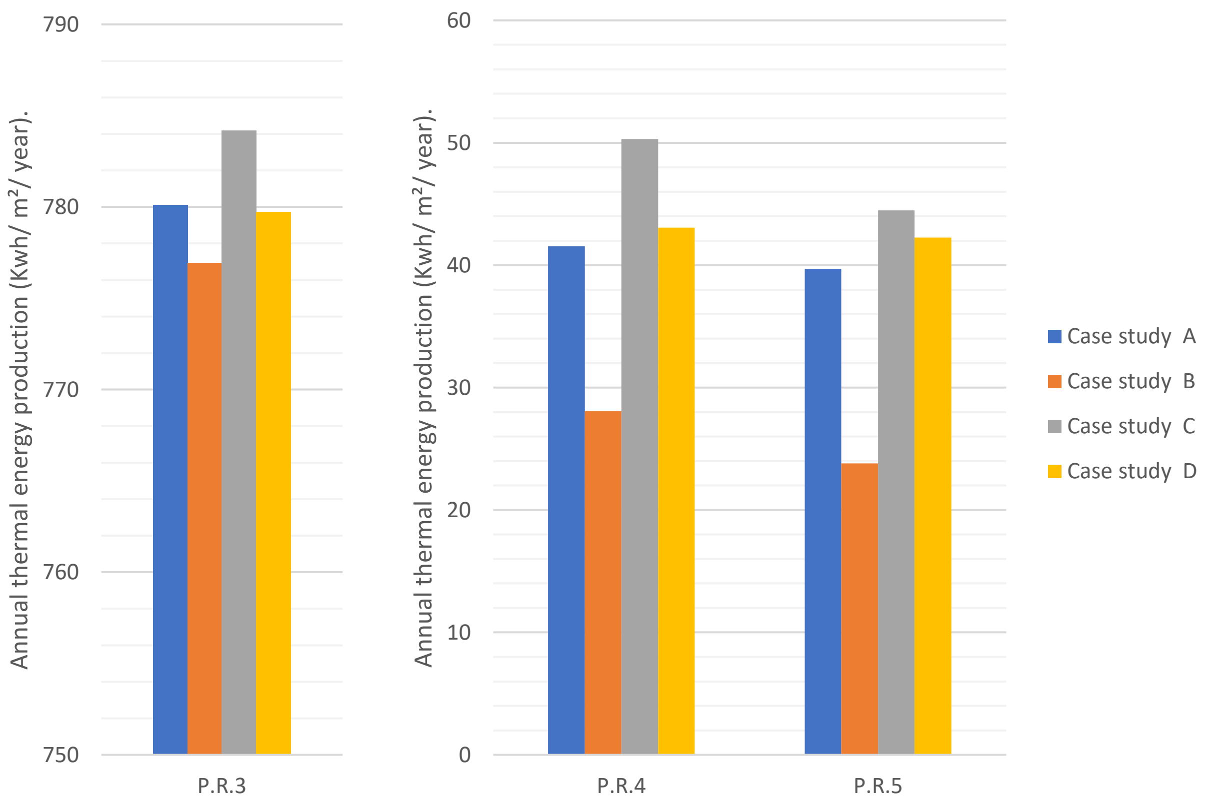


Figure VII. 18. Comparison between the 4 study cases, in terms of thermal energy production, according to the scenarios (P.R.3, P.R.4 and P.R.5).

Source: The author, 2023.

The thermal energy production was very significantly higher in scenario (P.R.3), where hybrid PVT panels were integrated into the roof with an average of 6m² per dwelling, compared to scenarios (P.R.4) and (P.R.5) where the hybrid PVT panels were placed on the south-facing facade, with averages of 6m² and 12m² respectively. Observing by the way a remarkably high yield from the roof-mounted panels despite the substantial panel surface area on the southern facades in case (P.R.5). In fact, the thermal production per unit area on the roof-mounted panels was more than 17 times greater than that on the panels fixed on south-facing facade.

Comparing (P.R.4) with (P.R.5), the overall energy production has marginally increased despite doubling the solar panel quantity. Furthermore, the energy production per unit area was lower in (P.R.5) compared to (P.R.4). This is due to the unavailability of surfaces that accumulate large annual quantities of solar energy. As a result, the additional surfaces used for the integration of more panels in scenario (P.R.5) are less receptive to solar rays (in correspondence with the generated 3d solar maps), leading to a decrease in average solar thermal production per unit of surface.

After comparing the four case studies in the three scenarios, it was found that case study (C) had the highest annual thermal energy production. This building (archetype C) has the greatest height, a flat roof without any vertical extensions, and receives the greatest amount of accumulated solar energy on its upper south-facing surface, as shown by the 3D solar visualizations.

While the thermal energy output per unit area was lowest for the panels in case study (B), particularly when comparing the facades on the southern side, a noticeable difference was observed compared to the other cases. It should be noted that case study (B) refers to the lowest-rise building situated among the four.

Regarding archetypes (A and D), the thermal energy production per unit area for cases of integrating panels on south-facing facades and roofs was nearly equal, albeit less than in the case of archetype (C). This could be due to the presence of vertical extensions for terrace access, as well as the complexity of facades that receive less cumulative insolation due to solar shading by themselves or by the surroundings.

The (Figure VII.19) below shows electrical energy production per unit area for the four cases, and according to the scenarios (P.R.3), (P.R.4) and (P.R.5).

The comparison of the three scenarios demonstrated that there is just little difference in the electricity production per unit area for the roof and south-facing facade, in contrast to the case of thermal production, when the production by roofs-mounted panels was much higher.

On the other hand, basing on the data presented in the tables (VII.4), (VII.5), (VII.6) and (VII.7) above regarding overall electricity production, it is evident that the (P.R.5) scenario, where the number of

PVT hybrid panels was doubled, produced significantly more electricity compared to the (P.R.3 and P.R.4) scenarios in all study cases.

When comparing the four study cases, the electrical production per unit area (Figure VII.19) was nearly identical. The (P.R.3) scenario, which integrated the panels on the roof, showed the closest approximation. Also, there was a close similar production in the (P.R.4 and P.R.5) scenarios, but with a slight decline in the (B) study case, although this decline was greater in (P.R.5), which means that the production was influenced by the lower cumulative solar radiation on the south facade of the archetype (B) compared to the other archetypes, due to its low height comparing to the others.

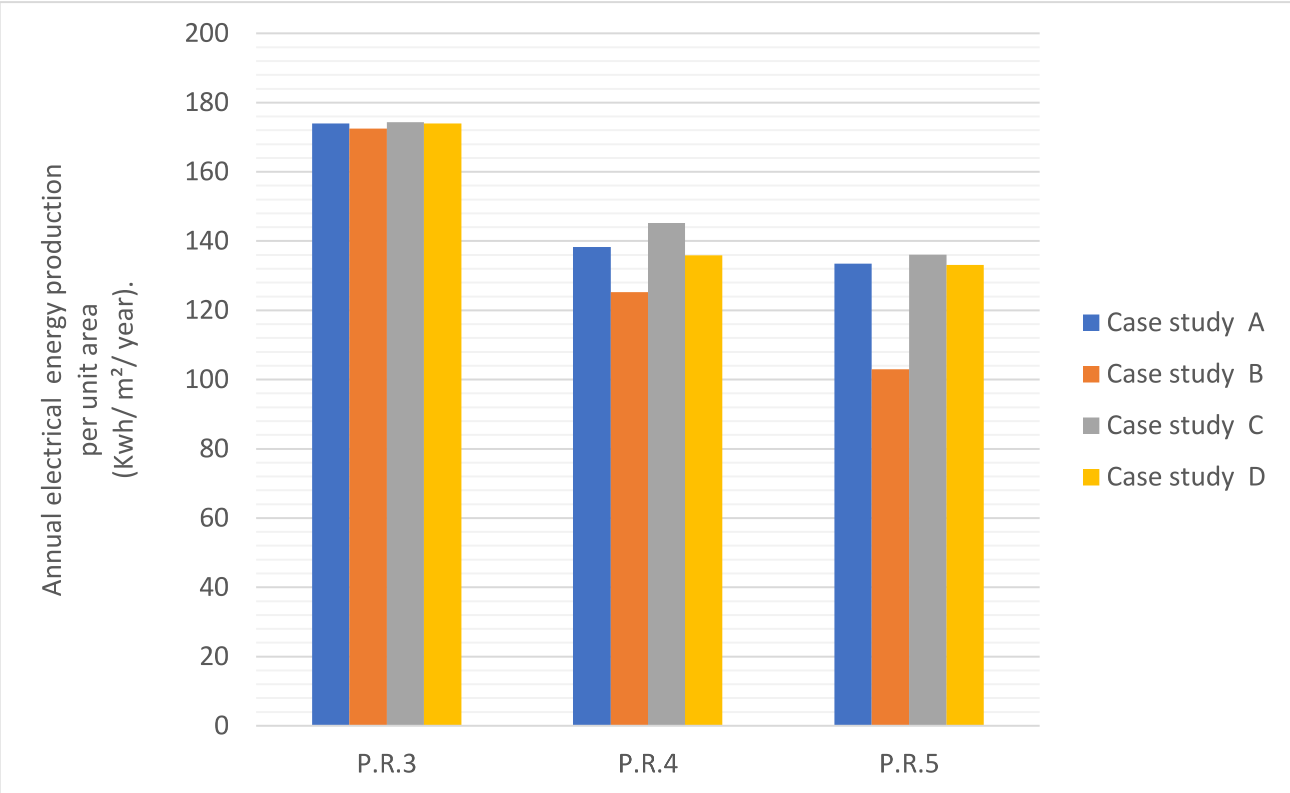


Figure VII. 19. Comparison between the 4 study cases, in terms of electrical energy production, according to the scenarios (P.R.3, P.R.4 and P.R.5).

Source: The author, 2023.

All of the aforementioned demonstrates that thermal production is predominantly linked to the amount of cumulative solar energy incident on the panel surfaces over extended periods, as opposed to electrical energy which is predominantly linked to the material quantity of the solar panel surfaces, with minimal impact from cumulative insolation rates.

The figures (VII.20), (VII.21), (VII.22) and (VII.23), illustrate the final annual energy consumption of gas and electricity before and after the hybrid energy renovation scenarios for the four case studies.

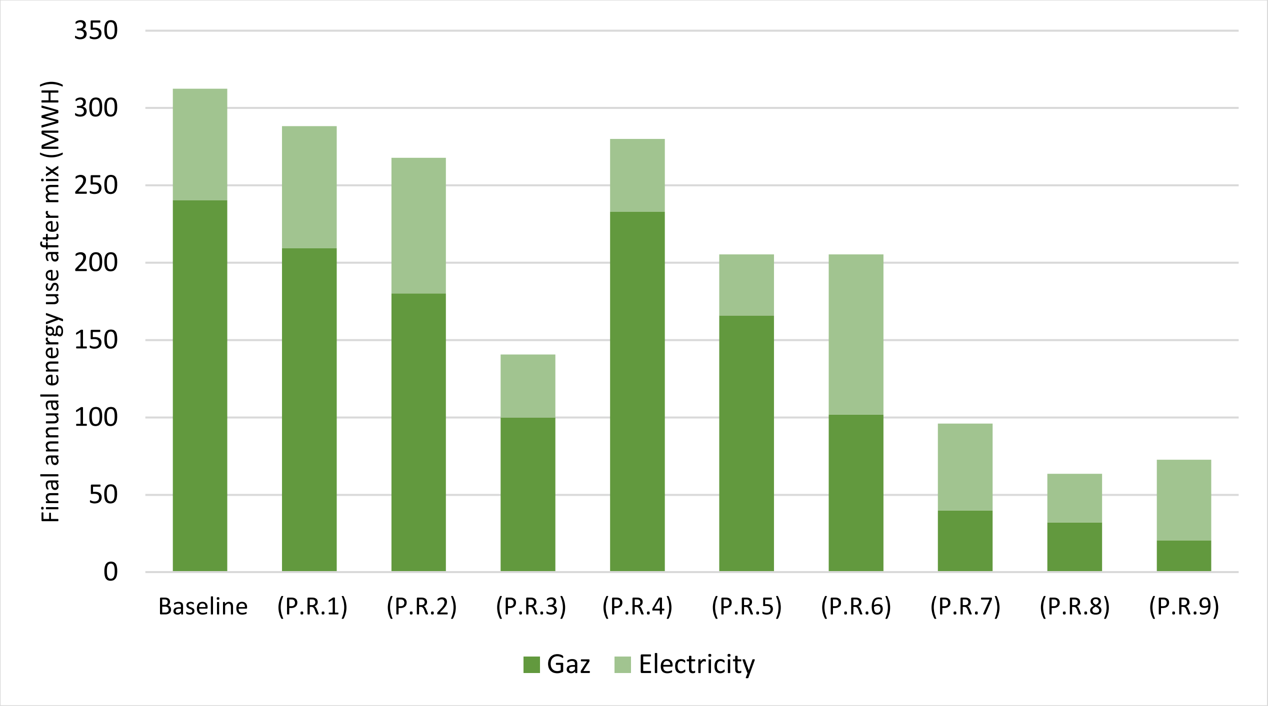


Figure VII. 20. Final fossil energy use after mix (Year 2021) (MWH), according to each scenario, for the case (A).

Source: The author, 2023.

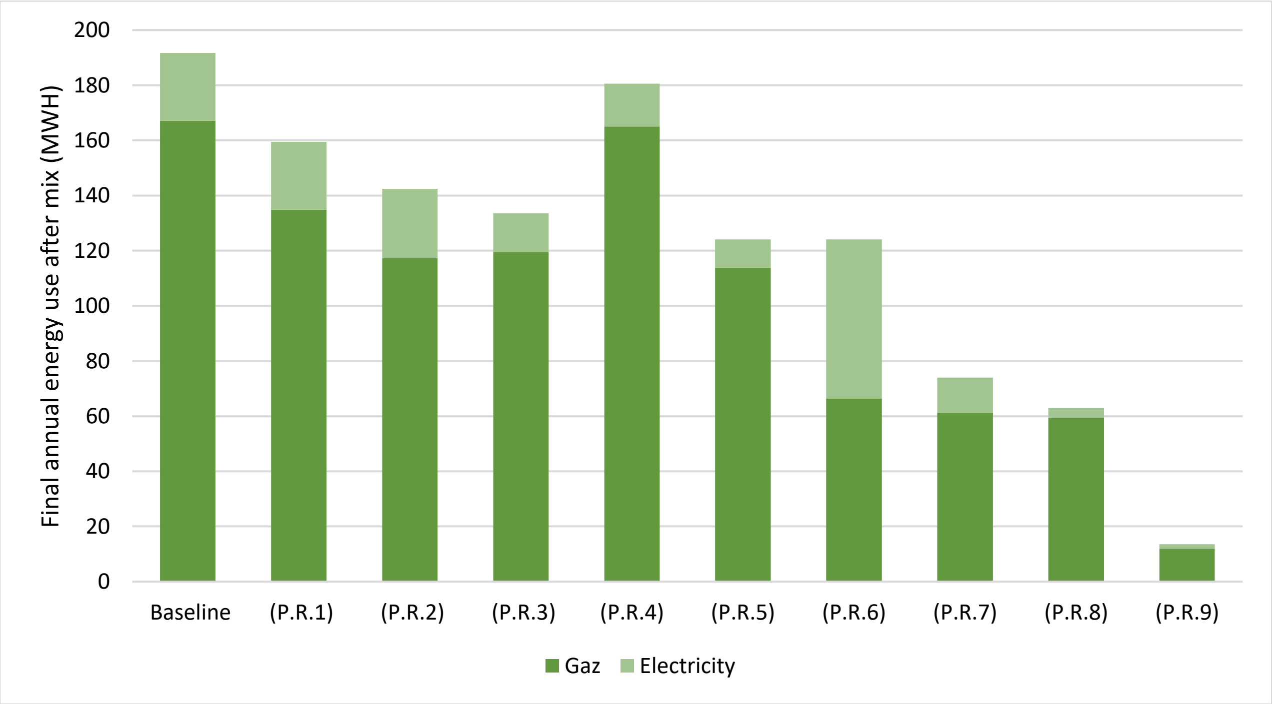


Figure VII. 21. Final fossil energy use after mix (Year 2021) (MWH), according to each scenario, for the case (B).

Source: The author, 2023.

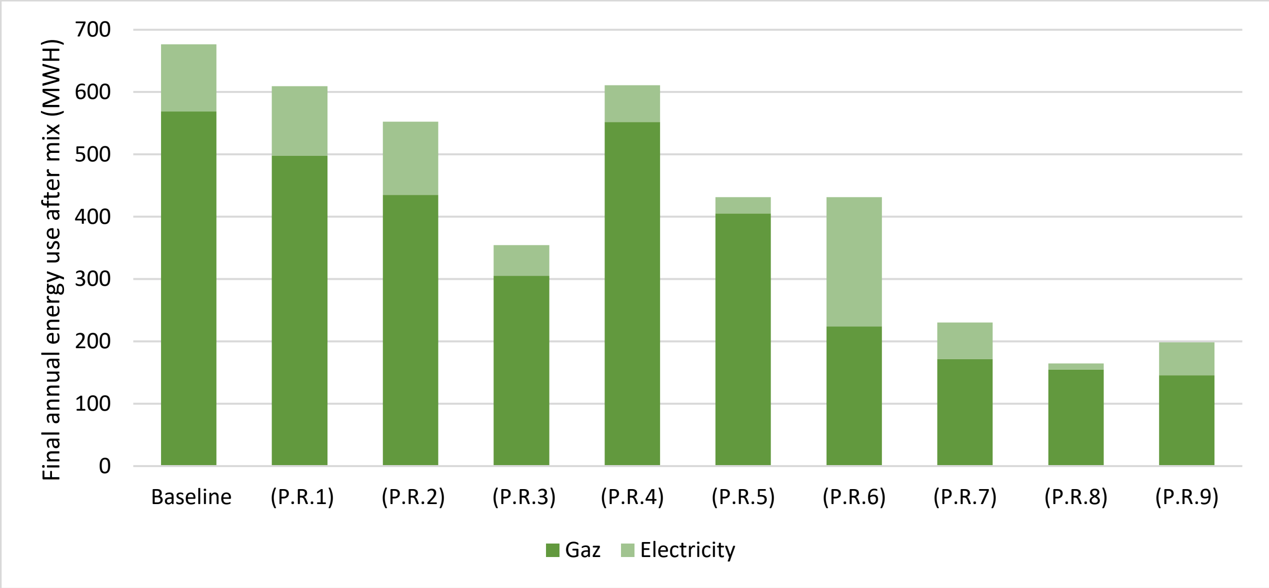


Figure VII. 22. Final fossil energy use after mix (Year 2021) (MWH), according to each scenario, for the case (C).

Source: The author, 2023.

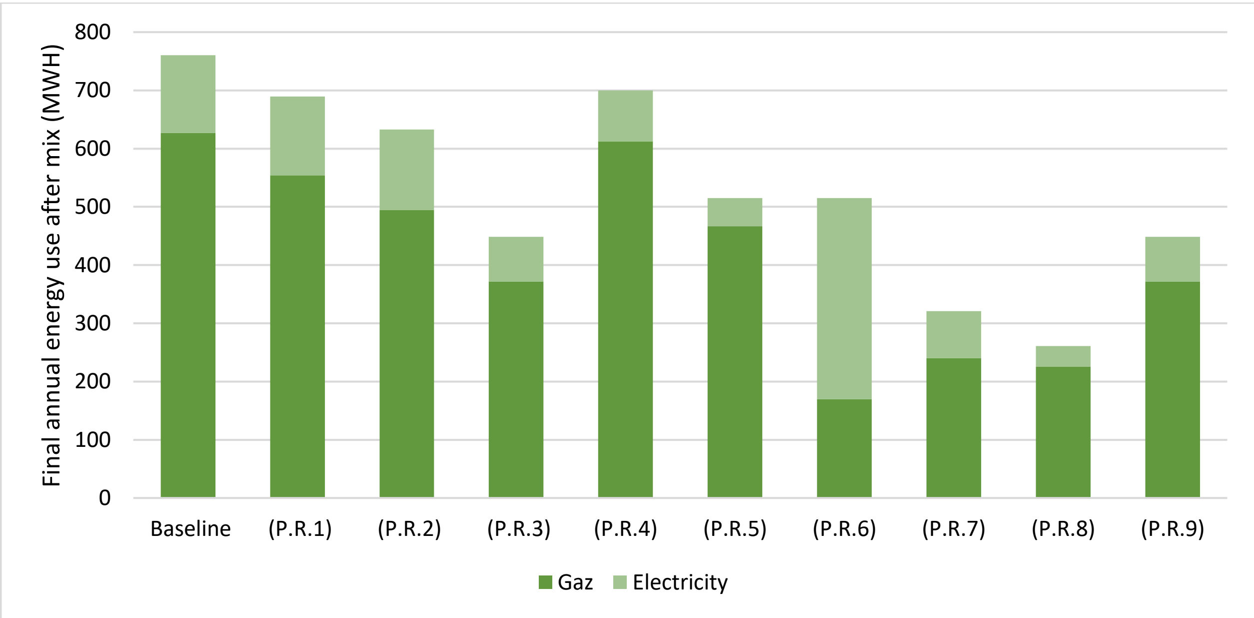


Figure VII. 23. Final fossil energy use after mix (Year 2021) (MWH), according to each scenario, for the case (D).

Source: The author, 2023.

The graphs demonstrate that annual energy consumption significantly decreased in (P.R.3), where PVT hybrid panels were integrated into the roof, compared to (P.R.1, P.R.2, P.R.3 and P.R.4) (the scenarios with only one intervention), while the use of triple glazing resulted in the second most significant reduction in energy consumption. Solar panel integration on south-faced facades had the lower impact on reducing energy consumption.

After comparing all the scenarios, the (P.R.7, P.R.8 and P.R.9) scenarios resulted in very significant reductions in energy consumption compared to the other scenarios based on a single intervention or a combination of interventions, where there was the replacement of single glazing with triple glazing and the extensive use of hybrid thermal photovoltaic panels on the roof, with an average of 6 m² of these panels per dwelling or in a larger area, either on the roof alone or on both the roof and the south-facing facade.

Also, an observation can be made that the study cases did not respond uniformly to the same scenarios, well-illustrated by the disparity between study case (B) and (C) in scenario (P.R.9). In this scenario, there was a significant reduction in energy consumption in study case (B), which classified it as the superior option, while study case (C) did not experience such a substantial reduction and thus was not the optimal solution for it. So, for this purpose, the section below will be devoted to show more details on these variances between the study cases in terms of their reactions to the 9 scenarios, and also the variances of reduction rates according to each form of interventions.

The (Figure VII.24) shows the percentage of reduction in annual energy consumption for gas, according to each scenario, for each case study.

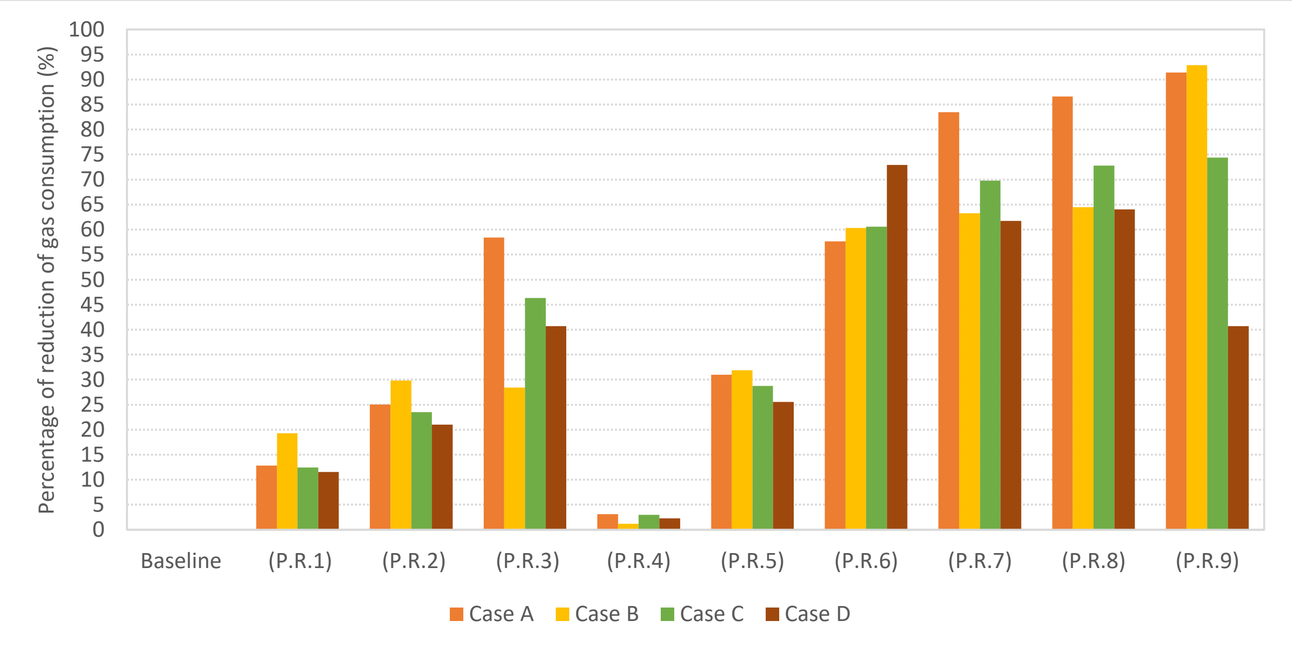


Figure VII. 24. Percentage of reduction in annual energy consumption for gas, according to each scenario, for each case study, in (%).

Source: The author, 2023.

Gas consumption decreased the most in case study (B), and then in case study (A), for scenarios (P.R.1, P.R.2 and P.R.5). These scenarios only involved changes to the glazing type in the building envelope, with the exception of the last scenario, which also included the addition of hybrid PVT panels on south-facing facades, but this panels' contribution was very modest (very marginal impact), in comparison with that of the high performant windows. On the other hand, the reductions were lower in the cases (D) and then in case (C) respectively, according to the same scenarios. This may be interpretated by the presence of the two buildings (A and B) located in the more exposed areas to prevalent cold winds, resulting in a greater decrease in the required thermal energy.

In scenarios (P.R.3) and (P.R.4), where reduction relied on incorporating hybrid PVT panels onto roofs or south-facing facades, the reduction was lowest in Case (B) and higher in the other cases studied. This is met by the low rise of the building and its small reception of high amounts of solar radiation along the days, compared to the other cases.

In the scenario (P.R.6), where the hot water supply system based on natural gas was changed by the use of electrical boilers, the reduction of natural gas use was higher in case study (D). This met by the high requirements for hot water in this building, comparing to the other ones, in correspondence with the energy simulation showed before, in (Figure VII.13).

In scenarios (P.R.3, P.R.7 and P.R.8), case study (A) showed a greater reduction. This was mostly due to the use of hybrid PVT integration on the roof or coupling it with triple glazing windows. In this case, thermal energy was produced at a slightly lower degree compared to cases (C) and (D) in scenario (P.R.3). However, the smaller volume of Archetype (A) allowed it for greater reductions compared to the other two cases. This occurred in scenarios (P.R.7 and P.R.8), where outdoor temperature fluctuations had an impact. Case study (A) was more affected than the cases (C and D), and subsequently benefited more from envelope thermal reinforcement, as previously mentioned. Using as much of the roof as possible to fit PVT panels in (P.R.9) meant that as the building got taller in relation to the roof size, the roof became less and less adequate. However, in case study D, there was a smaller reduction rate. This happened because of the roof's size in relation to its height and overall volume, as well as the vertical extension on the roof, which created a masking effect and reduced the area available for the integration of panels.

The evidence indicates that reducing heat loss through thermal insulation of the building envelope is largely dependent on the level of the envelope's exposure to external weather fluctuations and its level of protection from prevailing winds, which can be natural or obstructed by urban structures. On the other hand, energy production through the integration of PVT hybrid panels was much more dependent on the building envelope itself and its morphology properties, considering its height and roof surface as well as its capacity to accommodate solar panels; and even on its degree of exposure to solar radiation, in relation to the urban and natural surrounding context.

(Figure VII.25) displays the percentage of decrease in yearly electricity usage following every renovation scenario for the four case studies.

The rise in energy consumption in (P.R.1) and (P.R.2) can be attributed to an increased demand for artificial lighting, as previously explained. This rise was most significant in study case (A), which features the highest number of glazed surfaces facing south and hence suffered the most from reduced light quality.

The study found that scenario (P.R.3, P.R.4, P.R.5 and P.R.8) demonstrated the greatest reduction in electricity consumption within study case (C) compared to other cases. This study case is already consuming the least quantity of electricity per unit area, among the other cases and has the potential for larger southern facade surface areas, and receives more cumulative insolation due to its taller and less complex facade than the other buildings, according to the initial state energy analysis of the archetypes.

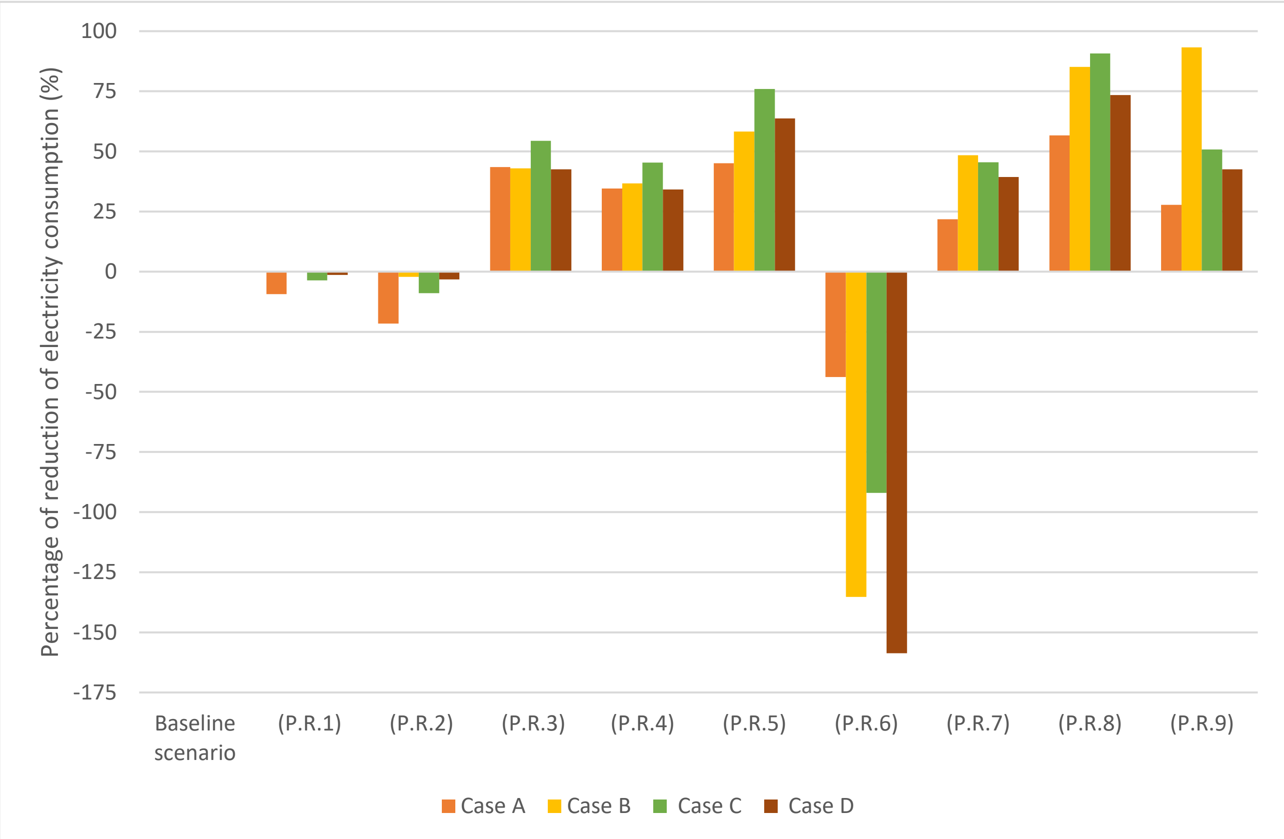


Figure VII. 25. Percentage of reduction or increasing in annual energy consumption for electricity, according to each scenario, for each case study, in (%).

Source: The author, 2023.

The electricity consumption reduction was higher in study case (D) compared to cases (A) and (B) in scenario (P.R.5), unlike in scenarios (P.R.3) and (P.R.4). This can be explained by the larger potential for cumulative solar energy over more surfaces that archetype (D) can provide as compared to the other two scenarios. This is attributed to the height of archetype (D) and the absence of surrounding disruptions.

Scenario (P.R.6) sees an increase in electricity consumption due to the replacement of the initial natural gas-based supply system with electric boilers. According to the energy analysis in (Figure VII.13), archetypes (D and B), which have the highest hot water demand per unit area, also logically contribute to a higher amount of electricity consumption in this scenario.

Due to the low electrical consumption per unit area in cases (C) and (B), and the smaller volume of the latter, the percentage of reduction was higher in these two cases compared to the other two cases, as per scenario (P.R.7).

Regarding scenario (P.R.9), Case Study (B) demonstrated a significant reduction in electrical consumption compared to other cases, due to the roof available surface's substantial importance in relation to the building's overall volume, unlike the other cases where the size of the roof was reduced in relation to the volume of the building as mentioned before.

The (Figure VII.26) below shows the percentage of reduction in total annual energy consumption according to each scenario, for each case study.

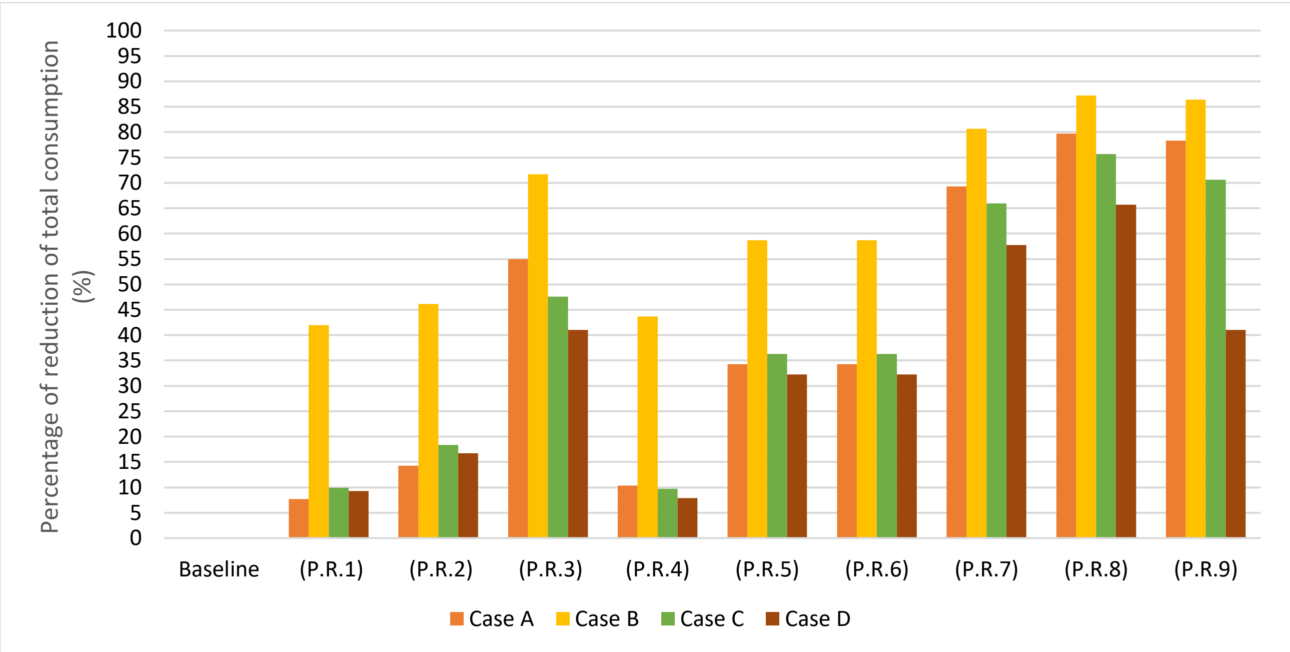


Figure VII. 26. Percentage of reduction in total annual energy consumption according to each scenario, for each case study, in (%).

Source: The author, 2023.

The diagrams illustrating the total energy usage reduction imply that Study Case (B) has a higher reduction in energy across all scenarios. This was due to the effectiveness of double and triple glazing in shielding the internal environment from external weather fluctuations is the reason behind this. It should be remembered that the context of this case study is the most sensitive to the prevailing cold winds. Also, the small size of the building envelope can greatly benefit from the integration of solar panels on the roof, seeing the ratio of roof area to building volume is greatest in this case (B).

In contrast, study case (D) experienced the lowest reduction in total energy consumption across nearly all scenarios. This can be attributed to the roof's small size relative to its height and volume, and the vertical extension which creates a masking effect and diminishes available surface area for panel integration. Additionally, archetype (D) is situated in a context that is highly protected from typical winter winds, which led to a lower effect of multi glazing windows.

To investigate the fluctuation in the electrical and thermal energy generated by the hybrid PVT system during each month of the year, and to analyse the various scenarios (P.R.3, P.R.4, P.R.5 and P.R.9), which are associated with the integration of this type of solar panels, a simulation of the monthly electrical and thermal energy production was carried out for the four cases studied and is presented in figures (VII.27), (VII.28), (VII.29) and (VII.30).

For scenarios (P.R.3) and (P.R.9), the data show that energy production, both thermal and electrical, increases during the hot summer period, with very high thermal production compared to electrical production, where production peaks were during the months (June, July and August). Conversely, both thermal and electrical generation fall during the winter months, with thermal generation particularly affected. The coldest periods of the year (January and December) saw the lowest levels of thermal power generation.

In contrast, when the panels are mounted on the southern facade, electricity production significantly outweighs thermal production in both (P.R.4) and (P.R.5) scenarios. Electricity generation significantly increases during winter compared to other times of the year or roof-mounted panel integration during the same period. Conversely, it decreases during summer. Thermal generation increases slightly in summer and decreases moderately in winter but to a much lesser extent than in scenarios (P.R.3) and (P.R.9).

Electricity production exceeds thermal production in scenarios (P.R.4) and (P.R.5). This suggests a direct correlation between electricity production and monthly total energy requirements. The suitable combination, is to use electrical appliances for heating or even hot-water boilers as seen in (P.R.6). However, the electricity output per surface unit, from the panel on the south-facing façade, was significantly lower than the thermal output from the panel on the roof, even at its peak.

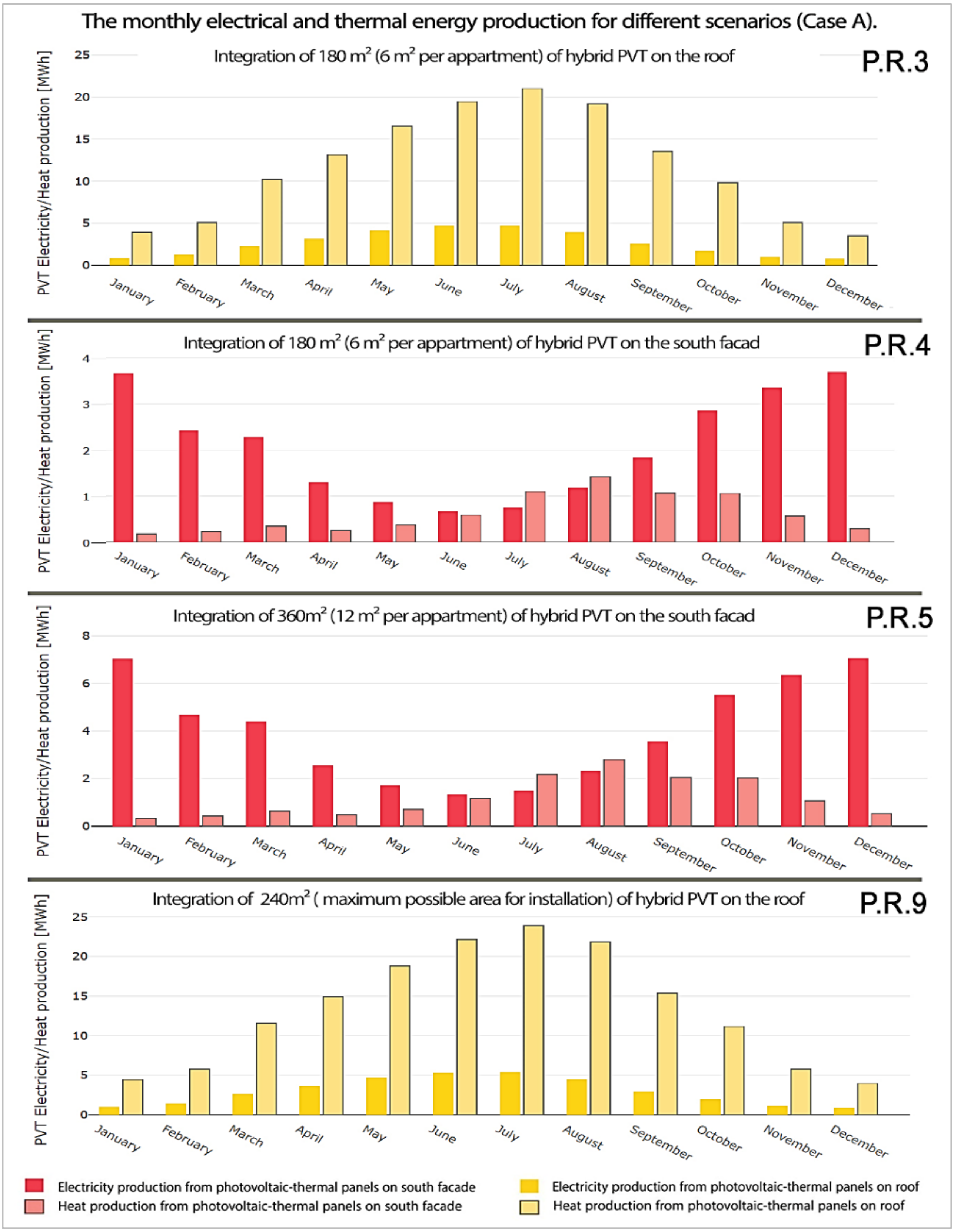


Figure VII. 27. Monthly electrical and thermal production for scenarios (P.R.3, P.R.4, P.R.5 and P.R.9), through the year, in case study (A).

Source: The author, 2023.

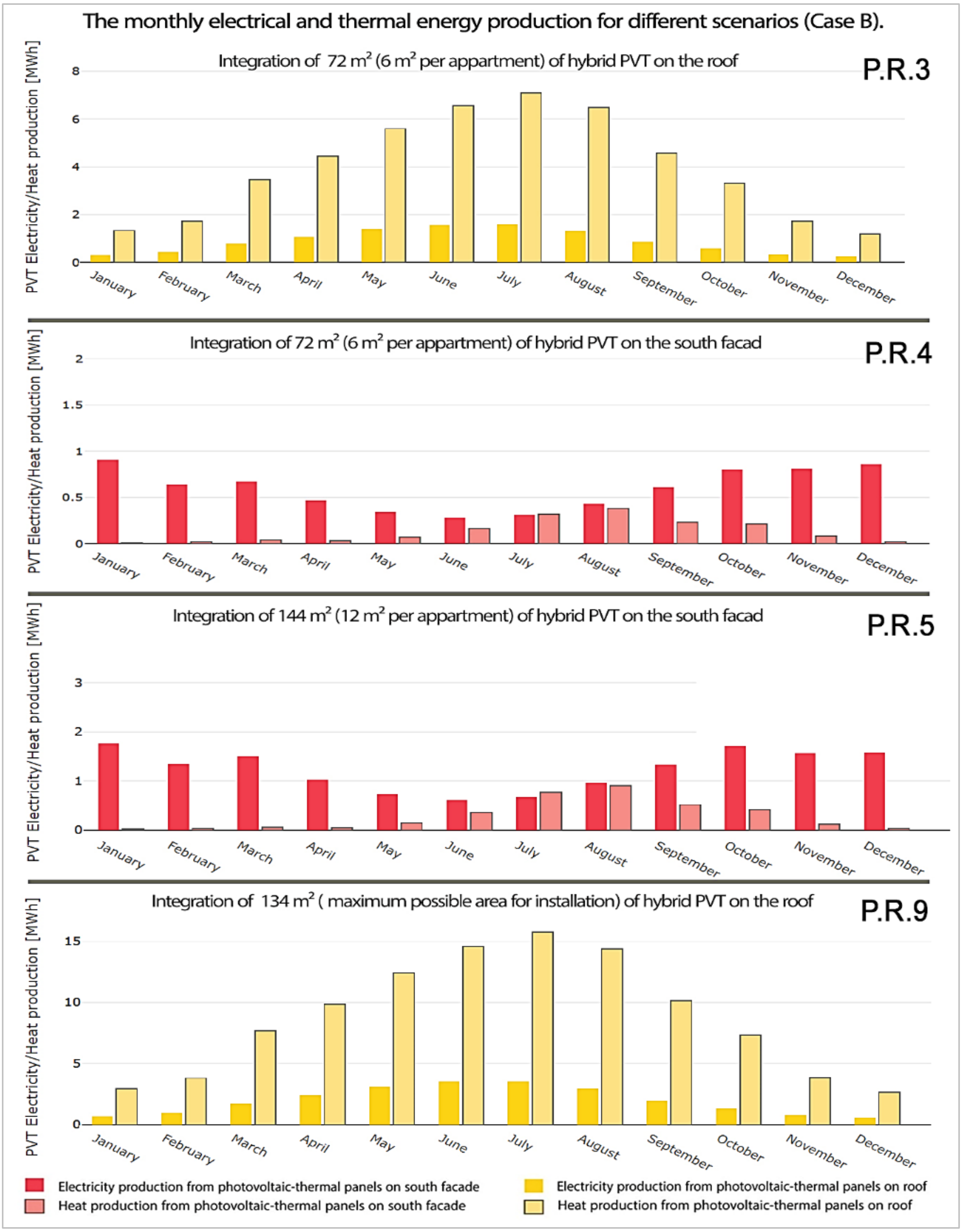


Figure VII. 28. Monthly electrical and thermal production for scenarios (P.R.3, P.R.4, P.R.5 and P.R.9), through the year, in case study (B).

Source: The author, 2023.

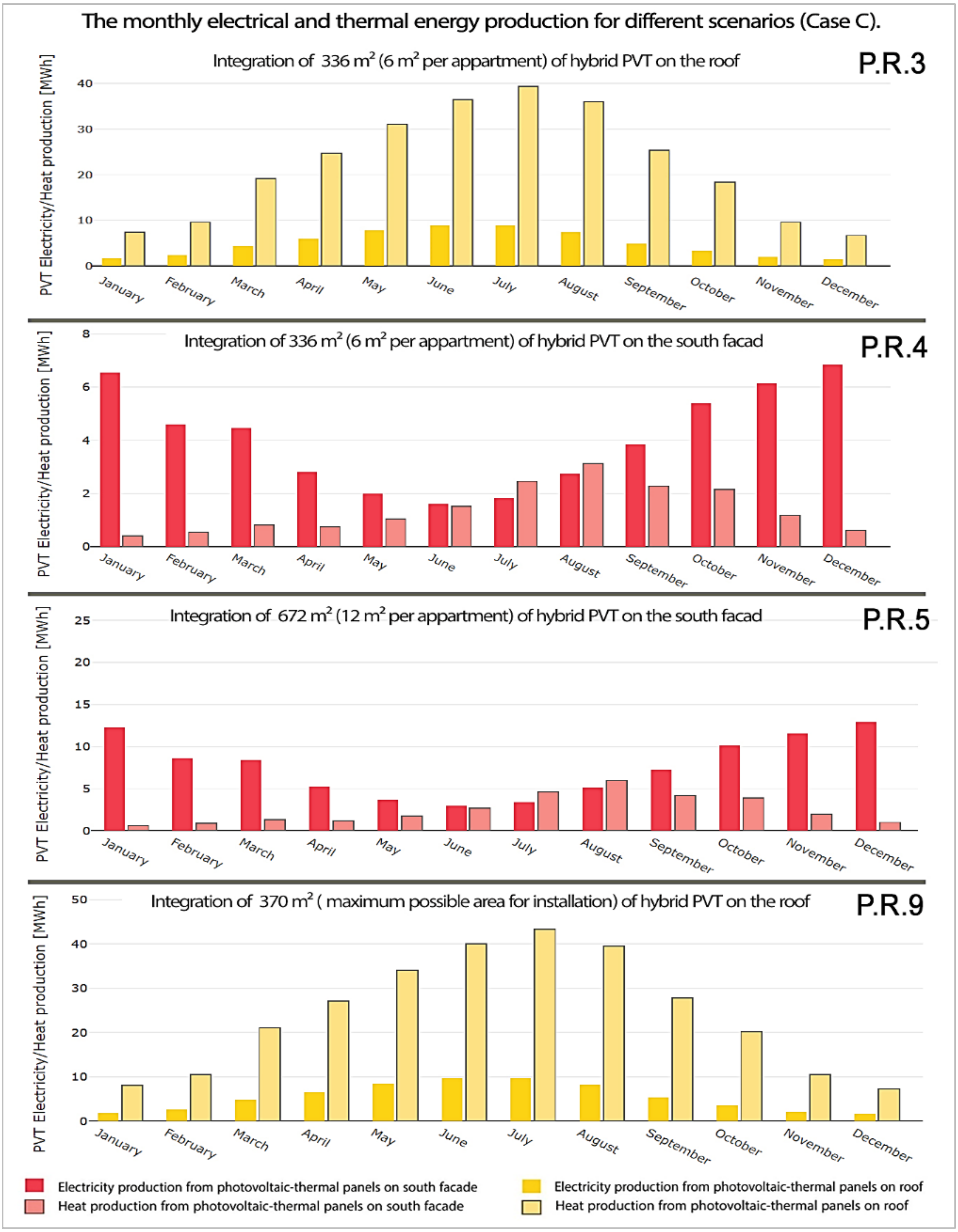


Figure VII. 29. Monthly electrical and thermal production for scenarios (P.R.3, P.R.4, P.R.5 and P.R.9), through the year, in case study (C).

Source: The author, 2023.

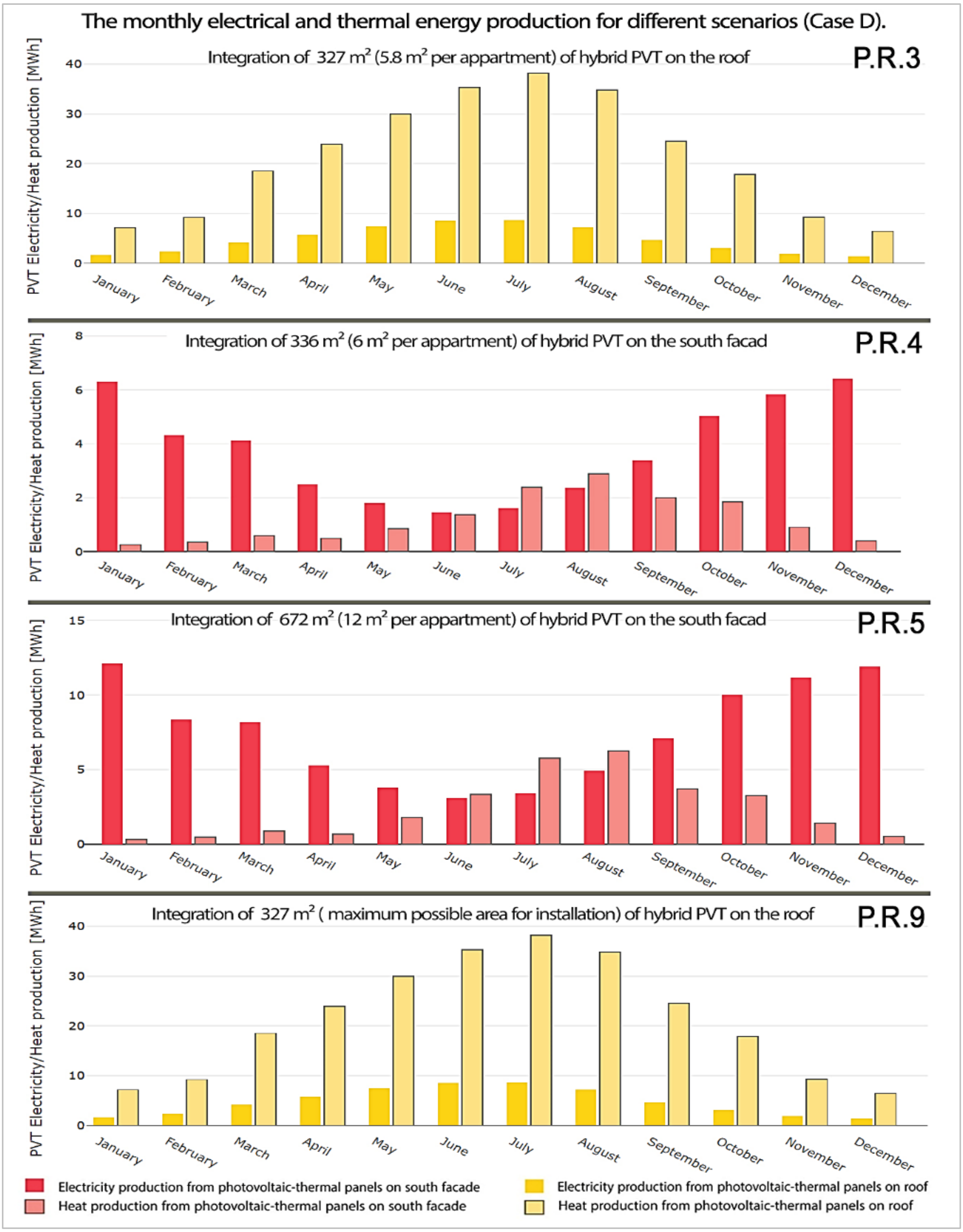


Figure VII. 30. Monthly electrical and thermal production for scenarios (P.R.3, P.R.4, P.R.5 and P.R.9), through the year, in case study (D).

Source: The author, 2023.

The energy analysis showed that the highest quantity of energy was used for heating and domestic hot water requirements, and that the production of thermal energy was very significant in the case of implementation of solar panels on the roof, but according to the graphs just above, there was an inverse correlation between monthly production and consumption, where the thermal production was minimal at the time when the thermal demand was at its peak, and vice versa; the thermal production was significant during the summer when the demand for it was very low.

It was therefore vital to find a means of responding to this disparity and fully utilize the enormous available thermal potential. The primary challenge associated with using solar energy as a renewable energy source centres on the disparity between its maximum availability during summer and when demand for it peaks during winter.

Seasonal Thermal Energy Storage (STES) seems to be an appropriate solution for addressing the mismatch between demand and supply for heating and even cooling (Ocłoń et al., 2023).

In the STES system, thermal energy produced primarily from sustainable and renewable sources is harvested and accumulated in the summer for use in the winter. This helps supplement and adjust the heat supply system and has the potential to coordinate the seasonal variation between heat supply as well as heat demand (Hesaraki et al., 2015) and further improve the overall efficiency of the heating system (de Gracia & Cabeza, 2015).

The STES concepts can be categorized into three primary types, depending on their storage mechanisms: sensible heat storage (SHS), latent heat storage (LHS), and thermochemical heat storage (THS) (Yang et al., 2021), and they are schematized in (Figure VII.31).

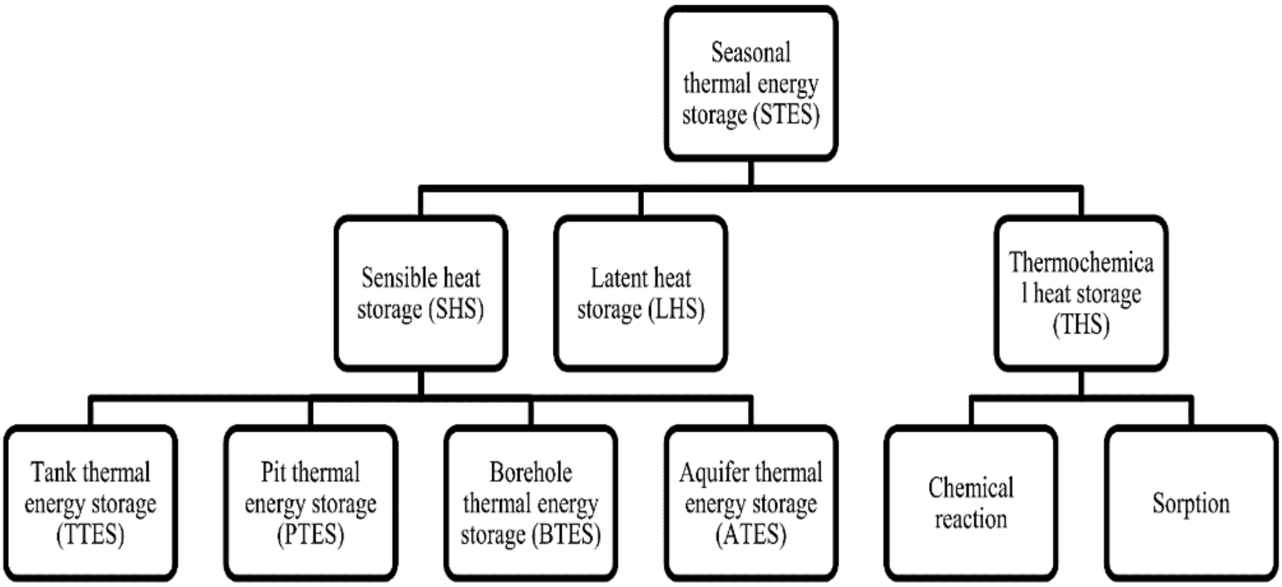


Figure VII. 31. Schematization of existent STES technologies.

Source: (Yang et al., 2021).

As example of system that belongs to this storage method, holes are excavated and drilled into the ground to insert vertical or horizontal tubes. This system is also known as borehole thermal energy storage (BTES) or duct heat storage in certain literature (Schmidt et al., 2003). The inserted tubes function as a heat exchanger, the free ground is the storage body (in Sweden as example, crystalline granite with little fracturing is more frequent (Gustafsson et al., 2010)), and water is employed as the transfer medium. Water-saturated clay as well as clay stones are appropriate materials for BTES due to their high thermal capacity and ability to prevent groundwater flow (Givoni, 1977).

A BTES, as schematized is (Figure VII.32), is an underground structure designed to store vast amounts of solar heat collected during summer months for use in winter. In essence, it functions as a giant underground heat exchanger.

A BTES comprises numerous boreholes that resemble typical drilled wells, each fitted with a polyethylene pipe featuring a "U" bend at its base, inserted after the drilling process. The borehole is then sealed with an exceptionally heat-conductive grout material to facilitate efficient heat transfer with the neighbouring soil (Gehlin, 2016).

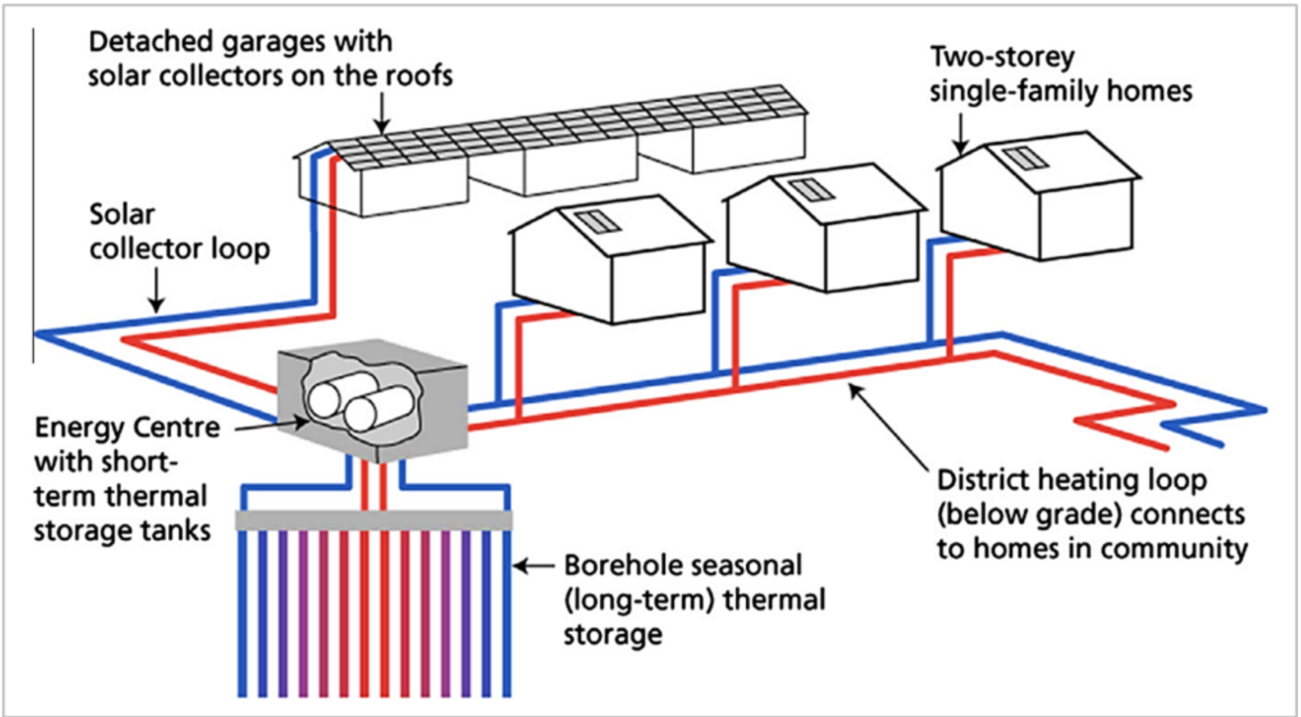


Figure VII. 32. Solar Seasonal Storage through a borehole thermal energy storage (BTES) system. Source: (Xu et al., 2014).

The illustration (Figure VII.33) below provides a comprehensive representation of this system. Part (a) displays the layout of the boreholes, which include ten circuits linked in parallel to the primary header, while part (b) displays each circuit, which includes 9 boreholes linked in parallel.

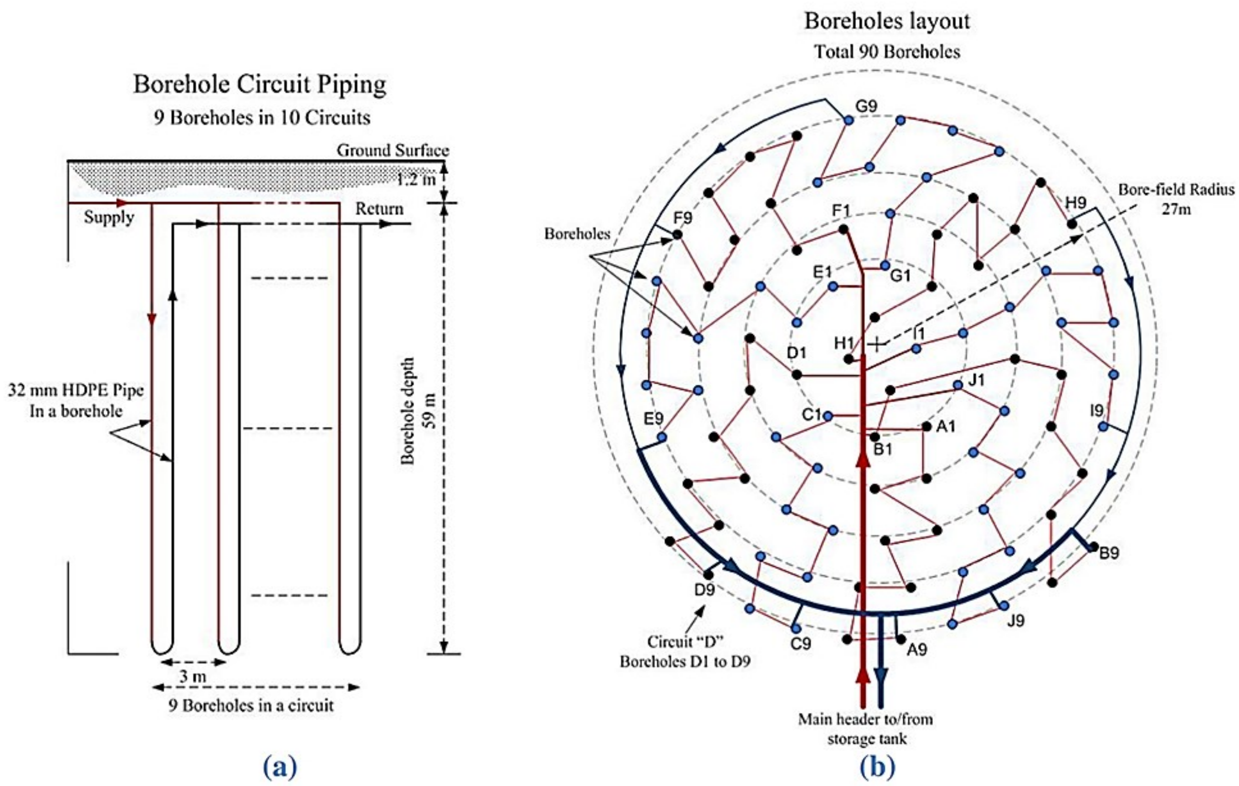


Figure VII. 33. Detailed schematization of boreholes circuit piping, as well as layout.

Source : (Rad et al., 2017).

VII.3.2. Environmental analysis

To examine how ecological improvement is affected by each individual or multiple intervention measures in each study case, the graphs in (Figure VII.34) have been produced to show the percentage reduction in operational carbon emissions in each case after each renovation scenario. The initial observation is that the production of greenhouse gases during the operational phase is entirely linked to the use of natural gas, when its combustion generates CO2, so the factors that have affected the consumption of natural gas and explained in the previous section are the same ones that affect the production of greenhouse gases.

Replacing single glazing with double glazing led to an annual reduction of greenhouse gas emissions of between 12% and 20%. This percentage increased to between 21% and 30% after replacing the double glazing with triple glazing.

The study utilized PVT hybrid solar panels on roofs measuring an average surface area of 6m² per apartment, resulting in reductions of 28 to 58%.

The (P.R.4) scenario showed comparatively minimal reduction in carbon emissions among all scenarios where the integration of hybrid solar panels was on south-facing facades, with its contribution in all study cases not exceeding 3 to 4%.

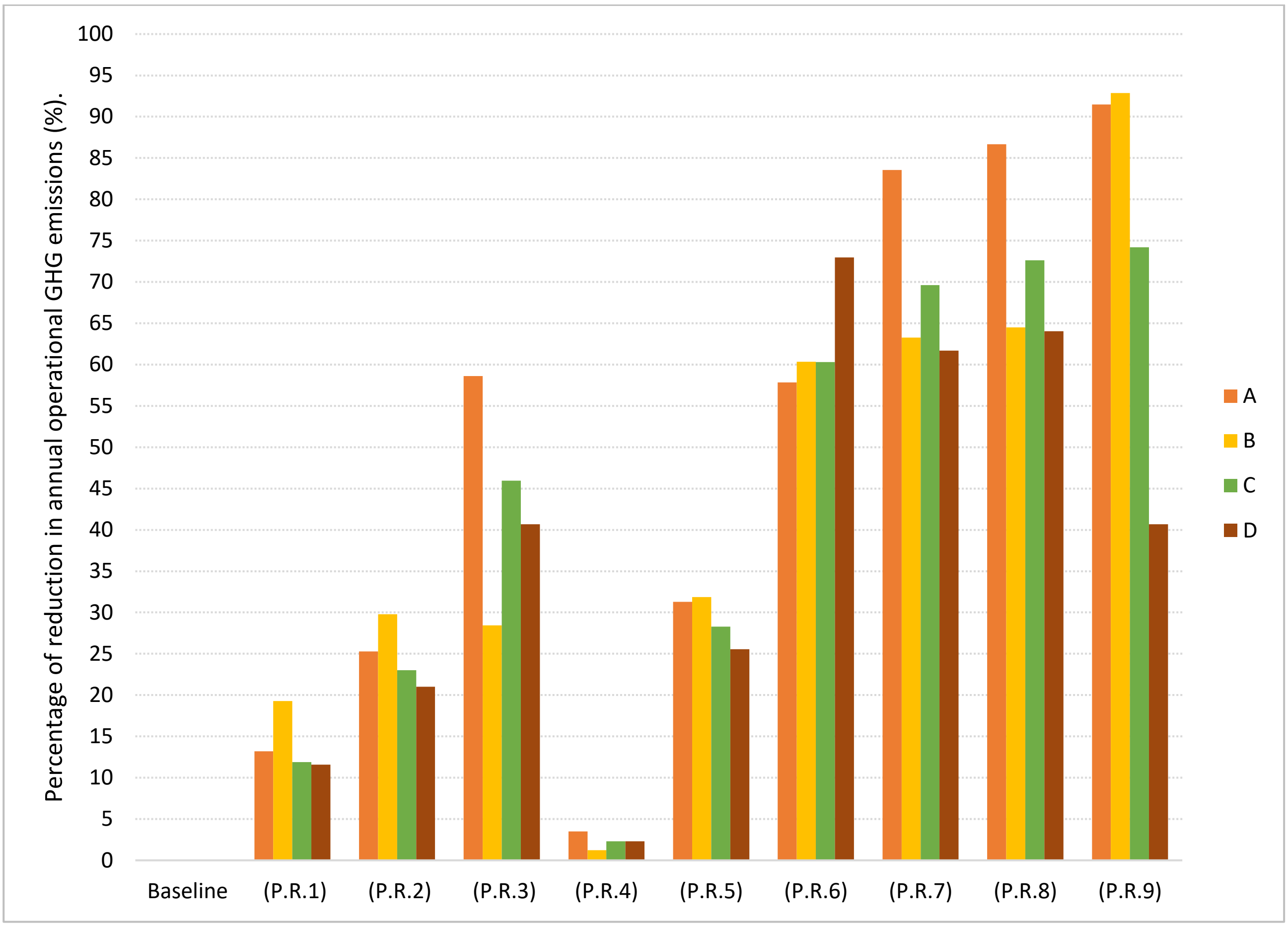


Figure VII. 34. Percentage of reduction in annual operational greenhouse gas emissions (CO2), according to each scenario, for each case study, in (%).

Source: The author, 2023.

The integration of various renovation measures (P.R.5, P.R.6, P.R.7, P.R.8 and P.R.9) resulted in substantial ecological improvements ranging from 25% in the worst case (P.R.5), to 93% in the best one (P.R.9), in which the hybrid PVT panels were integrated into the entire roof surface, generating enormous thermal energy that almost completely substituted the demand for hot water and heating, which was significantly reduced also by the use of triple glazing. This combination resulted in letting the archetypes in cases (A) and (B) becoming nearly zero carbon emitters.

VII.3.3. Energy and environmental evaluation against European benchmarks

To evaluate the energy and environmental status of the archetypes after various energy renovation scenarios, the tables (Table VII.8), (Table VII.9), (Table VII.10) and (Table VII.11) below include a comparison of their energy consumption and annual carbon emissions per unit area against European standards, specifically French, Italian and Spanish.

Table VII. 8. Energy and environmental classification of the archetype (A), according to each scenario by comparison with the European benchmarks.

Case A scenarios	Total fossil energy use after mix (Year 2021) (MWH/year)	Total fossil energy use after mix (Year 2021) (KWH/m²/year)	Energetic class			Total annual operational GHG emissions (ton of CO2)	Total annual operational GHG emissions (Kg of CO2/m2)	Environmental class	
			FR	IT	SP			FR	SP
Baseline	312.4	107.23	C	C	D	68.72	21.23	C	D
(P.R.1)	288.3	98.96	B	C	D	59.66	18.43	C	C
(P.R.2)	267.76	91.91	B	C	C	51.33	15.86	C	C
(P.R.3)	140.66	48.28	A	B	B	28.45	8.79	B	B
(P.R.4)	280.03	96.12	B	C	D	66.33	20.49	C	C
(P.R.5)	205.43	70.51	A	B	C	47.24	14.59	C	C
(P.R.6)	205.44	70.52	A	B	C	28.98	8.95	B	B
(P.R.7)	96.02	32.96	A	A	A	11.30	3.49	A	A
(P.R.8)	63.45	21.78	A	A+	A	9.17	2.83	A	A
(P.R.9)	67.67	23.23	A	A+	A	5.87	1.81	A	A

In relation to case study (A), there was a variation in the degree of energy improvement. It was considered to be at its best during scenarios (P.R.3, P.R.5, P.R.6, P.R.7, P.R.8, and P.R.9) as defined the French standard. However, according to the Italian and Spanish standards, the building energy state was only optimal during scenarios (P.R.7, P.R.8, and P.R.9). In terms of ecological improvement, the annual carbon emissions per unit area in archetype (A) were only optimal during the scenarios (P.R.7, P.R.8 and P.R.9), according to the French and Spanish benchmarks.

Table VII. 9. Energy and environmental classification of the archetype (B), according to each scenario by comparison with the European benchmarks.

Case B scenarios	Total fossil energy use after mix (Year 2021) (MWH/year)	Total fossil energy use after mix (Year 2021) (KWH/m²/year)	Energetic class			Total annual operational GHG emissions (ton of CO2)	Total annual operational GHG emissions (Kg of CO2/m2)	Environmental class	
			FR	IT	SP			FR	SP
Baseline	191.67	153.24	C	D	E	47.65	38.16	D	E
(P.R.1)	159.49	127.51	C	C	D	38.46	30.80	C	D
(P.R.2)	142.39	113.84	C	C	D	33.45	26.79	C	D
(P.R.3)	133.63	106.84	B	C	D	34.10	27.31	C	D
(P.R.4)	180.63	144.41	C	D	E	47.07	37.69	D	E
(P.R.5)	124.13	99.24	B	C	D	32.47	26.00	C	D
(P.R.6)	124.13	99.24	B	C	D	18.91	15.14	C	C
(P.R.7)	74.03	59.19	A	B	B	17.49	14.01	C	C
(P.R.8)	62.99	50.36	A	B	B	16.92	13.55	C	B
(P.R.9)	13.57	10.85	A	A+	A	3.40	2.72	A	A

Archetype (B) was initially regarded as a medium-energy consumer in accordance with French and Italian standards and a high energy consumer according to the Spanish standard in its baseline state. After exploring various scenarios, it was classified into better energy classes, but only after the renovation scenarios (P.R.7, P.R.8, and P.R.9) did it become classified as a high-energy performance archetype in line with the French standard, and solely after the scenario (P.R.9) as according to the Italian and Spanish standards.

The high level of ecological performance was achieved only after implementing scenario P.R.9 according to the French and the Spanish benchmarks, after it was classified as medium, or as major polluter according to the same benchmarks consecutively.

Table VII. 10. Energy and environmental classification of the archetype (C), according to each scenario by comparison with the European benchmarks.

Case C Scenarios	Total fossil energy use after mix (Year 2021) (MWH/year)	Total fossil energy use after mix (Year 2021) (KWH/m²/year)	Energetic class			Total annual operational GHG emissions (ton of CO2)	Total annual operational GHG emissions (Kg of CO2/m2)	Environmental class	
			FR	IT	SP			FR	SP
Baseline	676.62	78.61	B	B	C	161.09	17.74	C	C
(P.R.1)	609.61	70.83	A	B	C	141.91	15.63	C	C
(P.R.2)	552.56	64.19	A	B	C	124.05	13.66	C	C
(P.R.3)	354.56	41.19	A	B	B	87.04	9.59	B	B
(P.R.4)	610.93	70.98	A	B	C	157.32	17.33	C	C
(P.R.5)	431.23	50.10	A	B	B	115.53	12.72	C	B
(P.R.6)	431.23	50.10	A	B	B	63.94	7.04	B	A
(P.R.7)	230.50	26.78	A	A	A	48.95	5.39	A	A
(P.R.8)	164.81	19.15	A	A+	A	44.13	4.86	A	A
(P.R.9)	198.72	23.09	A	A+	A	41.55	4.58	A	A

With reference to the archetype (C), it demonstrated a good energy performance according to the French and Italian standards, but it belongs to an energy class of medium performance according to Spanish benchmark. However, following all energy renovation scenarios, the prototype has been upgraded to achieve high-level energy performance in line with French standards.

Nevertheless, the attainment of the optimal energy class in accordance with Italian and Spanish standards was not reached until the application of the scenarios (P.R.7, P.R.8 and P.R.9).

Concerning the ecological state, this archetype was classified as an average carbon emitter, but after the renovation scenarios it became high performant building ecologically after (P.R.7, P.R.8 and P.R.9) scenarios, according to the French standard, but also after (P.R.6) scenario according to Spanish standard.

Table VII. 11. Energy and environmental classification of the archetype (D), according to each scenario by comparison with the European benchmarks.

Case D Scenarios	Total fossil energy use after mix (Year 2021) (MWH/year)	Total fossil energy use after mix (Year 2021) (KWH/m²/year)	Energetic class			Total annual operational GHG emissions (ton of CO2)	Total annual operational GHG emissions (Kg of CO2/m2)	Environmental class	
			FR	**IT**	**SP**			**FR**	**SP**
Baseline	760.17	104.5396	B	C	D	178.62	22.93	C	C
(P.R.1)	689.53	94.82507	B	C	D	157.93	20.27	C	C
(P.R.2)	632.95	87.04412	B	C	C	141.07	18.11	C	C
(P.R.3)	448.45	61.67143	A	B	C	105.95	13.60	C	C
(P.R.4)	700.17	96.2883	B	C	D	174.49	22.40	C	C
(P.R.5)	515.14	70.84273	A	B	C	132.98	17.07	C	C
(P.R.6)	515.14	70.84273	A	B	C	48.33	6.20	A	A
(P.R.7)	321.1	44.15809	A	B	B	68.40	8.78	B	B
(P.R.8)	260.97	35.88894	A	A	A	64.28	8.25	B	B
(P.R.9)	448.45	61.67143	A	B	C	105.95	13.60	C	C

For case study (D), the building was initially classified as having good energy performance according to French standards, but medium energy performance according to Italian and Spanish standards. After implementing various renovation scenarios, the performance of the system improved optimally according to the French standard, specifically through the (P.R.3, P.R.5, P.R.6, P.R.7, P.R.8 and P.R.9) scenarios. But as regards the Italian and Spanish standards, only the scenario (P.R.8) was efficient in allowing the building to achieve high energy performance.

Ecologically, the building was initially classified as having medium performance according to both French and Spanish standards. After undergoing different scenarios, it maintained its classification, except for the (P.R.7 and P.R.8) scenarios where it achieved a good rating, and the (P.R.6) scenario, where it attained the higher ecological classification.

The aforementioned indicates variations regarding the evaluation of buildings' energy and ecological performance among different standards. It has been demonstrated that the Spanish standard is more rigorous than the other two, while the French standard being less stringent, compared with the present study cases. This variation may stem from the fact that the standards are established according to specific contextual factors and local energy consumption rates in these countries.

However, all relevant standards concur that integrating PVT hybrid panels in the whole roof surface, coupling it with seasonal thermal storage systems and upgrading from single glazing to triple glazing yielded optimal results in 75% of the case studies, in terms of energy. The exception being case study (D), which featured a large volume archetype with an enormous annual gas consumption, and this was also because of an insufficient roof surface, exacerbated by the presence of a vertical extension accessing the terrace that created a solar mask.

In the case of archetype (D), the use of the most receptive surfaces with the help of 3D solar maps, in the roof (average of 6 m² per apartment), in addition to the south-facing facade (average of 6 m² per apartment), was more effective and made the building a very efficient performer energetically.

This last-mentioned scenario, abbreviated as (P.R.8), also made archetypes (A) and (C) a high-performance building, but it didn't give the same performance in archetype (B), due to its low height compared to the other two, which didn't offer enough high cumulative solar surfaces, and consequently a reduced solar energy production in the south-facing facades of this case.

Replacing simple glazing with triple glazing windows and integrating hybrid PVT with an average of 6m² per apartment, coupled with a seasonal thermal storage system, was sufficient and enough to make the archetypes (A) and (C) high performance buildings, which means that the intensification of the renovation energy measures is related to the needs of the building, and the achievement of great results with these fewer interventions in this scenario does not require the introduction of more interventions or the use of a greater number of panels.

From an environmental standpoint, case studies (A) and (C) showed high environmental performance after implementing scenarios (P.R.7), (P.R.8) and (P.R.9). However, in case study (B), only scenario (P.R.9) resulted in high performance, owing to the large amount of natural gas energy used per unit area in archetype (B). This called for greater intervention, necessitating the integration of higher number of solar panels on the roof.

Concerning the case study (D), the high ecological performance was after the launch of the scenario (P.R.6), where the supply system of the demand for domestic hot water was changed by electric boilers, this is met by the great need of the archetype (D) to domestic hot water, as the energy analysis of the initial state has indicated.

VII.4. Conclusion

This final chapter presents the main findings and outcomes of the various analyses that explored the effects of archetypes' morphological and contextual variables at different levels on energy consumption, GHG emissions and solar exposure in Skikda's collective housing buildings. It also assesses the level of effectiveness of several scenarios that included single or multiple energy renovation measures based on passive or active strategies, or both of them. The chapter commenced with a detailed topographical examination, and culminated in the identification of Archetype (B) as being the most exposed to the prevailing winter winds compared to the other cases. This analysis was complemented by a solar analysis, which showed that the topography of the site also plays an important role in determining the amount of solar energy incident on the site and on the internal and external surfaces of the building. The solar analysis presented evidence that the surrounding morphology and urban context impact the annual accumulation of solar energy per unit area. This effect decreases with increasing in the building's volume and space between it and other surroundings buildings, as well as reductions in the complexity of the envelope and the heights of surrounding buildings.

The CEA simulation generated a graph showing the amount of energy received by the different surfaces of the four building types per month. The graph shows that as the building rises, the roof becomes less important in terms of providing places for energy production, unlike the south-facing facades, which become more useful as the height of the building increases, particularly in winter. And on basis of this information, it was decided that the next step would be to integrate hybrid PVT panels into these two surfaces for energy retrofit scenarios.

An analysis of measured real data for the four cases studied showed that the energy consumption of gas was much greater than that of electricity, and that gas and electric consumption was generally greater in the oldest archetypes, which were built with less insulation capacity; except during the coldest periods where the highest gas consumption was in archetype (B), which is the most sensitive to prevailing winds in the context, although this building is the most recent by the way.

The analysis showed also a weak negative correlation between energy consumption and the amount of solar radiation incident on all four building archetypes per unit area, and this suggests that the shape of the building and its urban environment do not significantly impact energy consumption, in relation to the aforementioned factors.

Next, on the basis of the measured data, a Bayesian calibration of the study results was performed. This involved conducting hundreds of simulations to reduce errors percentage within the acceptable intervals determined by annual, as well as monthly validation in accordance with ASHRAE guideline 14-2002.

The energy analysis simulation for the four case studies revealed that the greatest energy demand was for heating and domestic hot water supply. These requirements were predominantly supplied by natural gas, which is harmful to human health and the natural environment when burned. Whilst the electricity consumption, encompassing the requirements for lighting, cooling and various household appliances, was minimal.

The polynomial regression related to the hours of use of heating and air conditioning in their appropriate periods within the optimal temperature range, showed that the use of heating was excessive, and exceeded their necessary thresholds. on the other hand, the use of air conditioning was very minimal. this may be because of the behaviour of the inhabitants, their lifestyles and their preferences, or perhaps for economic reasons.

The analysis and environmental assessment of the archetypes' initial-state using European standards revealed that they are classified as medium greenhouse gas emitters, with no over-performance, nor over-emission of carbon.

On the scale of apartments belonging to the same buildings, the analysis showed that the apartments located on the lower floor consume more than those located on the intermediate and the upper floors, and that the apartments with a north-facing orientation consume more than those with a south-facing orientation, confirming the negative correlation between the accessibility of solar radiation and energy consumption.

The evaluation of the energy usage for the 21 apartments demonstrated that the majority of them are graded as average consumers, with the remainder being categorized as high energy wasters.

Following the assessment of the baseline situation, several energy renovation scenarios were launched, some of which were individual, such as the interventions that, by changing the type of glazing to other more thermally efficient types (double and triple glazing), resulted in good reductions in gas consumption, where this reduction was highest in study case B, where the building is in the context most sensitive to the prevailing winter winds. In contrast, the use of these two types of glazing led to higher electricity usage as they dimmed the natural light with their added glass layers, thereby increasing the need for artificial lighting.

Interventions also included the combination of hybrid PVT panels, placed on the roof or south-facing wall. Comparing their energy production revealed that the thermal output was notably higher with roof placement, rather than on the south facade, when using the same panel surface area. Electrical production was almost the same, with a slight increase found in the roof arrangement. The addition of solar panel surfaces on the south facade has led to an increasing in electrical energy production more than thermal energy. All that precedes, states that hybrid PVT electrical production is much more related to the quantity of solar panels in terms of surface, while its thermal production is much more related to the quantity of solar energy accumulated on the surface over time, recalling that the annual cumulative insolation rate is greater on roofs than on the facades.

The thermal monthly production of this panels is in negative correlation with heating needs which suggested the use of seasonal thermal energy system.

The use of many interventions in one scenario led to higher levels of performance in terms of energy and ecology, where energy consumption and ecology footprints were near to zero in some cases.

The efficiency and impact of renovations aimed at reducing heat loss through thermal insulation of a building's envelope depend largely on the degree of exposure to external climatic variations and the level of protection from prevailing winds, whether natural or obstructed by urban structures. Conversely, the production of energy using PVT hybrid panels is highly dependent on the building envelope itself and its morphology. This fragment considers various factors, such as the height of the buildings, the surface area of the roofs and their capacity to accommodate solar panels.

In summary, this study took many factors as many scales and their analysis showed that the topographical, urban, solar and behavioural aspects of the inhabitants were interconnected and affected energy consumption and the state of the environment. Each archetype is characterized by its unique envelope and urban/topographical context. As a result, these archetypes respond differently to the same scenarios.

The best scenario for one archetype may not be the best for others. The sufficient combination with lower requirements, and high energy and environmental performance (on the basis of the chosen European benchmarks) is to use triple glazing paired with hybrid PVT solar panels on the roofs, requiring an average of 6 m² of roof space per apartment for cases (A and C), and 12 m² per apartment for case (B). Concerning case study (D), the most environmentally friendly choice was the installation of high surface panels measuring 12 m² per apartment on the south-facing facade, along with the adoption of electrical boilers for hot water supply. Nevertheless, the most energy-efficient solution for archetype (D), it was optimal to divide this same surface area equally between the roof space and the south-facing facade. The integration strategy of this hybrid PVT should be accompanied by a thermal storage system.

The synergy between the various measures, the extent to which they are used, their careful selection and the strategic positioning of the hybrid PVT panels have been highly decisive and beneficial, leading to better energy and environmental results.

GENERAL CONCLUSION

1- General conclusion

The main objective of this present research was to analyse and evaluate the initial energy and environmental status of the collective housing in the Algerian city of Skikda, as well as its status after interventions according to hybrid renovation scenarios. The analysis of energy consumption and production, as well as carbon emissions, were based on linking them with spatial factors such as solar access, building morphology, and variances in urban and topographical contexts.

The study has been conducted in four collective housing buildings with varying morphologies, located in four different topographically and urbanistically distinct sites. The case studies include: case study A (Khaldi brothers' neighbourhood), case study B (Messiouene neighbourhood), case study C (Merdj-eddib AADL neighbourhood), case study D (Saadi brothers' neighbourhood).

The investigation began with a thorough reading and analysis of previous research on energy and ecology in the building sector.

After completing this step, the research questions, the hypothesis as well as objectives were defined, and a typo morphological study of all the existing collective housing in the city of Skikda was carried out in order to select the four case studies mentioned above according to certain criteria, in particular: building height, complexity of the architectural envelope, height heterogeneity, distance between urban buildings, as well as the topography of the site and its surroundings.

Previous literature contributed to the development of the first four theoretical aspects, which focus on the primary layer of knowledge, that is the conceptual framework. This framework presents the identification of energy-related concepts, alongside the historical evolution of its use and efficiency inside dwellings, as well as the various multi-scale factors that influence them. It also discusses international ecological issues, and the different conferences and institutions implicated in protecting and preserving earth and the living beings from pollutions along with greenhouse gases effects and repercussions. It similarly looked at urban areas that have a detrimental effect on the environment and contribute significantly to carbon emissions, particularly those linked to the construction sector, as well as the strategies and solutions planned for this sector.

To optimize energy performance and reduce ecological footprints, energy labels such as Passivhaus, Effinergie, Minergie, in addition to environmental labels such as BREEAM, HQE, and LEED have been created over the years. Certain types of energy-efficient buildings have been developed based on their energy consumption limits and the techniques and technologies they employ, notably, passive housing, NZEB, Positive-energy building, and BIPV....

Following this, the Algerian energy position was presented, along with the country's efforts and ambitions towards energy transition. The figures and data indicate that despite the immense renewable energy potential available in Algeria, particularly of solar origin, the largest share of energy production and use is still dependent on ephemeral and polluting fossil fuels. The data also revealed that although there are some projects and efforts, they still timid and mostly remain only on paper. Additionally, the data demonstrated that Algeria has adopted a gradual strategy based on long-term planning.

Finally, the concept of energy renovation was defined, including its objectives, types, stages, approaches, and methodological simulation tools. The analysis of previous research showed that different improvement measures have been effective in significantly reducing energy consumption and ecological footprint. This has been observed despite differences in the types of interventions, geographical contexts, and climate.

Moreover, a comprehensive analysis of the study context was conducted. This included a historical overview of the city of Skikda, as well as its meteorological and climatic characteristics. The types of residential structures present in the city were classified, and an overview of the city's big economic importance, and precariousness ecological and energetic status was shown. Then, the case studies were defined, and their location in relation to the city, the country, and the world was outlined.

After presenting the study context, the research methodology and investigation tools used were described. The workflow began by collecting data on the morphologies and different characteristics of buildings and their urban and topographical sites through specialized administrations, as well as field visits, and even by using Google Earth and existing topographical maps on Web sites. Then, through the existing commercial agencies of SONELGAZ in the city of Skikda, a collection of electricity and gas energy data was carried out. The energy historical data was in the form of quarterly bills. It was collected for some ground floor commercial and administrative premises, in addition to 21 apartments which are situated in the four buildings studied through sampling based on their height and orientation in relation to the four cardinal points.

This research utilised various computational simulation tools. Firstly, ArcGIS was used to model the geometry and geographical data of buildings. The generated files were then imported into Revit Autodesk tools in the form of 'Shapefile'. The objective was to produce 3D solar maps using the 'Insight 360' extension. This 'Shapefiles' were subsequently imported into the CEA simulation tool. The CEA tool utilises the reduced order UBEM approach, which considers the surrounding context and requires minimal data input. Concerning the climate data, they were provided by the METEONORM software package.

This was followed by an explanation of the various analyses of cases’ prior state that were carried out, notably the solar, topographical, energy and environmental analyses, as well as a description of the urban aspect of the four sites studied, after explaining the process of Bayesian calibration and both monthly and yearly validation of energy models by CEA, in addition to the polynomial regression of heating and air conditioning use behaviours, against actual energy data.

Then, a description was made for the energy renovation process used according to 9 scenarios of passive or active intervention only, or hybrid renovations which combine several improvement measures. This improvement measures were based on changing the type of existing single glazing to double and then to triple glazing, and integrating hybrid PVT solar panels, varying their locations and quantities according to different scenarios, and a change in the supply system for domestic heating and hot water was proposed in another scenario. The evaluation of the initial state, as well as the state after renovation was throughout using European standards, in particular French, Spanish and Italian; because of the close similarity of their climatic contexts to the context of the city of Skikda.

The last chapter, which provided the findings and interpretations, began with a detailed topographical assessment and determined consequently the Archetype (B) as being the most exposed to the prevailing winter winds when compared to the other examples.

This research was complemented by a solar analysis, which revealed that the topography of the site contributes significantly to influencing the amount of solar radiation incident on the site and on the interior and exterior surfaces of the structure; and also confirmed that urban factors have an influence on the yearly indoor and outdoor accumulation of solar energy per unit area too. This urban impact reduces as the volume of the building and the distance between it and the neighbouring structures rise, and as the complexity of the envelope and the heights of the surrounding buildings reduce.

The roof became less important in terms of the perception of stored energy as the structure became taller, although the importance became greater for the south-facing sides, especially in the winter period. Based on this knowledge, it was agreed that the next step would be to incorporate hybrid PVT panels into energy renovation scenarios using these two surfaces.

According to an analysis of measured real data for the four cases under study, gas use was much higher than electricity use, and both gas and electric consumption were generally higher in the oldest archetypes, which were constructed with less insulation capacity. The exception to this was during the coldest months, when the highest gas consumption was recorded in archetype (B), which is the most recent building but is also the most sensitive to the prevailing winds in the area. However, the building's shape and urban surroundings did not significantly affect energy consumption.

Heating and residential hot water supply accounted for the largest energy demand, according to the energy analysis simulation for the four case studies. The majority of these needs were met by burning natural gas, which is bad for both the environment and human health. While the amount of electricity used for lighting, air conditioning, and other domestic equipment was minimal.

According to the polynomial regression linked to the hours of use of air conditioning and heating in their respective times within the ideal temperature range, the use of heating was excessive and went above its required thresholds, in contrast to the use of air-conditioners, where the use was virtually little. This could be because to the way the locals live, their preferences, or their behaviours, or it could be for financial reasons.

With no overperformance or carbon over emission, the four archetypes are categorized as medium greenhouse gas emitters based on environmental assessment conducted using some European referential.

Other analysis confirmed the negative correlation between the accessibility of solar radiation and energy consumption on the scale of apartments within the same buildings. The apartments on the lower floors consumed more than those on the upper floors, and the apartments facing northward consumed more than those facing southward. The analysis of the energy consumption of the twenty-one apartments that fit into the four standard categories showed that most of them are classed as medium consumers, while the remaining dwellings are classified as high energy consumers.

After the baseline situation was evaluated, a number of energy renovation scenarios were introduced. In study case (B), however, this gas consumption reduction after adding high-performance windows was greatest because the building is situated in an area that is most vulnerable to the prevailing winter winds. On the other hand, because these two types of glazing lowered natural light levels with their additional glass layers, they increased the demand for artificial lighting, which in turn increased electricity use.

Hybrid PVT panels were mounted by scenarios on the south-facing wall or on roofs. By comparing their energy production, it was found that, for the same surface area of panels, thermal production was significantly higher when the panels were placed on the roofs rather than on the south-facing facade. Placing the panels on the roof resulted in a marginal increase in electricity production, which remained essentially the same as on the south-facing facade.

More electrical energy has increased as a result of the solar panel surfaces added to the south facade than thermal energy, which meant that the number of solar panels on a surface determines how much electricity is produced, whereas the cumulative insolation per unit area of solar energy that is produced over time determines how much thermal energy is produced, remembering that the rate of cumulative insolation is higher on roofs than it is on facades.

The adoption of seasonal thermal energy systems is recommended since there is a negative correlation between the thermal monthly production of these panels and heating demands.
The different comparisons between study cases' reactions to the different renovation scenarios showed that the effectiveness of thermal insulation renovations on a building's envelope depended largely on its exposure to external climatic variations, while the generation of energy using PVT hybrid panels is highly dependent on the building envelope and its morphology itself. When several interventions were used in one scenario, energy and ecological performance levels increased to the point where, in certain cases, energy consumption and ecological footprints were almost nil.
In closing, this study examined a wide range of variables at several scales, and its analysis revealed that the behavioural, urban, topographical and solar characteristics were interrelated and had an impact on environmental conditions and energy use. Each archetype is characterised by its envelope and its urban and topographical environment. As a result, these archetypes react differently to the same situations, where for some archetypes, a particular setting may not be as ideal as it is for another.
The findings of this scientific research, conducted at different stages, corroborate the hypothesis put forth at the outset of the thesis. It can be seen that the thermal characteristics and design of buildings, as well as their urban and topographical setting, affect sun access, energy usage, and carbon emissions. Furthermore, the results indicate that apartments on intermediate floors and those with southern exposure consume less energy. The research outcomes demonstrated also that the implementation of passive and active measures can significantly enhance the energy and environmental performance of residential buildings, with varying degrees of improvement contingent upon the characteristics of the urban environment and the specific intervention measure employed, even making it possible to achieve near-zero energy consumption and carbon emissions. Moreover, the integration of PVT hybrid panels, particularly on the roofs of collective housing buildings, has the potential to achieve exceptionally high levels of energy production and environmental performance.

In the light of climate change and energy issue, this study, which focused on Skikda's collective building stock, could offer Algerian energy decision-makers a vision for the future in terms of controlling energy consumption in one of the most energy-intensive industries, and reducing ecological footprint. A clean energy transition can also be facilitated by promoting the renovation of the urban stock by means of the synergy that could be through use of efficient appliances and boilers in the building sector, reinforcing the envelope, integrating renewable energy systems, and raising awareness among households, particularly in areas with significant solar potential.

2- Study limitations

The study was conducted from 2020 to 2022 and may not be representative of other periods in the past or distant future due to ongoing climate change.

Obtaining a significant amount of energy data was very hard, due to the consistent occupation of workers in SONELGAZ commercial agencies and the challenges associated with retrieving archives from the preceding two years for each quarter separately. Subsequently, energy data collection for the four archetypes used was based on sampling, obtaining energy consumption data from specific dwellings of different heights and orientations, and then deducting the total energy demand, which may introduce a degree of uncertainty as energy consumption varies from dwelling to dwelling and from individual to individual due to behavioural factors.

The CEA tool uses simplified archetypes as part of a reduced-order approach, but this may limit its ability to handle complex facades and roofs. The tool typically necessitates in-depth calibration using measured data.

It is important to note also that the METEONORM tool generates simulated climate data which does not reflect ideally real-time weather fluctuations.

The energy data from SONELGAZ were obtained quarterly, requiring division into monthly energy consumption based on climate data whilst considering possible uncertainties. This is necessary to validate monthly simulations of the CEA tool per the ASHRAE guideline 14-2002, which stipulates the use of either monthly or hourly data only. The values of factors related to occupant behaviour and habits, and which influence energy consumption, are unknown and undefined beforehand, which required the extraction of correlated values of setpoint temperatures and weekly hours of use through polynomial regression, for both heating and cooling needs.

The absence of an Algerian energy and environmental benchmark is considered one of the limitations of this study, which led to the use of benchmarks from other countries, like European ones, with a climate similar to the climatic context of the extreme northern Algeria.

The energy and environmental classifications of the same apartments or buildings were varied across these European benchmarks employed, in some cases. This highlights the need and significance of creating benchmarks and labels tailored to the Algerian context, considering the various aspects involved.

3- Future perspectives

An accurate analysis of the initial state is crucial for selecting the right measures. However, it is equally important to determine the optimal combination of measures, their respective locations and the appropriate auxiliary systems that compliment them, to achieve the best outcomes in energy and ecology, conducive to sustainable development. This also should include consideration of economic and social aspects. These factors must be evaluated and factored into future research, comprising short- and long-term cost-benefit studies, alongside sociological studies exploring occupants' attitudes towards these innovative interventions and renewable energy technologies.

The simulation tools utilised do not account for the impact of trees on shading and microclimates. As the absence or minimal presence of trees in the four cases studied had little influence. A combination method of these tools and those incorporating vegetation effects would be intriguing to get more precise simulation results, particularly for situations with significant tree presence in terms of both size and quantity.

This multiscale study was conducted in a singular city and within a singular climatic context. Future research, which bases on multiscale reflection also, and considers case studies in various climatic contexts, may reveal new conclusions and insights.

The energy analysis of the initial state as well as after the renovation can be carried out on a larger scale, extending even to the scale of the whole city, which put the research of some methods and approaches based on this kind of simulation tools, interesting to make delicate planification or renovations, for more sustainable cities.

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APPENDICES

Appendix 1: typographical morphological analysis of existing habitats in the town of Skikda.

Typological classifications	Maps of building typologies	Photographic shots of the facades
“Frères Saadi” neighbourhood (1982). **Number of storeys:** R+14. **Typology’s urban form:** isolated buildings. **Urban layout:** Free. **Ground floor function:** commercial function. **Orientation of main facades:** east/west. **Type of roof:** flat, inaccessible. **Balcony type:** Loggias. **Facade overhangs:** extensive. **External joinery:** Aluminium or wood. **Construction system:** PASCAL’S heavy prefabrication process.		
“Frères Saadi” neighbourhood (1982). **Number of storeys:** R+4 and R+3. **Typology’s urban form:** isolated buildings. **Urban layout:** Free. **Ground floor function:** habitation. **Orientation of main facades:** east/west and North/ south. **Type of roof:** flat, inaccessible. **Balcony type:** Loggias. **Facade overhangs:** very few. **External joinery:** Aluminium or wood. **Construction system:** PASCAL’S heavy prefabrication process.		
“Frères Saadi” neighbourhood (1982). **Number of storeys:** R+7. **Typology’s urban form:** isolated buildings. **Urban distribution:** Linear. **Ground floor function:** commercial function. **Orientation of main facades:** east-west. **Type of roof:** flat, inaccessible. **Balcony type:** Loggias. **Facade overhangs:** medium. **External joinery:** Aluminium or wood. **Construction system:** PASCAL’S heavy prefabrication process.		
“Frères Saadi” neighbourhood. **Number of storeys:** R+5. **Typology’s urban form:** adjoining buildings forming an "L" shape. **Ground floor function:** commercial function. **Orientation of main facades:** east-west. **Type of roof:** flat, inaccessible. **Balcony type:** cantilever balcony + Loggias. **Facade overhangs:** few. **External joinery:** Aluminium or wood. **Construction system:** column-beam system.		
The Saker brothers’ estate. **Number of storeys**: R+7. **Typology’s urban form:** slab urbanism. **Distribution: almost linear.** **Ground floor function:** commercial function. **Orientation of main facades:** east-west. **Roof type:** flat, inaccessible. **Balcony type:** Loggias and cantilever. balconies. **Facade overhangs:** medium. **External joinery:** Aluminium or wood. **Construction system:** PASCAL’S heavy prefabrication process.		

The Saker brothers' estate.
Number of storeys: R+5.
Typology's urban form: isolated buildings.
Distribution: unrestricted.
Ground floor function: habitation function.
Orientation of main facades: east/west.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.


The Saker brothers' estate.
Number of storeys: R+5.
Typology's urban form: isolated or semi-detached buildings in the form of bars.
Distribution: open urban blocks.
Ground floor function: residential or commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.


The Saker brothers' estate.
Number of storeys: R+7.
Typology's urban form: slab urbanism.
Function ground floor + 1st floor: commercial function.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.


The Saker brothers' estate.
Number of storeys: R+5.
Typology's urban form: L-shaped typology**.**
Ground floor function: commercial function.
Orientation of main facades: east/west and north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilevered balconies and loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.


20th August 1955 estate.
Number of storeys: R+4.
Typology's urban form: isolated buildings.
Urban distribution: Free distribution.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible**.**
Balcony type: loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.


Salah Boulekaroua housing estate.
Number of floors: R+4.
Typology's urban form: isolated buildings**.**
Urban distribution: Linear layout and open blocks.
Ground floor function: residential.
Orientation of main facades: east/west and north/south.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Salah Boulekaroua housing estate.
Number of floors: R+6.
Typology's urban form: semi closed block.
Ground floor function: commercial function.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilevered balconies.
Facade offsets: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua housing estate.
Number of floors: R+5.
Typology's urban form: closed block.
Ground floor function: commercial function.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible**.**
Balcony type: loggias and cantilevered balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua (AADL) housing estate. (2008).
Number of storeys: R+9 and R+12.
Typology's urban form: isolated building.
Ground floor function: commercial function.
Orientation of main facades: north-west/south-east.
Type of roof: flat inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Merdj eddib (AADL) housing estate. (2008)
Number of floors: R+5 and R+9 and R+12 and R+15.
Typology's urban form: isolated typologies.
Urban distribution: open urban blocks.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies and loggias.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua (AADL) housing estate. (2008).
Number of storeys: R+13.
Typology's urban form: isolated building.
Ground floor function: commercial function.
Orientation of main facades: north-west/south-east.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua housing estate.
Number of floors: R+4.
Typology's urban form: bar shapes.
Urban distribution: open blocks.
Ground floor function: residential.
Orientation of main facades: north/south and east/west.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: no.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Aissa Boukerma promotional housing estate.
Number of floors: R+5.
Typology's urban form: isolated and threaded typologies.
Urban distribution: closed blocks.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulkaroua housing estate.
Number of floors: R+6.
Typology's urban form: freely distributed.
Ground floor function: residential.
Orientation of main facades: north/south and east/west.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Merdj eddib housing estate (2011).
Number of storeys: R+5.
Typology's urban form: in the form of a bar.
Function ground floor + 1st floor: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade recesses: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Merdj eddib housing estate
Number of floors: R+4 and R+5.
Typology's urban form: Isolated typologies.
Urban distribution: open block.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Zeramna housing estate.
Number of storeys: R+6.
Typology's urban form: in the form of a long bar.
Ground floor function: commercial and residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies and loggias.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua housing estate.
Number of floors: R+4.
Ground floor function: commercial and residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Merdj eddib promotional housing estate.
Number of floors: R+4 and R+5.
Typology's urban form: closed block through threaded typologies.
Ground floor function: commercial and residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

"Les Oliviers" housing estate
Number of storeys: R+4.
Typology's urban form: Isolated bar typologies.
Urban distribution: parallel typologies based on the topography of the land.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: no.
External joinery: Aluminium or wood.
Construction system: column-beam system.

700 units housing estate.
Number of storeys: R+4.
Typology's urban form: U-shaped typology. linear layout.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: loggias.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

"Esperance" housing estate.
Number of storeys: R+4.
Typology's urban form: isolated typologies.
Urban distribution: free distribution.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies**.**
Facade overhangs: No.
External joinery: Aluminium or wood**.**
Construction system: PASCAL'S heavy prefabrication process.

Bouyala housing estate.
Number of storeys: R+7.
Typology's urban form: continuous typology in the form of a bar.
Linear layout.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Messiouene social housing estate (2017).
Number of floors: R+5.
Typology's urban form: continuous or isolated typology
Urban distribution: Open blocks.
Radio concentric layout.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: recessed balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Messiouene (L.S.P) housing estate (2017).
Number of floors: R+5.
Typology's urban form: continuous typologies.
Urban distribution: Free distribution, depending on the topography of the site.
Ground floor function: commercial or residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Aissa Boukerma housing estate.
Number of floors: R+6.
Typology's urban form: continuous or isolated typology.
Urban distribution: Open block.
Free distribution.
Ground floor function: commercial**.**
Orientation of main facades: east/west.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Housing estate 700 apartments.
Number of storeys: R+4 and R+6.
Typology's urban form: open, mixed-use block.
Ground floor function: commercial or residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade recesses: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Housing estate (700 units).
Number of storeys: R+6.
Typology's urban form: continuous in the form of a bar.
Function ground floor + 1st floor: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Outcrops on the facade: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Ammar Chetaibi housing estate.
Number of storeys: R+6.
Typology's urban form: continuous in the form of a bar.
Ground floor function: Residential.
Orientation of main facades: North/south or east/west.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: Few.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Ammar Chetaibi housing estate.
Number of storeys: R+5.
Typology's urban form: continuous in the form of a bar.
Ground floor function: commercial.
Orientation of main facades: east/west.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: Few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

"Les oliviers" housing estate.
Number of storeys: R+5.
Typology's urban form: continuous in the form of a bar.
Free distribution.
Ground floor function: Commercial.
Orientation of main facades: north-east/south-west
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: Few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Les Olivier's housing estate.
Number of storeys: R+5.
Typology's urban form: continuous in the form of a bar.
Free distribution.
Ground floor function: Residential.
Orientation of main facades: Several orientations.
Type of roof: flat, inaccessible.
Balcony type: loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Boulevard Brahim Maiza.
Number of storeys: R+11.
Typology's urban form: slab urbanism.
Function ground floor + 1st floor + 2nd floor: administrative.
Orientation of main facades: Several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: column-beam system.

500-unit housing estate.
Number of storeys: R+3.
Typology's urban form: continuous typology.
Free distribution.
Ground floor function: Commercial.
Orientation of main facades: Several orientations.
Type of roof: flat, inaccessible.
Balcony type: Balconette.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

500-unit housing estate
Number of storeys: R+9.
Typology's urban form: isolated typologies.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

500-unit housing estate.
Number of floors: R+4.
Typology's urban form: continuous U-shaped typology.
Ground floor function: commercial premises.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

500-unit housing estate.
Number of floors: R+4.
Typology's urban form: continuous L-shaped typology.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system**.**

500-unit housing estate.
Number of storeys: R+5.
Typology's urban form: closed block.
Ground floor function: commercial premises.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

500-unit housing estate. (1983).
Number of storeys: R+4.
Typology's urban form: open blocks.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

500-unit housing estate. (1983).
Number of storeys: R+5.
Typology's urban form: isolated typologies.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Housing estate 700 units. (1983).
Number of storeys: R+9.
Typology's urban form: isolated typologies.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Aissa Boukerma housing estate.
Number of floors: R+3.
Typology's urban form: isolated typologies.
Urban distribution: Open blocks.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: 2-panel inclined roof.
Balcony type: No balconies.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: light prefabrication.

Ayachi Brothers housing estate.
Number of storeys: R+5.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat inaccessible.
Balcony type: loggias and extended advanced balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Bouabbaz housing estate.
Number of floors: R+8.
Typology's urban form: isolated typology.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Messiouene housing estate.
Number of storeys: R+4 and R+5.
Typology's urban form: continuous typologies.
Urban distribution: Free distribution.
Ground floor function: residential or commercial.
Orientation of main facades: several orientations.
Type of roof: flat inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Saadi Brothers housing estate.
Number of storeys: R+5.
Typology's urban form: continuous typology in the form of a bar.
Ground floor function: commercial.
Orientation of main facades: east-west.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Merdj eddib housing estate
Number of floors: R+5.
Typology's urban form: open, mixed-use block.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies and loggias.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

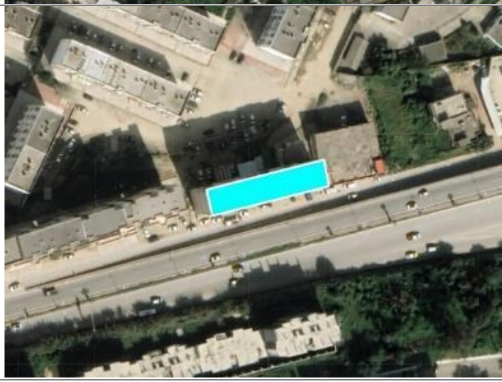
Bouabbaz housing estate.
Number of storeys: R+12.
Typology's urban form: continuous typology in the form of a bar.
Ground floor function: residential.
Orientation of main facades: east-west.
Type of roof: flat, inaccessible.
Balcony type: extended loggias.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Boudjemaa Lebardi Street.
Number of storeys: R+5.
Typology's urban form: open, mixed-use block.
Ground floor function: residential.
Orientation of main facades: several orientations.
Roof type: flat, inaccessible.
Balcony type: cantilever and recessed balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Bouabbaz housing estate.
Number of storeys: R+9.
Typology's urban form: isolated typologies.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Offsets on the facade: many.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Merdj eddib housing estate.
Number of storeys: R+6.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.


Merdj eddib housing estate.
Number of storeys: R+5.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.




Cité Zeramna
Number of storeys: R+6.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: loggias and cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.


Zeramna housing estate.
Number of storeys: R+5.
Typology's urban form: threaded typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.


Zeramna housing estate.
Number of storeys: R+5.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: no.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.


Zeramna housing estate.
Number of storeys: R+5.
Typology's urban form: slab urbanism.
Urban distribution: linear.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilevered balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Cité Zeramna
Number of floors: R+5.
Typology's urban form: isolated or continuous typologies.
Urban distribution: Open block.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilevered balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Zeramna housing estate.
Number of floors: R+5.
Typology's urban form: continuous U-shaped typology.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilevered balconies and loggias.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Zeramna housing estate.
Number of storeys: R+6.
Typology's urban form: continuous typology in the form of a bar + in the form of an L, forming an open urban block.
Ground floor function: Residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Zeramna housing estate.
Number of storeys: R+7.
Typology's urban form: continuous typology in the form of a bar + isolated typology.
Ground floor function: commercial + residential.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilevered balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

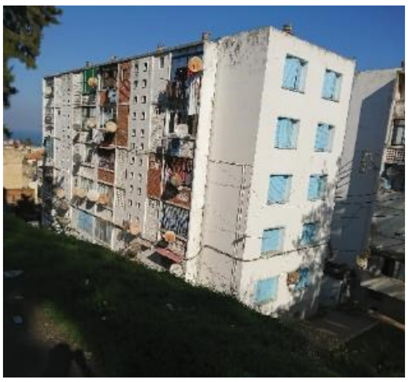
Zeramna housing estate.
Number of storeys: R+5.
Urban form: continuous typology in the form of a bar + isolated typology.
Ground floor function: commercial + residential.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilevered balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua housing estate.
Number of storeys: R+6.
Typology's urban form: continuous typology in the form of a bar.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: loggias and cantilevered balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua housing estate.
Number of floors: R+7.
Typology's urban form: slab urbanism.
Function ground floor + 1st floor: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: loggias and cantilevered balconies
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Salah Boulekaroua housing estate.
Number of floors: R+6.
Typology's urban form: isolated typology.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Hamoudi Toubi street (Bel air).
Number of floors: R+6.
Typology's urban form: isolated typologies, in the form of bars.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.



Bouyala housing estate
Number of storeys: R+4.
Typology's urban form: continuous typologies in the form of bars, with a free distribution.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Bouyala housing estate.
Number of storeys: R+4.
Typology's urban form: continuous typology in the form of a bar.
Urban distribution: Free layout.
Ground floor function: Residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Khaldi brothers housing estate.
Number of storeys: R+5.
Typology's urban form: continuous typology in the form of a bar.
Urban distribution; Free layout.
Ground floor function: Residential.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: Medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Khaldi Brothers housing estate.
Number of floors: R+9.
Typology's urban form: isolated typologies.
Urban distribution: Free layout.
Ground floor function: Commercial.
Orientation of main facades: North-west/South-east.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Boukermouche housing estate.
Number of floors: R+9.
Typology's urban form: isolated typologies.
Urban distribution; Free layout.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Boukermouche housing estate.
Number of storeys: R+4 and R+5.
Typology's urban form: continuous typology in the form of a bar Freely distributed.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Boukermouche housing estate.
Number of storeys: R+4.
Typology's urban form: continuous typology in the form of a bar.
Ground floor function: residential.
Orientation of main facades: east/west.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Boukermouche housing estate.
Number of storeys: R+6.
Typology's urban form: continuous typology in the form of a bar.
Urban distribution: linear.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Oued el wahche housing estate.
Number of storeys: R+5.
Typology's urban form: continuous typology in the form of a bar.
Urban distribution: Free distribution.
Ground floor function: Residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Oued el wahche housing estate.
Number of floors: R+6.
Typology's urban form: mixed open block.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Oued el wahche housing estate.
Number of storeys: R+7.
Typology's urban form: continuous typologies in the form of bars.
Urban distribution: Free distribution.
Ground floor function: commercial.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Boukermouche housing estate.
Number of floors: R+6.
Typology's urban form: isolated.
Ground floor function: commercial.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Boukermouche housing estate.
Number of floors: R+5.
Typology's urban form: 3 terraced typologies.
Ground floor function: commercial.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Khaldi brothers housing estate.
Number of storeys: R+7 and R+8.
Typology's urban form: continuous typology in the form of a bar.
Ground floor function: commercial.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Oued el wahche housing estate.
Number of storeys: R+8.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Oued el wahche housing estate.
Number of storeys: R+7.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: north-east /south-west.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.


Oued el wahche housing estate.
Number of storeys: R+6.
Typology's urban form: continuous typologies in the form of bars.
Ground floor function: commercial.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.


Oued el wahche housing estate.
Number of storeys: R+6.
Typology's urban form: U-shaped typology.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.


Oued el wahche housing estate.
Number of storeys: R+6.
Typology's urban form: bar typology.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.


Oued el wahche housing estate.
Number of storeys: R+6.
Typology's urban form: bar typology.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: Loggias.
Facade overhangs: medium**.**
External joinery: Aluminium or wood.
Construction system: column-beam system.


Oued el wahche housing estate.
Number of storeys: R+6.
Typology's urban form: bar typology.
Ground floor function: commercial.
Orientation of main facades: north/south.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Oued el wahche housing estate.
Number of floors: R+5.
Typology's urban form: L+U typology.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Oued El wahche housing estate.
Number of storeys: R+7.
Typology's urban form: bar typology.
Ground floor function: commercial.
Orientation of main facades: North/South.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies and loggias.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Oued El wahche housing estate.
Number of storeys: R+7.
Typology's urban form: L-shaped typology.
Ground floor function: commercial.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: many.
External joinery: Aluminium or wood.
Construction system: column-beam system.

El qobia housing estate
Number of storeys: R+5.
Typology's urban form: bar typology.
Free distribution.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: no.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

El qobia housing estate.
Number of storeys: R+4.
Typology's urban form: bar typology.
Ground floor function: commercial.
Orientation of main facades: east/west.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Khaldi brothers housing estate.
Number of storeys: R+6.
Typology's urban form: typologies in the form of bars.
Urban distribution: parallel distribution according to the topography of the site.
Function ground floor + 1st floor + 2nd floor: commercial.
Orientation of main facades: north-west/south-east.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Khaldi brothers housing estate.
Number of storeys: R+9.
Typology's urban form: isolated typologies.
Urban distribution: juxtaposed, at the edge of the mechanical track.
Ground floor function: residential.
Orientation of main facades: north-west/south-east.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: medium.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

Mekki Ourtilani housing estate (Souika).
Number of storeys: R+6.
Typology's urban form: bar typology.
Ground floor function: residential.
Orientation of main facades: east/west.
Type of roof: flat, inaccessible.
Balcony type: loggias.
Facade overhangs: No.
External joinery: Aluminium or wood.
Construction system: column-beam system.

Bouabbaz housing estate.
Number of storeys: R+4.
Typology's urban form: isolated typologies or in the form of a bar.
Ground floor function: residential.
Orientation of main facades: several orientations.
Type of roof: flat, inaccessible.
Balcony type: cantilever balconies.
Facade overhangs: few.
External joinery: Aluminium or wood.
Construction system: PASCAL'S heavy prefabrication process.

700 housing units. **Number of storeys**: R+4. **Typology's urban form:** U-shaped typology. **Ground floor function:** residential. **Orientation of main facades:** several orientations. **Type of roof:** flat, inaccessible. **Balcony type:** cantilevered or recessed balconies. **Facade overhangs:** many. **External joinery:** Aluminium or wood. **Construction system:** column-beam system.		
700 housing units. **Number of storeys: R+4.** **Typology's urban form:** isolated typologies. **Ground floor function: residential.** **Orientation of main facades:** several orientations. **Type of roof:** flat, inaccessible. **Balcony type:** cantilever balconies. **Facade overhangs: few.** **External joinery:** Aluminium or wood. **Construction system:** "PASCAL'S heavy prefabrication process.		
700 housing units **Number of storeys:** R+3 and R+4. **Typology's urban form:** continuous typologies in bar form. **Urban distribution:** Open-plan layouts. **Ground floor function:** residential. **Orientation of main facades:** several orientations. **Type of roof:** flat, inaccessible. **Balcony type:** loggias. **Facade overhangs:** few**.** **External joinery:** Aluminium or wood. **Construction system:** "PASCAL'S heavy prefabrication process.		

Appendix 2: Monthly energy consumption of gas and electricity for the 21 homes in the 4 buildings studied, over 8 quarters.

	Case study A		Case study B	Case study C		Case study D	
R+15				5	6		
R+14						5	6
R+13							
R+12							
R+11							
R+10							
R+9	5	6				3	4
R+8				3	4		
R+7							
R+6							
R+5	3	4	3				
R+4							
R+3			2				
R+2				1	2		
R+1	1	2				1	2
RDC			1				
Orientations	North and East	North and south	East and West	North-west	South-east	North and north-east	South and south west

The table above shows the location of each flat in relation to the buildings and the points of the compass.

The graphs below show the energy consumption of gas and electricity for each quarter:

Quarter (1): October 2020.

Quarter (2): January 2021.

Quarter (3): April 2021.

Quarter (4): July 2021.

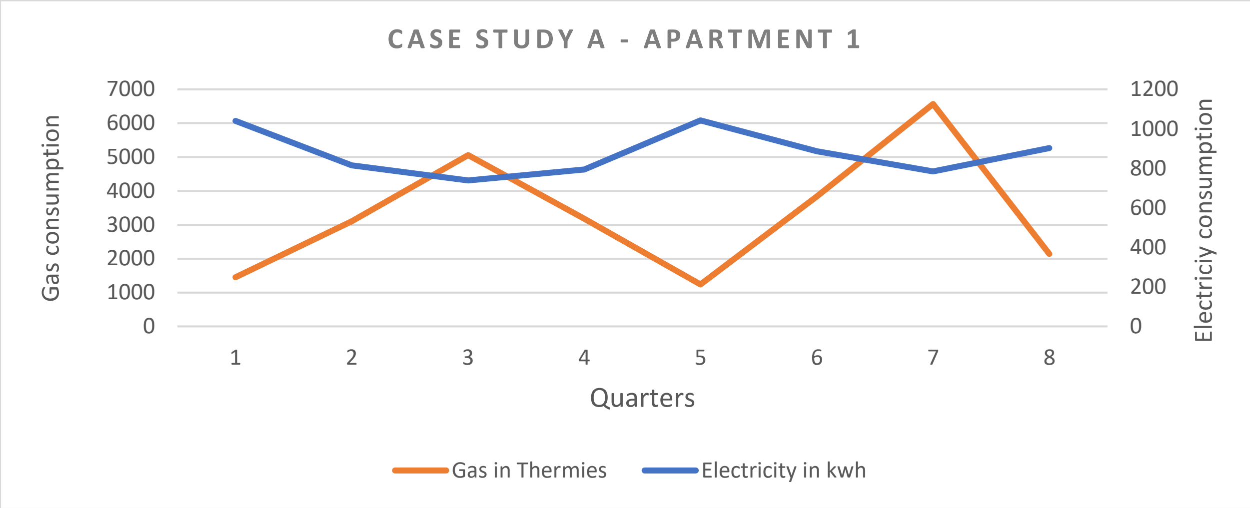
Quarter (5): October 2021.

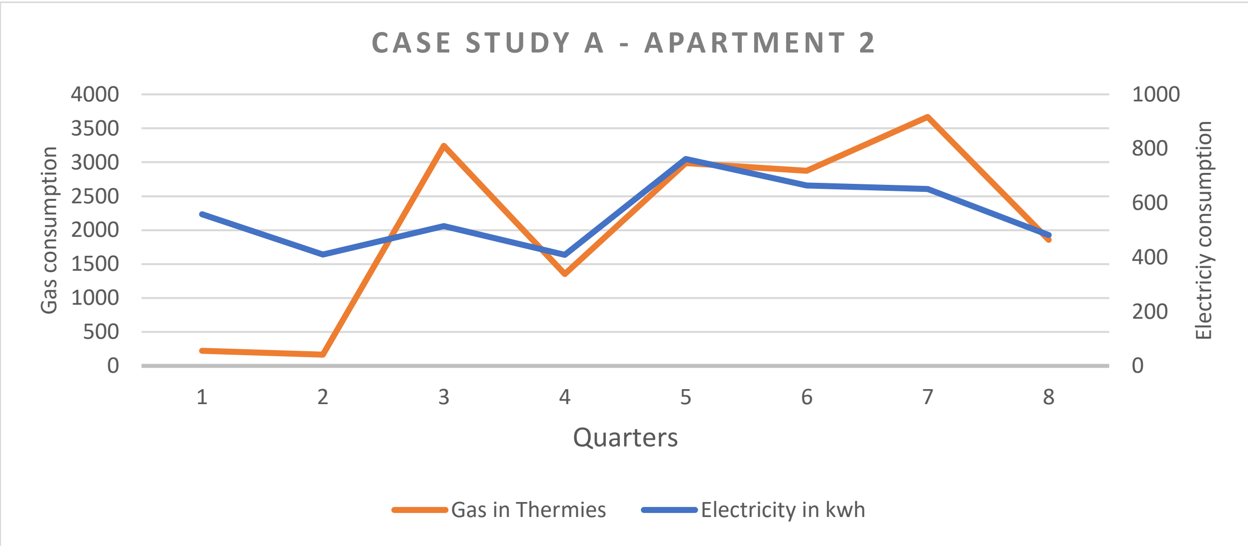
Quarter (6): January 2022.

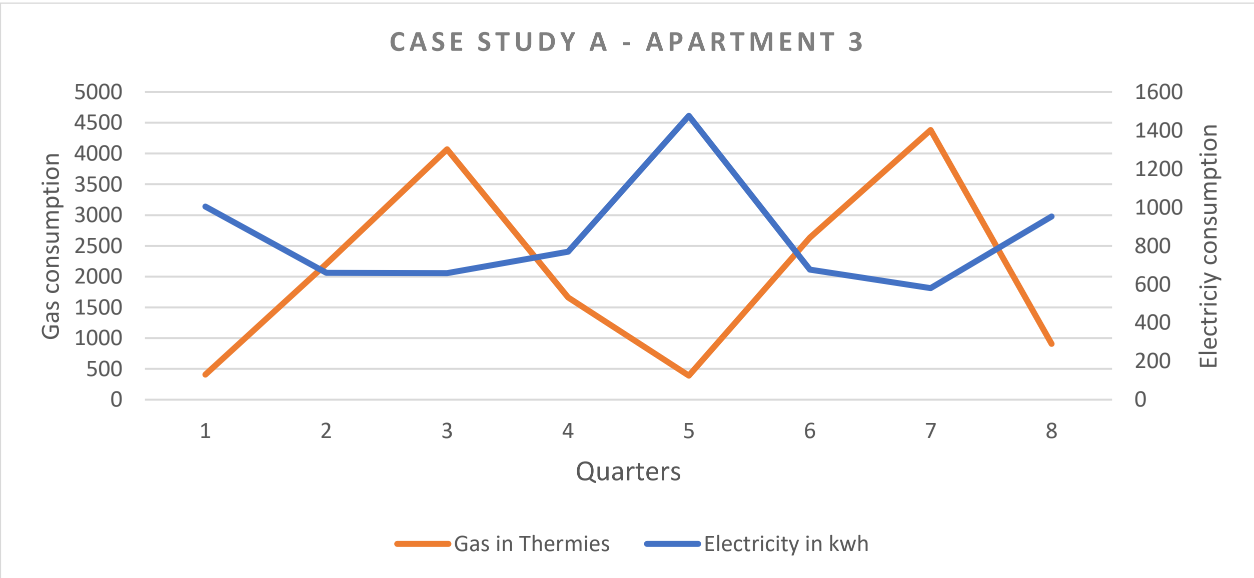
Quarter (7): April 2022.

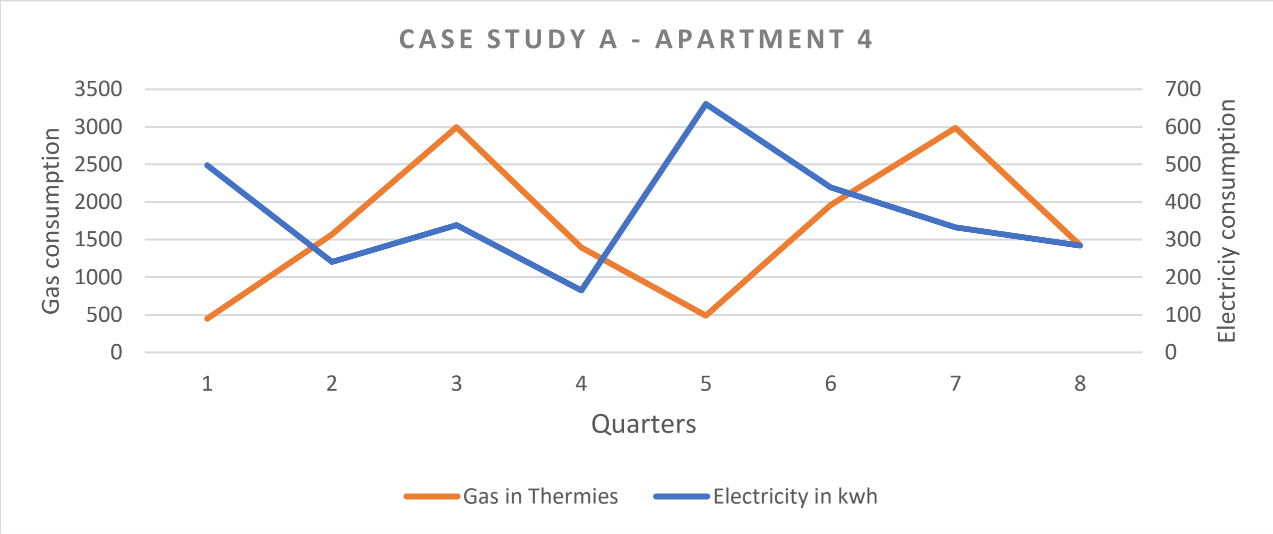
Quarter (8): July 2022.

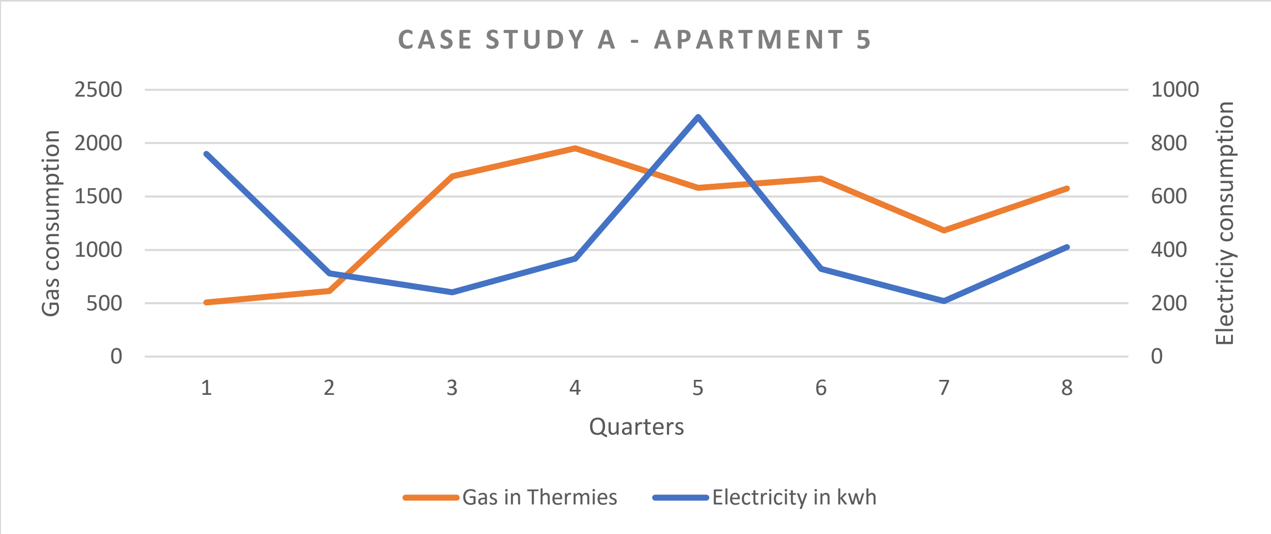
The energy data for gas is in (thermies), while that for electricity is in (Kwh).

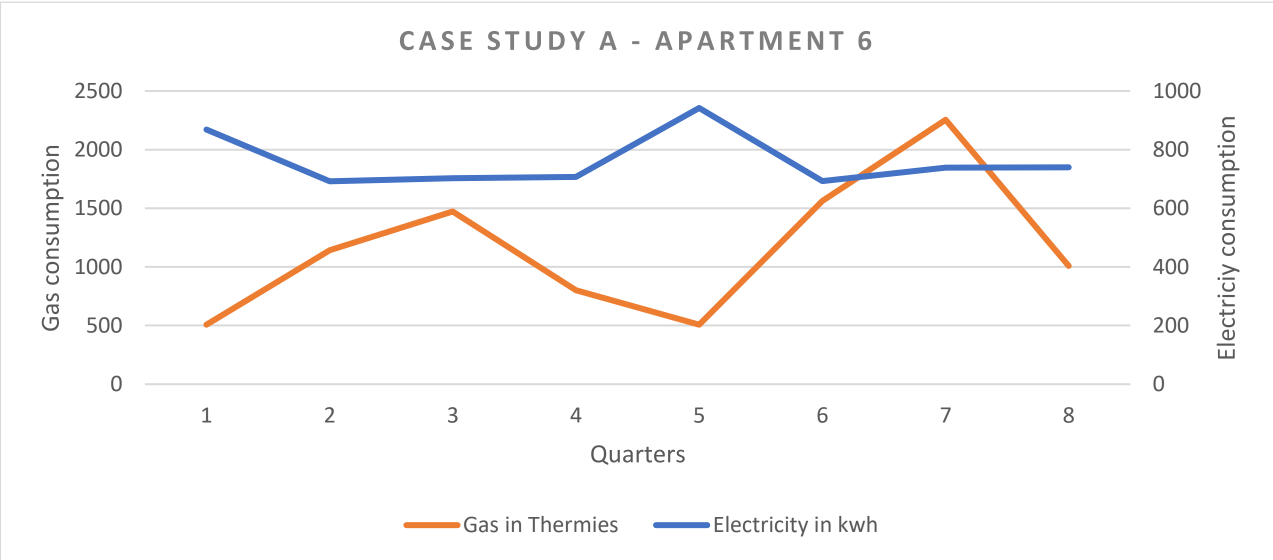

CASE STUDY A - APARTMENT 1
Gas consumption
7000
6000
5000
4000
3000
2000
1000
0
1200
1000
800
600
400
200
0
Electriciy consumption
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

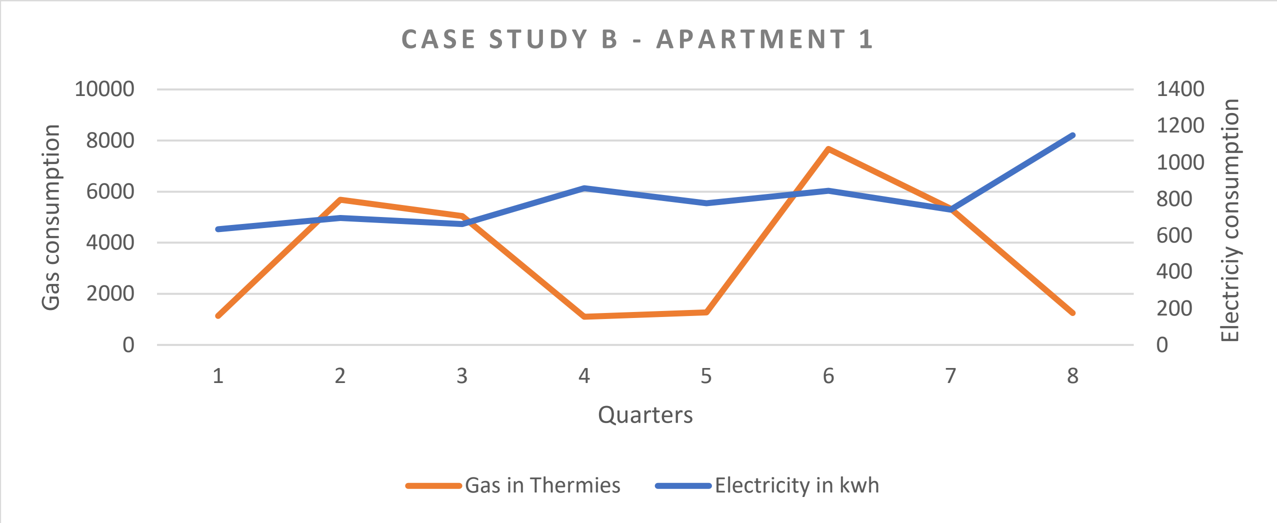

CASE STUDY A - APARTMENT 2
Gas consumption
4000
3500
3000
2500
2000
1500
1000
500
0
1000
800
600
400
200
0
Electriciy consumption
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

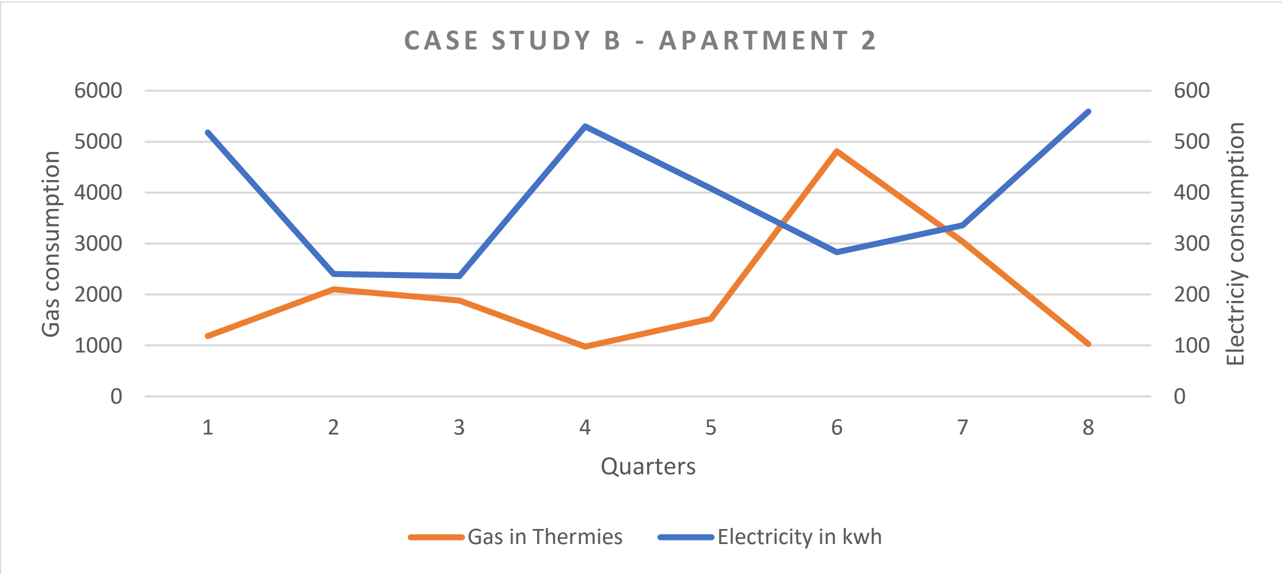

CASE STUDY A - APARTMENT 3
Gas consumption
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1600
1400
1200
1000
800
600
400
200
0
Electriciy consumption
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

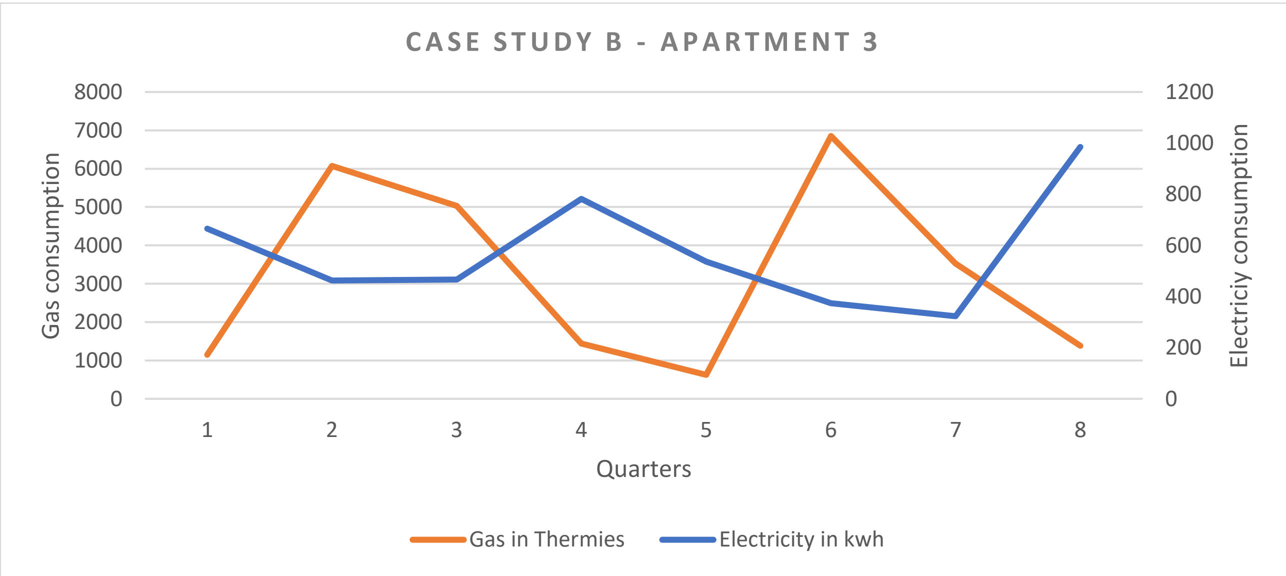

CASE STUDY A - APARTMENT 4
Gas consumption
3500
3000
2500
2000
1500
1000
500
0
700
600
500
400
300
200
100
0
Electriciy consumption
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

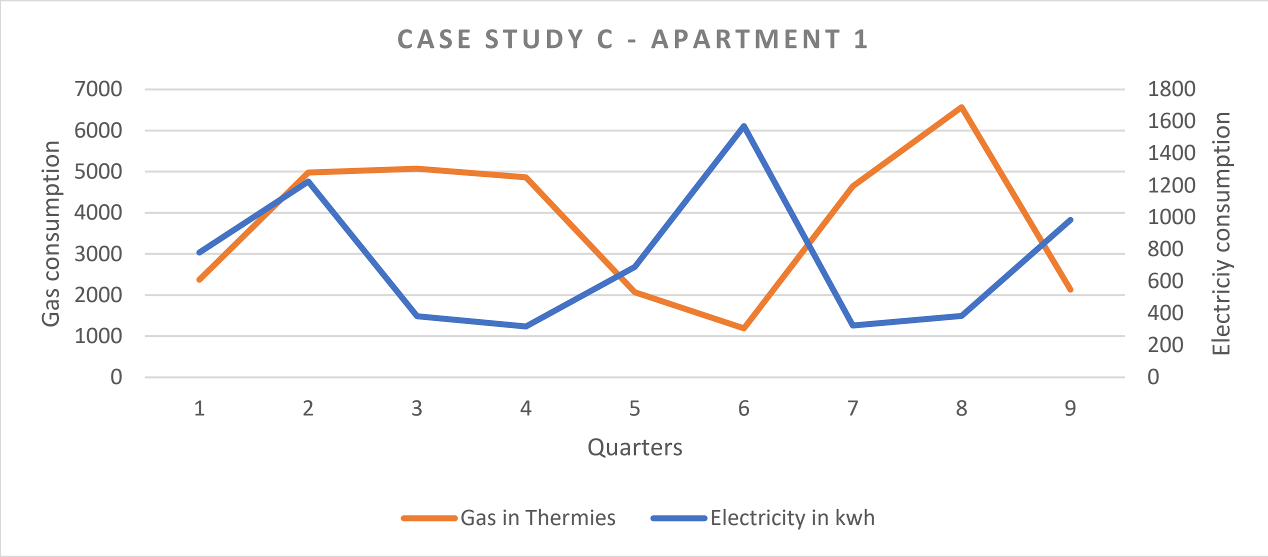

CASE STUDY A - APARTMENT 5
Gas consumption
2500
2000
1500
1000
500
0
1000
800
600
400
200
0
Electriciy consumption
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

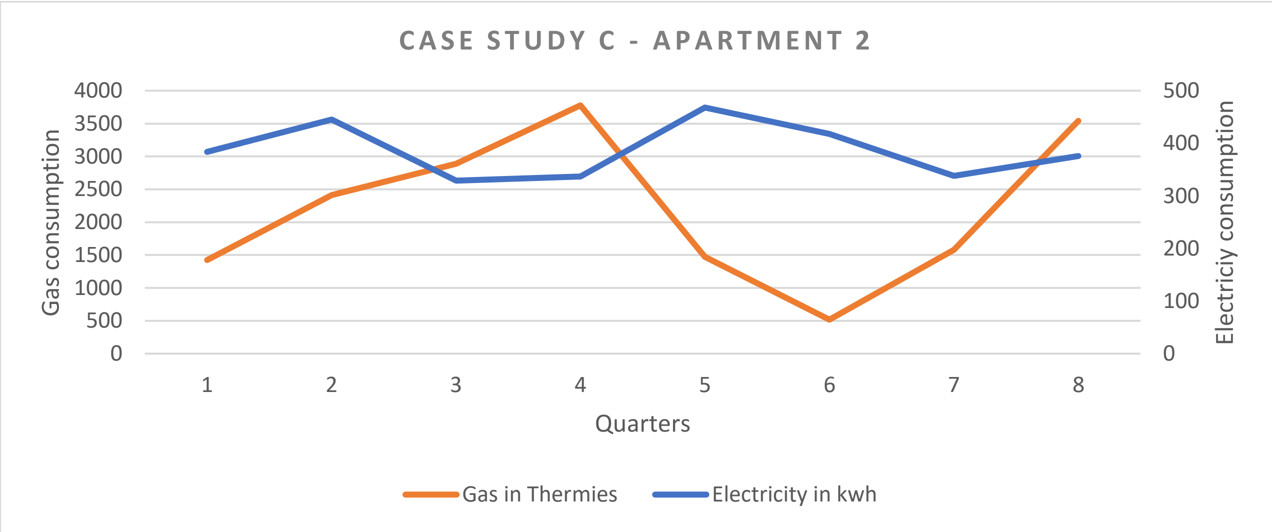

CASE STUDY A - APARTMENT 6
Gas consumption
2500
2000
1500
1000
500
0
1000
800
600
400
200
0
Electriciy consumption
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

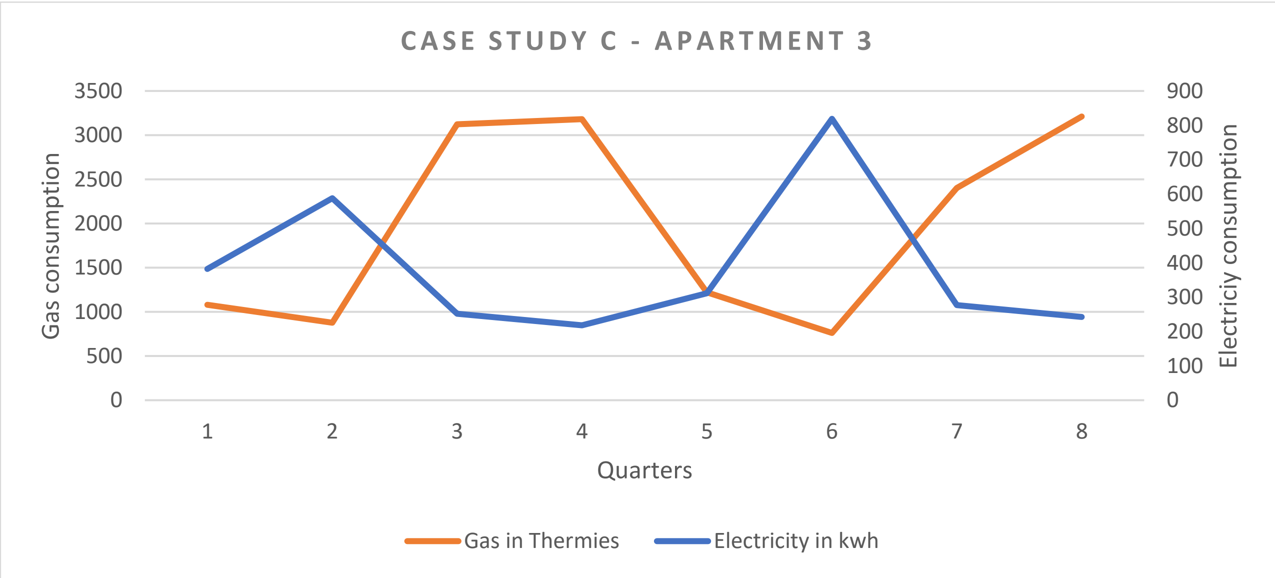

CASE STUDY B - APARTMENT 1
Gas consumption
10000
8000
6000
4000
2000
0
1400
1200
1000
800
600
400
200
0
Electriciy consumption
1 2 3 4 5 6 7 8
Quarters
Gas in Thermies
Electricity in kwh

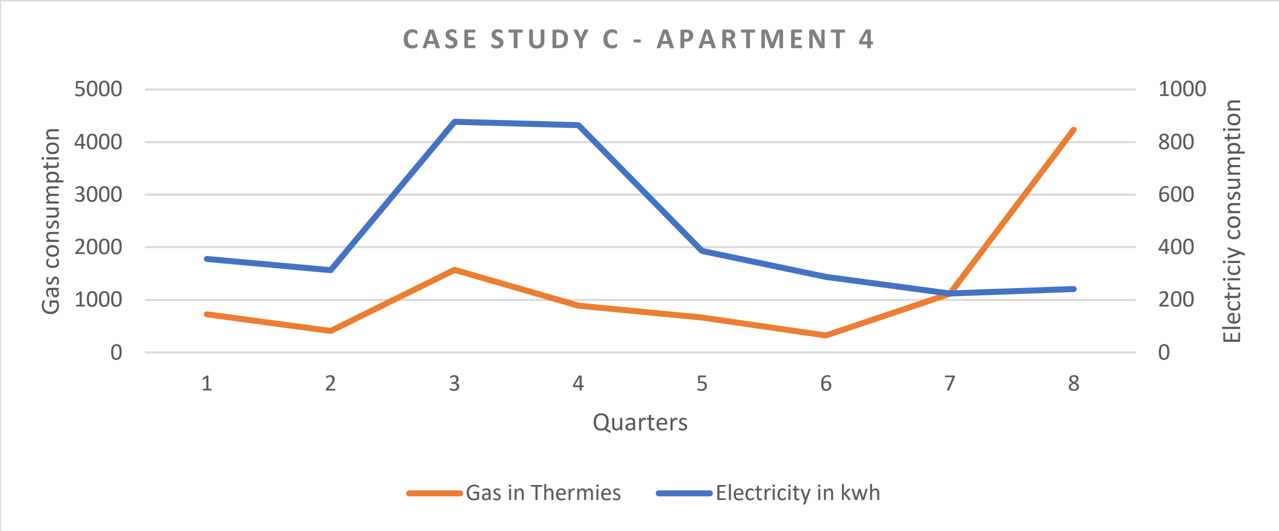

CASE STUDY B - APARTMENT 2
Gas consumption
6000
5000
4000
3000
2000
1000
0
600
500
400
300
200
100
0
Electriciy consumption
1 2 3 4 5 6 7 8
Quarters
Gas in Thermies
Electricity in kwh

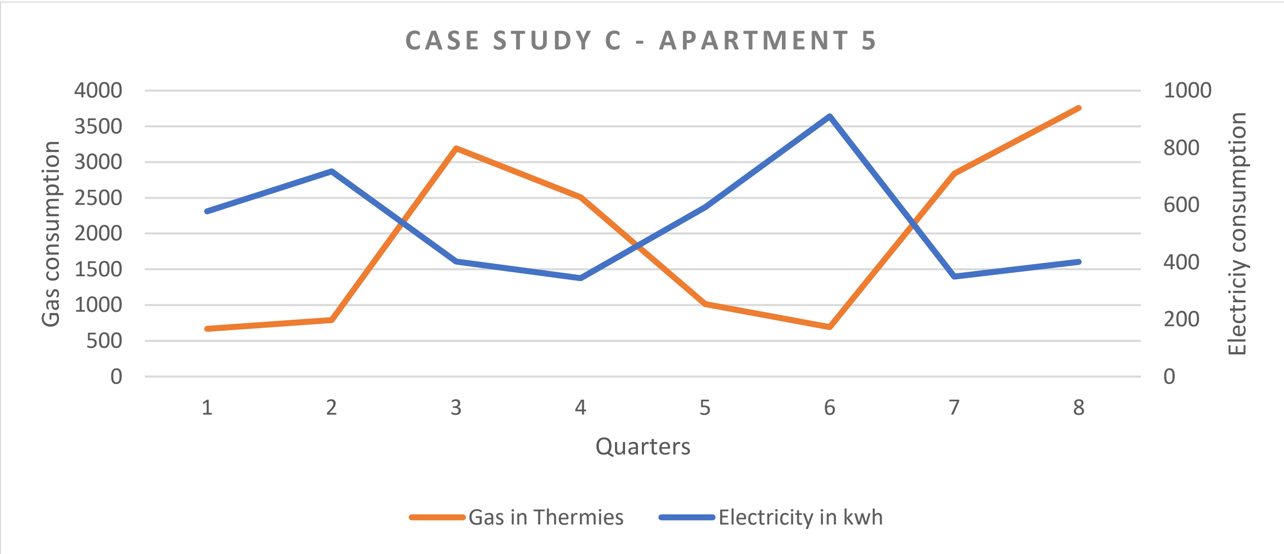

CASE STUDY B - APARTMENT 3
Gas consumption
8000
7000
6000
5000
4000
3000
2000
1000
0
1200
1000
800
600
400
200
0
Electriciy consumption
1 2 3 4 5 6 7 8
Quarters
Gas in Thermies
Electricity in kwh

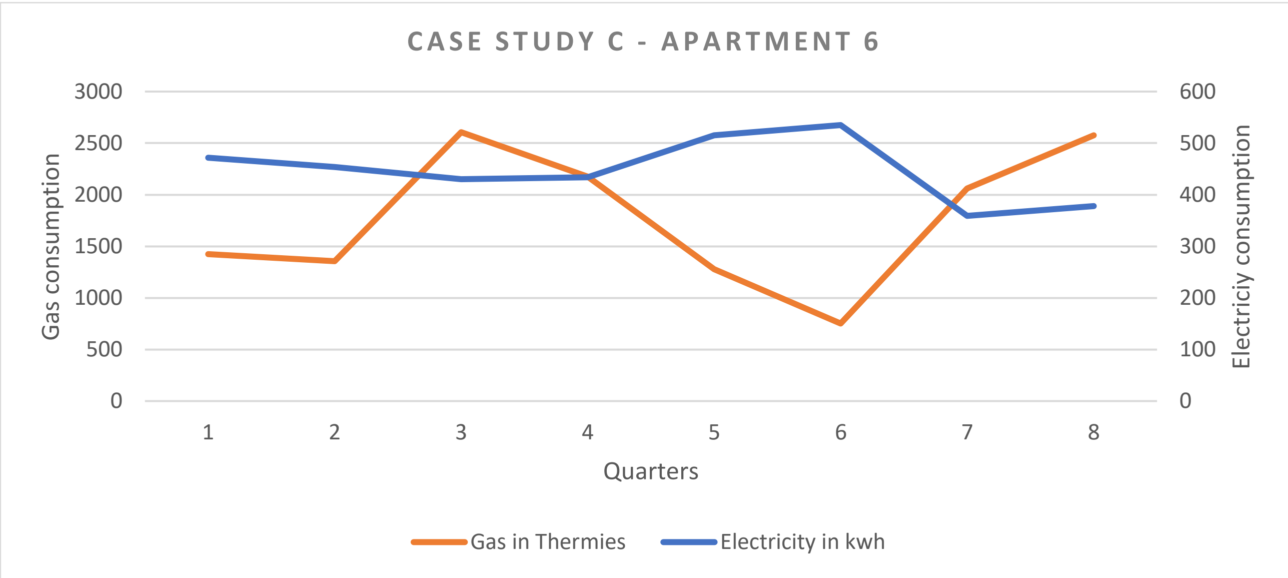

CASE STUDY C - APARTMENT 1
Gas consumption
7000
6000
5000
4000
3000
2000
1000
0
Electriciy consumption
1800
1600
1400
1200
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9
Quarters
Gas in Thermies
Electricity in kwh

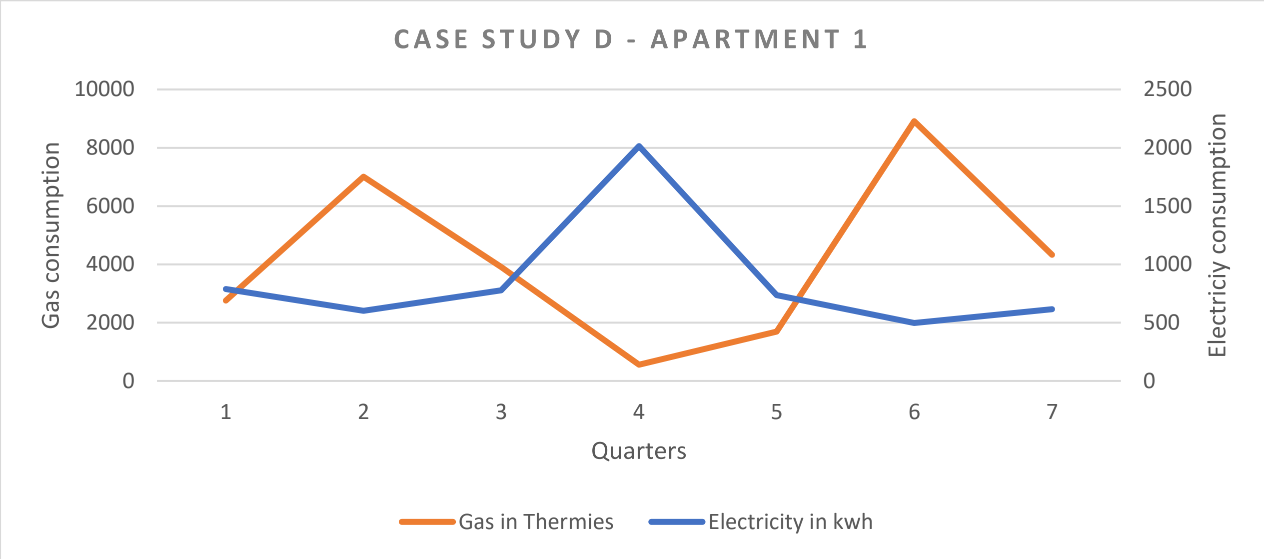

CASE STUDY C - APARTMENT 2
Gas consumption
4000
3500
3000
2500
2000
1500
1000
500
0
Electriciy consumption
500
400
300
200
100
0
1 2 3 4 5 6 7 8
Quarters
Gas in Thermies
Electricity in kwh

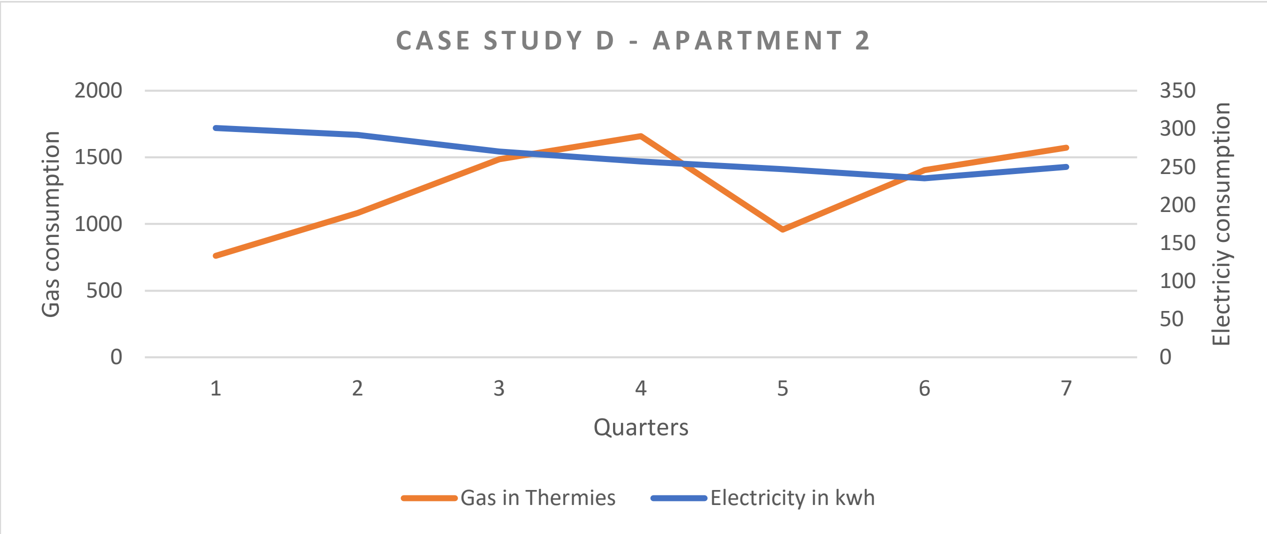

CASE STUDY C - APARTMENT 3
Gas consumption
3500
3000
2500
2000
1500
1000
500
0
Electriciy consumption
900
800
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8
Quarters
Gas in Thermies
Electricity in kwh

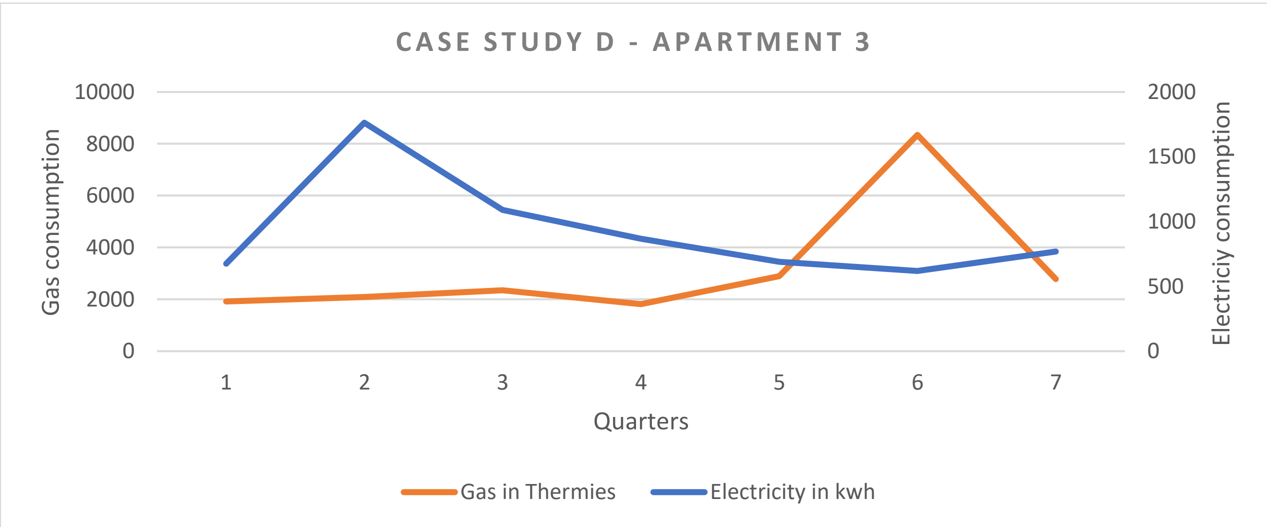

CASE STUDY C - APARTMENT 4
Gas consumption
5000
4000
3000
2000
1000
0
Electriciy consumption
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

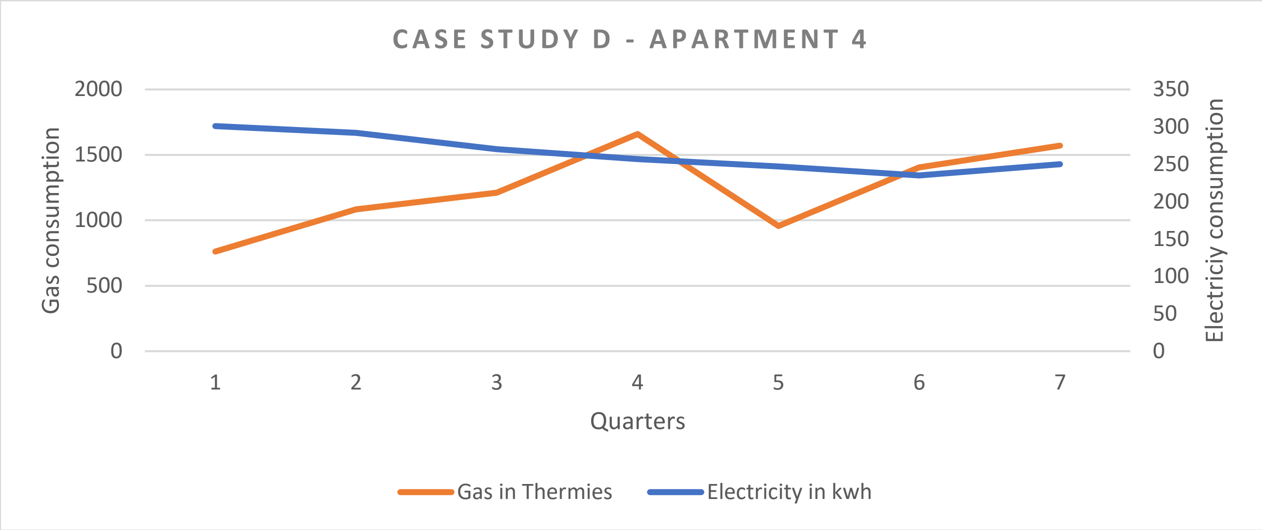

CASE STUDY C - APARTMENT 5
Gas consumption
4000
3500
3000
2500
2000
1500
1000
500
0
Electriciy consumption
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

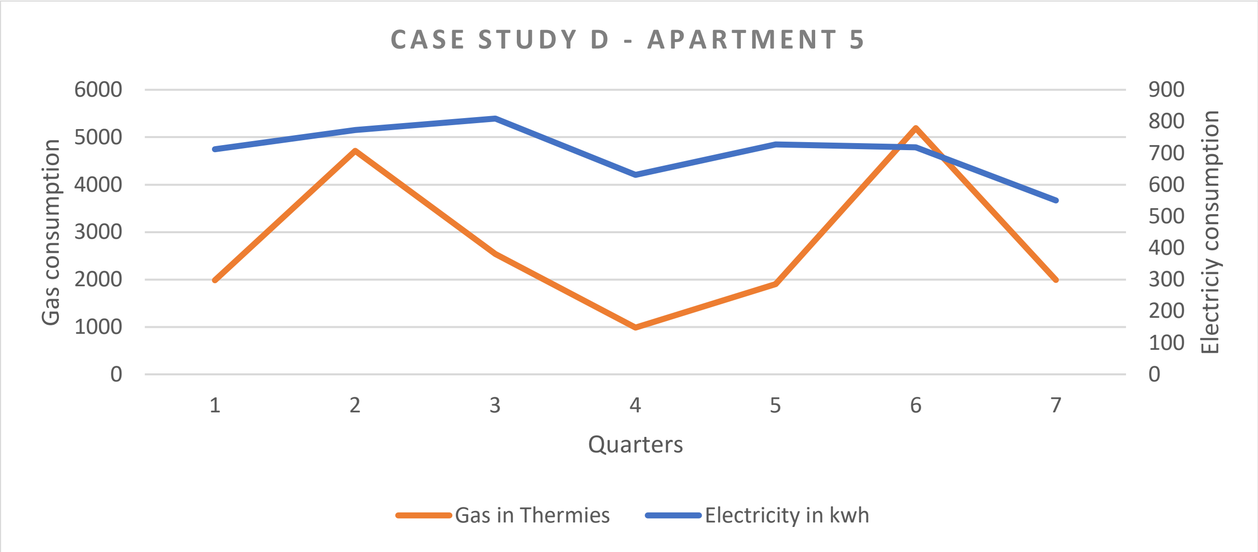

CASE STUDY C - APARTMENT 6
Gas consumption
3000
2500
2000
1500
1000
500
0
Electriciy consumption
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
Quarters
Gas in Thermies
Electricity in kwh

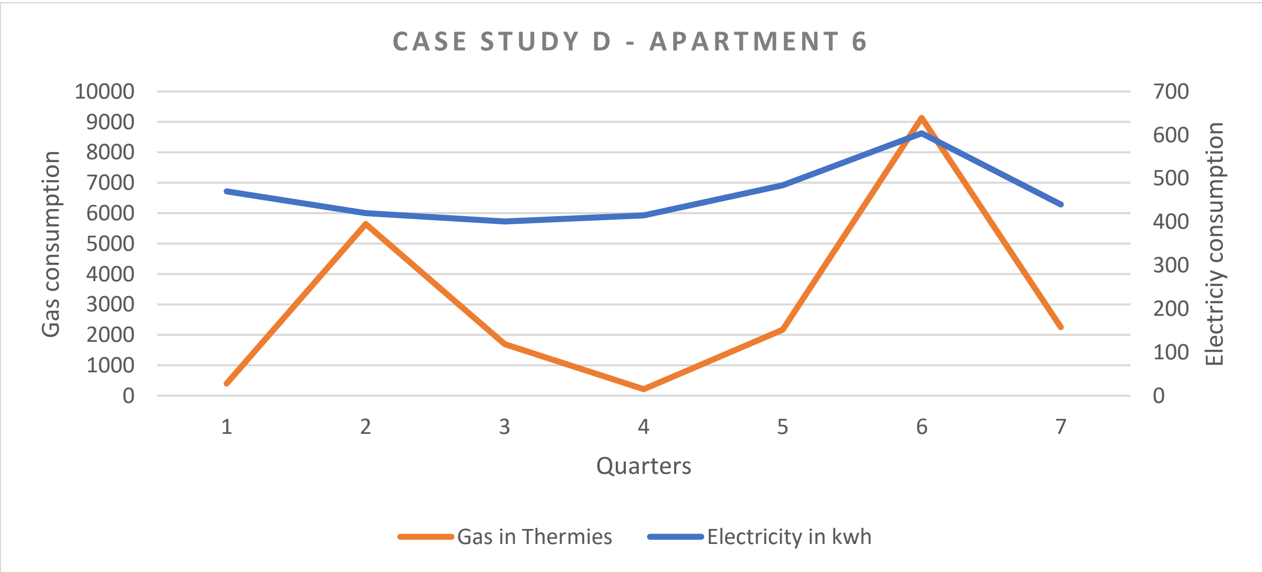

CASE STUDY D - APARTMENT 1
Gas consumption
Electriciy consumption
10000
8000
6000
4000
2000
0
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
Quarters
Gas in Thermies
Electricity in kwh


CASE STUDY D - APARTMENT 2
Gas consumption
Electriciy consumption
2000
1500
1000
500
0
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
Quarters
Gas in Thermies
Electricity in kwh


CASE STUDY D - APARTMENT 3
Gas consumption
Electriciy consumption
10000
8000
6000
4000
2000
0
2000
1500
1000
500
0
1
2
3
4
5
6
7
Quarters
Gas in Thermies
Electricity in kwh


CASE STUDY D - APARTMENT 4
Gas consumption
2000
1500
1000
500
0
350
300
250
200
150
100
50
0
Electriciy consumption
1
2
3
4
5
6
7
Quarters
Gas in Thermies
Electricity in kwh


CASE STUDY D - APARTMENT 5
Gas consumption
6000
5000
4000
3000
2000
1000
0
900
800
700
600
500
400
300
200
100
0
Electriciy consumption
1
2
3
4
5
6
7
Quarters
Gas in Thermies
Electricity in kwh


CASE STUDY D - APARTMENT 6
Gas consumption
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
700
600
500
400
300
200
100
0
Electriciy consumption
1
2
3
4
5
6
7
Quarters
Gas in Thermies
Electricity in kwh

Appendix 3: a sample bill for electricity and gas consumption in Algeria, drawn up by SONELGAZ.

الشركة الجزائرية لتوزيع الكهرباء و الغاز
Société Algérienne de Distribution de l'Electricité et du Gaz

Facture de consommation de l'Electricité et du Gaz — **فاتورة إستهلاك الكهرباء و الغاز**

Société par action au capital social de: 64 000 000 000,00 DA
Direction de distribution : BELOUIZDAD
RC N°: 05/0970521 B 06
NIS : 000516019000263
NIF : 096916010012742
RIB N°: 00100623030030068482
RIP N°: 00799999000038062618
Agence commerciale : ASSELAH HOCINE
5 Bd M Benboulaid

Assistance	3303	مساعدة
Dépannage		إصلاح الأعطاب
Réclamation		شكاوي
Pour Plus d'Informations		للمزيد من المعلومات

Facture n°:	515200403235	(1)	فاتورة رقم :
Etablie le:	28/04/2020		حررت في :
Référence/PDL :	16501 17 25030 2 08	(2)	المرجع :
Lieu de consommation:	[redacted]		مكان الإستهلاك :
Prochaine relève vers le:	07/07/2020		الرصد القادم حوالي :

Client n°: 5187P001012
[redacted]

NIF:
RC N°:

Période du : 2ème Trimestre 2020 — الفترة : الثلاثي الثاني 2020

Vos conommations — استهلاكاتكم

	الإستهلاك Consommation	المبلغ بالدينار Montant en DA HT	
Electricité	311,00 kWh	1038,23	الكهرباء
Gaz	1 786,64 Th	403,93	الغاز

Redevances fixes HT (Abonnement) (DA)	164,16	الاتاوات الثابتة (إشتراك) (دج)
Frais & Prestation HT (DA)	0,00	رسوم و خدمات (دج)
Montant HT (DA)	1606,32	المبلغ دون رسوم (دج)
TVA à 9% (DA)	118,15	ر.ق.م 9 % (دج)
TVA à 19% (DA)	55,77	ر.ق.م 19 % (دج)
Total TVA (DA)	173,92	ر.ق.م (دج)
Droit Fixe sur consommation (DA)	50,00	المستحقات الثابتة على الاستهلاك (دج)
Taxe d'habitation (DA)	150,00	رسم على المسكن (دج)
Contribution (DA)	0,00	مساهمة (دج)
Montant REPE (DA)	0,00	مبلغ ر.ك.د.ت (دج)
Montant RGPE (DA)	0,00	مبلغ ر.غ.د.ت (دج)

Net à payer TTC (DA) (3) **1980,24** صافي الدفع متضمن جميع الرسوم (دج)
الف وتسع مائة وثمانون دينار جزائري وأربع وعشرون سنتيم
Mille neuf cent quatre-vingts Dinar(s) et vingt-quatre centime (s)

Timbre (paiement en espèce) (DA)	20,00	الطابع (دفع نقدا)
Total à payer (en espèces) (DA)	**2000,24**	المستحق الإجمالي (نقدا)
Sauf erreur ou omission		عدا خطأ أو نسيان
Date limite du paiement	16/05/2020	اخر اجل للدفع

Passé ce délai, nous nous réserverons le droit de procéder à la suspension de la fourniture d'énergie — بعد مرور هذا الأجل، يمكننا فصل تزويدكم بالطاقة

Nous vous informons qu'en application des dispositions de l'article 85 du Décret Exécutif 10-95 du 17.03.2010, vous êtes redevable d'un montant de 2474,17 DA, faute de quoi la fourniture d'énergie sera suspendue.

نعلمكم أنه تطبيقا لأحكام المادة 85 من المرسوم التنفيذي 10-95 بتاريخ 17.03.2010، أنكم مدينون بمبلغ 2474,17 دج، وإلا سيتم فصل تزويدكم بالطاقة.

Clé EBP (649) (4) **Clé EBB** 683

Vos contrats — عقودكم

الكهرباء Electricité

رقم العداد N° Compteur	تعريفة Tarif	إستطاعة PMD	المعامل Coef	البيان السابق A. index	البيان الجديد N.index
001124	54M	6kW	1.0	47 478 R	47 478 R

N°Compteur/رقم العداد 001124	الشطر 1 Tranche 1	الشطر 2 Tranche 2	الشطر 3 Tranche 3	الشطر 4 Tranche 4
Quantité/ الكمية	125,00	125,00	61,00	0,00
Prix unitaire/ ثمن الوحدة	1,7787	4,1789	4,8120	

Montant HT (9%)	744,70	المبلغ د.ر (9 %)
Montant HT (19%)	293,53	المبلغ د.ر (19 %)

الغاز Gaz

رقم العداد N° Compteur	تعريفة Tarif	التدفق DMD	المعامل PCS	البيان السابق A. index	البيان الجديد N.index
000324	23M	5m3h	9.6	11 466 R	11 466 E

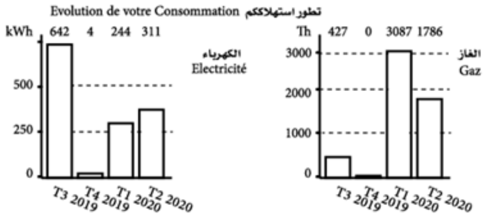
N°Compteur/رقم العداد 000324	الشطر 1 Tranche 1	الشطر 2 Tranche 2	الشطر 3 Tranche 3	الشطر 4 Tranche 4
Quantité/ الكمية	1125,00	661,64	0,00	0,00
Prix unitaire/ ثمن الوحدة	0,1682	0,3245		

Montant HT (9%)	403,93	المبلغ د.ر (9 %)
Montant HT (19%)	0,00	المبلغ د.ر (19 %)

Espace information — معلومات

- Montant de votre consommation moyenne par jour — 21.76 DA/Jour — متوسط إستهلاككم اليومي
- Contribution au coût permanent dy Sytème — 3,58 DA — المساهمة الدائمة في تكاليف صيانة نظام الشبكة

Evolution de votre Consommation تطور استهلاككم



Information Importante : Vous pouvez régler votre facture au niveau de n'importe quelle agence commerciale, au niveau des bureaux d'Algérie poste, par virement, Par chèque bancaire ou postal, par paiemetn en ligne

معلومة تهمكم :
يمكنكم تسديد فواتيركم، في أي وكالة تجارية، في مكاتب بريد الجزائر، عبر صك بنكي أو بريدي، عبر التحويل المصرفي عبر الموقع الالكتروني

للحصول على تفاصيل أكثر حول فاتورتكم تصفحوا موقع الشركة www.sdc.dz أو اقتربوا من أي وكالة تجارية
Pour plus de détails sur votre facture, veuillez consulter le site www.sdc.dz ou adressez-vous à n'importe quelle agence commerciale.