République Algérienne Démocratique et Populaire
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
Université 8 Mai 1945 Guelma

Faculté des Sciences et de la Technologie
Département d'Architecture
Laboratoire de Génie Civil et Hydraulique (LGCH)

THÈSE

EN VUE DE L'OBTENTION DU DIPLOME DE DOCTORAT EN 3ème CYCLE

Domaine : Architecture, Urbanisme et Métiers de la Ville Filière : Architecture
Spécialité : Architecture

Présentée par

BENSEHLA Sofiane

Intitulée

The impact of the urban form on energy consumption and solar access, case of individual housing subdivisions in Constantine

Soutenue le : 14/12/2021 Devant le Jury composé de :

Nom et Prénom	Grade		
Mr ALKAMA Djamel	Professeur	Univ. du 8 Mai 1945 Guelma	Président
Mr LAZRI Youcef	Professeur	Univ. du 8 Mai 1945 Guelma	Encadreur
Mme HARIDI Fatma Zohra	M.C. A	Univ. du 8 Mai 1945 Guelma	Examinatrice
Mr ZEMMOURI Noureddine	Professeur	Univ. de Biskra	Examinateur
Mr REHAILIA Hassib	Professeur	Univ. de Badji Mokhtar-Annaba	Examinateur

Année Universitaire : 2020/2021

الحمد لله كما ينبغي لجلال
وجهه وعظيم سلطانه

Dedications

I would like to dedicate this modest work, with my deep conviction, to all those who have always believed in and without doubt in Science. That light which enlightens the spirits and allows them to transcend the limits set by societies and cultures in their periods of degeneration.

To those who silently fought for better days;

To those who bear only good for others;

To those who live only in and through truth;

To those who know how to put their ideas into practice and how to succeed;

To those who taught me rigour and patience.

I dedicate this work to my dear parents, my brothers and sisters for their support, their patience and their sacrifices at all times to see me a good man.

To my future wife !

To my close friends Ahmed, Mohamed, Yassine, Ammar, Khaled, Oussama ... Especially for their moral support and for all the good times we spent together throughout the years of study.

To all my friends and colleagues of laboratory and doctoral students of the University 8 May 1945 of Guelma and also to all those who know me from near or far.

To all the people I have not mentioned but whom I hold in my heart and to all those who have supported me from near or far.

BENSEHLA Sofiane

Acknowledgements

In the light of this work, I would first like to thank ALLAH All-Powerful for all the wonders he does in my life and for giving me the courage, strength, goodwill and especially the patience to complete this modest scientific contribution.

Then, I am extremely grateful to many people who made the completion of this Ph.D. thesis possible. I would like to address my warmest thanks to:

My supervisor ***Pr. LAZRI Youcef*** *for his guidance and support during these years, his expertise, understanding, and patience added considerably to my research study experience.*

The team of the Civil and Hydraulic Engineering Laboratory (LGCH) where I belong and its director **Pr. Nouaouria Mohamed Salah** *for their scientific services and orientations*

Pr. Miguel Centeno Brito *for accepting me as a research student at the University of Lisbon, for his excellent advice, his scientific accuracy, the independence he granted me in giving me the freedom to pursue this research and for being a reliable guide throughout this work.*

Dr. Jerome Kaempf *for offering me the opportunity and essential guidance to work with brilliant building energy modelling tool CitySim.*

I would also like to express my deep gratitude to the members of the jury; ***Pr. Djamel ALKAMA, Dr. Fatima-Zohra HARIDI, Pr. Noureddine ZEMOURI, and Pr. Hassib REHAILIA.***

I would like to thank all those who have helped me from near or far during these years of research and study.

I cannot conclude without a word of thanks to all my teachers and colleagues.

Abstract

Climate change and energy are more topical than ever. Many governments around the world are striving to meet these challenges, especially for the future, which would see severe climate change if the environmental problems caused persist. To address these two issues, it is needed to promote the use of renewable energy and the introduction of energy efficiency measures particularly in urban areas. Buildings are indeed among the world's largest consumers of primary energy, principally of fossil origin. The increase or decrease of this consumption is due to the regime of several factors, citing; climate change; typo-morphological factors on the three scales; urban, architectural and envelope; occupant behaviour as well as the energy potential brought by the integration of on-site renewable energy solutions. However, to overcome this situation, a lot of work has been done on the issue of energy in buildings, but without considering the assessment of the future climate.

In this respect, seeking a present and future projection related to the energy and climate change issue, this research project aims to examine energy demand, local solar energy production and the impact of urban typo-morphological factors on cooling and heating needs as well as on solar access, in present and future climate scenarios. The focus of the study is on the case of individual housing subdivisions in Algeria, in the metropolis of Constantine. To this end, the study method starts with the selection of four different urban residential forms in the city through an analysis of subdivision housing in the city's commune. Through a closer examination of the selected cases, the geometric and typo-morphological factors of the buildings were identified. In addition, the actual energy consumption data estimated for the four urban forms were obtained. Then, the urban energy model of the urban forms was carried out using the urban building energy modelling tool CitySim. This model goes through three tools, starting by AutoCAD and SketchUp with an identified 3D geometric urban form modelling, then the 3D model is imported into the CitySim software, where the latter requires the addition of the climatic data of the location and building input data. Using test simulations, at this stage, the calibration method of the building energy model and the modelling of the future climate of 2050 have been carried out. In the analysis of the impact of urban form factors on the energy behaviour, solar irradiation and the evolution of the latter two components on the future projection, a mathematical linear regression model was used. For the evaluation of solar techniques in urban forms, the method developed by Professor Raphael Compagnon is used. Finally, an approach to model photovoltaics on buildings and how rooftop photovoltaic production can reduce energy needs in current and future scenarios was discussed.

The results obtained showed that the variation of typo-morphological factors leads to a wide range of heating and cooling requirements, per unit of building volume, which differ by a factor of 2 and 6, respectively, between the urban forms. The solar energy assessment shows that there is significant solar potential on roofs. A relatively small photovoltaic area can eliminate most of the electricity demand for all urban forms.

The results tend to improve the energy efficiency of housing and further enhance its environmental quality. They can also contribute to a strategy of reducing energy consumption and moving towards clean energy in the residential sector.

Key words: Constantine, urban form, Solar energy, energy consumption, future climate.

Résumé

Le changement climatique et l'énergie sont plus que jamais d'actualité. De nombreux gouvernements dans le monde s'efforcent de relever ces défis, notamment pour l'avenir, qui verra un changement climatique grave si les problèmes environnementaux causés persistent. Pour répondre à ces deux enjeux, il est nécessaire de promouvoir l'utilisation des énergies renouvelables et l'introduction de mesures d'efficacité énergétique, particulièrement dans les zones urbaines. Les bâtiments sont en effet parmi les plus gros consommateurs d'énergie primaire, principalement d'origine fossile. L'augmentation ou la diminution de cette consommation est due au régime de plusieurs facteurs, citant le changement climatique, les facteurs typo-morphologiques des trois échelles : urbaine, architecturale et de l'enveloppe, le comportement des occupants ainsi que le potentiel énergétique apporté par l'intégration de solutions d'énergie renouvelable sur site. Cependant, pour surmonter cette situation, de nombreux travaux ont été réalisés sur la question énergétique au niveau du bâtiment, mais sans prendre en compte l'évaluation liée au futur climat.

A cet égard, en cherchant une projection actuelle et future liée à la problématique de l'énergie et du changement climatique, ce projet de recherche vise à examiner la demande énergétique, la production locale d'énergie solaire et l'impact des facteurs typo-morphologiques urbains sur les besoins de refroidissement et de chauffage ainsi que sur l'accès au soleil, dans des projections climatiques actuelles et futures. L'étude se concentre sur le cas des lotissements en Algérie, dans la métropole de Constantine. Dans cette optique, la méthode d'étude commence par la sélection de quatre formes résidentielles urbaines différentes dans la ville de Constantine à travers une analyse des logements de lotissement dans la commune de la ville. Par un examen plus approfondi des cas sélectionnés, les facteurs géométriques et typo-morphologiques des bâtiments ont été identifiés. De plus, les données réelles de consommation énergétique estimées pour les quatre formes urbaines ont été obtenues. Ensuite, le modèle énergétique urbain des formes urbaines a été réalisé à l'aide de l'outil de modélisation énergétique des bâtiments urbains CitySim. Ce modèle passe par trois outils, en commençant par AutoCAD et SketchUp avec une modélisation identifiée des formes géométriques urbaines en 3D, puis le modèle 3D est importé dans le logiciel CitySim, où ce dernier nécessite l'ajout de toutes les données d'entrée du site climatique et des bâtiments. En utilisant des simulations de test, à ce stade, la méthode de calibration du modèle énergétique du bâtiment et la modélisation du climat futur de 2050 ont été réalisées. Dans l'analyse de l'impact des facteurs de forme urbaine sur le comportement énergétique, l'irradiation solaire et l'évolution de ces deux dernières composantes sur la projection future, un modèle mathématique de régression linéaire a été utilisé. Pour l'évaluation des techniques solaires dans les formes urbaines, la méthode développée par le professeur Raphael Compagnon est utilisée. Enfin, une approche de modélisation du photovoltaïque sur les bâtiments et de la manière dont la production photovoltaïque en toiture peut réduire les besoins énergétiques dans les scénarios actuels et futurs a été discutée.

Les résultats obtenus ont montré que la variation des facteurs typo-morphologiques entraîne une large gamme de besoins en chauffage et en refroidissement, par unité de volume du bâtiment, qui diffèrent d'un facteur 2 et 6, respectivement, entre les formes urbaines. L'évaluation énergétique solaire montre qu'il existe un potentiel solaire important sur les toits. Une surface photovoltaïque relativement petite peut éliminer la majeure partie de la demande d'électricité pour toutes les formes urbaines.

Les résultats tendent à améliorer l'efficacité énergétique des logements et à renforcer leur qualité environnementale. Ils peuvent également contribuer à une stratégie de réduction de la consommation d'énergie et de passage à une énergie propre dans le secteur résidentiel.

Mots clés : Constantine, forme urbaine, énergie solaire, consommation d'énergie, climat futur.

الملخص

تغير المناخ والطاقة أكثر أهمية من أي وقت مضى. تعمل العديد من الحكومات في جميع أنحاء العالم على مواجهة هذه التحديات ، خاصة بالنسبة للمستقبل ، الذي سيشهد تغيرًا حادًا في المناخ إذا استمرت المشكلات البيئية التي تسببها. لمواجهة هذين التحديين ، من الضروري تعزيز استخدام الطاقات المتجددة وإدخال تدابير كفاءة الطاقة ، لا سيما في المناطق الحضرية. تعتبر المباني بالفعل من بين أكبر مستهلكي الطاقة الأولية ، وخاصة من أصل أحفوري. تعود الزيادة أو النقصان في هذا الاستهلاك إلى نظام عدة عوامل ، مستشهدة بتغير المناخ ، والعوامل الشكلية المطبعية للمقاييس الثلاثة: الحضرية والمعمارية والمغلفة ، وسلوك الركاب وكذلك إمكانات الطاقة المقدمة . من خلال دمج حلول الطاقة المتجددة في الموقع. ومع ذلك ، للتغلب على هذا الوضع ، تم القيام بالكثير من العمل بشأن قضية الطاقة على مستوى البناء ، ولكن دون مراعاة التقييم المتعلق بالمناخ في المستقبل.

في هذا الصدد ، من خلال البحث عن توقعات حالية ومستقبلية مرتبطة بمسألة الطاقة وتغير المناخ ، يهدف هذا المشروع البحثي إلى دراسة الطلب على الطاقة ، والإنتاج المحلي للطاقة الشمسية وتأثير العوامل المطبعية. بالإضافة إلى الوصول إلى الشمس ، في التوقعات المناخية الحالية والمستقبلية. تركز الدراسة على حالة التقسيمات الفرعية في الجزائر ، في مدينة قسنطينة. من هذا المنظور ، تبدأ طريقة الدراسة باختيار أربعة أشكال سكنية حضرية مختلفة في مدينة قسنطينة من خلال تحليل التطورات السكنية في بلدية المدينة. من خلال الفحص المتعمق للحالات المختارة ، تم تحديد العوامل الهندسية والمورفولوجية المطبعية للمباني. بالإضافة إلى ذلك ، تم الحصول على بيانات استهلاك الطاقة التقديرية الفعلية للأشكال الحضرية الأربعة. بعد ذلك ، تم إنتاج نموذج الطاقة الحضرية للأشكال الحضرية باستخدام أداة نمذجة الطاقة للمباني الحضرية CitySim. يمر هذا النموذج بثلاث أدوات ، بدءًا من AutoCAD و SketchUp بنمذجة محددة للأشكال الهندسية الحضرية ثلاثية الأبعاد ، ثم يتم استيراد النموذج ثلاثي الأبعاد إلى برنامج CitySim ، حيث يتطلب الأخير إضافة جميع بيانات الإدخال الخاصة بالموقع المناخي و البنايات. باستخدام محاكاة الاختبار ، في هذه المرحلة ، تم تنفيذ طريقة معايرة نموذج طاقة المبنى ونمذجة المناخ المستقبلي لعام 2050. في تحليل تأثير عوامل الشكل الحضري على سلوك الطاقة ، والإشعاع الشمسي وتطور هذين المكونين الأخيرين على الإسقاط المستقبلي ، تم استخدام نموذج رياضي للانحدار الخطي. لتقييم تقنيات الطاقة الشمسية في الأشكال الحضرية ، يتم استخدام الطريقة التي طورها البروفيسور رافائيل كومبانيون. أخيرًا ، تمت مناقشة نهج لنمذجة الخلايا الكهروضوئية على المباني وكيف يمكن أن يقلل إنتاج الخلايا الكهروضوئية على الأسطح من احتياجات الطاقة في السيناريوهات الحالية والمستقبلية.

أظهرت النتائج التي تم الحصول عليها أن الاختلاف في العوامل الشكلية المطبعية يؤدي إلى مجموعة واسعة من متطلبات التدفئة والتبريد ، لكل وحدة من حجم المبنى ، والتي تختلف بمعامل 2 و 6 ، على التوالي ، بين الأشكال الحضرية. يُظهر تقييم الطاقة الشمسية أن هناك إمكانات شمسية كبيرة على أسطح المنازل. يمكن للمنطقة الكهروضوئية الصغيرة نسبيًا أن تلغي معظم الطلب على الكهرباء لجميع الأشكال الحضرية.

تميل النتائج إلى تحسين كفاءة الطاقة في المنازل وتحسين جودتها البيئية. يمكنهم أيضًا المساهمة في استراتيجية تقليل استهلاك الطاقة والتحول إلى الطاقة النظيفة في القطاع السكني.

الكلمات المفتاحية: قسنطينة ، الشكل الحضري ، الطاقة الشمسية ، استهلاك الطاقة ، المناخ المستقبلي

CONTENTS

Part II. Practical work: energy study at the level of the urban form

CHAPITRE IV : Environment study

CHAPITRE V : Material and methodology

ACRONYMS

AOGCMs	*Atmosphere-ocean general circulation models*
BAPV	*Building applied photovoltaics*
BIPV	*Building integrated photovoltaics*
BREEAM	*Building research establishment environmental assessment method*
CDER	*Centre for the Development of Renewable Energies*
CNERIB	*National Centre for Integrated Building Studies and Research*
COP	*Coefficient of performance*
CSP	*Concentrated solar power*
DHW	*Domestic hot water*
DHW	*Domestic hot water*
DTR	*regulatory technical document*
EPFL	*École Polytechnique Fédérale de Lausanne*
FAR	*Floor area ratio*
GHG	*Greenhouse gas*
GSA	*Groupemen Sonatrach Agip*
HBM	*low-cost housing*
HLM	*Housing moderate rents for linear planning*
HVAC	*Heating, ventilation and air conditioning*
IGBP	*International geosphere-biosphere programme*
IPCC	*Intergovernmental panel on climate change*
LEED	*Leadership in Energy and Environmental Design*
LOD	*Level of detail*
LPG	*Liquefied petroleum gas*
MTEER	*Ministry of Energy Transition and Renewable Energies*
NG	*Naturel gas*
NSIDC	*National Snow and Ice Data Center*
ONM	*national meteorological office*
PV	*Photovoltaic*
RCP	*Representative concentration pathway*
RE	*Renewable energy*
SKTM	*Society of Electricity and Renewable Energy*
ST	*Solar thermal*
SVF	*Sky view factor*
UCCRN	*Urban climate change research network*
UHI	*Urban heat island*
Unep	*United nation environment program*
UNFCCC	*United Nations Framework Convention on Climate Change*
ZEB	*Zero energy buildings*
ZHUN	*new urban housing zones*

NOMENCLATURE

CDD	*Cooling degree-day*	*°C*
ENv	*Energy needs per volume*	*KWh/m³*
$E_{threshold}$	*Illuminace of the outside vertical surfaces*	*Lx*
EUI	*Energy use intensity*	*KWh/m²*
E_w	*Average illuminance for workplane*	*Lx*
$G_{Future\text{-}passive\text{-}threshold}$	*Future Passive irradiation threshold*	*KWh/m²*
$G_{present\text{-}passive\text{-}threshold}$	*Present Passive irradiation threshold*	*KWh/m²*
$G_{threshold\text{-}pv}$	*Roof or façade annual irradiation for photovoltaic*	*KWh/m²*
$G_{threshold\text{-}st}$	*Roof or façade annual irradiation for solar thermal collectors*	*KWh/m²*
HDD	*Heating degree-day*	*°C*
NOCT	*Nominal operating cell temperature*	*℃*
Pmax	*Maximum power*	*Wp*
T_{base}	*Base temperature*	*°C*
Ti	*Mean daily temperature*	*°C*
T_{max}	*Maximum indoor setpoint temperature*	*°C*
T_{min}	*Minimum indoor setpoint temperature*	*°C*
U	*Thermal transmittance of the envelope*	*Wm-2 K-1*
Vmp	*Maximum power voltage*	*V*

LIST OF TABLES

LIST OF FIGURES

General introduction

GENERAL INTRODUCTION

I.1. Context of the study

Due to the necessities of society, all human production - be it urban or architectural - is systematically inscribed in an environment, with which it interacts and maintains a set of more or less complex and diverse relationships, essentially due to different factors. Among these various factors are those related to the environmental-climatic dimension and the production of the built environment.

Today's urbanisation is rapidly evolving, a global phenomenon that is emerging with different densities, typologies, and fabrics. According to the Population Service of the United Nations Department of Economic and Social Affairs, the map in figure 1 shows a prospective study on the percentage of urbanised areas and the amount of population in 2030, in 233 countries or areas more than 50% of the areas are denoted by the colour beige meaning a percentage of urbanisation ranging from 60% to 100% , the study reveals that 30% of the world's population lived in cities in 1950, 55% of the world's population lives in cities in 2018, and 68% of the world's population will be urban citizens in 2050 (United Nation 2018). For instance, in Algeria, this proportion will reach 85% in 2050 (figure 2) (United Nation n, d).

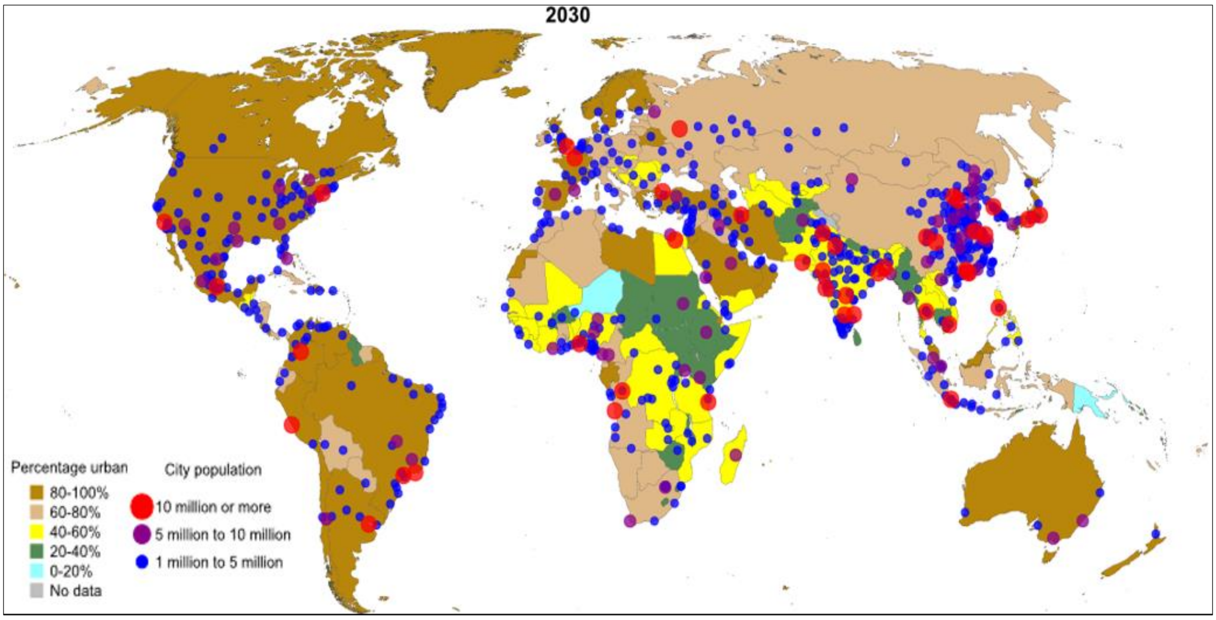


Figure 1. Percentage of urbanised areas and the amount of population in 2030.

Source: United Nation 2018.

This much of information clearly explains that cities will be forced to densify and expand to accommodate a larger population with its needs (Angel, Parent et al. 2011). Society seeks to live in cities with adequate quality, while the nature of the city depends directly on its architectural and urban quality, where both components are the result of the culture in their field and the collective work of the experts of the city. On the one hand, this forcing will lead to the growth of cities with banal proliferation and poor execution of the built environment, the signs of which are more visible in developing countries today (Montavon 2010). On the other hand, thinking about building a sustainable environment is poor and slower against the quick responding to the needs of the built environment and energy, while the latter severely affects the natural environment. In the future, this task will be more demanding, characterised by a built environment suffering from a lack of fresh air, sunlight and producing a large amount of greenhouse gas emissions due to the use of fossil energies.

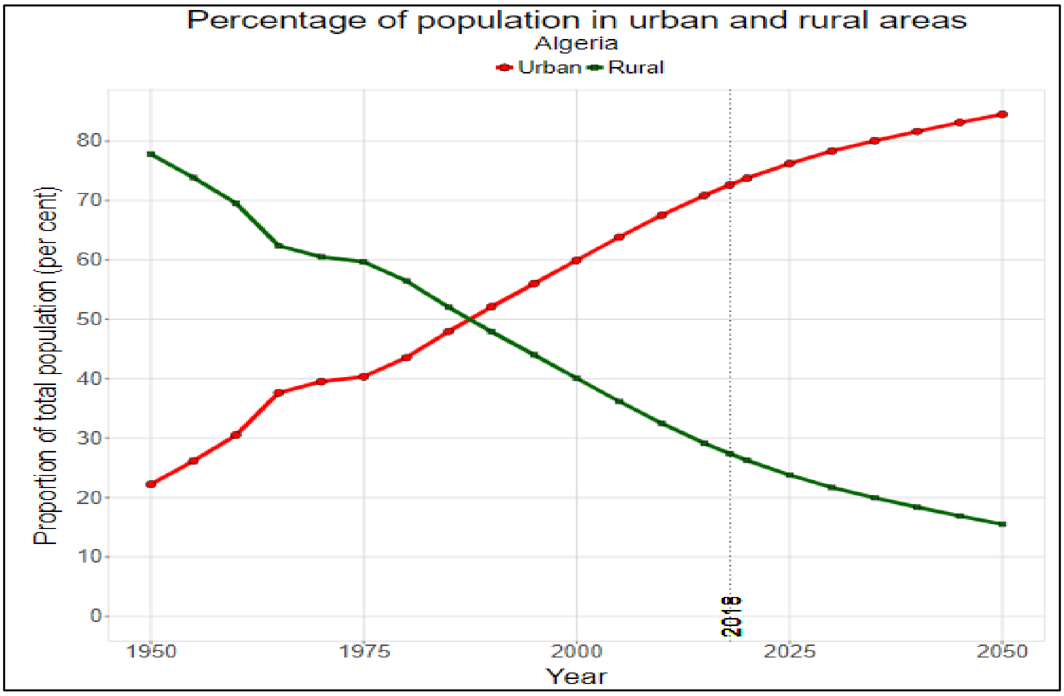


Figure 2. Urban and rural population in Algeria as a percentage of the total population, 1950 to 2050. Source: United Nation n, d.

On the issues of climate change, greenhouse gas emissions, energy efficiency, renewable energy and preservation of the natural environment, many governments around the world are working to address these challenges, especially for the future, which will experience a severe climate change if the caused environmental problems continue (Owusu and Asumadu-Sarkodie 2016).

Algeria as one of this government that seeks to manipulate these issues, it still suffers from the use of high energy fossil source which still increasing to supply its energy needs in the different sectors against renewable energy that is knowing a slight increase over the years (figure 3) (Bouraiou, Necaibia et al. 2020).

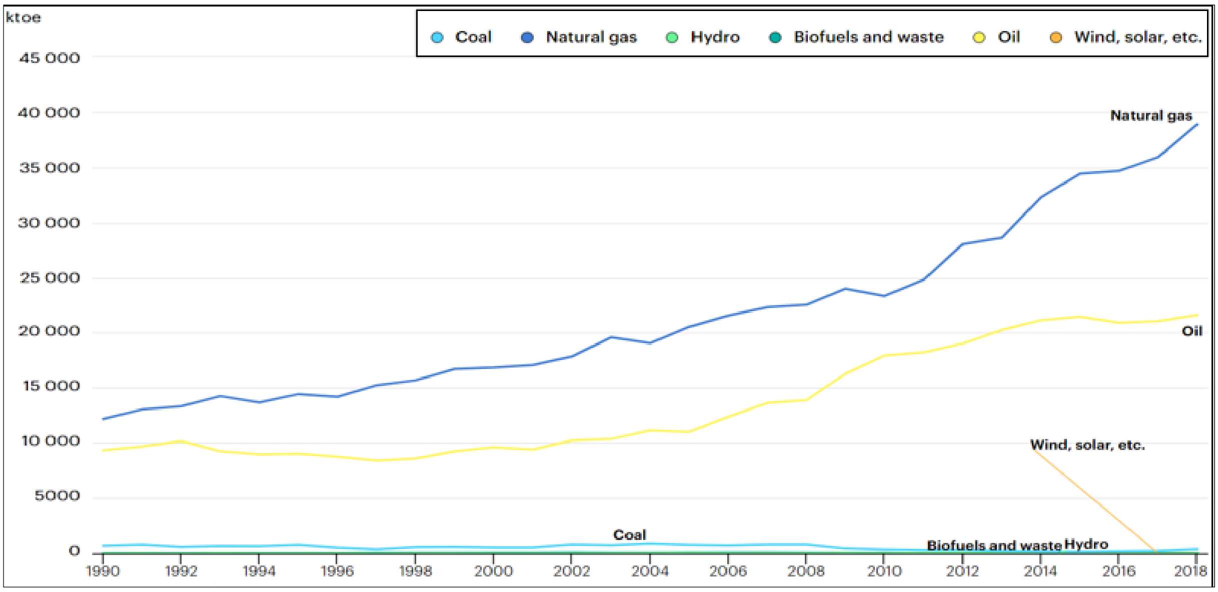


Figure 3. Total energy supply (TES) by source, Algeria 1990-2018.

Source: (IEA n, d).

Even in the antique world, the consideration of climate in the built environment was taken into account (Harzallah 2007), and despite the absence of gas pollution due to the use of fossil energy, cities were not really sustainable.

In the climate, one of the major factors is the sun, whose energy supply - the solar deposit - is both abundant, natural and free; it can therefore meet the environmental and economic requirements of society (Siret 1997), and by its vital role, the sun is a fundamental element in our world. The doctors in medicine says that the house where the sun enters, the doctor will not enter it, the medical findings of the researchers Louis Pasteur and Robert Koch showed that direct sunlight can eliminates a harmful germs inside houses, like the tuberculosis bacillus (Montavon 2010). Moreover, as the solar irradiation is an important constituent of the climate and very important for human comfort (heating, hygiene, energy...) (Sanaieian, Tenpierik et al. 2014), solar availability in the urban context could vary significantly, decisively depending on the urban morphology (Chatzipoulka, Compagnon et al. 2016, Morganti, Salvati et al. 2017, Chatzipoulka and Nikolopoulou 2018).

"How does this element affect the ways of organising our immediate environment, of conceiving architecture and the city, which by definition creates shadows?" (Siret 2013) it is a subject that many civilizations and researchers have experienced.

During the last century and especially during this decade, architects and urban planners have started to address solar radiation in their architecture and urban design and many tools have been developed for this purpose. Famous one like Le Corbusier have even designed buildings using solar projection (Kamal and Studies 2013). Similarly, the bioclimatic approach considers passive solar as a key factor in its conceptions by taking advantage of solar heat gain and sunlight, as well as protection from direct solar irradiation during hot periods (Manzano-Agugliaro, Montoya et al. 2015). Combined with active solar energy generation in the building design, solar will be taken into account much more than other times.

Many researchers assume that the sustainable city of the 21st century is a "solar city" (Kanters and Horvat 2012, Kanters and Wall 2016). Renewable solar energy can supply cities naturally and free of charge, heat, and cool buildings, ensure suitable daylight, provide hot water and generate electricity, and this will only be achieved through adequate urban planning with solar energy from the planning stage, the latter approach has been gaining traction recently through previous studies on a global scale such as measuring the effect of urban forms on solar energy potential (Montavon, Scartezzini et al. 2004, Cheng, Steemers et al. 2006, Chatzipoulka, Compagnon et al. 2016).

In the urban context, the consideration of solar potential starts by thinking adequately in the forms of the urban layout, the grid, the street, the plots, the arrangement of blocks, etc. In the architectural context, adaptation to solar radiation is done through the implantation, the height, the orientation, the use of the plot ratio of the building, as far as the architectural envelope is concerned, architects must pay attention to the fenestration ratio and the type of materials in the envelope (Siret 1997) for active solar energy, PV systems or ST collectors should be placed in sized dimensions in the urban context or integrated in buildings (BIPV or BAPV) as mini-systems or on roofs in general (Peronato 2019). To achieve this, urban planning and architecture must be designed to take advantage of the sun (Siret 2013). It is up to urban planners and architects to formulate the criteria of evaluation and spatial organization that allow to have an efficient exposure of the housing places to ensure a sustainable well-being and to take into account the solar energy benefit starting from a passive design with the guarantee of lighting and energy production. These criteria will certainly dictate guidelines such as the orientation of buildings and the configuration of volumes susceptible to guarantee an interior comfort with a reduction of energy consumption, thus the problem of the control of solar access at the level of the district in order to optimize and provide a sanitary and renewable energy production comes back to a priori considerations. As part of a well-defined urban and environmental context, the planning of buildings should therefore depend on a series of rational and contextual criteria and parameters specific to this scale**.**

I.2. Problematic

In Algeria, at the dawn of this third millennium, the process of urbanisation is galloping due to demographic growth, and cities have therefore increased their needs and posed numerous issues, energy challenges being one of the first problems that have already taken on greater importance. Algeria's resident population is 40.4 million, of which 70% live in cities (European Training Foundation 2018). Only in the residential sector, the consumption of electricity reached 2 653 (GWh) in 2020, representing 33% of the total electricity consumption, and it reached 10 974 (million m3) in gaseous products, representing 60% of the total consumption of gaseous products, it represents, therefore, a large energy consumer at the national level followed by the industrial sector (Ministry of energy 2020). This shows that today's cities face many challenges and that tomorrow's cities will be denser and more energy-intensive, whose challenges will become more numerous, this requires a lot of investment and load in terms of energy and makes it difficult to find a way to meet the expectations of the countries. Knowing that many fossil fuels are running out, therefore, this makes the future task more constraining in terms of the choice of this or that type of energy, so the energy challenges are unfolding and are going to unfold in the urban areas.

The energy issue, and more particularly that related to the housing sector, is more topical than ever (Ghedamsi, Settou et al. 2016). First, the proliferation of housing, equipment and infrastructure projects has undoubtedly increased the share of energy consumption. Moreover, natural gas has become more affordable over the last two decades, driving households to consume even more, mainly for heating. Other reasons as economic or social may also find their place. Hence, the housing sector may be a decisive element in reducing energy consumption, especially for a country whose income is extremely depending on fossil fuels and whose share of exports is continuously decreasing, in order to satisfy a large part of the local energy consumption (Bouraiou, Necaibia et al. 2020). A survey found that more than

90% of Algeria's electricity generation comes from natural gas-fired power plants (Khraief, Shahbaz et al. 2018). Also, the individual type consumes 94% of this total energy against the collective type which consumes only 6% (Latreche and Sriti 2018), presenting these values, a quick awareness is required to rethink the increasing energy control in the urban environment especially with the issue of climate change.

Algeria has a very powerful solar potential at world level, and this is reflected in its geographical location, its vast desert basin and its favourable climate. For the whole of its national territory, it is estimated that the average duration of insolation is more than 2,500 hours per year, this value rising to 3,500 hours per year in the Sahara (Table 1). With this insolation capacity, the average energy received amounts to 1,700 kWh/m2/year in the north to 2,650 kWh/m2/year in the south (Harouadi, Mahmah et al. 2007). These potentials can be a real source of renewable energy on the whole Algerian perimeter in urban, rural and Saharan areas. According to the International Renewable Energy Agency (IRENA), the evolution of renewable energies in Algeria is remarkable in the years 2015-2016-2017, of which the largest production is that of solar photovoltaic which represents 60% with a capacity of 400 MW (IRENA n,d). However, this production is largely due to the exploitation of photovoltaic farms and concentrated solar power on virgin surfaces in the south of the country, its transportation and maintenance are costly, and the most urbanised and energy-intensive areas dominate the northern part of the country. This paradox leads to change or develop the previous reflection in the way of benefiting from solar renewable energy, mainly in urban areas.

The widespread use of solar irradiation in urban areas is becoming an obvious and feasible strategy to promote sustainable and environmentally friendly development (Bruun Jørgensen, Croce et al. 2018). As far as the solar potential in urban areas is concerned, researchers are looking to achieve a true symbiosis between solar energy and the urban environment of the future (Kanters and Horvat 2012, Kanters and Wall 2016, Bruun Jørgensen, Croce et al. 2018). The idea starts with a passive strategy to take advantage of daylight and solar heating gains while arriving at the active strategy, at which point solar photovoltaic and thermal technology systems are integrated. In addition, solar technologies are knowing a huge development and spread out over the world, but the judicial use of solar energy in cities is not only a question of available technology, but mainly of urban form and local climatic needs (Vartholomaios 2015, Chatzipoulka, Steemers et al. 2020).

Then, the use of solar potential in urban areas requires a good understanding of the energy consumption of urban forms, their evolution, as well as consistency between urban forms factors and solar irradiation. The relationship between solar potential, urban form, and the energy consumption of buildings is essential for energy optimization at the building and urban scales (Sarralde, Quinn et al. 2015, de Lemos Martins, Adolphe et al. 2016, Reinhart and Davila 2016, Ahmad, Mourshed et al. 2017, Zhang, Xu et al. 2019). Many researchers have studied the effect of urban forms on building energy demand (Ratti, Raydan et al. 2003, Robinson, Haldi et al. 2009, Wong, Jusuf et al. 2011, Vartholomaios 2015, de Lemos Martins, Faraut et al. 2019, Trepci, Maghelal et al. 2020). Some have investigated the urban morphological factors and their impact on the availability of solar radiation in roofs and façades (Chatzipoulka, Compagnon et al. 2016, Mohajeri, Upadhyay et al. 2016, Chatzipoulka and Nikolopoulou 2018, Poon, Kämpf et al. 2020, Xu, Li et al. 2020), while others have explored its sensitivity to urban forms and its impact on both solar potential and energy demand(de Lemos Martins, Faraut et al. 2019). An international study was done by Lobaccaro et al analyzed passive and active solar of 34-reel urban samples show comprehension of how to get a successful solar strategies adoption in a new and existent urban context (Lobaccaro, Croce et al. 2019).

However, all these studies contemplate the present climate, not considering the expected rise in demand due to a warmer climate, as discussed in (Jankovic, Podrascanin et al. 2019). Many works were done world widely studying the heating and cooling needs over different climate change scenarios (Reyna and Chester 2017, Gi, Sano et al. 2018, Berardi and Jafarpur 2020). In climate zones where both heating and cooling periods are relevant for energy demand, such as in cold semi-arid regions, climate change is expected to decrease the heating load while increasing the cooling needs, leading to more electricity demand in the summer (Li, Yang et al. 2012).

Bridging the gap identified in the literature and seeking a future projection, this project of research examines energy demand, local solar energy production and the impact of urban typo-morphological factors on cooling and heating needs as well as on the solar access, during current and future climate projections. The prospecting is mainly interested in the case of housing estates in Algeria, at the level of the metropolis of Constantine, designed essentially in the light of the view, which represents an example of a prime to edge deficient as regards the concern of solar access, of which the latter plays a natural task essential for the energy optimization by a healthy and durable quality.

After this shield of the target topic, issues may be extracted for further investigation in the interest of the subject.

- **As presented above, some studies consider an energy switch in the future climate, considering a climate change scenario of 2050 in the city of Constantine as a new study area, how might the energy behavior and solar irradiation received in the four case studies change?**
- **Under current and future climate scenarios, what are the main factors in urban form that impact energy consumption and solar access?**
- **Regarding the energy evolution over the next 30 years, including climate change, to what extent solar technology can address energy consumption at the urban scale?**
- **The four residential urban forms were designed 32 years ago according to the old urban construction policies, these policies do not have points on climate change and different solar benefits in urban areas, knowing that the choice of the case studies was based on the difference on the urban form, and under the current and future climate scenarios, which form tends to have a better profile in terms of energy consumption and solar benefits?**

I.3. Objectives

The use of solar techniques to improve energy in urban areas can be divided into four techniques: passive, daylight, photovoltaic and solar thermal. This thesis has the objective to promote a sustainable urban built environment by studying the energy behaviour and potential uses of solar irradiation in urban areas in the context of climate change.

- **The first objective of this study is to determine the most important urban form factors that could have a high impact on energy demand and solar access. In many studies in the field of energy and urban built environment, researchers have focused on a few urban form factors such as density, H/W ratio and site coverage. A few have integrated all urban form factors and tried to reveal the most important ones, in our study, for each urban form case, all urban form**

factors were determined and, by going through a mathematical analysis, the most influential factors were selected to continue the overall study.

- **The second objective of this study is to examine the energy behaviour of four urban residential forms and to evaluate the amount of solar irradiation under different solar techniques and climate scenarios. Besides analysing the energy behaviour and solar irradiation in urban forms, the combination of these two studies and the consideration of climate change will lead to reveals more important results that will establish adequate links between the evolution of energy demand, solar irradiation, and the degree to which different solar techniques can be a key support to meet the energy demand in urban areas.**
- **The third objective of this study is the analysis of the impact of urban form factors on energy behaviour, solar irradiation and on the evolution of the latter two components over the years in the selected urban areas. This analysis demonstrates the relationships between urban form factors and energy behaviour, as well as solar irradiation, which can dictate a guideline for a more sustainable urban form aimed at reducing energy consumption and benefiting from solar techniques. Furthermore, linking the development of energy demand and solar irradiation over time to urban form factors is an important new research gap, which allows the formulation of recommendations to design more resilient buildings and to gives urban energy optimisation strategies for future projection.**
- **Lastly, the fourth objective of this study is the test application of renewable solar energy to urban residential forms revealing the results in the current climate and for 30 years until 2050. This part focuses on the conversion of solar energy into electrical energy, which aims to enhance the energy efficiency of housing and to promote the environmental quality of housing, which is deficient and irregular in most of the old or recently built housing. However, it is relevant to approach the energy issue from a purely technical point of view, which would lead to the assessment of urban housing forms as an addition of fulfilment criteria. Considering the future projection this promotion attempt tends to show the advantages of an active solar technique even considering a severe climate change.**

For this purpose, the study method starts with the selection of four different urban residential forms in the city of Constantine through an analysis of subdivision housing in the city's commune. Through further examination of the selected cases, the geometric and typo-morphological factors of the buildings were identified from several documents such as the urban master plans of the city of Constantine (namely, plans directeurs d'aménagement et d'urbanisme. PDAU 1989_Revised in 2015), the land use plan of the four zones (namely, plan d'occupation des sol, POS), the communal technical map, the plans (i.e., district plan, building height, type of users), and the thermal regulation document of residential buildings in Algeria (DTR-C3.2 1997, Centre National d'Etudes et de Recherches Intégrées du Bâtiment 2011, DTR-C3.4 2016). Also, the use of other useful information is considered such as orthophotos, identification of areas on maps (i.e. green surfaces, trees, type of surface) and site visits. Moreover, the estimated energy consumption data for the four urban forms was obtained from the city's electricity and gas distribution company. Then, the urban energy model of the urban forms was carried out using the urban building energy modelling tool CitySim (Kämpf 2009). CitySim Pro is developed at the Solar Energy and Building Physics Laboratory of the Swiss Federal Institute of Technology in Lausanne (EPFL) by doctor Jérôme Kämpf. The energy model of the urban building goes through three tools, starting with AutoCAD and SketchUp with an identified modelling of the urban geometrical shapes in 3D, then the 3D model is imported into the CitySim software, where the latter requires the addition of all the input data of the climatic site and the buildings (properties and materials of the envelope, renewable energy, behaviour of the occupants ...., etc.). Using test simulations, at this stage, the calibration method of the building energy model and the modelling of the future climate of 2050 were carried out. In the analysis of the impact of urban form factors on energy behavior, solar irradiation and the evolution of the latter two components on the future projection, a mathematical linear regression model was used. For the evaluation of solar techniques in urban forms, we used a method developed by Professor Raphael Compagnon.

Finally, an approach to modelling photovoltaics on buildings and how rooftop photovoltaic production can reduce the energy needs in current and future scenarios was discussed.

I.4. Hypothesis

Following the content of the study context, three distinct hypotheses are formulated to demonstrate the main statement of the present thesis.

- **Impact of urban form on energy demand and solar access will accentuate in future climate, and the energy gap presents a connection with typo morphological factors.**

Looking at the evolution of energy demand and solar access in the current and future climate can show a change, in particular that heating needs, cooling needs and solar irradiation are directly linked to climatic conditions and may also depend on the characteristics of the urban form.

- **A small area of PV system (20 m²) per building would satisfy electricity demand in the present climate and for next 30 years, and the PV could trigger the replacement of gas with electricity to satisfy heating needs in the heating season.**

In some regions, a small rooftop PV system can cover a large part of the energy demand, while in other regions systems such as building integrated PV (BIPV) or building applied PV (BAPV) are required to achieve high PV production. This hypothesis is based on the high amount of solar irradiation in the cold and semi-arid region of Constantine.

- **The built environment in Algeria, mainly subdivision housing, presents a compromised environment and is considered unsuitable for solar techniques and in terms of energy efficiency.**

Beyond a prototype of construction of residential subdivisions in Algeria which is based on the division of plots, the adjacent buildings on the one hand and the small vis-a-vis on the other hand, as well as these subdivisions are not built on a concept of energy efficiency, this could create an unsustainable environment and may present a deficit in many aspects like the benefit of solar energy.

I.5. Thesis structure and research approach

The current thesis report starts by general introduction, then is made of two main parts and each part contains three chapters, overall, six chapter, at the end of which a conclusion appears.

Chapter 1 introduces the concept of urban form and other key concepts related to the built environment, as well as the different factors of urban form that need to be defined in studies such as the interaction between climate and urban form, and energy use at the neighbourhood level. The chapter also discusses the relationship between urban form and solar access as well as with energy use.

Chapiter 2 defines the concept of climate change from the global to the urban scale. At the urban scale, sections of the chapter discuss the relationship between climate change and cities, particularly in the context of urban adaptation to climate change, as well as the main organisations involved in climate change research, such as the Intergovernmental Panel on Climate Change (IPCC). Simultaneously, urban energy consumption and production in relation to climate change were debated. the chapter also provides an overview on minimising energy demand in buildings, in particular through on-site urban solar energies technics.

Chapiter 3 covers the Algerian legislative and regulatory corpus on energy efficiency and renewable energy, the discussion takes into account the analysis of the residential sector and the energy situation of the country.

Chapiter 4 introduces the environment of the study, the city of Constantine as an object of study is presented and discussed in four sections: first, a historical. Secondly, a climatic study of the city. In addition, an epistemological study and a classification containing the type of housing in the city was discussed, this study was further elaborated to discuss the type of individual housing in the city. Also, it aims to show the fourth selected urban forms as targeted case studies.

Chapiter 5 provides a comprehensive overview of the methods and tools used in conducting the study. It treats the screening of the case studies by the identification of their typo-morphological properties in several scales. Then, it explains the criteria for the selection of Citysim as an urban building energy modelling tool capable to meet the study specifications.

Chapiter 6 focuses on the impact of urban form factors on energy consumption and solar potential of urban forms during the present and future climate. The first part of this chapter deals with the selection of urban form factors that exert a significant influence on energy behaviours and solar irradiation received. In the course of the study, sections are based on mathematical approaches such as Pearson correlation or linear regression models and 3D simulated models to thoroughly understand the relationships between the study components. In addition, the chapter contains a study on the application of renewable energy in the residential urban forms.

Chapter I

Relationship between urban form and energy

I.1. Introduction

Urbanised areas such as cities, towns and villages contain a significant amount of population worldwide. Cities can present a variety of urban compositions, an in-depth study of the city from an energy, climate, social, planning or geography point of view as a large urban system must be subjected to the study of its composition and elements at a small scale.

The city has a variety of urban forms and buildings, and at the scale of the town plan, many components could be discussed at several scales of the built environment, such as elements of urban form and land use plans.

This chapter introduces the concept of urban form and other key concepts related to the built environment, as well as the different factors of urban form that need to be defined in studies such as the interaction between climate and urban form, and energy use at the neighbourhood level. The chapter also discusses the relationship between urban form and solar access as well as with energy use. The discussion focuses on most of the studies in the literature review that focus on understanding the impact of urban form factors on solar energy access and use.

On the basis of several studies that deal with urban form, climate and energy use, a variety of typo-morphological factors have to be defined at this level, starting with occupant behaviour through building envelope characteristics to urban properties. Some researchers have based their study on a few factors of urban form, for example, studies that focus on the relationship between urban form and solar access consider the following factors: density, street orientation and aspect ratio (H/W) as the main factors influencing solar irradiation in the urban context (Sanaieian, Tenpierik et al. 2014). Others study the energy use of building based on the shape of the building and its envelope characteristics (Fallahtafti and Mahdavinejad 2015).

Furthermore, the physical interactions between climate and buildings, and between buildings, are a key factor in energy consumption. The most notable assessments in this area take into account five factors that affect energy consumption in the built environment, including: urban climate, urban morphology, building physics, heating, ventilation and air conditioning (HVAC) systems and occupant behaviour (Goulding, Lewis et al. 1992, Council 2004).

I.2. Urban form

I.2.1. Definition of concepts related to urban form

The term 'urban form' is used in many disciplines recently, urban planning, geography, architecture, or urban sociology. Indeed, any researcher who is experienced in his or her field knows that the word 'form' is a convenient word in many disciplines. In order to better understand what urban form could be, it is useful to first understand the concept of form, and then to relate it to the urban context.

"Form" has several definitions and is characterized according to the field of study to which it relates.

According to the Larousse dictionary, it means an object, a way of materializing, lines, an organization of the contours of a thing, a configuration, it can also be an aspect, an event, or a way of expression (Patrick Bacry 1995).

Pursuant to the Lexico dictionary, form means the visible shape or configuration of something; for example, body shape, design, style, type of arrangement…, it defines a particular way in which something exists or appears; example: the structure of a word, phrase...., it can express a type or variety of something; as an artistic or literary genre (Oxford-Lexico n,d).

From a first view, we can note that, the urban form is a concept developed to define and characterize a form of parts in the fabric of cities.

Working on the basis of the need term, we will then group together the significant definitions of urban form.

According to Raynaud, the expression urban form was addressed during the 1970s after some typo-morphological studies, such as the typological study of Venice by Muratori (1959) and the typo-morphological study of Padua by Aymonino et al (Raynaud 1999).

In urbanized region, urban forms were defined as spatial composition and configuration of any fixed elements, representing the density and the spatial design of transport and communication infrastructure in a spatial land use (Anderson, Kanaroglou et al. 1996).

Furthermore, the urban form presents the physical characteristics of a city, defining the shape, dimensions and configuration of a part or the whole of an urban area. Its scale allows it to be analyzed and structured (Živković 2020).

It can be an element in the urban spatial structure; this last one contains, also, the urban interactions and a series of principles organized between the urban form and urban interaction (Bourne 1982).

The characteristics of urban form in the city include the type of urban settlement, such as a business district or suburbs as well as principal agglomeration. Nevertheless, scale is the important point of urban form and has been defined as the "*morphological attributes of an urban area at all scales*" (Williams, Burton et al. 2000).

Urban form has a wide range of meanings, and the polysemy of the term includes urban type, urban fabric, urban composition, urban pattern, urban representation, urban project, urban plan. All these meanings can be used to identify the concept of urban form (Raynaud 1999).

Lévy provides a new approach to the term, defining urban form as a diversified concept, presented in different forms, each form being identified according to the urban planner's examination of the urban form (Lévy 2005);

Cityscape's form: study the visual and sensitive aspects of the configuration of the urban space.

Social form: study the forms of organization of society in the urban space.

Urban fabrics form: study the elements that constitute urban space.

Path's form: study the geometrical aspects of the urban space.

Bioclimatic form: study the climatic and environmental data of the urban space.

The different civilizations and periods of urbanization have given rise to numerous urban forms, the difference between which is explained typologically (DJEDDOU 2016).

I.2.1.1. *Urban configuration*

The urban configuration is one of the angles of the study of urban form, according to Philipp Rode et al "*Building configuration is the arrangement of height, volume, footprint shape and size of individual buildings and their relationship to each other*" (Rode, Burdett et al. 2014). From this definition, we can say that the analysis of the configuration in the build environment covers numerous points. Further, the study must start with the analysis of the configuration of each building, which is identified by its typo-morphological characteristics such as plot ratio, height, compactness of the volume...etc.

I.2.1.2. *Urban morphology*

In the 18th century, Johann Wolfgang Von Goether first used the term morphology to express "*the science that deals with essence of form"*. Subsequently, the word was used in several fields, and it was in the 19th century in Europe that morphology began to be used in the study of cities (Oliveira, Barke et al. 2018). Urban morphology is the science of the physical built environment, which has a large overlap with urban form, used in the study of the physical form of cities and towns. It is known in many fields such as geography, history, architecture, planning, spatial economics... Urban morphology focuses on the study of the urban fabric and the relationship of its components, the study aims to draw out the process of their composition over time and across different spatial scales (Rode, Burdett et al. 2014, Oliveira, Barke et al. 2018, Chiaradia 2019).

The most convenient definition of morphological or formal analysis in the urban context comes from Moudon, who set it in three points (Moudon 1997).

1. Urban form is defined by three fundamental physical elements: buildings and their related open spaces, plots or lots, and streets.

2. Urban form can be understood at different levels of resolution. Commonly, four are recognized, corresponding to the building/lot, the street/block, the city, and the region.

3. Urban form can only be understood historically since the elements of which it is comprised undergo continuous transformation and replacement.

One could conclude that these notions lead to the study of the forms of the built environment from different angles and at different scales.

I.2.2. Characterisation and factors of urban form

The analysis of an urban form consists of studying its modularity to its urban configuration. Modularity refers to the arrangement and juxtaposition of buildings, while the urban configuration leads to study the typo-morphological factors of this urban form (Dempsey, Brown et al. 2010, Živković 2020)

According to Bergamini, the study of urban form is structured in three main ways; referring to: (a) the urban plan, (b) urban fabric, (c) the land building utilization. In the town plan, the most visible features or elements of the urban form are the street pattern, the plot pattern and the building pattern, these elements are in a hierarchy, where one pattern is included in the others (figure I- 1) (Kropf 2014, Bergamini 2019).

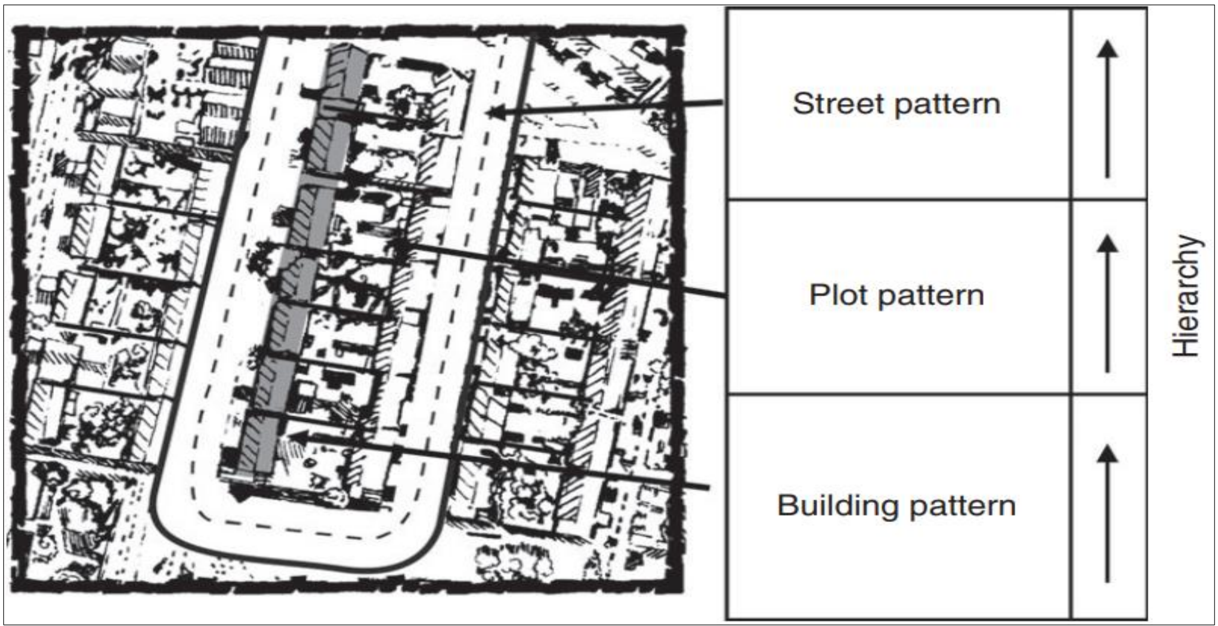


Figure I- 1.Basic elements of urban form.

Source: Bergamini, 2019

Screening on the elements, each pattern is composed from sub-elements (arrangements, types...). Figure I- 2 illustrate an overview of urban form elements and land use plans at the town plan scale. The street pattern can be presented in two groups: the traditional, which exists since the creation of the city, and the suburban, which reflects the development of the cities. Within the traditional groups, four types of street patterns can be identified: (a) regular (orthogonal); (b) irregular; (c) deliberate irregular; and (d) baroque. In suburban groups, four other street patterns can be found: (i) grid or modified grid; (ii) curvilinear; (iii) curvilinear: super-block around a common centre; and (iv) contemporary (Filion 2012).

With regard to the plot pattern, it corresponds to the subdivision of land into plots, isolated lots and lots as separate properties, these subdivisions can form four types of plot patterns: (a) type X; (b) type H; (c) type Y; and (d) curvilinear (Sgroi 2011).

The street block can be composed depending on the organisation of the streets around the plots, several of these organisations lead to a set of neighbourhoods structured by streets, referring to Louf and Barthelemy (Louf and Barthelemy 2014), four groups of *building blocks* can be distinguished:

Group A: marked by a medium-sized block with a checkerboard pattern of squares and rectangles.

Group B: characterised by small blocks and various non-uniform and distributed shapes.

Group C: characterised by a variety of shapes in the arrangement of the blocks and contains small and medium sized blocks.

Group D: characterised by small blocks with square and rectangular shapes.

In addition, these groups can contain two types of building blocks (building patterns). The first is linear alignments which are represented by three sub-linear alignments: (a) collinear, (b) curvilinear, and (c) road alignment. The second category is non-linear alignments, which contains two elements (Zhang, Ai et al. 2013): (a) grid like and (b) unstructured.

Based on the paper of Conzen and Papers, 1960, the urban fabric which has its origins in organic characteristics can find its place in the structuring of the town plan (Conzen and Papers 1960). Urban fabrics can have different configurations; referring to Bergamini, four are identified.

(a) open urban fabric (loose land division with a low building percentage).

(b) scattered urban fabric (similar to (a), but with unbuilt or irregular land division).

(c) closed or compact urban fabric (all the block's land has been occupied).

(d) semi-compact urban fabric.

Furthermore, at the scale of the town plan, the concept of land use and buildings is also defined (Conzen and Papers 1960), this concept indicates the use of the land, it presents the land according to the activity that is developed or planned in this area (residential, commercial, industrial, or recreational).

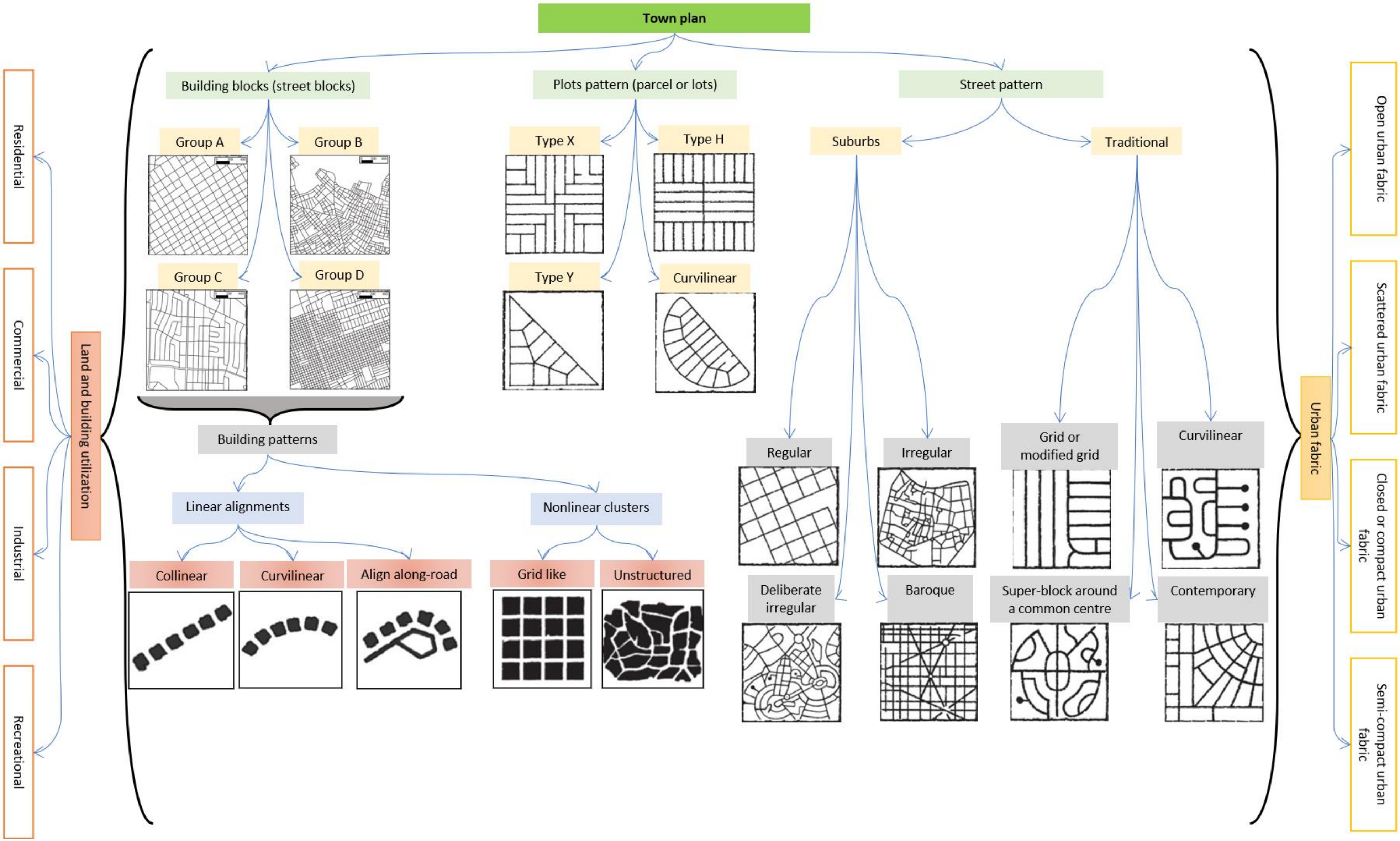


Figure I- 2. Overview of urban form elements and land use plans at the town plan scale.

Source: Bergamin 2019; Conzen & Papers 1960; Filion 2012 ; Sgroi, 2011 ; Louf and Barthelemy 2014.

I.2.2.1. *Typo-morphological factors*

In each urban area, the typo-morphological factors can be broken down into other scales for a more precise analysis, these scales are the urban block scale, the building or architectural scale, and the envelope scale. Each scale contains different factors (Dempsey, Brown et al. 2010, de Lemos Martins, Faraut et al. 2019, Živković 2020), however, other factors arise from the correlation between defined typo-morphological factors, these new factors such as complexity and average building height can help in many studies, especially those related to solar access (Chatzipoulka, Compagnon et al. 2016).

I.2.2.1.1. Urban block scale

a) Density

In the urban framework, the concept of density is used to define a relationship between a specific element (N) that represents the number of inhabitants, dwellings, services or floor space, and a reference space (S) based on the element, leading to calculate area density, volume density, etc. It is worth noting that the surface density is the most widely used.

Mathematically the density is calculated by the formula D (P) = N / S (Berghauser Pont and Haupt 2009, Hanin, Le Fort et al. 2012, Silva, Oliveira et al. 2017).

Also, it is noteworthy that the same density may take very different forms, as detached houses generally have a lower density than semi-detached houses. While this is not always the case, as shown in Figure I- 3 (Silva, Oliveira et al. 2017).

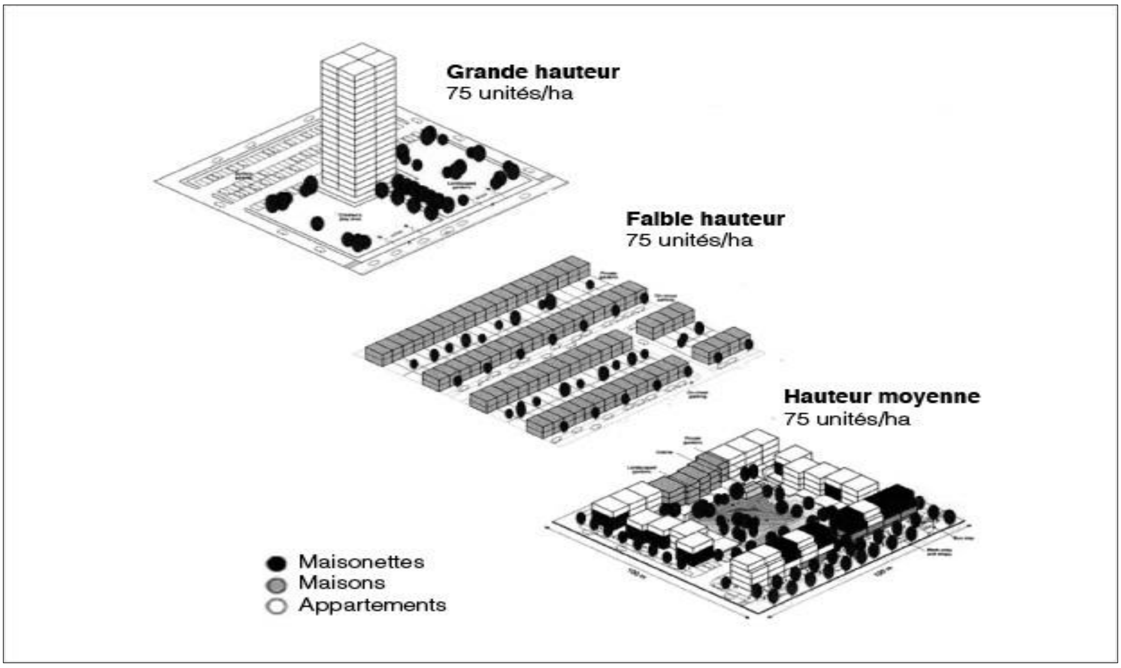


Figure I- 3. Relationship between density and urban form (all 75 units/ha).

Source: Urban Task Force (1999).

In the type of density or the densification strategies figure two elements. First, the urban renewal which focuses on physical changes in different urban areas of the city according to economic and social needs, it is defined "*as a process that includes clearance of slum or blight areas, urban redevelopment, urban revitalization, building rehabilitation, preservation and conservation to improve urban fabric, and meet some economic and social objectives*." (Lee 2009) (figure I- 4 shows an example in Paris). Second, the soft density which is defined here as a strategy to increase urban density through additions to existing buildings, such as unit infill, lateral expansion or roof heightening. these strategies can be implemented in suburban and central areas (Peronato 2014) (figure I- 5).

Figure I- 4. Urban renewal strategy in Paris.

Source: Rider Levett Bucknall (RLB) 2019.

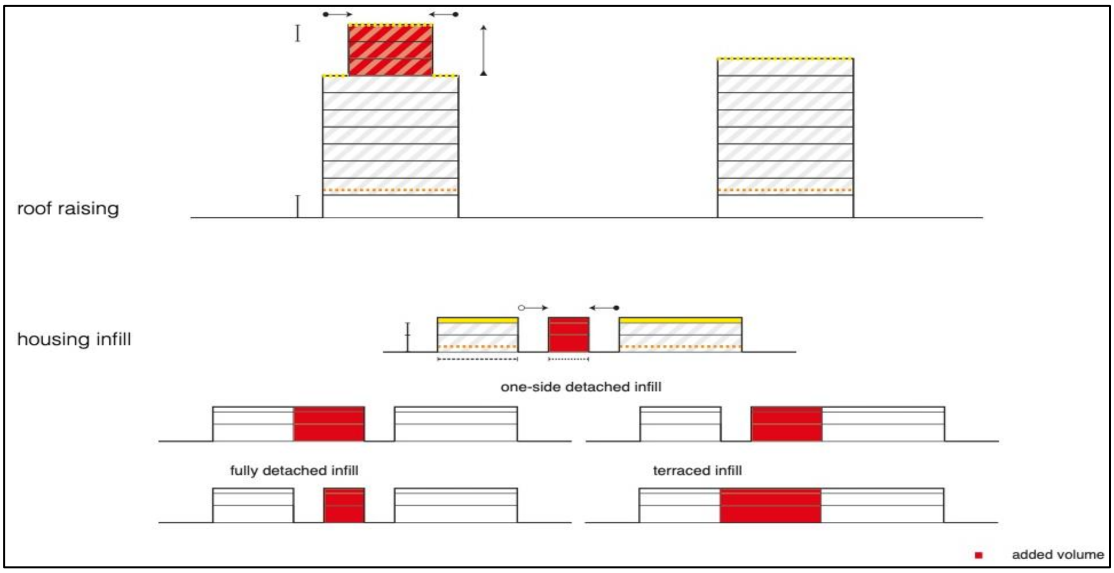


Figure I- 5. Densification strategies.

Source: Giuseppe Peronato 2014.

b) Floor Area Ratio

The floor area ratio (FAR) is the ratio of the building's floor area to the total area of the building lot/parcel (figure I- 6). It is an important component in the urban scale that allows for the calculation of building volume on a development site, and enables discussion of topics such as population density, heat island intensity or energy use. A high FAR value means a high building volume value and the FAR can be expressed by the synonyms *"plot ratio," "floor space ratio," "floor space index," "gross plot ratio,"* and *"site ratio"* (O'Brien 2019, Zhang, Chen et al. 2019). Mathematically, the FAR is calculated by the following formula,

$$\text{Floor Area Ratio} = \frac{\text{Total Building Floor Area}}{\text{Gross Lot Area}}$$

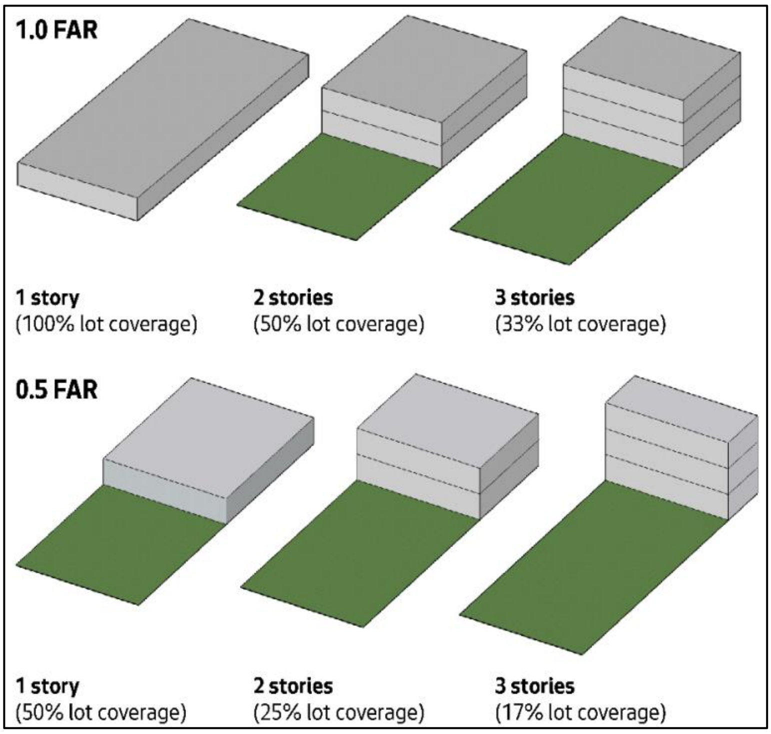


Figure I- 6. Illustrations of Floor area ratio (FAR) limits.

Source: Accessory Dwelling Units Final EIS, City of Seattle, 2018.

c) Site coverage

The site coverage is defined as the footprint of the building and its entire projected area as seen from above and is closely related to the density of the area (figure I- 7) ((Urban-redevelopment-authority 2019). To calculate the site coverage, we can use the following formula,

$$\text{Site coverage} = \frac{\text{Area computed as site coverage}}{\text{Net site area}}$$

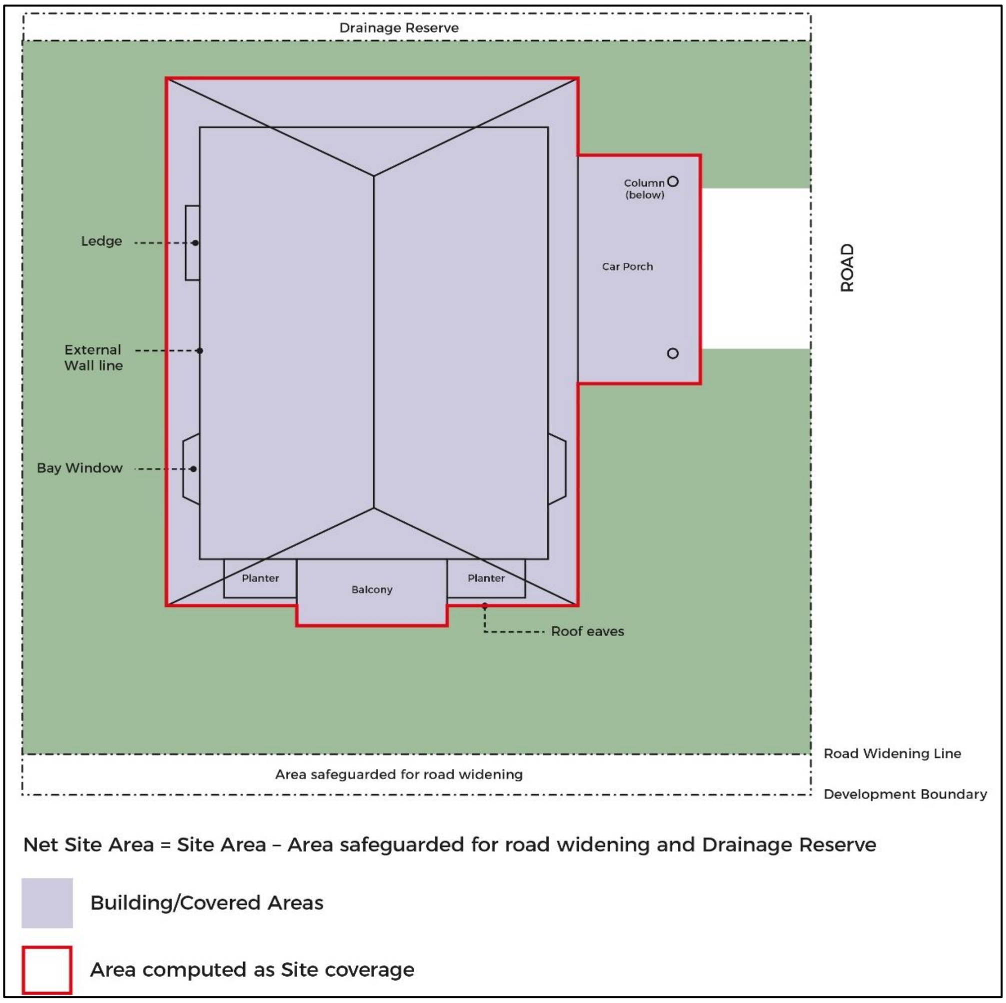


Figure I- 7. Illustrations of Site Coverage Plan Example for a Detached House.

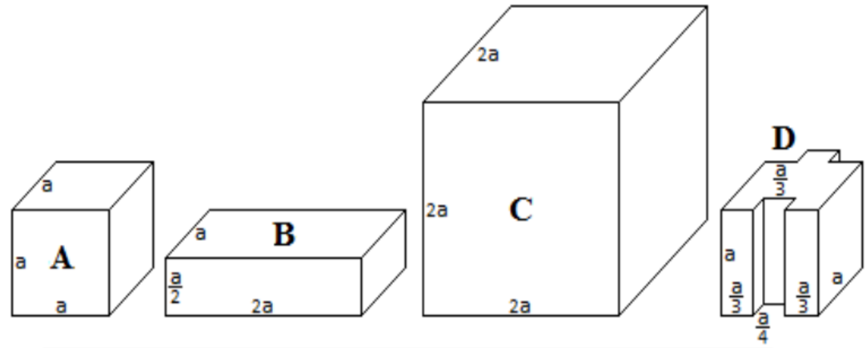
*Source: Urban redevelopment authori*ty, A Singapore Government Agency Website.

d) Shape Factor (compactness)

The form factor or compactness of the building refers to the same measure, the form factor refers to the ratio of the thermal envelope area of the building to its volume, and the compactness refers to the ratio of the volume area to its thermal envelope, it is interesting to note that some researchers express compactness as the shape factor. The thermal envelope area is the area that distinguishes the indoor environment from the outdoor environment (Danielski, Fröling et al. 2012, Parasonis, Keizikas et al. 2012). The value of the form factor is determined by the shape of the object for a determined volume as shows figure I- 8.

The compactness is expressed by the formula,

$$R_C = \sum_{Building} \frac{Area\ exter}{Volume}$$



	A	B	C	D
Volume	a^3	a^3	$8a^3$	a^3
Thermal envelpe	$6a^2$	$7a^2$	$24a^2$	$7a^2$
Shape factor	6/a	7/a	3/a	7/a

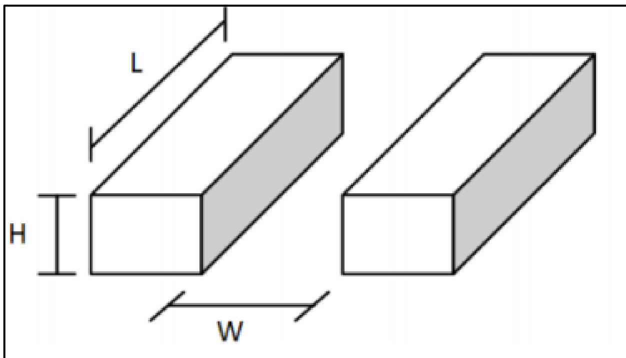
Fig. 1: The shape factor of buildings with different sizes and shapes. The parameter ‘a’ symbolizes a unit of length.

Figure I- 8. The shape factor of buildings with different sizes and shapes.

Source: Danielski et al 2012.

e) Aspect ratio (H/W)

The aspect ratio (AR) is the relationship between the height of an element and a reference width in the element's property frame. At the urban form scale, the aspect ratio is the relationship between the average height H of building walls and W the width of the road (Street Width) or space-between buildings (AR= H/W) (Davis, Frederick et al. 2003). The road/space-between type at this scale can take many forms. According to references (Nicholson 1975, Afiq, Azwadi et al. 2012) the narrow street between two continuous rows of buildings presents a street canyon, at this point, there are different types of street canyons depending on the aspect ratio (H/W) and the ratio (L/W) of the canyon. Figure I- 9 illustrates six classifications of the street canyon: avenue, regular, deep, short, medium, and long street canyons.



Aspect Ratio	Classification
H/W < 0.5	Avenue canyon
H/W = 1	Regular canyon
H/W > 2	Deep canyon
L/H < 3	Short canyon
L/H = 5	Medium canyon
L/H > 7	Long canyon

Figure I- 9. Geometric and classification of street canyon.

Source: Afiq et al 2012.

Referring to (Mahaya 2014) three types of roads can be distinguished basing on the aspect ratio (H/W); the canyon shape (H/W>2), the dihedral shape (0.5<H/W<1), and the open shape (H/W<0.25).

f) Contiguity

Adolphe defines the contiguity aspect of a building as a relationship between the area of the vertical envelope which is adjacent to other buildings and the total area of the envelope in which the building is open to outdoor spaces (Adolphe 2001).

At the urban fabric scale, the average contiguity is calculated from the contiguity of individual buildings weighted by their floor area to reduce the effect of large buildings. The contiguity factor Ct can be calculated by the formula below,

$$C_t = \sum_{buildings} \frac{A_{adj}\, A_{floor}}{A_{vert}} / \sum_{buildings} A_{floor}$$

where A_{vert} *is the exterior area of the vertical envelope for a given building,* A_{adj} *is the area of the vertical envelope adjacent to other buildings, and* A_{floor} *is the floor area of the building (Adolphe 2001).*

g) Complexity

Complexity in architecture is used to calculate the aesthetics (M) by the formula (M=O/C) where O is the order of the element (window or nich...) and C is the complexity as the frame (façade) (Birkhoff 1933). For (Morvaj 2012), urban complexity can be explained as successive urban scales, indicating hierarchical orders of structure within a city. It can be presented as factors used to measure the diversity, spatial distribution or mix present within urban areas, or used in different forms in relation to energy consumption (Salat, Bourdic et al. 2010).

Referring to (Chatzipoulka, Compagnon et al. 2016, Chatzipoulka and Nikolopoulou 2018), which meets the specifications of the thesis study, at the level of urban form, complexity is defined by the ratio of the total area of building façades to the area of the study site [m² / m²], expressed by:

$$Com = \sum_{Building} \frac{Area_{façades}}{Area_{site}}$$

h) Building height characteristics (m)

In building height characteristics, several factors can be extracted citing, maximum building height, minimum building height, mean building height, mean building height weighted by footprint area (MeH), and standard deviation of building height (StH) (He, Li et al. 2019, Hagen 2021, Wei, Hu et al. 2021).

The mean buildings height (m) (figure I- 10) is expressed by the formula:

$$\bar{h} = \frac{\sum_{i=1}^{N} h_i}{N}$$

The mean standard deviation of building height (m) is used to describe the degree of building heights randomness, and it is calculated by the formula:

$$StH = \sqrt{\frac{\sum_{i=1}^{N}(h_i - \overline{h})}{N-1}}$$

where $\bar{h}$ is the mean building height, StH is the standard deviation of building height, hi is the height of building i, and N is the total number of buildings in the area.

The calculation of mean building height (m) weighted by footprint area (MeH) is illustrated in figure x.

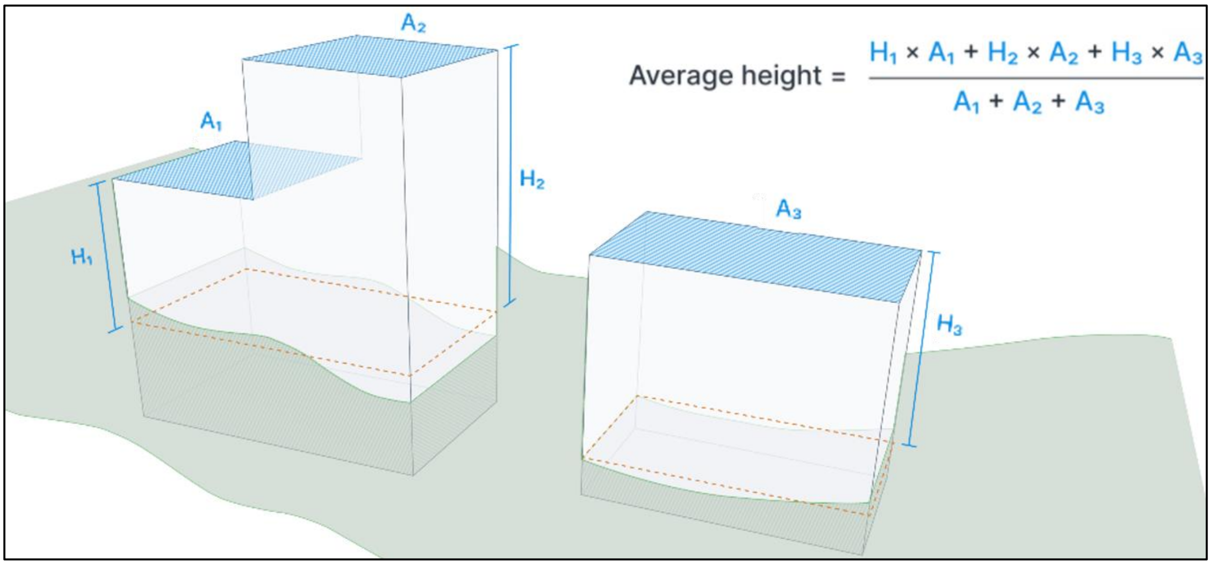


Figure I- 10. Calculation of mean building height for different heights.

Source: Kristine Hagen (spacemaker) 2021.

i) Standard deviation of building footprint area (Stf m²)

The standard deviation of each building footprint is a further aid to determining the shape of the building (i.e., regular or irregular shape) (Lwin 2010). At the urban form scale, the StF serves as a variable to measure the horizontal randomness of the urban site. A lower value of StF indicates a very regular distribution of total site coverage (Chatzipoulka, Compagnon et al. 2016). StF (m²) is calculated by the formula:

$$StF = \sqrt{\frac{\sum_{i=1}^{N}(A_i - \overline{A})}{N-1}}$$

where $\bar{A}$ is the mean building area, StF standard deviation of each building footprint area, *Ai is the area of building i, and N is the total number of buildings in the area.*

j) Rugosity

The rugosity in urban areas is defined by the average height of the urban canopy which is considered as a vertical density, consisting of built and unbuilt surfaces as well as vertical and horizontal features and vegetation. It demonstrates how air mass, wind speed, and wind direction are manipulated through obstructions or undeveloped or unbuilt spaces. According to (Adolphe 2001) it is possible to distinguish the absolute rugosity *(H_m)* and the *relative rugosity (R_a).*

Absolute rugosity (Hm) characterizes only the average height of the urban canopy (spaces below the street roofs and between buildings that is less than the mean height of buildings), Hm is provided by the product of the height of the buildings and their area, divided by the total built and unbuilt area, it is expressed by the formula,

$$Hm = \frac{\sum_{built} A_i h_i}{\sum_{built} A_i + \sum_{nonbuilt} A_j}$$

Where A_i is the footprint area of building i, h_i is the height of the building i, and A_j is the area of nonbuilt element j (Adolphe, planning et al. 2001).

relative rugosity (R_a) presents the mean square deviation of the canopy height for a specific direction, weighted by the width of each element in the section plane, it takes into account built and unbuilt elements and can be expressed as below:

$$R_a = \frac{\left[\sum_i (h_i - h_a)^2 {l_i}^2\right]^{1/2}}{\sum_i l_i}$$

Where h_a is the mean height of the urban canopy in the direction a, h_i is the height of the (built or nonbuilt) element i of the canopy, l_i is the width of the element i of the canopy in the plane of direction a, and $\sum l_i$ is the diameter of the urban canopy which was studied (Adolphe, planning et al. 2001).

k) Porosity (%)

Referring to (Steane and Steemers 2004, Fouad 2007) the porosity of urban fabric means the total volume of air in urban hollows and their relationship to the volume of the urban canopy. It is measured as a percentage and is used as an indicator to assess the penetration of solar radiation and the speed of airflow in urban hollows. Using the formulas of (Adolphe 2001) porosity is calculated as follow:

$$P_o = \frac{\sum_{open\ spaces} \pi {r^2}_{hi} L_i}{\sum_{open\ spaces} V_i + \sum_{built} V_j}$$

where L_i is the length of the open space i, r_{hi} is the equivalent hydraulic radius of the open space i, V_j is the mean volume of the built volume j, and V_j is the mean canopy volume above open space i.

The equivalent hydraulic r_{hi} is calculated by the formula:

$$r_h = \frac{lh}{1+h}$$

where h is the height of the canopy for the street (mean height of the adjacent built and nonbuilt spaces), and l is the mean street width (Adolphe 2001).

l) Urban sinuosity

Sinuosity is used to distinguish the type of space (street, courtyard, or enclosed space), it is characterised by directions and length, it is defined in a specific direction as the sum of the lengths of the street segments weighted by a coefficient typical of the angle between the direction of the street and that direction (Adolphe 2001). The relative sinuosity is given by the formula:

$$S_o = \frac{\sum_{street\ segments} L_i \cos^2(\Theta_i)}{\sum_{street\ segments} VL_i}$$

Where Li is the length of the linear segment i, and Θ_i is the angle between the given azimuth (of flow) and the azimuth of linear segment i.

m) Mineralization (%)

This indicator shows the distribution of mineral surfaces in the urban fabric by calculating the ratio between unused surfaces (green or water spaces) and the total surface. It aims to show the internal characteristics of the surfaces in the urban fabric. This urban indicator is useful in studying the impact of different minimum surfaces on microclimatic conditions (Adolphe 2001). The mineralization is given by the formula:

$$M = \frac{1}{A_T}(A_T - \sum_i A_u$$

where A_T is the total area of the studied urban fabric, and A_u is the useful area of the element i of water or vegetation (Adolphe 2001).

n) Sky View Factor (SVF %)

The sky view factor (SVF) is designed to study the degree of openness of a point on a specific surface (ground, facades, roofs, roads...) to the sky. It is useful in forestry and urban climatology studies, allowing the analysis of radiative changes and temperatures in these areas (Holmer, Postgård et al. 2001). According to (Watson and Johnson 1987), it shows the ratio between the radiation received by a flat surface and that of the whole hemispherical radiating environment, it can be related to the H/W ratio in a simple canyon (figure I- 11 a) ,varying from 0 to 1, a low value of SVF indicates that the sky is totally obscured in the studied spaces (low parts of the facades in the canyon, very closed spaces), when its value is close to 1 it means that the surface has a large opening to the sky (open spaces, roofs, big road) (Oke 1988).

From a technological point of view, the SVF can be evaluated by a photographic process, the fisheye device (figure I- 11 b) (Gong, Zeng et al. 2018).

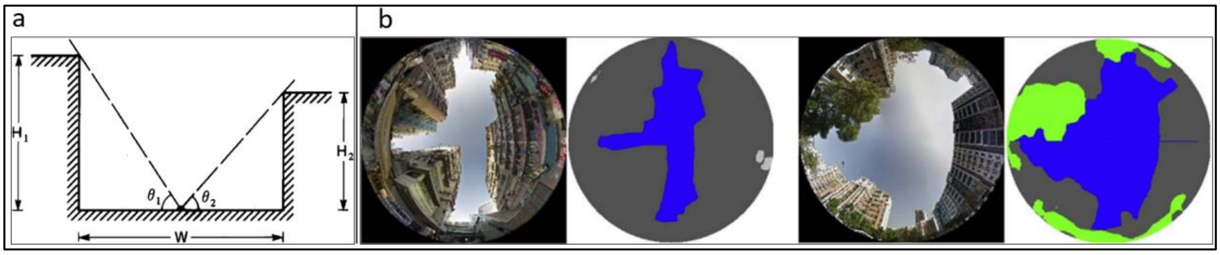


Figure I- 11. measuring SVF basing on H/W ratio in canyon road (a) and on the photographic method (fish-eye lens) (b).

Source: Oke 1988 (a) and Gong et al 2018 (b).

According to (Mazria 1981) cited by (DJAAFRI 2014) The sky view factor can be given by the formula:

$$SVF = \frac{S_{sky}}{S_{disk}}$$

where S_{sky} is the area of the viewed sky in a stereographic projection and S_{disk} is the area of the whole projection.

o) Albedo

At the Earth scale, the part of the incoming solar energy diffused by the Earth towards space is called planetary albedo.

The average albedo value in the urban environment is the fraction of incoming solar radiation reflected by different surfaces in the urban environment (reflection coefficient), expressed as the ratio of incoming to outgoing radiation (Stephens, O'Brien et al. 2015). The albedo value varies between 0, with 100% absorption of incoming radiation without reflection (such as black surfaces), and 1, with 100% reflection of incoming radiation (such as white surfaces) (kent 2019). It represents an important indicator in the study of the urban microclimate (Salvati, Kolokotroni et al. 2020). Table I- 1 illustrates different value of albedo in urban environment (Santamouris 2013).

Table I- 1: Albedo value of different urban materials.

source: Santamouris, 2013.

Surface	Albedo	Surface	Albedo
Streets		*Paints*	
Asphalt (fresh 0.05, aged 0.2)	0.05-0.2	White, whitewash	0.50–0.90
		Red, brown, green	0.20–0.35
Walls		Black	0.02–0.15
Concrete	0.10–0.35		
Brick/Stone	0.20–0.40	*Urban areas*	
Whitewashed stone	0.80	Range	0.10–0.27
White marble chips	0.55	Average	0.15
Light-coloured brick	0.30–0.50		
Red brick	0.20–0.30	*Other*	
Dark brick and slate	0.20	Light-coloured sand	0.40–0.60
Limestone	0.30–0.45	Dry grass	0.30
		Average soil	0.30
Roofs		Dry sand	0.20–0.30
Smooth-surface asphalt (weathered)	0.07	Deciduous plants	0.20–0.30
Asphalt	0.10–0.15	Deciduous forests	0.15–0.20
Tar and gravel	0.08–0.18	Cultivated soil	0.20
Tile	0.10–0.35	Wet sand	0.10–0.20
Slate	0.10	Coniferous forests	0.10–0.15
Thatch	0.15–0.20	Wood (oak)	0.10
Corrugated iron	0.10–0.16	Dark cultivated soils	0.07–0.10
Highly reflective roof		Artificial turf	0.50–0.10
after weathering	0.6–0.7	Grass and leaf mulch	0.05

I.2.2.1.2. Building / Architectural scale

In many studies that deal with energy in conditioned or unconditioned space at the urban scale, a lot of attention is paid to the building characteristics (Felkner, Brown et al. 2019, Hong, Chen et al. 2020, Hong, Ezeh et al. 2020). The relationship between the energy behaviour of buildings is related to the impact of architectural typo-morphological factors, thermo-physical properties, occupant behaviour, as well as the type of energy use. As far as architectural typo-morphological factors are concerned, these are used with different definitions in studies and evaluations of energy efficiency, solar energy (including passive solar energy, daylight, photovoltaic integration, solar thermal collector integration), and indoor thermal comfort of buildings (Le Guen, Mosca et al. 2018). For this purpose, the necessary architectural typo-morphological factors that need to be mentioned are:

a) Size and shape of building

The size of the building includes the roof and facade areas, height, width, length and volume of the building. From these characteristics, useful factors such as the compactness of the building and the ratio of building area to volume can be calculated (Su 2011). Determining the size and area of the roof and facades facilitates better design for the integration of renewable energy such as PV panels or ST collectors (Biyik, Araz et al. 2017). Understand the relationship between building geometry, renewable energy and energy consumption is essential to achieve high energy performance buildings (Araji 2019).

b) Building orientation

The building orientation is defined by the orientation of its façades. There is a close link between the orientation of the building and the reception of solar radiation, which explains the impact of the building orientation on heating and lighting derived from solar radiation (Yüksek and Karadayi 2017). Therefore, the orientation of the building plays an important role in reducing the energy consumption of the building. Often, good building orientation is based on placing the façade adjacent to its energy-intensive interior spaces towards the orientation that offers the best sources of sunlight and ventilation (Abanda and Byers 2016). Generally, the orientation of buildings at an angle of 20-30º to the south (of the longer facade) is considered best in the northern hemisphere, allowing maximum capture of solar heat and radiation (Chen, Zhang et al. 2020).

c) Building plan form

The building plan in 2D dimension allows to understand the boundaries and interior geometry of the building, its separation is useful to characterize each space of the plan according to the activity and energy use (Peri, Foresta et al. 2013, Hong, Ezeh et al. 2020).

d) Number, size, and height of floors

Another key building characteristic that affects energy consumption is the height, number and area of floors, the determination of which can help in calculating volume, building height, density, floor area ratio as well as energy intensity. In a canyon street, the relationship between floor area, height and direct sunlight is important. In wintertime, calculating the amount of direct sunlight and direct heat solar gain reaching the floors is an important strategy for the energy efficiency of the building (Nabil, Mardaljevic et al. 2006, Vartholomaios 2015).

I.2.2.1.3. Envelope scale

The building envelope is the principal physical barrier of the building between the indoor and outdoor environment. It is made up of a series of components that act as a structural support, protection system and assurance of the well-being of the interior space against the effects of the environment such as temperature, wind, precipitation, humidity and solar radiation (Arnold 2016). However, the characteristics of the building envelope are important elements in determining the energy performance of a building. As mentioned in the urban form and building scales, a set of typo-morphological factors can also be derived at the envelope scale:

a) Walls

Walls are an important part of the building envelope and play a role in ensuring thermal and acoustic comfort inside the building. The energy efficiency of the building and the indoor comfort are mainly related to the thermal resistance (R-value) of the wall, for instance in high-rise buildings. In addition, walls can be a place for clean energy supply, such as building-integrated and building-applied photovoltaics (BIPV and BAPV) (Sadineni, Madala et al. 2011, Zomer, Costa et al. 2013).

b) Fenestration (windows and doors)

Fenestration is all open parts of the building envelope, such as doors, windows and skylights. These openings are necessary for the proper functioning of the building interior. From an energy point of view, the proper integration of fenestration can lead to a comfortable and high energy efficiency of the building. Skylights and windows can provide natural ventilation points, improve indoor air quality by reducing condensation, ensure natural light, passive solar heating and cooling (Sadineni, Madala et al. 2011). For windows, the characteristics of the glazing and the tightness of the frame are essential.

Glazing G-value

The G-value of glass is the fraction of incident solar radiation that is transformed into heat gain inside a room. Ranging from 0 to 1, it is given as a decimal or percentage and shows the heat transmitted from the glass by the sun. A g-value close to 1 (100%) means that the glass has high solar transmittance, while a g-value close to 0 signifies that the glass is almost opaque and does not allow high solar heat to enter. In general, double glazing has a g-value of 0.7, while high performance triple glazing can have a g-value of 0.5 (Bednar 2020).

Glazing and frame U-value

The U-value (W/m^2K) indicates the rate of heat transfer through an element as a function of temperature difference. For the whole window (glass and frame), the U-value is presented by the Ug-value of the glass and the Uf-value of the frame (green building store 2018).

c) Window/wall (W/W) ratio

The window to wall ratio (W/W) is given as the ratio of the window area to the total area of the external wall surfaces, while the window to floor ratio (G/F) is given as the ratio of the glazing area to the floor area. Both building characteristics are important for the energy use in the building, in particular, a high W/W ratio will gain extra heat in summer and lose heat in winter (Peri, Foresta et al. 2013, Hong, Ezeh et al. 2020). They have a considerable impact on energy consumption and play an important role in the realisation of high energy performance buildings such as in Zero Energy Buildings (Troup, Phillips et al. 2019).

d) Roofs

The roof is the upper covering of the building, it is an important part of the envelope as the walls; it ensures thermal comfort inside the building; however, the roof is very exposed to solar radiation, rain and wind. Therefore, the roof is highly insulated compared to other parts of the building envelope, its thermal resistance (R-value) or heat transfer (U-value) indicate whether the building is able to guarantee high energy efficiency and thermal comfort or not. It can also be a good opportunity to install photovoltaic panels or solar thermal collectors. The types of roofs can be divided into three categories: pitched or sloping roofs, flat or terraced roofs and curved roofs (Sadineni, Madala et al. 2011).

e) Thermal insulation and thermal mass

In a wall or roof, thermal insulation is a material or combination of materials with high thermal resistance, which is intended to reduce the transfer of thermal energy through conduction, convection, and radiation. The right choice and integration of thermal insulation ensures thermal well-being, reduces energy consumption, and allows for a reduction in the size of the HVAC system during design. For the placement of thermal insulation in the building envelope, it is recommended that to achieve its best performance, it should be placed as close to the heat entry surface as possible and has about 50% of the wall thickness (Sadineni, Madala et al. 2011).

Another important thermal physical characteristic for the envelope is the thermal mass, it is the capacity of the material to absorb heat, store it and release it late, all the building components participate in thermal mass starting from the thermophysical properties of the building material of walls, roof, floor, partitions, and furniture. The store of thermal energy is also affected by building orientation, thermal insulation, HVAC system and occupancy patterns (Sadineni, Madala et al. 2011).

f) Infiltration and airtightness

Infiltration defines the movement of air into the conditioned area of a building, either through leaks, cracks, or otherwise through openings in the building envelope. The movement of air from inside the building to the outside refers to exfiltration. The airtightness of a building refers to the resistance to air leakage to the interior or exterior through leaks or cracks in the building envelope. The three factors of infiltration, exfiltration and airtightness of a building are essential for energy efficiency, indoor comfort, and air quality. They are determined by the pressure difference over the building envelope due to changes in the indoor or outdoor environment (temperature, mechanical ventilation equipment, etc.) and are affected by the age of the building, the properties of the building envelope, the environment, and climatic factors (Sadineni, Madala et al. 2011).

g) Construction year

Identifying the year of construction of the building helps to identify the thermo-physical properties, e.g., depending on government policies, buildings built at the same period have comparable thermal properties. In addition, categorizing building typologies by year of construction allows for a specific scale for the application of construction or energy regulations such as energy optimization or renovation (Hong, Ezeh et al. 2020).

I.3. Relationship between urban form, energy, and solar access

I.3.1. Relationship between urban form and solar access

The relationship between the sun and the earth is such that the sun is constantly moving across the sky due to the rotation of the earth and the planetary orbit. During the year, this mechanism determines the solar energy reaching the earth, which is defined by: "*(1) the distance from the earth to the sun, (2) the distance the sun's rays travel through the atmosphere, (3) the angle at which these rays strike an intercepting surface, and (4) the time the sun is above the horizon"* (Johnson 1981). In addition, the amount of solar energy (solar irradiation) on the earth is related to atmospheric conditions, which have an impact on the share of direct, diffuse, and reflected solar radiation at the earth's surface.

The sun is a major factor in the climate and is a source of light and energy for living beings on earth (Siret 1997). In the earth the development of human activities is based on the existing energy, this energy can be fossil, renewable or flow energy. Fossil energy is the stock energy that its use causes greenhouse gas emissions, such as coal, oil, and natural gas. Renewable energy is the inexhaustible energy that comes from the sun, directly in the form of light and heat, or indirectly through atmospheric cycles and photosynthesis. Flow energy presents the flow of energy throughout living things within an ecosystem such as plant biomass. All these energies that are available on earth originate directly or indirectly from the sun (De Herde and Liébard 2005).

Moreover, different solar irradiations are present as an important constituent of the climate and very essential for indoor (heating, hygiene, lighting, energy...) and outdoor (lighting, heating, wind pressure) human comfort (Knowles 1981, Van Esch, Looman et al. 2012, Sanaieian, Tenpierik et al. 2014). The direct and judicial use of solar energy can be implemented passively for daylighting and heating (mainly by bioclimatic design) and actively (photovoltaic and thermal solar collectors) to produce electricity and domestic hot water (Hachem, Fazio et al. 2013). Furthermore, solar availability in the urban context could vary significantly and this is depending on the urban form, building morphology and the building envelope characteristics (Morganti, Salvati et al. 2017).

I.3.1.1. *Effect of urban form factors on solar access*

There are several parameters that can influence the solar access at this level, such as density, building orientation. It is hence important to pay attention to solar rights and their benefits during the planning and construction process (Littlefair 1998, Sanaieian, Tenpierik et al. 2014). Those factors and others of the urban form in its several scales present an essential impact on solar access to the neighbours and buildings. Several studies have touched these subject, many authors have investigated the urban morphological factors and their impact on the availability of solar radiation in roofs and façades (Chatzipoulka, Compagnon et al. 2016, Mohajeri, Upadhyay et al. 2016, Chatzipoulka and Nikolopoulou 2018, Mohajeri, Gudmundsson et al. 2019, Poon, Kämpf et al. 2020, Xu, Li et al. 2020), while others have explored its sensitivity to urban forms and its impact on both solar potential and energy demand (de Lemos Martins, Faraut et al. 2019). For instance, Littlefair studied passive solar urban design and ensuring solar access in obstructed forms by relating the urban geometry to the solar access (Littlefair 1998, Littlefair 2001). Okeil has produced a generic building form model called the Residential Solar Block (RSB). By comparing the distribution of direct solar radiation on urban surfaces between RSB, slab and pavilion, it was found that the generic RSB model has the best profile in terms of energy-efficient urban design in cities at 25° latitude (figure I-12) (Okeil 2010).

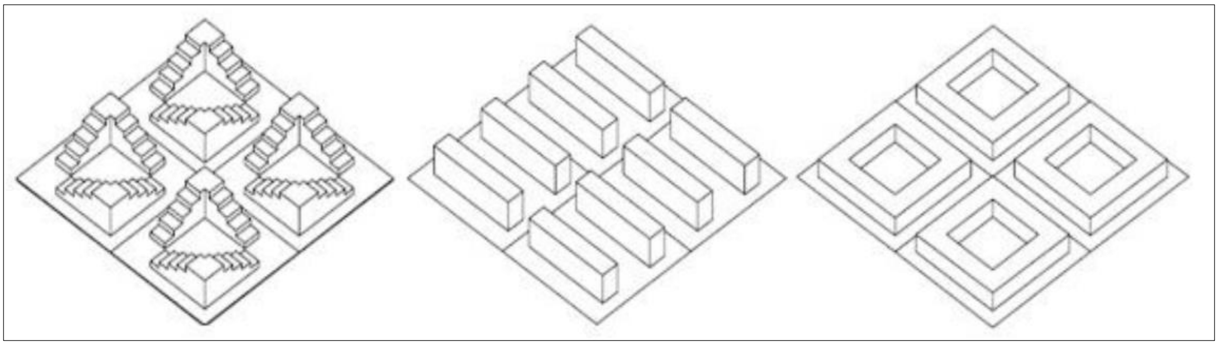


Figure I- 12. RSB, slab and pavilion-court.

Source: Okei 2010.

Kämpf and Robinson worked on maximising incident solar radiation and minimising the energy demand of buildings on an urban scale, based on the design of a multi-objective optimisation algorithm (Kämpf and Robinson 2009). Other studies show that urban density affect the solar potential of buildings by increasing shading by surrounding buildings (Ratti, Raydan et al. 2003, Chatzipoulka, Steemers et al. 2020).

Cheng et al perform a parametric study to discuss the best urban configuration based on the examination of the relationships between building form, density, and solar potential via three design criteria: (1) openness at ground level; (2) daylight availability on the building façade, and (3) photovoltaic potential on the building envelope, the results provide useful guidance for planning high-density solar cities (Cheng, Steemers et al. 2006)

Chatzipoulka et al conducted a study on the relationships between urban geometry variables and solar availability over different time periods. The results show that urban layout has a significant impact on solar availability on the ground and on facades. Density, mean outdoor distance, site coverage, directionality and complexity are the most influential factors for solar availability of open spaces, while building facades are mostly affected by density, complexity, standard deviation of the building height and directionality. Nevertheless, direct solar irradiance on the ground and facades was found to be influenced by changing solar elevation angles (Chatzipoulka, Compagnon et al. 2016).

A study of four geometric shapes of urban blocks and their solar potential in the city of Lund, southern Sweden, shows that morphology has a significant impact on solar energy potential, with access to sunlight decreasing by 10-75% if urban blocks are surrounded by other buildings (Kanters and Horvat 2012). Other studies prove that the shape of the roof and the orientation of buildings have a considerable impact on solar energy (Ghosh and Vale 2006).

A study of the effects of urban design parameters (street width and orientation) and building design parameters (roof shape and building envelope design) on solar access to the urban canyon, and the viability of passive solar heating strategies in residential buildings shows that street width and orientation have a significant influence on total global radiation (Van Esch, Looman et al. 2012). Another study on the microclimatic behaviour of two semi-enclosed attached courtyards in a hot dry region another study shows that in terms of shading, a higher h/w ratio along a given axis will minimize the direct exposure of horizontal and vertical surfaces to the sun (Meir, Pearlmutter et al. 1995). According to Sanaieian et al there are three main factors that affect solar access in an urban environment, "(a) *urban density,* (b) *orientation of the building's façade, (*c) *building outlines and streets (ratio of building heights to the street widths)"*(Sanaieian, Tenpierik et al. 2014).

I.3.1.2. *Methods for solar analysis in urban areas*

Various methods and tools exist to calculate daylighting and solar access in urban areas. Simplified methods are already in use, such as the ray-tracing method based on simulation on radiance software (Scartezzini, Montavon et al. 2002), and the daylight factor (DF) which defines the ratio of daylight illuminance on a plane to illuminance on a horizontal plane in an unobstructed outdoor environment; the last is useful to indicate the visual adequacy of indoor daylight (Sanaieian, Tenpierik et al. 2014). Another method introduced by Redweik et al. focuses on the evaluation of the solar potential of building surfaces in urban blocks, based on the calculation of hourly shadow maps for the assessment of direct solar radiation and sky view factor maps, this method helps also in the assessment of diffuse radiation (Redweik, Catita et al. 2013). Irradiance maps could also serve as a brilliant tool and method to study the solar potential in an urban context, they are based on sophisticated modelling tools such as the GIS interface (Gadsden, Rylatt et al. 2003, Mardaljevic and Rylatt 2003). Ratti et al. use the method of image processing techniques to assess the built potential and daylighting criteria in a hot and arid climate (Ratti, Raydan et al. 2003). Thus, a five mainly methods for solar analysis in urban areas can be drawn on as conclusion:

- **Raytracing**
- **Daylight Factor**
- **Shadow maps**
- **Irradiation maps**
- **Image-processing techniques**

I.3.2. Relationship between urban form and energy consumption

According to Sanaieian et al. 2014 the energy consumption in cities is categorised into three main groups:

Operational energy used for the heating and cooling of dwellings and for appliances used within them. This can be grouped into building-related operational energy and use-related operational energy.

Embodied energy used for the manufacturing, distribution and deployment of materials used in the construction of dwellings and their associated infrastructure.

Transport energy (both private and public) used for transport

In an urban form operational and embodied energy present high impact on energy consumption. During the lifetime of a building (50 to 100 years), many studies were indicated that the operational energy part is much more significant (Hui 2001, Codoban and Kennedy 2008).

The following section is concerned on the Relationship between urban form and building energy consumption.

The energy consumption in the buildings of an urban form is linked to the climatic conditions, the factors of the urban form in its several scales, and the occupant behavior (Ko 2013) (figure I-13). The urban form has significant impact on the microclimate such as solar radiation, daylight, wind flow, and local temperature (Middel, Häb et al. 2014, Wei, Song et al. 2016). Furthermore, the energy consumption in buildings is related to the factors of the urban form such density, height, orientation, and envelope characteristics. Several research drawn a conclusion on the impact of the urban form on energy consumption in building.

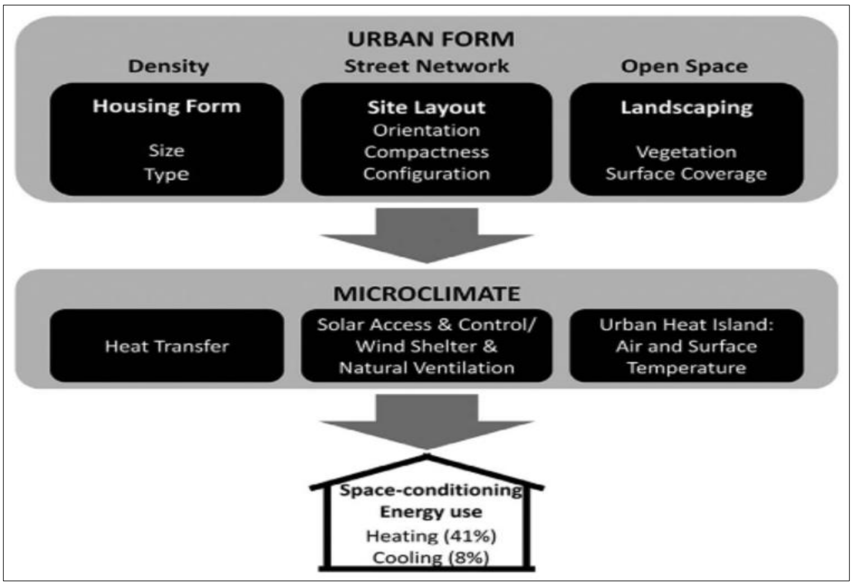


Figure I- 13. Relationship between urban form factors, microclimate, and energy use.

Source: Ko 2013.

Baker and Steemers summarizes that energy consumption is affected by (a) building design by a factor of 2.5 times; (b) system efficiency by a factor of 2 times; and (c) occupant behavior by a factor of 2 times. The same study also shows that if a building with a poor design and an inadequate energy system is occupied by energy-wasting occupants, it can consume 10 (2.5 x 2 x 2 = 10) times more energy (Baker and Steemers 2003). A study by Ewing and Rong (2008) presents a causal link between urban form and residential energy consumption in U.S, where urban form affects residential energy consumption directly through electric transmission and distribution (T&D) losses, and indirectly through housing stock and urban heat island (UHI) formation. The urban form variables investigated in this study are housing size, type, and density (Ewing and Rong 2008). A study conducted by Rode et al in four cities (London, Paris, Istanbul, and Berlin) shows that the relationship between urban morphology and heating energy efficiency is relevant and can result a difference in heat-energy demand of a factor of up to six.

A building characterized by high compactness and height has the greater efficiency compared to a single detached house at the neighborhood scale (figure I- 14) (Rode, Burdett et al. 2014). while another study proves the opposite and indicates that high-rise buildings are more energy-intensive than low-rise buildings (Steadman, Hamilton et al. 2017).

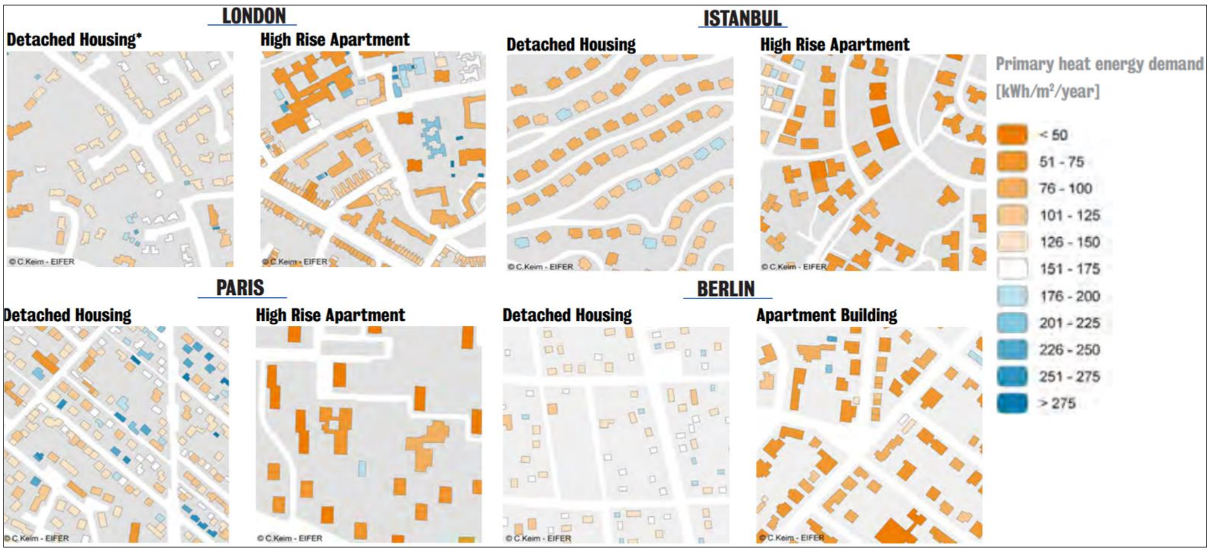


Figure I- 14. Average heat energy demand per square metre of floor area in four cities. (Semi-detached housing has been put in the same category for this study as detached housing. Both are presented under 'Detached' housing).

Source: Rode et al 2011.

Certain research indicates that the reduction of energy use in urban areas can be obtained through denser urban development and higher population density (Resch, Bohne et al. 2016, Güneralp, Zhou et al. 2017, Osorio, McCullen et al. 2017). Conversely, Stromann-Andersen and Sattrup observed that total building energy consumption increases in high-density urban environments, affecting daylight availability and passive solar gains (Strømann-Andersen, Sattrup et al. 2011). This is also proven by other studies, where high shading in urban areas is linked to high density, a result on the evaluation of different proportions and shapes of courtyards in urban blocks in regard to thermal performance came to the conclusion that self-shading can have a significant impact on building energy demand (Muhaisen and Gadi 2006, Yaşa and Ok 2014). A study in an Abu Dhabi neighborhood shows how urban density can improve energy performance and reduce solar gain by decreasing the distance between buildings and/or increasing the number of stories in buildings (figure I- 15) (Mirkovic and Alawadi 2017).

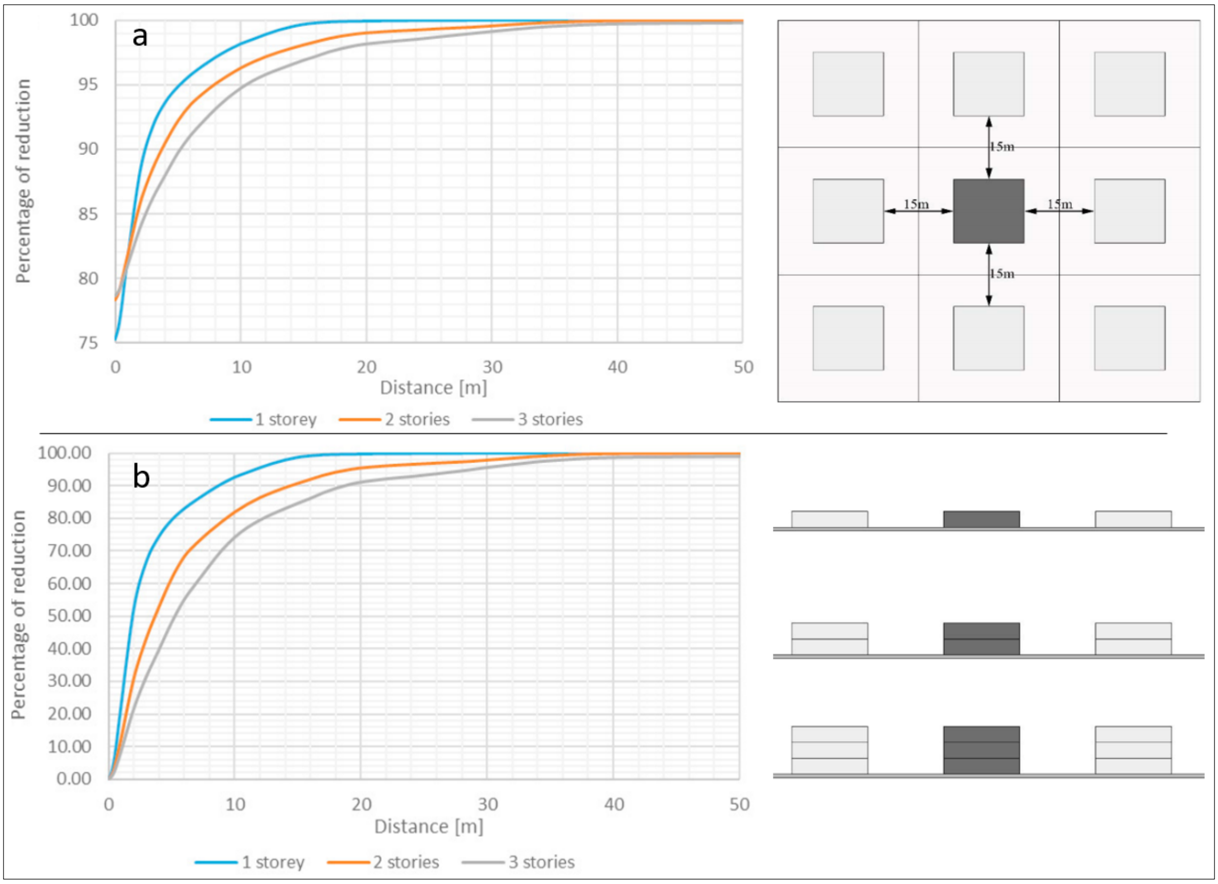


Figure I- 15. Percentage of cooling (a) solar gains reduction by changing the distance between the buildings (right).

Source: Mirkovic and Alawadi 2017.

The urban heat island (UHI) is another factor that has found place on the impact on energy consumption, its degree of impact is related to its elements; buildings, roads, absorption, and reflection of solar radiation by street surfaces, its effect can lead to the increase of temperature in the street and result in a low need of heating in the building in winter, however in the summer it leads to a high need of cooling (Ewing and Rong 2008). Li et al conclude that the UHI intensity of a city is directly linked to the density (Li, Schubert et al. 2020), while others indicate that the major cause of UHI intensity is the spatial contiguity of urban development (Debbage and Shepherd 2015).

The design of the street layout generally determines the orientation of the streets and the configuration of the buildings which are essential for solar access and wind flows. In recent simulation studies on building energy, a high importance was given to the surrounding urban configurations which can strongly modify radiation and convective heat transfers in buildings (Gros, Bozonnet et al. 2016, Fahed 2018).

The importance of the building envelope as a multifactor of the urban form plays an important role in energy consumption. Solar shading devices, glazing G-value, glazing U-value and wall conductivity can account for 60% of the overall impact of the factors (de Lemos Martins, Faraut et al. 2019). The ratio of a building's surface area to volume (S/V ratio) is also a relevant factor to heat transfer into or out of a building. Since the heat loss of a building is related to its surface area and the respective thermal properties of the materials, some researchers have explained the strong relationship between the compactness of buildings (surface area versus volume) and energy consumption (Steemers 2003).

I.4. Conclusion

The city is a complex system with different sizes, shapes, structures, and compositions, characterized by very diverse interactions such as those between climate and the built environment. At the level of the city, different urban forms, urban fabrics, street patterns and building forms can be distinguished. This chapter presents the concepts related to urban form, the discussion of the factors at urban form reveals three main scales of typo-morphological factors: the urban form scale (block scale), the building scale (architectural), and the envelope scale. Each of these scales is broken down into several factors. The trilogy of climate, urban form and energy consumption is mainly interrelated and has different interactions. As an important element of climate, solar radiation, its access at the urban form level is mainly related to factors of density, street orientation and aspect ratio (H/W). Solar energy can play a major role in minimizing energy in the building, in this respect it is conditioned by the openings of the building as well as the thermo-physical characteristics of the envelope.

The relationship between urban form and energy use is explained by the impact that typo-morphological factors of urban form exercise on energy use such as density, building orientation, and thermo-physical characteristics of the envelope. The link between urban form and climate mainly affects energy use, e.g., in a warm climate, cities with high urban density affect the energy use of buildings, leading to a high need for cooling in the warm season and helping to minimize the need for heating in the cold season.

Chapter II

Climate change and energy improvement at the urban scale

II.1. Introduction

The world is experiencing an unprecedented era of human migration and settlement patterns. Currently, most of the Earth's population lives in urban areas, and this will continue, as cities become denser and larger. At the same time, the Earth is experiencing another phenomenon, climate change. Human activity is increasing global temperatures and greenhouse gas emissions at an increasing rate, impacting the natural environment, and making it unhealthy for living. As a result, climate change and increasing urbanisation are leading to changes in the microclimate that directly affect liveability and increased overall energy consumption in cities. At this stage, climate change mitigation and adaptation can be implemented in several areas and ways, including energy improvement in the urban environment (Pachauri, Allen et al. 2014).

This chapter defines the concept of climate change from the global to the urban scale. At the urban scale, sections of the chapter discuss the relationship between climate change and cities, particularly in the context of urban adaptation to climate change, as well as the main organisations involved in climate change research, such as the Intergovernmental Panel on Climate Change (IPCC). Simultaneously, urban energy consumption and production in relation to climate change were debated. From the point of view of energy at the urban scale, which is the main concern, the chapter also provides an overview on minimising energy demand in buildings, in particular through on-site urban solar energies technics. Other sections have been devoted to the perspective of sustainable energy buildings and the concept of energy modelling of urban buildings.

II.2. Impact of climate change on energy at the urban form scale

II.2.1. Climate change

Climate change is defined as the change in the average meteorological conditions such as temperature, precipitation, and wind in a region and which persists for an extended period, typically decades or longer. This phenomenon is brought due to natural variability and predominantly by human being mainly burning fossil fuels, which add heat-trapping gases to earth’s atmosphere (UNFCCC 2011).

Several assessments show multiple lines of evidence that the climate is changing across our planet and hold full responsibility towards the human being. The most convincing evidence of climate change comes from the recorded signs in the atmosphere, land, oceans, and cryosphere. Assessments show that atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased over the past couple of decades.

These gases are resulting from the growing use of energy and expansion of the global economy (Cubasch, D. Wuebbles et al. 2013), figure II- 1 illustrates the main drivers of climate changes. The negative effect of climate change is the warming of the Earth's surface and lower atmosphere, as greenhouse gases absorb some of the heat radiation leaving the Earth and radiate it back, increasing the warmth of the Earth's surface. Some consequences of climate change are already visible today, due to the change in precipitation the severity and occurrence of droughts are reducing in some areas and increasing in others (Marolla 2020). Air pollution is also one of the perceived consequences, the use of burned fossil fuels and the rise in temperature affect human health directly through the degradation of air quality (Portier, Thigpen-Tart et al. 2010). These greenhouse gases continue to increase, and the planet may experience a warming of 1.4 to 5.8°C over the next 100 years, according to predictions by a top panel of international experts (Ghali 2011).

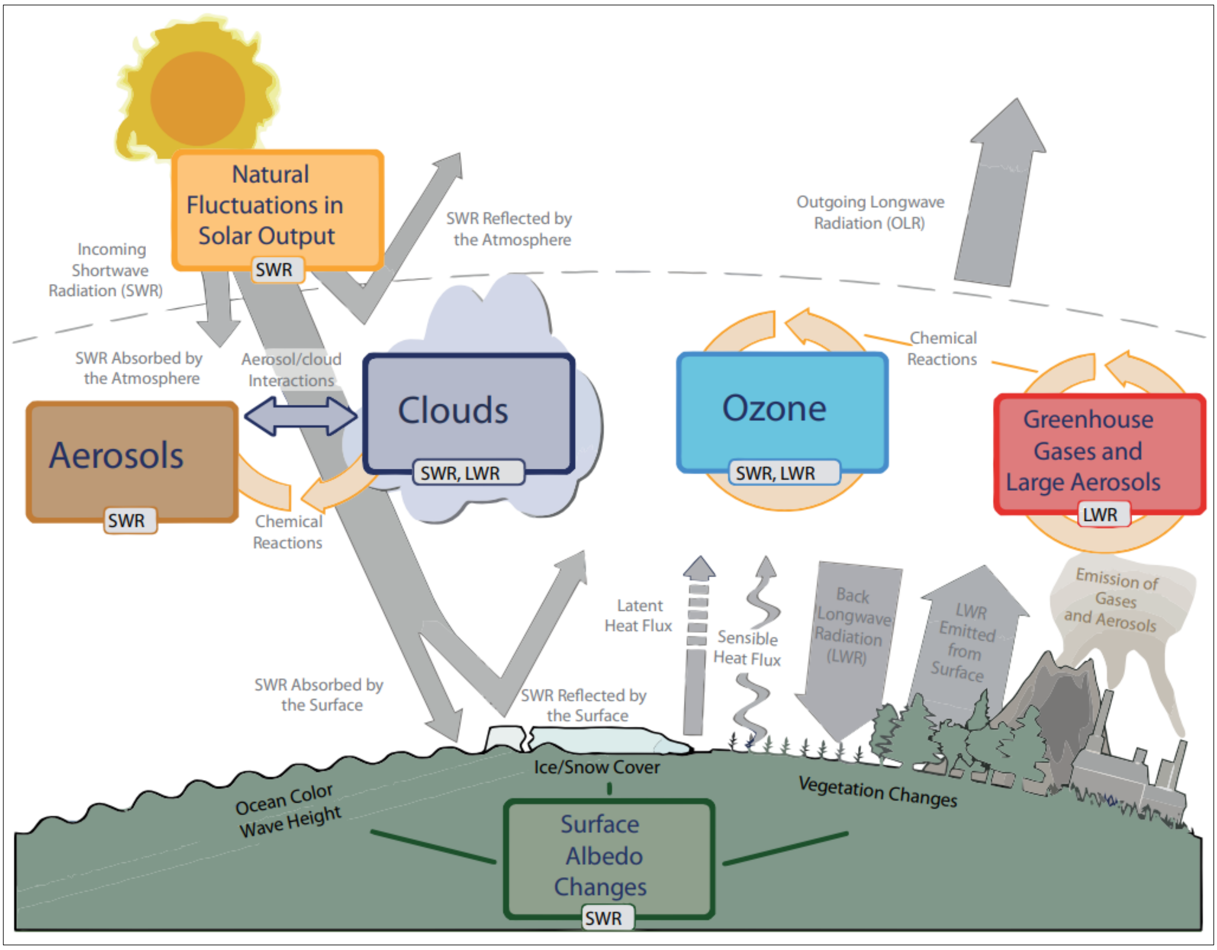


Figure II- 1. Key factors driving climate change.

The radiative energy equilibrium that exists from incoming shortwave solar radiation (SWR) to outgoing longwave radiation (OLR) is affected by the 'drivers' of the global climate, such as natural fluctuations in solar output (solar cycles) and human activity changing the aerosols and the emissions of gases. Source : Forster et al 2007.

II.2.2. Relationship between climate change and cities

Cities are becoming increasingly populated. They are home to 70% of the world's population and tend to have more inhabitants in the future, these will lead to an intensive urbanization process with a high production of urban heat islands and huge energy needs, transportation and buildings are the main sources of greenhouse gas emissions. One study shows that cities are responsible for 75% of global CO_2 emissions (UNEP 2020). And with actual context of global warming, the situation will be even more complex in urban areas.

It is important to understand the relationship of complex interactions and the shift between climate change and urbanized areas. Urbanization modifies their local environments through the various physical phenomena it generates, mainly urban heat islands (higher temperatures, especially at night, compared to outlying rural areas) and local flooding that may be accentuated by climate change, for instance, numerous studies have found that long-term assessments of surface air temperature changes in urban areas are associated with the intensity of urbanization (Kolokotroni, Davies et al. 2010, Iqbal and Quamar 2011). These microclimate dynamics can be influenced by increasing temperatures due to climate change, and the properties of building materials also have an influence on generating different temperature regimes in the urban climate, which can alter the energy demand in buildings (Jackson, Feddema et al. 2010). In addition, dense urban environments have a notable impact on anthropogenic heat emissions and surface roughness, linked to wealth level, energy consumption, microclimatic and regional conditions.

Therefore, cities must be an integral part of the response to climate change. Currently, many cities are undergoing profound changes in urban energy, transport, water use, land use, ecosystems, growth patterns, consumption, and lifestyles, in addition, they are setting policies that promote environmental sustainability (Hughes, Chu et al. 2020).

II.2.2.1. Adapting cities to climate change

The great opportunity for cities is to understand the interactions between climate change mitigation and adaptation. for instance, approaches that aim to improve air quality, reduce the urban heat island effect, improve resource efficiency in the built environment and energy systems, as well as promote land use and urban forestry for urban carbon storage are potentially capable of contributing to the reduction of greenhouse gas emissions while improving a city's resilience. These adaptation and mitigation approaches are based on sustainable development that takes advantage of the city's current resources and technical means, considers the needs of the inhabitants, and respects the natural environment (Rosenzweig, Solecki et al. 2018).

Different neighbourhoods have different microclimates. Thus, another useful point in adapting cities to climate change lies in the use of urban monitoring networks to record the impacts of extreme weather effects at the neighbourhood scale, which can be used to understand the variety of climate risks across the city. Most organizations that deal with climate change mitigation and adaptation studies recommend that governments must develop and implement climate action plans at the outset of their policies. At that point, they should specify short-term and long-term goals, opportunities for further implementation, budgets, and practical measures to evaluate ongoing development. The most advanced mitigation actions can include energy, transportation, waste and water management, infrastructure, natural resources, and health policies. The implementation of these policies is more favourable during the planning phase accompanied by the coordination of all actors during each step of the process (Rahman 2013).

According to figures II- 2 which illustrates the main strategies and phases used by planners and designers to facilitate the integration of mitigation and adaptation in cities, urban planning at all scales has a key role to play in the overall response to climate change, from the micro to the macro scale of the built environment, several strategies and implementations can be applied (Raven, Stone et al. 2016). Some of the key strategies are: adopting energy efficiency and public transport to reduce greenhouse gas emissions; the reformulation of urban form designs; the use of ecological and non-polluting building materials; the reinforcement of the vegetal environment on the urban scale.

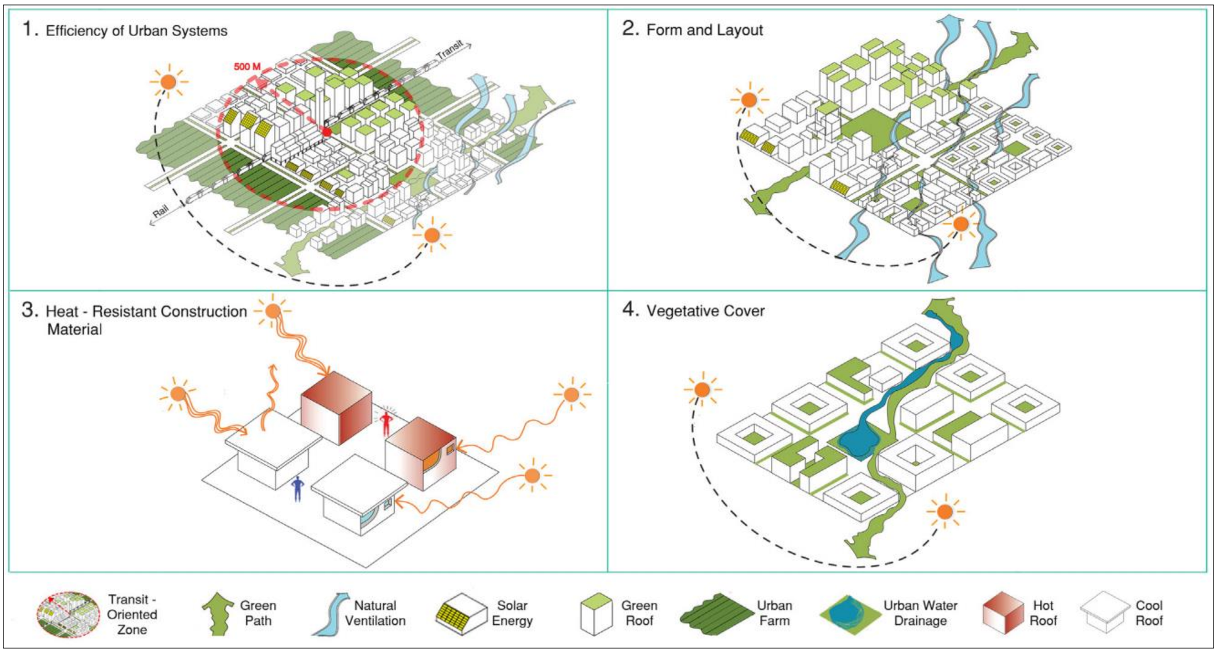


Figure II- 2. Urban and architectural strategies to facilitate climate change mitigation and adaptation in cities.

Source: Urban Climate Lab, Graduate Program in Urban & Regional Design, New York Institute of Technology, 2016.

The importance of decisions made in the built environment resides in the fact that they have long-term consequences (depending on the lifetime of the built environment, more than 50 years), which can be a key factor in either reducing greenhouse gas emissions and responding to climate risks, or in making the task of adaptation and mitigation more consequential. Therefore, urban planning and design must adopt long-term plans for climate change that reach physical and legal framework scales.

The climate intervention from a planning and design strategies can follow four phases (figure II- 3) (Raven, Stone et al. 2016):

Climate analysis mapping: it aims to understand the climatic conditions in individual local climates of city centres in small and a large scale, including their interactions with each other such as air mass frequency and exchange, seasonal occurrence of thermal and air quality effects of the urban climate, assessment of stress zones as well as energy optimization based on the assessment of the urban climate.

Public space evaluation: In this phase, based on descriptive and quantitative spatial and temporal climate assessment, the consideration of public space evaluation through interactive geographic information systems and surveys that help citizens predict their potential changing use of public space, is an important task in the process of planning and urban development of public spaces.

Planning and design intervention: In the context of urban climatology, the planning and design intervention aims to improve air quality and thermal conditions in the use of both spaces (indoor and outdoor), which includes tasks such as reducing urban heat islands by treating urban spaces, urban ventilation by taking advantage of favourable air exchange and wind.

And post intervention evaluation approach: This involves assessing the microclimatic performance of urban design and planning intervention to improve outdoor thermal comfort by maintaining moderate temperatures for long periods with fresh air. This assessment can be carried out through in situ thermal assessments or population surveys.

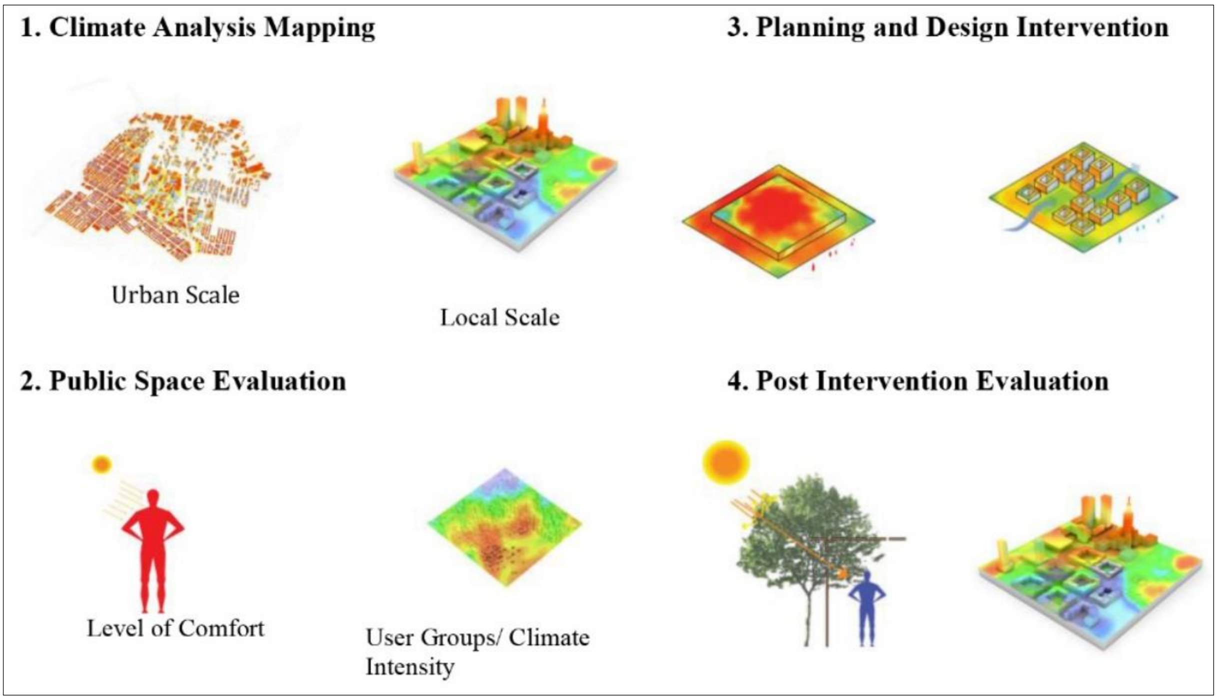


Figure II- 3. Urban planning and concepts for climate change adaptation.

Source: Urban Climate Lab, Graduate Program in Urban & Regional Design, New York Institute of Technology, 2016.

II.2.2.2. Top organisations engaged in climate change research

Around the world and for decades, several organisations and authorities have been established through international meetings, conferences, and protocols to conduct high-level studies on climate change on earth. Their main objective is to develop climate change mitigation and adaptation strategies (Geography and Global Climate Change Clearinghouse 2010). The world's leading climate change research organizations are:

- *U.S. Environmental Protection Agency (EPA) - Climate Change Science.*
- *NOAA Education - Climate Change and Our Planet.*
- *Intergovernmental Panel on Climate Change (IPCC).*
- *National Center for Atmospheric Research (NCAR).*
- *Center for Remote Sensing of Ice Sheets (CReSIS).*
- *National Climate Data Center (NCDC).*
- *World Meteorological Organization.*
- *United Nations Environment Programme (UNEP), Climate Change.*

- *United Nations Framework Convention on Climate Change (UNFCCC).*
- *Pew Center on Global Climate Change.*
- *Food and Agriculture Organization (FAO) of the United Nations – Climate Change.*
- *National Snow and Ice Data Center (NSIDC).*
- *International Geosphere-Biosphere Programme (IGBP).*
- *Urban Climate Change Research Network (UCCRN).*

These organizations are following the development path of climate change mitigation and adaptation, they have provided several reports on the state of global warming, the trajectory of climate change and predictive studies on temperatures and greenhouse gas emissions, one of the most promising reports being the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, which received the Nobel Prize in 2007((Geography and Global Climate Change Clearinghouse 2010).

II.2.2.3. Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to evaluate scientific information on climate change, assess the environmental and socio-economic consequences of climate change, and formulate feasible strategies for addressing it. The IPCC's multi-volume assessments and studies have played an important role in guiding governments in the adoption and implementation of climate change policies and have met the need for authoritative guidance from the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). In addition, the IPCC has produced a series of assessment reports, technical papers, and methodological reports (from 1990 to 2021), all of which have been extensively used by policy makers and scientists (Houghton, Meira Filho et al. 1995, Shukla, Skea et al. 2019).

Interesting studies have been carried out by the IPCC which present the development of long-term emissions scenarios and climate change projections, this development starts with the assessment of significant past changes in climate change, these changes are related, for example, to the carbon intensity of energy supply, the income gap between developed and developing countries. The evolution of future greenhouse gas (GHG) emissions is uncertain and is linked to very complex dynamic systems, defined by different driving forces such as demographic development, socio-economic development, and technological change. The output scenarios present a picture of what the future might look like and can show the impact of driving forces on future emissions (Nakicenovic, Alcamo et al. 2000).

The entire scenario set of greenhouse gas emissions is developed to 2100, and the result shows four qualitative scenarios of possible future worlds and CO2 emissions presented in families A1, A2, B1 and B2 (Figure II- 4). Each scenario represents a different direction for future growth. The four scenarios outline divergent futures that include a significant share of the uncertainties underlying the main driving forces (Nakicenovic, Alcamo et al. 2000).

1. The A1 storyline in its family contains three groups characterised by their technological emphasis: fossil fuel intensive (A1FI), non-fossil fuel sources (A1T), or a balance between all sources (A1B). This scenario is presented as the most severe, characterised by very rapid economic growth, and the rapid introduction of new and more efficient technologies.

2. The A2 storylines and scenario family depict a very diverse world, characterised by a continuous average increase in world population as well as economic development mainly focused on regions and per capita economic growth and slow technological progress compared to the other scenarios.

3. The B1 scenario family presents a changing world with the same world population that peaks in the middle of the century and then declines as in the A1 scenario. It is also defined by quick adjustments in economic structures towards a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. It also considers sustainable tasks in the economic, social and environmental fields, however, without additional climate initiatives.

4. The B2 scenario presents a world based on locally sustainable economic, social, and environmental solutions. It is characterised by a continued increase in world population that is lower than in A2, less rapid and more diverse technological change than in B1, and intermediate economic development.

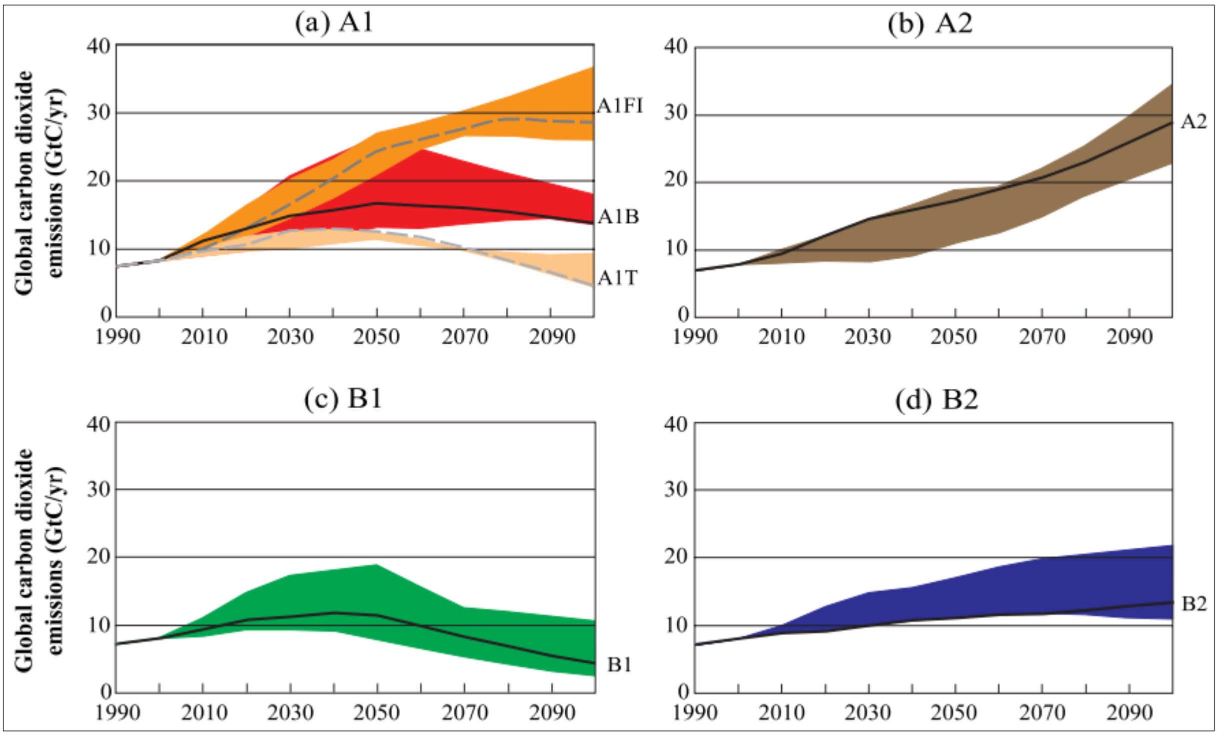


Figure II- 4. Range of annual global CO2 emission in the SRES scenarios (GtCO2)

Source: IPCC, 2000.

In its latest report, AR5 (IPCC Fifth Assessment Report), the IPCC presents four scenarios of radiative forcing trajectories to 2300, called RCP (Representative Concentration Pathway) scenarios (Figure II- 5). These scenarios are derived from a high-level assessment that includes the collection of about 900 mitigation scenarios in a database and cover atmospheric concentration levels in 2100 from 430 ppm CO2eq to over 720 ppm CO2eq, comparable to the 2100 forcing levels between RCP 2.6 and RCP 6.0. In addition, scenarios outside this range have also been assessed, including some with 2100 concentrations below 430 ppm CO2eq. These scenarios allow to model the future climate projection and especially the surface temperature of the Earth in relation to probable greenhouse gas concentration trajectories. Each scenario has a probabilistic value and is based on radiative forcing (the difference between the radiative power received and the radiative power emitted by the Earth system). The RCP2.6 scenario corresponds to a forcing of +2.6 W/m^2, the RCP4.5 scenario to +4.5 W/m^2, and similarly for the RCP6 and RCP8.5 scenarios. As this number increases, the earth-atmosphere system becomes more energetic and warmer (Moss, Babiker et al. 2008, Pachauri, Allen et al. 2014).

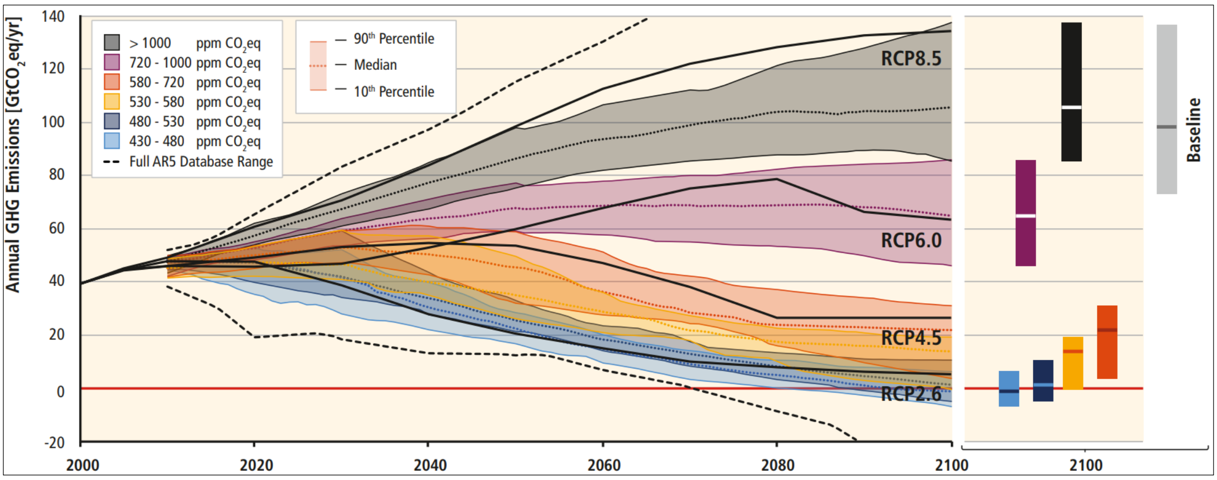


Figure II- 5. Pathways of global GHG emissions (GtCO2eq/yr) in baseline and mitigation scenarios for different long-term concentration levels.

Source: IPCC 2014.

The projection of climate change is the basis for many global climate model simulations. Climate models are extremely complex systems that rely on many components and a well-established physical principle. These models have been made to reproduce the observed characteristics of recent climate and past climate. Such atmosphere-ocean general circulation models (AOGCMs) are known as confidence models and provide credible quantitative estimates of future climate change, typically at continental and larger scales. It is interesting to note that the confidence of climate models is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation) (Intergovernmental Pane On Climate Change 2007). The models developed and are tested at several levels such as the global level and the component level. In climate models, numerical methods are tested in standardised trials, organised in activities such as the quasi-biennial workshops on partial differential equations on the sphere, while the physical parameterisations used in climate models are tested in numerous case studies (some based on observations and others idealised), organised in programmes such as the Atmospheric Radiation Measurement (ARM) programme, the European Cloud Systems (EUROCS) and the Cloud Systems Study (GCSS) of the Global Energy and Water Cycle Experiment (GEWEX). These activities have been ongoing for a decade or more, and many results have been published. It may also be of interest to view other climate models such as: Model Intercomparisons and Ensembles, Metrics of Model Reliability, and Testing Models Against Past and Present Climate (Randles, Russell et al. 2004, Intergovernmental Pane On Climate Change 2007).

Climate projections indicate that surface temperatures will increase over the 21st century under all assessed emissions scenarios. In addition, the ocean will continue to warm and acidify, global mean sea level will become higher, heat waves are expected to become more frequent and longer, and extreme precipitation events will increase in intensity and frequency in many regions. According to IPCC AR5 the increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is likely to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5 (Pachauri, Allen et al. 2014) (Figure II- 6).

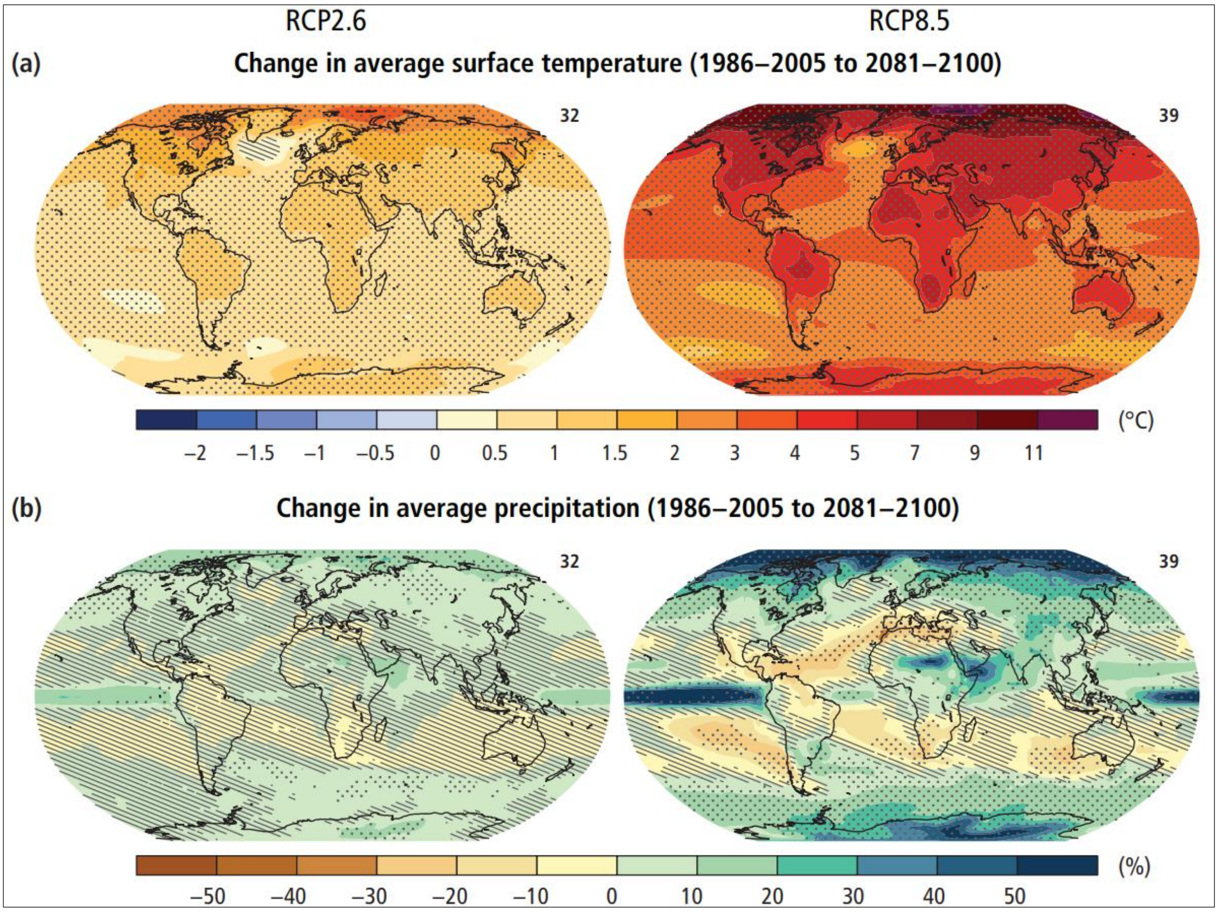


Figure II- 6. Change in average surface temperature (a) and change in average precipitation (b) based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios.

Source: IPCC 2014.

The two IPCC assessment reports AR4 (2007) and AR5 (2014) presented climate change scenarios, which the consistency of climate change projections and the magnitude of change between the two reports were not considered significant.

II.2.3. Climate change and energy consumption of urban forms

Climate has a significant impact on the thermal energy behaviour of the urban form, phenomena such as the urban heat island, energy consumption and air quality in the urban form are directly related to the immediate microclimate (Vallati, Vollaro et al. 2015).

The study of climate and its effects as a dynamic system primarily depends on the scale and the type of the environment. In addition, climate change is increasingly affecting energy use at the urban scale, as rising temperatures and changes in rainfall patterns can lead to a decrease in heating demand and an increase in cooling (air conditioning) needs, which in turn leads to an increase in electricity demand (Ebinger 2011). At this scale, climate is studied as an urban climate system, being the modified form of regional climate in a more detailed spatial scale and related to energy and material flows in the urban area. Studying the link between urban energy performance and climate involves understanding how global climate variations are carried over the urban climate and how they affect the performance of buildings and energy systems (figure II- 7). At this stage, climate variations can be magnified or mitigated at the urban scale according to the design of the urban form, the shape of the buildings and the building materials (urban form factors) (Ho, Ren et al. 2015, Nik, Perera et al. 2021).

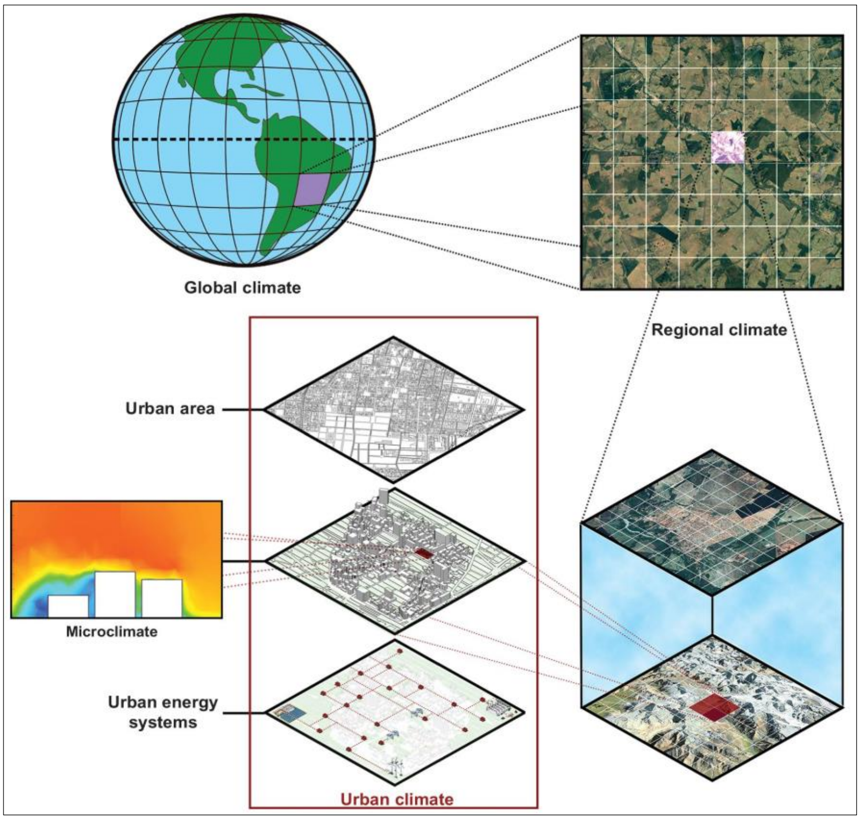


Figure II- 7. The energy performance of urban areas is tightly connected to the urban climate conditions. Variations in the global climate affect the regional and urban climate.

Source Nik, Perera et al. 2021.

The building sector in turn has a significant impact on climate change, with greenhouse gas (GHG) emissions accounting for 25% of total emissions, more than doubling since 1970 to 9.7 $GtCO_2eq$ in 2018. The majority of GHG emissions are indirect CO_2 emissions from electricity consumption in buildings, the sector also accounted for 36% of final energy use in 2018 (IEA 2019).

Moreover, several studies have examined the effect of current and future climate on energy demand in urban areas. Gi et al. studied the heating and cooling needs under different climate change models. Results indicate that global heating and cooling needs are projected to increase by a factor of 2.1-2.3 by 2050 and by a factor of 3.8-4.5 by 2010 (Gi, Sano et al. 2018). Other researchers have also investigated the effect of climate change to 2070 projection on the energy demand of 16 prototype buildings in Canada, which showed an average decrease of 18% to 33% and an increase of 15% to 126% in the intensity of energy consumption for heating and cooling, respectively (Berardi and Jafarpur 2020). Based on multiple climate change scenarios in Los Angeles, California, Reyna and Chester in their study expected that residential electricity demand could increase by 41-87% between 2020 and 2060 (Reyna and Chester 2017). Also, research conducted by Felkner et al evaluates the energy performance of different urban growth and densification scenarios considering three building types: low-rise, mid-rise, and high-rise, under climate change conditions from 2018 to 2100, in the West Campus area of downtown Austin, Texas. The results show that in terms of operational energy, energy use increased continuously from decade to decade in each scenario and that the high-rise scenario is the most efficient option for densification (Felkner, Brown et al. 2019).

Another interesting study presented by the IPCC in the fifth assessment reports (AR5) shows the major trends in heating and cooling energy consumption and its main drivers (figure II- 8). The future projection of heating and cooling demand in residential and commercial buildings is estimated to increase by 79% and 84%, respectively, during the period 2010-2050 under a business-as-usual scenario (no significant change in people's attitudes and priorities, or major changes in technology, economics, or policies, so normal circumstances can be expected to remain unchanged). In the main drivers, the increase in the number of households and the surface area per household leads to an increase in energy consumption, although the reduction in the number of persons per household and the specific energy consumption leads to a decrease in energy consumption in residential buildings (IPCC 2014).

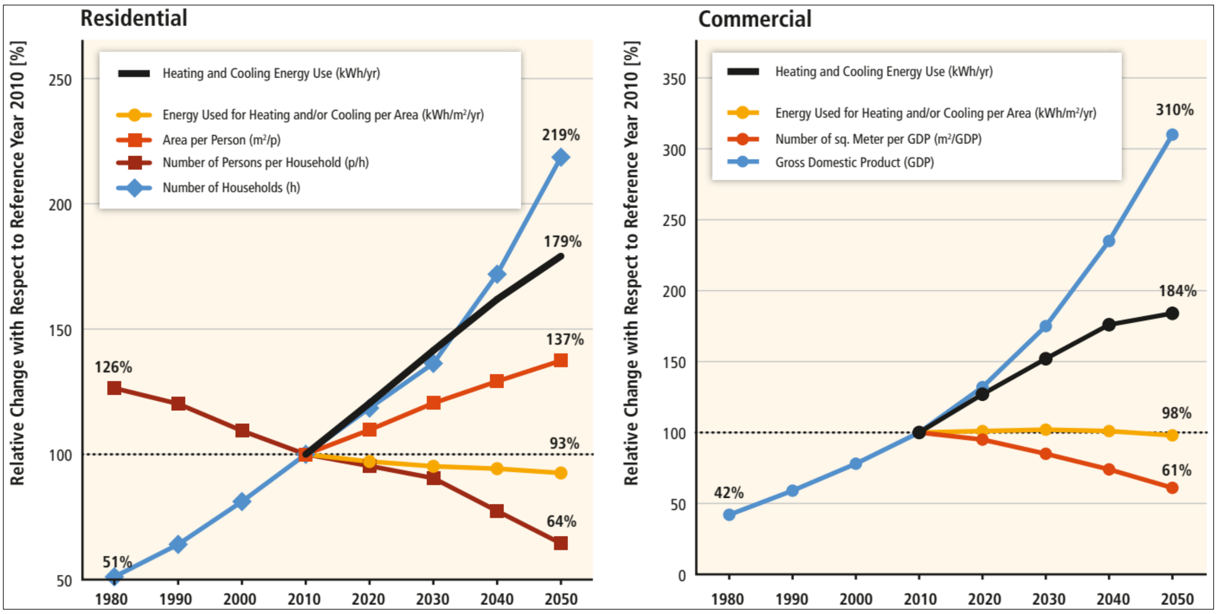


Figure II- 8. Trends in the different drivers for global heating and cooling thermal energy consumption in residential and commercial buildings.

Source: IPCC 2014.

For climate zones that have both heating and cooling periods relevant to energy demand, such as in cold semi-arid regions, climate change is projected to decrease the heating load while increasing cooling needs, leading to increased electricity demand in summer (Li, Yang et al. 2012). Overall, in a business-as-usual scenario, global energy demand for heating is expected to increase until 2030 and then level off. Energy demand for cooling is unlikely to increase rapidly over the period 2100 (Ebinger 2011). Various empirical studies have demonstrated that total energy demand is a function of external conditions, in particular temperature; lower temperatures lead to relatively high energy demand (high heating need), intermediate temperatures lead to lower energy demand, and higher temperatures lead to higher energy demand once again (high cooling need) (figure II- 9) (Thatcher 2007, Guan and environment 2009, Hekkenberg, Moll et al. 2009).

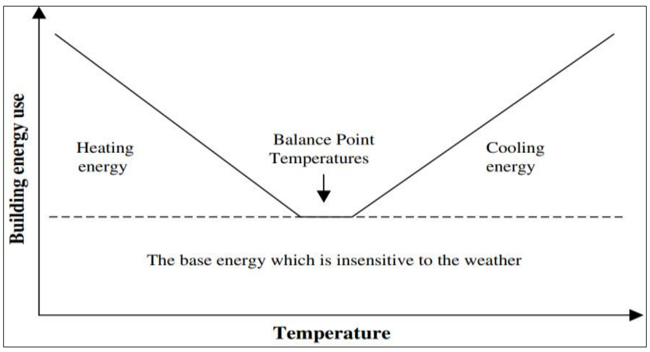


Figure II- 9. The relationship between building energy use and the outdoor temperature.

Source: Guan, 2009.

II.2.4. Climate change and energy production of urban forms

Climate change is the world's greatest environmental challenge and there are multiple suggested keys for mitigation and adaptation, in the urban context, which is a major source of anthropogenic climate change and through policies, many sustainable solutions can be implemented in the social, economic, and environmental field. However, renewable energy can play an important role in climate change adaptation strategies, as it can meet the energy needs of cities and the prospect of protecting natural environments (Suman 2021).

The design, sizing, and integration of renewable energy into the urban form starts with a better understanding of the energy demand and its evolution through the time, as well the characteristics of the urban form. The integration of renewable energies into the grid and their use in the urban context is influenced by urban form, mainly its factors and the mutual interactions among buildings. These tasks lead to the consideration of energy system design in the early stages of urban planning and urban infrastructure, from the scale of the building to that of the urban form (Perera, Coccolo et al. 2018).

The main priority for the integration of renewable energy in the urban context is to maintain the energy supply of buildings, however, the temporal variation in the availability of energy from renewable sources, such as solar photovoltaic panels, makes their integration very difficult.

At the urban form and building scale, the concept of urban energy microgeneration defines on-site thermal or electrical energy production that can be directly used by the consumer-producers (Peronato 2019). This renewable energy generation comes from systems that can be installed at the building scale, such as solar, wind, geothermal, biomass, etc. (Table II- 1) (Staffell, Brett et al. 2015).

Table II- 1. Different types of microgeneration technologies.

Source: Staffell et all 2015

Technology	Energy conversion process	Renewable	Higher efficiency
Condensing boilers	Gas → Heat		
Biomass boilers	Sustainable fuel → Heat	✓	
Heat pumps	Electricity + Sun→ Heat		✓
Solar photovoltaic	Sun → Electricity	✓	
Solar thermal	Sun → Heat	✓	
Micro wind	Sun* → Electricity	✓	
Internal combustion engines	Gas → Heat + Electricity		✓
Stirling engines	Gas → Heat + Electricity		✓
Fuel cells	Gas → Heat + Electricity		✓

Renewable energy resources, which are climate driven, may be sensitive to future climate change. Moreover, and at the urban context, the impact of climate change on renewable energy production drives to study the influence of the changed climate variables such as precipitation, temperature, irradiation or win on the urban energy microgeneration systems.

A study on the impact of climate change on eight key renewable technologies shows interesting results, assessing the influence of two different warming scenarios on utility-scale and residential solar PV, concentrated solar power, wind, bioenergy and hydropower, the results indicate that the risks for renewable energy sources are relatively minor. In addition, the pronounced warming scenario has a greater impact on renewable energies: globally, the potential for concentrated solar power and residential rooftop photovoltaics has increased by 2% and hydroelectric potential by 6%. Global bioenergy potential increased by 32%, while industrial-scale photovoltaic and wind power potential decreased (Gernaat, de Boer et al. 2021).

Solar energy sources are susceptible to climate change, mainly photovoltaic (PV) generation is linked to changes in solar irradiation, also, climate change tends to influence urban form by increasing temperature and leads to a significant risk of heat island or can create differences in wind speed or pressure, these can lead to a decrease in the efficiency of energy production from PV panels or to its destruction (Solaun and Cerdá 2019).

Furthermore, micro wind turbines are expected to contribute to the reduction of greenhouse gas emissions, while it allows to cover a part of electricity consumption in the domestic sector, their performance is based on the potential and characteristics of the wind. As a climate variable, the wind can undergo a significant change with climate change. High wind speeds result in high energy production by micro wind turbines and vice versa (Greening and Azapagic 2013).

Regarding global warming, the number of hot days and the hot season will increase due to the increase in temperature, especially in cities, which suggests that buildings need to be cooled more than heated, this leads to seek for more production of electricity with renewable manners, at this point, the consideration of photovoltaic energy is prioritized over solar thermal collector (Rahaman and Iqbal 2019).

Among the urban energy microgenerations, photovoltaic solar energy is the most promising and appropriate type of energy conversion, as it is known for its high utilization, experienced technologies, energy efficiency, as well as its ability and ease to be modelled in complex urban forms. In addition, the lifetime of a photovoltaic panel (about 25 years) compared to other renewable technologies might also be relevant (Gerlak, Weston et al. 2018, Solaun and Cerdá

2019). This leads to the consideration of solar PV as an essential element of the climate change mitigation strategy (Mitrašinović 2021).

II.3. Improving the energy efficiency of the urban form through solar energy

II.3.1. Question: how to minimize energy demand in buildings?

Population growth and the rapid development of the building sector have resulted in an increase in global energy demand. This problem needs to be addressed and accompanied by clean energy production and improved energy efficiency in buildings (Belussi, Barozzi et al. 2019). Worldwide, improving energy efficiency and reducing energy consumption in buildings are crucial elements for the sustainability of cities. The energy supply in buildings, the environmental conditions, as well as the degree of minimisation of energy consumption that corresponds to human well-being can indicate whether or not the concept of energy efficiency is guaranteed at the building level (Omer 2008, Bakar, Hassan et al. 2015)(Omer 2008, Bakar, Hassan et al. 2015).

Minimising energy consumption in buildings is based on building energy analysis which starts with an assessment of the physical properties of the consuming buildings, the thermal and radiative interactions between buildings and with the external weather conditions, the energy systems in the buildings as well as the type of energy consumption (heating, cooling, lighting, cooking...). Secondly, the behaviour of the occupants is a further factor (Bakar, Hassan et al. 2015). Other strategies can then be explored and implemented, such as the improvement of energy systems within buildings, enhancement of buildings physical characteristics, as well as using renewable energies (Luo, Zhang et al. 2019).

In addition, energy consumption in a building is mainly dominated by the heating, ventilation, and air conditioning (HVAC) system, and subsequently by lighting. Nevertheless, the HVAC system appears to be the biggest energy consumer in a building (Korolija, Marjanovic-Halburd et al. 2011, Mohammed, Mustapha et al. 2011). Furthermore, occupant comfort inside the building is an indicator of energy consumption via energy systems, especially HVAC systems and lighting, the more comfort is provided to the occupants of a building, the higher the energy consumption. At this point, energy efficiency can be related to the design and efficiency of HVAC systems, hence many HVAC systems can be recognized (Figure II- 10) (Wang, Yang et al. 2010, Parameshwaran, Kalaiselvam et al. 2012). On the other hand, away from active HVAC systems, energy demand reduction is also based on building design criteria, which are achieved through the adoption of appropriate and optimised parameters for orientation, shape, envelope system, passive heating and cooling mechanisms, shading, and glazing (Pacheco, Ordóñez et al. 2012).

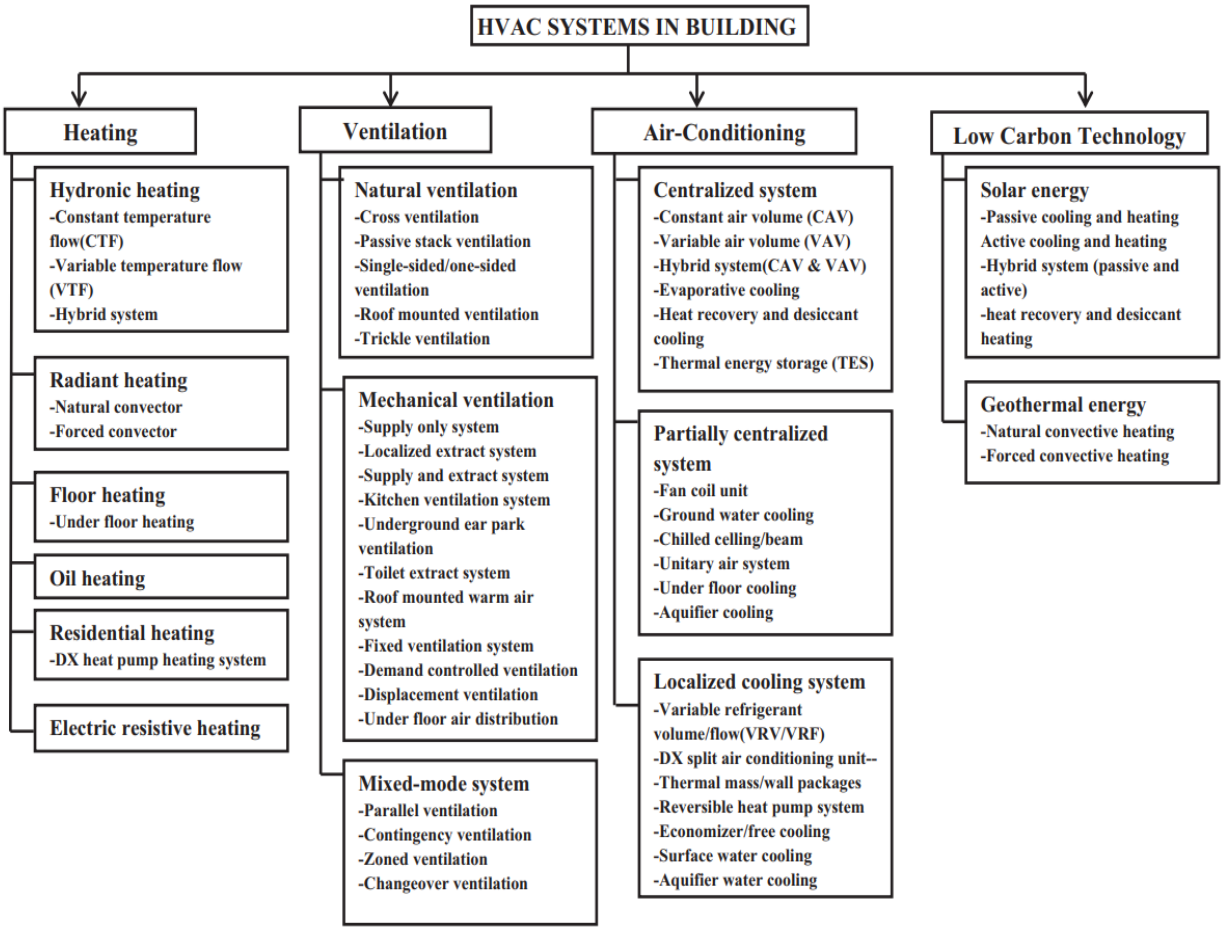


Figure II- 10. Diversity of HVAC systems in buildings.

Source : Parameshwaran, Kalaiselvam et al. 2012

In fact, the building envelope is an important part of a building that constitutes the main thermal barrier between the indoor and outdoor environment. It has a significant influence on the energy consumption and comfort of the building, even if no active applications are implemented. Therefore, passive strategies can help to address energy consumption in a free and sustainable manner. The outdoor environment is a tremendous source of renewable energy, for instance, passive solar heat in the cold season can provide heating for the building, particularly when the thermal storage wall properties in the building envelope meet the required thermal efficiency. Daylighting and natural ventilation have been highlighted as two strategies that ought to be used to reduce energy consumption, particularly for cooling and lighting (Jamaludin, Inangda et al. 2011).

Furthermore, accompanied by passive and active strategies (air conditioning, heat pumps, electric lighting ....), renewable energy can be another key solution for energy efficiency and improve human comfort in buildings by feeding active strategies with clean energy. Different renewable energy resources can be adopted in the design of the building envelope (Kheiri 2018). Solar energy being one of the main renewable energy resources used in buildings. Next sections treat the different uses and advantages of solar energy in buildings.

As discussed above, the assessment of a building's energy consumption is a first step in energy efficiency. It aims to examine the energy consumption performance, the life cycle costs of systems, to make a comparison of systems and to identify possible improvements, such as upgrading equipment and systems. However, these tasks require methods to accomplish them, in particular methods to perform the prediction of energy consumption of buildings. Bakar et al determined four methods used to perform the prediction of building energy consumption mainly heating and cooling; the forecasting method; the computer-aided analysis; the degree-day method and the bin method. Table II- 2 summarizes a comparative analysis on the scope use, advantages, input needed and limitation of the methods (Bakar, Hassan et al. 2015).

Table II- 2. Comparative analysis for the methods used to perform building energy consumption prediction. Source: Bakar et al, 2015.

Method	Scope of use	Advantages	Limitation	Input needed
Forecasting	Large building	Good for solving complex applications such as nonlinear problems	Requires very detailed and sufficient data	– Building physical data – Load consumption
Computer-aided	Large building	Easy to use and very systematic approach	The availability of simulation tool is limited	– Load consumption – Utility bill
Degree-day	Small building	Calculation involved is simple to perform manually	The application is only efficient for heating	Temperature data
Bin	Large building	The calculation is more accurate since it is based on hourly data rather than daily averages	This method requires a hand calculation procedure	Ambient temperature

II.3.2. On-site urban Solar energies

Solar radiation is one of the most versatile and abundant sources of renewable energy in the urban context. It can be used both directly and indirectly, also it can make a significant contribution to reducing grid energy consumption and carbon emissions from fossil fuels. In order to adequately utilise the advantages of solar energy in energy supply, passive solar measures should be considered first, particularly in the early stages of building design and conception (building orientation, shape, building materials, fenestration, internal room arrangement and external landscaping), followed by the active solar strategy (solar PV and/or solar thermal collector). Besides, for high performance buildings such as Zero Energy Buildings (ZEB) and Building Integrated Photovoltaic (BIPV), both strategies must be integrated in the early stages of building design (Henemann 2008, Eshraghi, Narjabadifam et al. 2014).

In its active or passive forms, solar energy can meet all the energy needs of buildings: space heating, lighting, domestic hot water (DHW), electricity, and even space cooling (figure II- 11) (Munari Probst, Roecker et al. 2013).

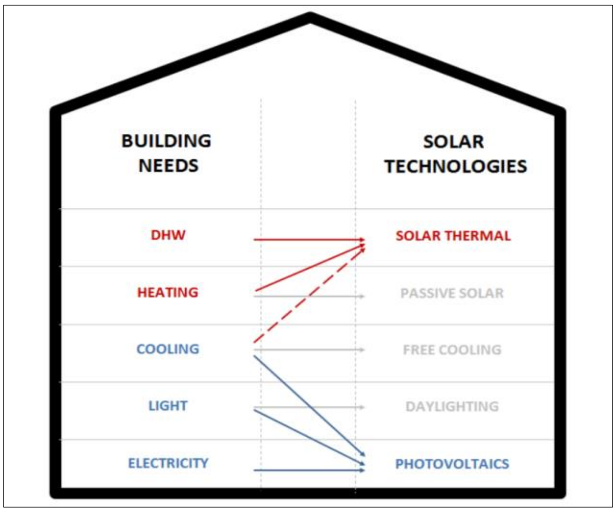


Figure II- 11. Different solar technologies covering different building energy needs.

Source: Munari Probst, Roecker et al. 2013.

II.3.2.1. Passive solar heat

Passive solar heating, also called passive solar design, is defined by two components: heating and cooling. Passive solar heating systems allow sunlight to be captured in the building materials and then release the heat during periods when the sun is not shining, such as at night. In addition, passive solar cooling systems use shading, thermal mass and natural ventilation to reduce unwanted heat during the day and store cool night air to cool the building, especially during the summer (figure II- 12) (Funk 2010). Some basic conceptual interventions are required in passive solar design and need to be considered even if the climate or geography are different; the location of the building; form and compactness; envelope and fenestration; the internal organization; orientation and sunshine; solar protections; the orientation and external coatings of the envelope; orientation and winds; natural ventilation; construction materials and their thermal performance; the thermal inertia of the building (Hyde 2012, DJAKPO 2016).

Passive solar heating can integrate other techniques to improve its benefits during the cold season, figure II- 13 shows four techniques that can be implemented to improve passive solar heating (Manzano-Agugliaro, Montoya et al. 2015).

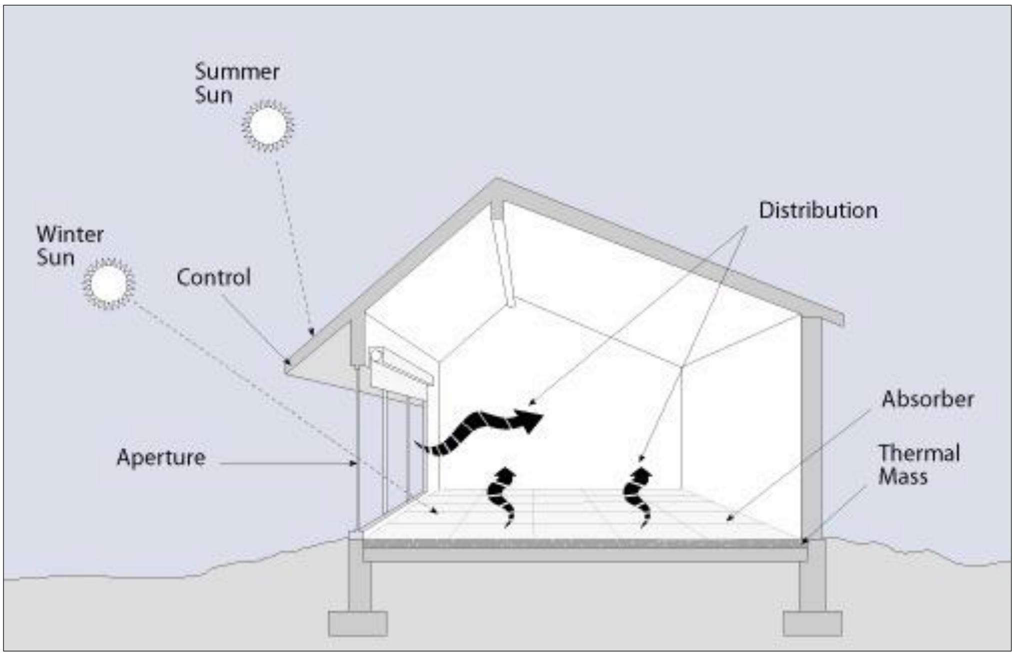


Figure II- 12. The five key elements of passive solar design.

Source: Funk 2010.

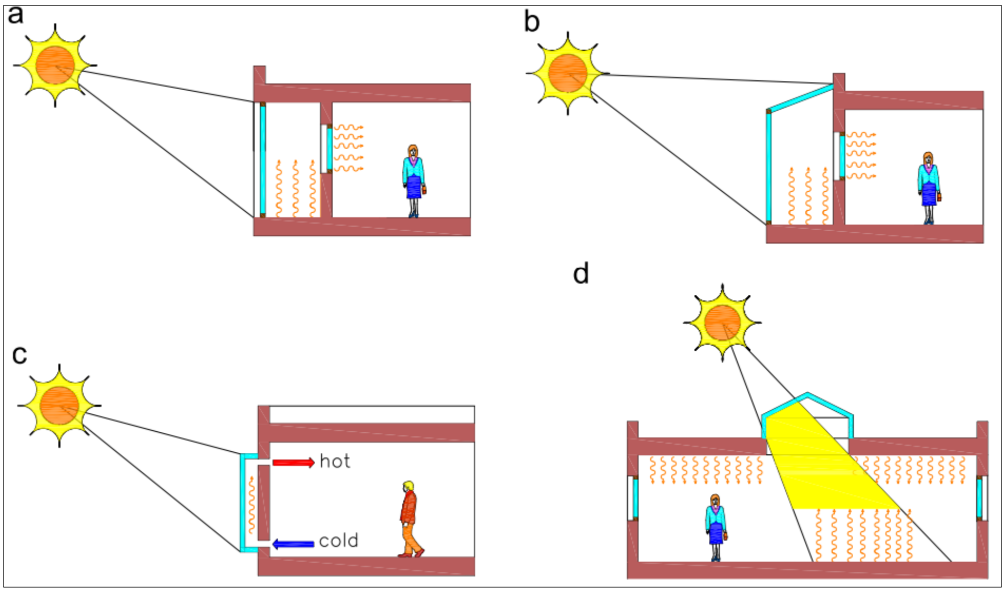


Figure II- 13. Techniques for passive solar heating.

"(a) Representation of a glassed-in gallery for a space in the passive solar heating zone; (b) representation of an adjoined greenhouse for an area in the passive solar heating zone; (c) representation of a Trombe wall for an area in the passive solar heating zone; and (d) representation of roof openings for a space in the passive solar heating zone".

Source : Manzano-Agugliaro, Montoya et al. 2015

II.3.2.2. Daylight

Lighting is one of the largest energy consumers in the building sector. Artificial lighting fixtures produce only a small range of light wavelengths, which is not efficient in terms of lighting comfort. Daylighting can be used to replace energy-intensive artificial lighting during the day, especially in commercial buildings with high lighting consumption. In addition, solar radiation improves the quality of lighting in buildings as it covers the whole visible light spectrum to which human vision is adapted (Funk 2010).

The integration of daylighting into building design can be addressed by different strategies (Figure II- 14) as well as being influenced by many factors. Direct sunlight is an important source of light, but it can cause glare problems. In contrast, diffuse daylight generated by cloudier days is less intense, but can be more easily controlled. Lighting requirements also vary according to the function of the space: classroom, office, hall, etc. Therefore, a small variation in the level of light can have a significant impact on the quality of the space. Also, a small change in light level may not be important in a large room. In urban areas, neighbouring buildings can create shadows during the day and in certain seasons. The shape of the building, room layout, size, type of glass and position of windows all influence the occupants' access to natural light (Funk 2010, Laksmiyanti and Salisnanda 2019).

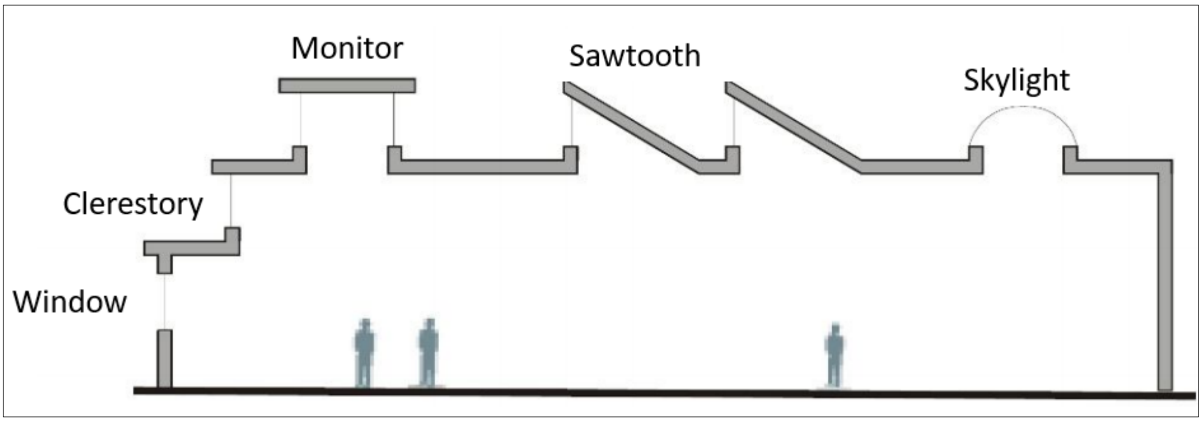


Figure II- 14. Daylighting strategy.

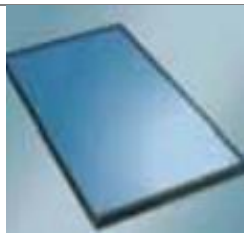
Source: Laksmiyanti and Salisnanda 2019.

II.3.2.3. Photovoltaic solar energy

Among active solar energy strategies, photovoltaics is one of the most promising renewable energy systems. Its origins date back to 1839 when the physicist Antoine-César Becquerel observed the photovoltaic reaction when conducting elements generate a current in the presence of light (photons). Subsequently, further studies developed the concepts and photovoltaic cells have been recognised worldwide to produce electricity from the sun. These photovoltaic (PV) cells consist of one or two layers of a semiconductor material, generally silicon. When sunlight is incident on the cell, an electric field is generated through the layers, known as the photovoltaic effect. The amount of energy generated by PV panels depends on the solar potential, specifically the sunlight. However, the higher the intensity of the sunlight hitting the cells, the greater the amount of electricity generated. Photovoltaic technologies have undergone a lot of development in cells: monocrystalline, polycrystalline and thin-film amorphous (table II- 3). It also has great advantages over other renewable energy technologies, it is a flexible system that can be installed in both small and large installations (in urban areas and on large empty sites), the lifetime of the PV system is also remarkable and can reach 30 years (Funk 2010, Rawlings 2010).

Table II- 3. The properties of PV cells.

Source: Rawlings 2010.

Property	PV cell type		
	Monocrystalline silicon	ne silicon Polycrystalline silicon	Thin film amorphous silicon
Appearance			
Cell efficiency at standard test conditions [1]	15–17%	14–15%	8–12%
Module efficiency	13–15%	12–14%	5–7%
Area of modules required per kWp [2]	7 m2	8 m2	16 m2
Area per kWp [2] of building materials incorporating PV cells	Glass–glass laminates: 8–30 m2 (depends on cell spacing)	Glass–glass laminates: 10–30 m2 (depends on cell spacing)	Solar metal roofing: 23.5 m2 Glass–glass laminates 25 m2
Advantages/disadvantages	Most efficient but highest cost	Cheaper than monocrystalline but slightly less efficient	Considerably cheaper but about half the efficiency of monocrystalline Offers the widest range of options for

	integration into building elements

Notes: [1] Standard test conditions (STC) are 25 °C, light intensity of 1000 W/m2 and air mass (spectral power distribution) of 1.5 and a cell temperature of 25 °C; [2] kWp = peak output power (kilowatts) (solar PV products are rated by their output power at STC)

II.3.2.4. Solar thermal collectors

Solar thermal energy takes direct advantage of the sun's radiation to obtain heat. In general, this type of energy is used to directly heat buildings or to generate domestic hot water. However, solar thermal power plants use this technology to generate electricity - so-called solar concentrators (Funk 2010).

Within active solar thermal systems, two main families can be identified according to the medium used for heat transport: air collector systems and hydraulic collector systems (Figure II- 15) (Munari Probst, Roecker et al. 2013).

Air collector systems are used immediately to preheat fresh air for ventilation in buildings. Heat can also be stored by forcing air to circulate in a bed of stones below ground. This system is also less efficient than hydraulic systems.

Hydraulic systems allow the storage of solar gains and are suitable for both domestic hot water (DHW) and space heating. Hydraulic solar thermal systems can be divided into three technologies:

- Evacuated tubes collectors
- Glazed flat plate collectors
- Unglazed flat plate collectors

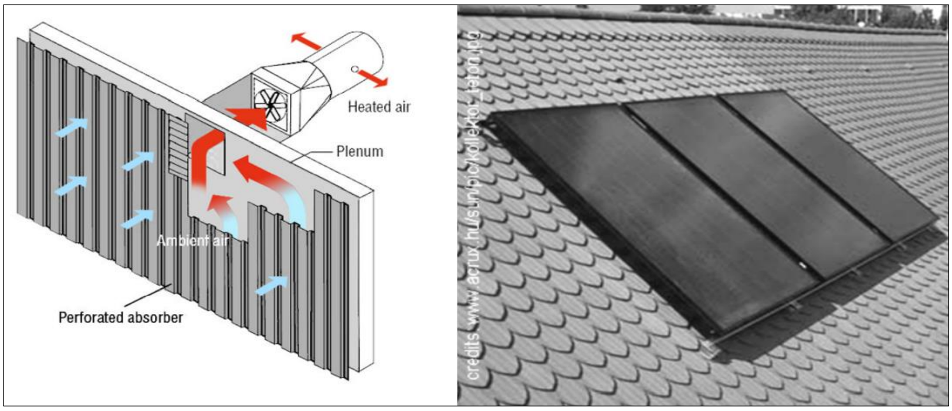


Figure II- 15. Solar Wall collector system (left). Glazed flat plate thermal collectors applied on a tilted roof (right).

Source : Munari Probst, Roecker et al. 2013.

II.3.3. The future of solar-powered sustainable buildings (prospect)

Climate change is one of the most serious global issues. Global energy demand is increasing, as are anthropogenic greenhouse gas (GHG) emissions. This trilogy is strongly linked to urbanized areas. The building sector accounts for 39% of global GHG emissions and generates almost 40% of the annual increase in global CO2 emissions (figure II- 16, left), which further raises the issue of global warming. Thus, reducing carbon emissions in buildings will be key to meeting the Paris climate targets and achieving net zero emissions by 2050. In addition, the use of precious energy resources must be as efficient and minimized as possible while promoting the increased penetration of renewable energy in achieving a low carbon economy (Cheekatamarla 2021, Tang, Guo et al. 2021).

Global warming will in turn increase the demand for electricity in the building sector, mainly for cooling needs (Figure II- 16, right). Energy efficiency and the integration of renewable energy must remain a top priority for energy efficient buildings. Several research studies have investigated the types of buildings that can respond to the perspective of climate change adaptation and mitigation strategies, high energy performance by generating green electricity production as well as human well-being. Among this type of buildings, it is possible to mention the most proposed and studied types in the last decade: the Zero Energy Building (ZEB), the Building Integrated Photovoltaic (BIPV) and the Building Applied Photovoltaic (BAPV). From their designations, it is clear that the first one is the most appropriate building type that can contain the other two types and meet energy, wellbeing and environmental expectations (Nagaoka, Ota et al. 2021, Seo and Suh 2021).

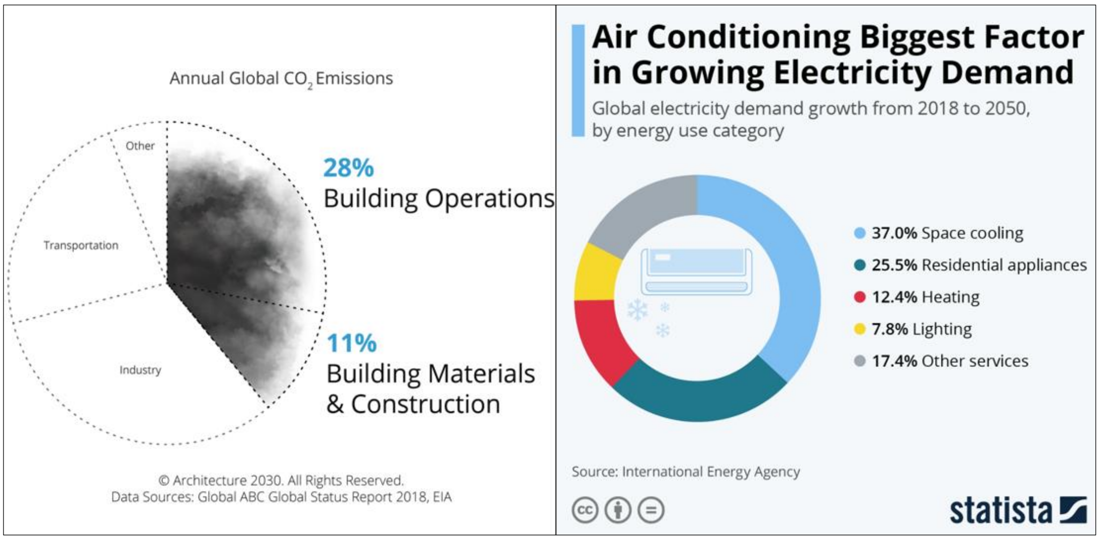


Figure II- 16. Annual Global CO2 Emissions (left). Global electricity demand growth from 2018 to 2050, by energy use category (right).

Source: IEA 2020.

II.3.3.1. BIPV (Building Integrated Photovoltaics)

The BIPV (Building Integrated Photovoltaics) method technically refers to systems and concepts in which the photovoltaic element is integrated into the building envelope, or replaces the traditional building element, while meeting all the requirements of the building envelope such as mechanical strength and thermal insulation. This offers a double benefit: on the one hand, to produce energy and on the other hand, to provide a building element of the final structure. This strategy can be implemented at the beginning of the construction project, during, or after the renovation of a part of the building (roofs, windows, cladding) (Ghosh 2020).

The European BIPV standard EN 50583 specifies five categories of BIPV: (A) horizontal sloped, non-accessible, (B) horizontal sloped accessible, (C) vertical non-accessible, (D) vertical accessible and (E) externally integrated (Figure II- 17) (Nebojsa Jakica 2019).

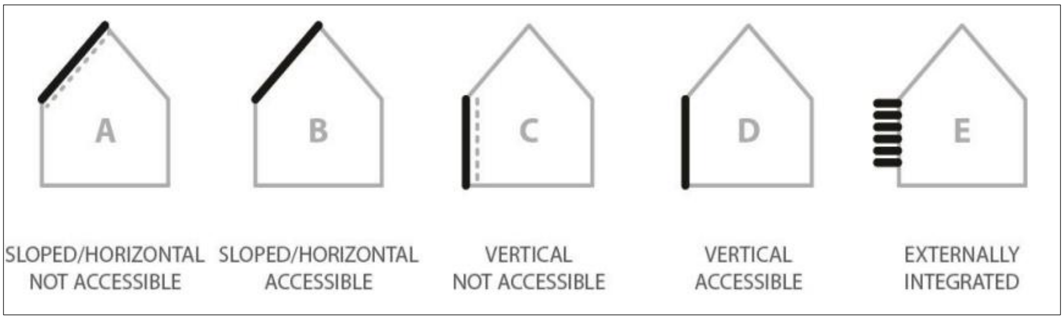


Figure II- 17. BIPV categories.

Source: Nebojsa Jakica 2019.

Recently the BIPV technologies known a great development, on the function, the materials used, their mechanical and electrical characteristics, five main categories of BIPV products can be distinguished (Shukla, Sudhakar et al. 2017): (a) BIPVs foil products; (b) BIPVs tile products; (c) BIPVs module products; (d) BIPVs solar cell glazing; (e) BAPV (figure II- 18).

Figure II- 18. Classification of BIPVs Product.

Source : Shukla, Sudhakar et al. 2017.

II.3.3.2. BAPV (Building Applied Photovoltaics)

The BAPV (Building Applied Photovoltaics) system consists of installing PV modules on existing surfaces in buildings by superimposition once the construction of the project is completed. This approach is the one adopted for traditional photovoltaic solutions and does not replace the building element, unlike BIPV. It is only used for energy production and can rather mitigates heat gain by shading the roof or wall to avoid direct solar heat (Ghosh 2020).

II.3.3.3. ZEB (Zero Energy Building)

According to (Marszal and Heiselberg 2009), the zero-energy building concept is related to the following key points:

Primary energy – units of the balance.

Total energy demand = for operating the building + associated with occupancy.

Fixed maximum energy use. Developed at the meeting since it should be a value achievable in all countries. A starting point could be the energy use for a low-energy buildings.

Distinguish between residential and non-residential.

Application all types of renewable energy sources.

Regulations of the grid-building interaction.

Referring to Oh, Hong et al. 2017, a net-zero energy building is a conception of building that introduce from the first steps a combination of various strategies (passive and active) to meet high energy performance, response to all energy demand, respect naturel environment and guarantee human comfort. Figure II- 19 illustrates all these strategies. Passive strategies for nZEBs involve reducing the building's energy demand, such as heating and cooling loads, through architectural design techniques at an early stage of design, while active strategies save the remaining load through active techniques and technologies, such as renewable energy (Oh, Hong et al. 2017).

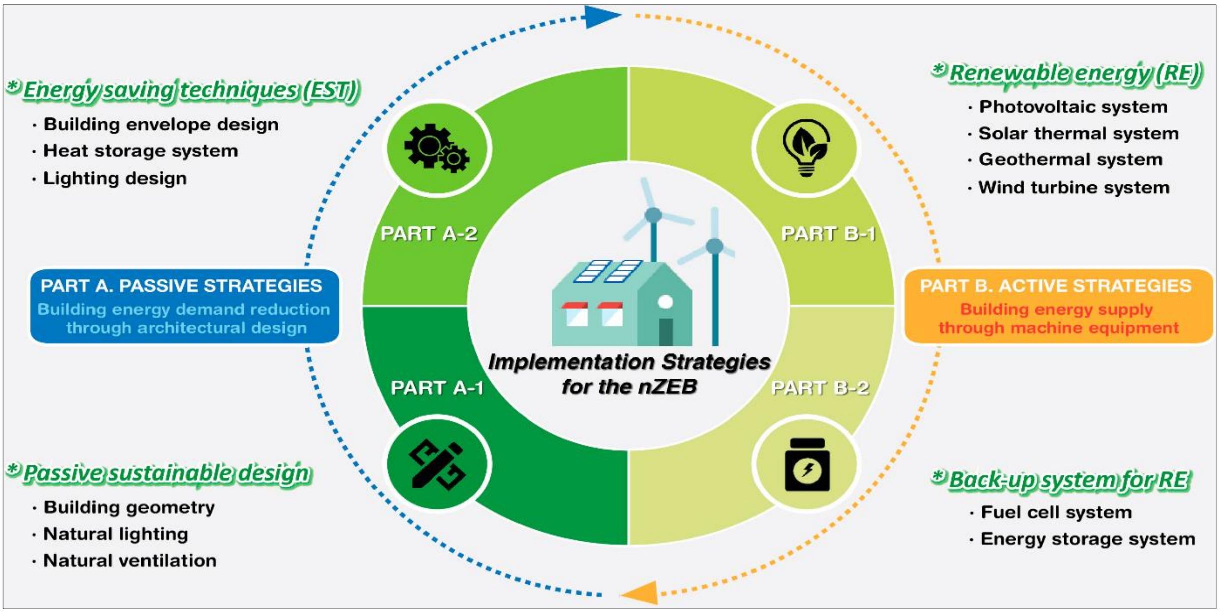


Figure II- 19. Passive and active strategies for implementing net-zero energy building.

Source : Oh, Hong et al. 2017.

In general, the ZEB concept presents an energy-efficient building, where the building can satisfy all energy demand with cheap, locally available, and non-polluting renewable sources. It generates sufficient on-site renewable energy to match or exceed its annual energy consumption and help to mitigation of CO2 emissions regarding other type of buildings (Torcellini, Pless et al. 2006). In addition, calculating the energy balance of a building equipped with renewable energy systems and/or interacting with the electricity grid and aiming to achieve "ZEB" requires assessment methods. At this stage, calculation methods such as LEED or BREEAM can help in this task (Marszal, Heiselberg et al. 2011).

II.4. UBEM as a tools and methods to transition of urban areas towards energy efficiency and carbon neutrality

II.4.1. Urban building energy definition and methods

Most methods used to estimate the energy demand of urban buildings use a limited number of building models and scale them according to the floor area of the buildings, which does not capture the full complexity of urban buildings and does not reflect high accuracy. These methods are mainly based on top-down building stock energy models providing assessments of one or more buildings and do not take into account the interactions between buildings. However, these methods have restricted their ability to predict the performance of a group of buildings, especially in an urban context (Hong, Chen et al. 2020). However, the Urban Building Energy Model (UBEM) is a bottom-up building energy model that constitutes an analytical tool for modelling buildings at the city scale and assessing energy-efficient building environment scenarios at the building, neighborhood, and city scale (Johari 2021). The UBEM method is built in successive steps, an overview of the literature has been proposed where the modelling procedure in UBEM is demonstrated in figure II- 20. The identification of the geometric properties of the buildings by 3D models (shape, geometry and geospatial positions) presents the first step, then, the identification of the non-geometric properties of the buildings (material, system and occupancy) by building archetypes that represent the most important characteristics of the building stock, after that, the definition of the climatic conditions is given as data file. Finally, all these inputs are imported into a UBEM simulation tool where the thermal models are run and simulated. The results can then be exported and presented in several formats and time evaluations depending on the simulation tool (hourly, daily, monthly, annual) (Johari, Peronato et al. 2020).

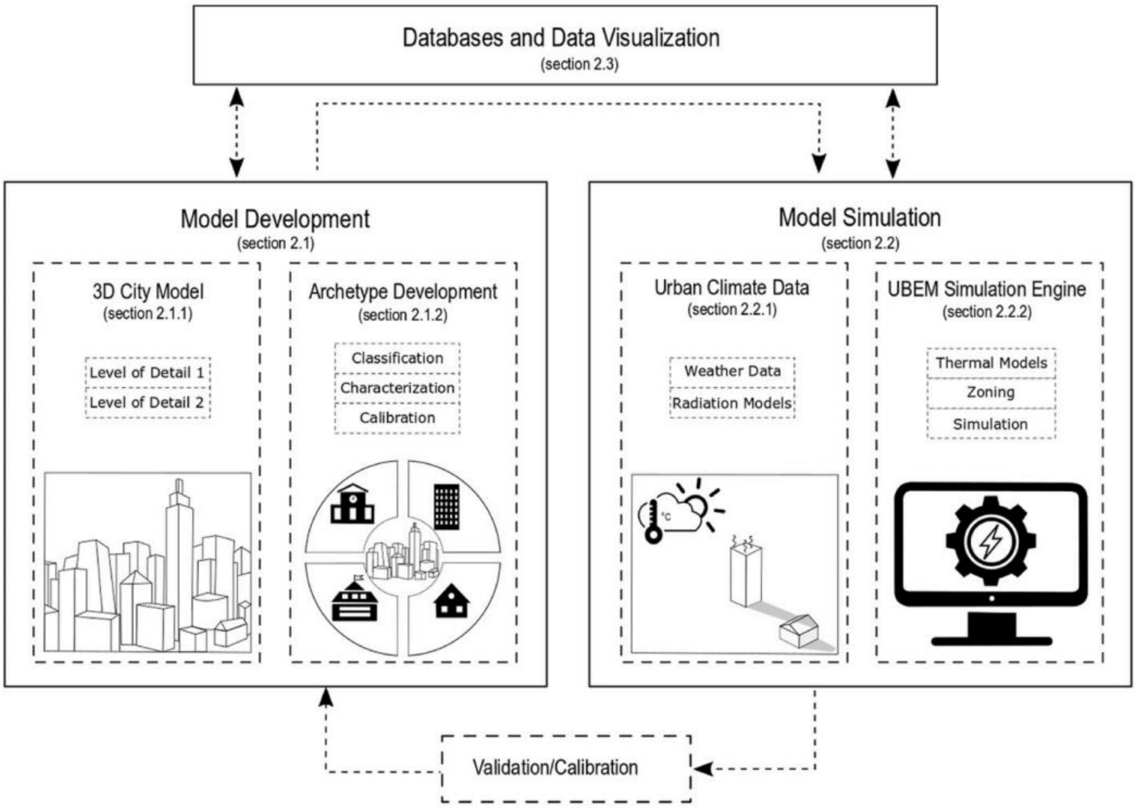


Figure II- 20. Overview of urban building energy modelling.

Source: Johari 2021.

II.4.2. Urban building modeling tools

Urban Building Energy Modelling (UBEM) is a way to address energy efficiency and sustainability in the urban context. There are a number of UBEM tools that have a variety of computing resources and user inputs. Hong, Chen et al et al provide a summary of the most commonly used UBEM tools. The majority of them are stand-alone applications like CitySim and UMI, while some are web-based like CityBE. As UBEM uses geographical and geometrical data, most UBEM tools integrate GIS datasets or use virtual city models based on CityGML. Furthermore, at the simulation stage and based on the thermal engine, some UBEM tools use physics-based simulation engines, such as CityBES and UrbanOpt which use EnergyPlus, while others use their reduced order models, such as SimStadt, CitySim, City Energy Analyst and TASER. Table I- 4 presents the most well-known UBEM tools by taxonomy of tool spatial scale, modelling approach, data input and application platform (Hong, Chen et al. 2020).

Table II- 4. Urban building energy modeling tools.

Source : Hong, Chen et al. 2020.

Approach	Tool		Developer	Calculation method	Target Users
Physics-based dynamic simulation method	CityBES	Web-based data and computing platform to evaluate energy performance of city buildings	LBNL	EnergyPlus	Urban planners, policy makers
	MIT UBEM Tool	Tool for citywide hourly energy demand load calculation	MIT	EnergyPlus	Urban planners, policy makers
	UMI	Urban modeling interface for energy performance analysis of neighborhoods	MIT	EnergyPlus	District energy managers
	Virtual EPB	Automatic building energy model creation leveraging machine learning simulation using high performance computing	ORNL	EnergyPlus	Urban planners, policy makers
	Tool by Columbia University	Tool for community-scale energy performance analyses using calibrated building energy models	Columbia University	EnergyPlus	District energy managers
	Tool by Cambridge University	Tool for building energy analysis for community scale and display emission map	Cambridge University	EnergyPlus	District energy managers
	UrbanOPT	Modeling tool to integrate energy loads and renewable energy at the district level to develop	NREL	EnergyPlus and OpenStudio	District energy managers
	COFFEE	Tool for utility customer optimization for furthering energy efficiency	NREL	EnergyPlus and OpenStudio	Utility program
	CitySim	Decision support tool for urban energy planners and stakeholders to minimize energy usage and emission	EPFL	CitySim solver	Urban planners, policy makers
	SEMANCO	Semantic tools for carbon reduction in urban planning	FUNITEC	Tool specific simulation engine	Urban planners, policy makers

Reduced-order calculation method	SimStadt	Urban energy tool for energy analysis for city districts	Hochschule für Technik Stuttgart	ISO/CEN standards based reduced-order model	Urban planners, policy makers
	Energy Atlas	Spatio-semantic representation of the city structure including energy related information	Technische Universit€ at München	ISO/CEN standards based reduced-order model	Urban planners, policy makers
	LakeSIM	Modeling tool for infrastructure to help analyze energy efficiency of new city block development	ANL	ISO/CEN standards based reduced-order model	Urban planners, policy makers
	Tool by Georgia Institue of Technology	A tool for building energy modeling with GIS at urban scale	Georgia Institute of Technology	ISO/CEN standards based reduced-order model	Urban planners, policy makers
	OpenIDEAS	Open-source framework for integrated district energy assessment	KU Leuven	Modelica based reduced order model	District energy managers
	TEASER	Tool for multiple building energy performance evaluation	RWTH Aachen University	Modelica based reduced order model	District energy managers
	City Energy Analyst	Computational framework for the analysis and optimization of energy systems in neighborhoods and city districts	ETH Zurich	Tool specific calculation modules	Urban planners, policy makers
Data-driven method	UrbanFootprint	Planning tool for access to land use, policy, and resource across a range of sectors	Calthorpe Analytics	Private data-driven solution	Urban planners, policy makers
	Tool by New York University	Web-based tool to visualize energy benchmark and predict energy performance	New York University	Data-driven regression model	Urban planners, policy makers
	CoBAM	Tool to estimate the adoption of energy efficient technologies for building stocks	ANL	Data-driven regression model, ISO/CEN standards based reduced-order model	Policy makers

II.5. Conclusion

Climate change is the world's greatest environmental challenge, causing global warming at an unsustainable rate. At the city level, with increasing population and without a sustainable vision, this phenomenon is amplified by anthropogenic greenhouse gas emissions and impacts the urban environment requiring high energy needs and resulting in an unsustainable environment.

Around the world, several organisations and authorities have been formed through international meetings, conferences, and protocols to conduct high-level studies on climate change on earth. Their main objective is to devise strategies for mitigating and adapting to climate change. For instance, the Intergovernmental Panel on Climate Change is one such interesting organisation. The IPCC has produced interesting reports, targeting adaptation and mitigation in many areas and at many scales, such as energy at the scale of cities and buildings. Thus, cities must be an integral part of the response to climate change based on sustainable development that takes advantage of the city's current resources and technical means, considers the needs of the inhabitants, and respects the natural environment.

At the planning and design stage, climate analysis mapping, public space assessment, intervention planning and design, and post-intervention evaluation approach could be the important strategies that can be followed as climate intervention at this scale.

Furthermore, energy at the urban scale is a key parameter that can either amplify global warming by using fossil resources or contribute to adaptation and mitigation of global warming. From the above sections it can be concluded that total energy demand is a function of external conditions, in particular temperature; low temperatures lead to relatively high energy demand (high heating requirement), intermediate temperatures lead to lower energy demand, and high temperatures again lead to higher energy demand (high cooling requirement). Energy demand in cities is related to the physical interactions between buildings. At this stage, five factors influence the energy performance of buildings in the urban context, namely urban climate, urban morphology, building physics, heating, ventilation, and air conditioning (HVAC) systems and occupant behaviour.

On the one hand, the minimisation of energy consumption in buildings is based on the energy analysis of buildings which encompasses the factors mentioned, as well as on the exploration and implementation of other strategies such as the improvement of energy systems in buildings, the improvement of the physical characteristics of buildings, as well as the use of renewable energy microgeneration systems. On the other hand, building energy assessment that contains all factors from occupant behaviour to the interaction of the microclimate at the urban scale, especially in the early design process, requires sophisticated methods and tools that can provide useful predictive results. Thus, the Urban Building Energy Model (UBEM) can provide an analytical tool for modelling buildings at a large scale and evaluating energy efficient building environment scenarios at the building, neighbourhood, and city scale.

Different renewable energy resources can be adopted in the design of the building envelope. Solar energy is one of the most favourable energy sources that can be used in different techniques (passive heat, daylight, PV, and solar thermal collectors). As the building can integrate the above strategies (passive, active, renewable energy microgeneration), it can meet the standards of an energy efficient building. Building types such as Zero Energy Buildings (ZEB), Buildings Integrated Photovoltaic (BIPV) and Buildings Applied Photovoltaic (BAPV) are most likely to meet the requirements of high energy efficiency and climate change adaptation in the present and future visions.

Chapter III

Regulatory and legislative corpus

III.1. Introduction

Energy and climate change are recognised as a major global challenge, and it is therefore the governments who are initiating the actions to tackle this issue through their policies. On the one hand they aim to meet the energy needs by a continuous energy supply, especially in the primary sectors such as the building sector, and on the other hand, they struggle against climate change via the origin and the way of energy production.

In view of the urban growth of the population in emerging countries, the building sector is one of the most dynamic sectors. Algeria accounts as one of these countries, during the last decades it has experienced a galloping urbanization, which has induced a strong increase in demand and energy consumption. Today, the residential sector alone consumes 18,140 K toe almost 33% of total energy (Ministry of energy 2020). On the scale of its territory, Algeria has a relatively enviable position in terms of energy sources. On the one hand, its hydrocarbon reserves largely cover the current rates of consumption and allow it to remain serene for a longer period. On the other hand, in terms of renewable energy, the Algerian territory has high abundant renewable energy, which can cover a large part or almost the total consumption and be a further key to face climate change, however, the development of energy saving in this field remains slow.

This chapter discusses the factors that have led to the residential sector taking an important place in terms of energy in the Algerian framework, also, this part introduces the regulatory and legislative corpus adopted in terms of energy management and renewable energy, in the same context, it is essential to show the renewable energy reserves in the Algerian territory and its current situation in this area. Finally, the study of energy improvement in the residential sector in Algeria is presented.

III.2. Residential built environment and energy consumption

III.2.1. Worldwide and Algerian residential built environment

As housing is probably the most sensitive and promising human need, it plays an important economic, social, and environmental role as it is the most basic form of household investment and overlaps with different sectors such as energy. In an international context, housing is closely linked to population, with demographic changes driving housing demand. Current and recent statistics indicate that the world's population has grown from 1 billion in 1800 to 7.7 billion today, resulting not only in a high demand for housing but also a soaring demand for energy. Currently, governments, especially in emerging countries, are addressing the issue of high demand for housing and energy in the same time (Roser, Ritchie et al. 2013, Zhang, Jin et al. 2020).

In many countries of the world, as in Algeria, the issue of housing has taken on considerable proportions over time, which has prompted the government to react in this direction and engage in the realisation of numerous programs to meet this need, and recently not only to meet this need in number but to meet it with a sustainable manner in its different necessities (Boissonade, Méquignon et al. 2016, SBIA YASMINE 2017).

After the independence, Algeria experienced several urban, social, economic, and political changes, especially in the housing sector. The country was characterised by the eccentricity of the large cities on the coast, a phenomenon that was aggravated by the strong attraction of the northern part of the country, which has undergone great development and constitutes points of convergence for other agglomerations in search of opportunities for work, study and even housing. Therefore, urbanisation in this country has undergone a remarkable change with an accelerated urbanisation rate of 32% in 1966 to 58.3% in 1998, and 86% in 2008 according to the results of the 5th general population and housing census (RGPH 2008).

During the period from 1962 to 1999, the country experienced unbalanced development in the housing sector. In 1962, the housing stock that was already existing and abandoned by the French colonisation was estimated at nearly 1,950,000 housing units and the Algerian population was 10 million inhabitants, with an occupancy rate per dwelling (TOL) of 5.6 p/housing. The need for housing was considered sufficient, which weakened the perspective of a housing crisis (Benmatti 1982, Heraou 2018).

In 1966, the housing stock was 1,980,000 housing units and the population was estimated at 12,096,347 inhabitants, at that time the housing conditions were considered satisfactory but 80% of the housing was overcrowded due to the size of the Algerian family, this period also witnessed a remarkable increase in unplanned housing such as barracks and slums.

In 1977, the demographic growth was estimated at 3.48% per year, on average, with the country's population reaching 16,948,000 inhabitants, which placed Algeria among the first countries in the world in terms of demographic evolution. On the other hand, the housing rate did not exceed 1.5%, since the real estate stock was estimated in 1977 at 2,208,712 housing units, which caused the housing need not to be met in a favourable way, and made the housing occupation rate (TOL) increase from 6.1 to 7.7 p/l. At this time the state estimated a need for 700,000 housing units, in addition to the demolition of houses over 50 years old with a high rate of ageing and the construction of administrative housing, while neglecting the socio-cultural factors (Benmatti 1982).

The period between 1977 and 1987 was characterised by a weak demographic growth compared to the previous one, the resident population at 22,971,558 people indicates indeed a slight decrease of the demographic growth which goes down to an average annual rate of 3.06%. During this period, the housing crisis reached its peak on the threshold of the first five-year plan, while the rate of implementation of urban housing programmes reaching only 25%, as well as a deficit estimated at 900,000 dwellings. Simultaneously, important programmes were implemented by the state for public housing construction, as well as measures to liberalise private individual construction. In addition, the Ministry of Urban Planning and Construction (MUCH) and the Ministry of Planning and Regional Development (MPRD), established in 1979, outlined many nationwide strategies to fill the housing gap (Benmatti 1982, Heraou 2018).

Until the 1998 period the initiative of the state was not remarkable as in other periods, changes in its housing policy were conjugated by a weak response to the housing crisis. In 1998, a new housing strategy was adopted, which totally disengaged the state from the construction of housing. Its role was limited to financing social housing for low-income households, furthermore, it helps to granting of aid for the construction or extension of rural housing in order to maintain the population in rural areas. New formulas have been launched, such as rental, sale and participatory social housing for the middle classes who are able to mobilise savings to benefit from the granting of state aid and to access property directly (Heraou 2018).

Figure III- 1 illustrates the housing stock, inhabited and not inhabited in 2008 according to the type of construction which is 6236954 dwellings and of which the individual type dominates.

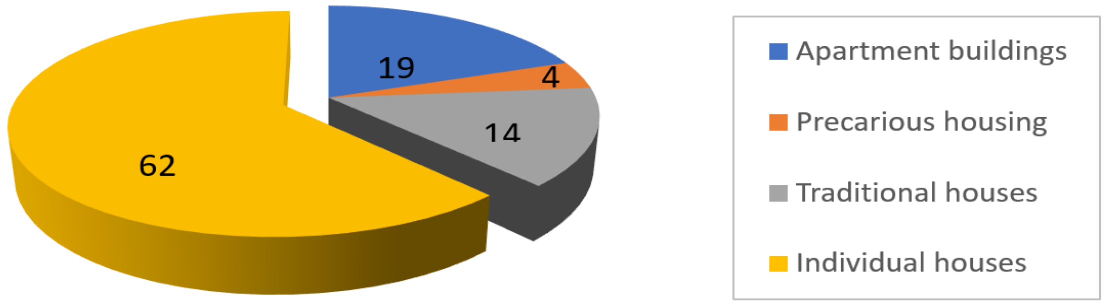


Figure III- 1. Distribution of the total housing stock (inhabited not inhabited) by type of construction.

Source: Saliha 2008.

Today, after more than half a century of independence and a multitude of experiments to eradicate the housing crisis in Algeria, the problem of the housing crisis persists. In addition to the quantitative deficit, the crisis also appears through the decline in the quality of housing and the urban environment, these are due to the major insufficiencies of the architectural production and urban planning plans, which merge the concepts of sustainability and well-being.

III.2.2. Algerian energy consumption from a global point of view

Algeria is considered worldwide as a country rich in fossil energy resources. In 2013, Algeria recorded 12.2% of the world's oil reserves and 4.5% of the world's natural gas reserves. It has the seventeenth largest oil reserves in the world and the fourth largest in Africa. It also has the tenth largest stock of natural gas in the world and the second largest in Africa (Amri 2017).

In 2020, oil production in Algeria amounted to about 1.3 million barrels per day. While natural gas production was measured at 81.5 billion cubic metres. However, the country is among the largest oil producers in Africa and is the tenth largest in the world and the first in Africa for natural gas production. Between 2009 and 2019, oil and natural gas consumption increased from 327 (thousand barrels per day) and 0.64 (exajoules) to 545 (thousand barrels per day) and 1.63 (exajoules), respectively, which represents an increase compared to previous years (statist 2020). Figure III- 2 shows the total final consumption (TFC) by source, where oil and natural gas sources show a dominant value. Furthermore, the extensive use of oil and natural gas is associated with a higher impact on CO_2 emissions. As reported by the International Energy Agency (IEA), CO_2 emissions have increased from 51.2 Mt in 1990 to 137.3 Mt in 2018, more than doubling (IEA 2018).

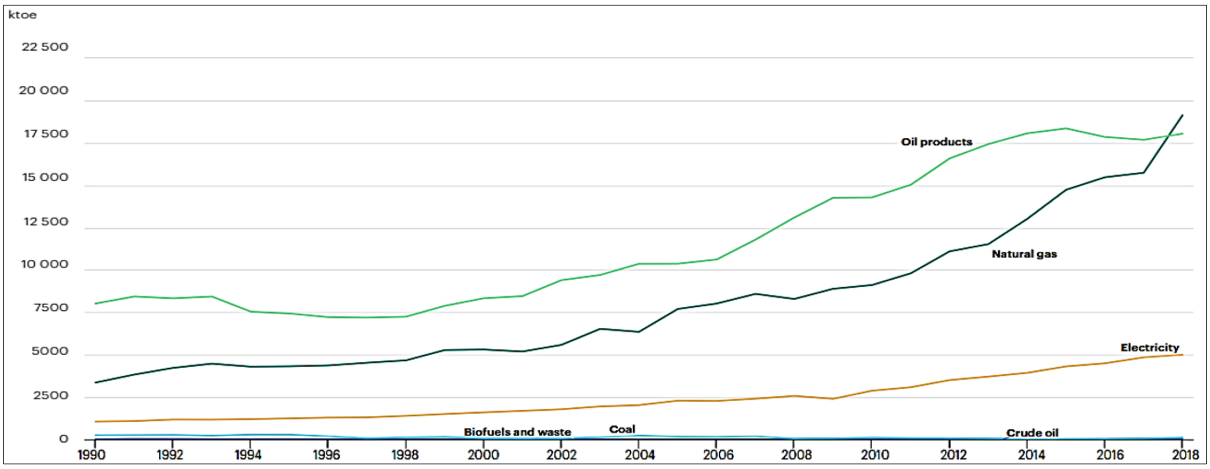


Figure III- 2. Total final energy consumption (TFC) by source, Algeria 1990-2018.

Source: IEA 2018.

With regard to final consumption, it amounts to 50.4 Mtoe in 2019 against 48.1 Mtoe in 2018, reflecting an increase of 2.2 Mtoe, that is (+4.6%), mainly driven by natural gas and, to a lesser extent, oil products, LPG and electricity. Figure III- 3 illustrates the final national consumption by product, it is clear that the share of natural gas (34%) occupies the largest value, followed by oil products (32%) and electricity 28% (Ministry of energy 2020).

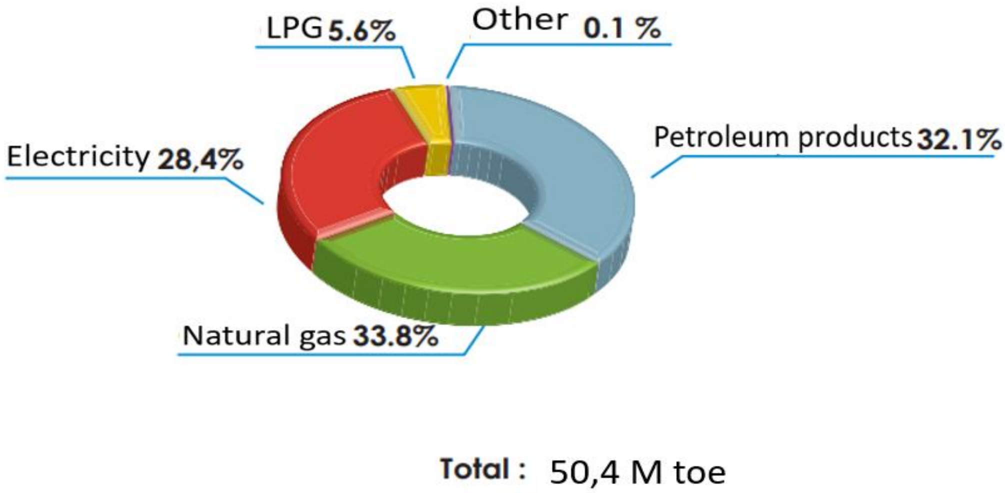


Figure III- 3. Structure of final energy consumption by product.

Source: Ministry of energy 2020.

By sector of activity, the evolution of final consumption in 2019 shows the following data:

- Increase in the consumption of "Households and others" by 5.0% to 23.5 Mtoe, driven by the residential sub-sector (2.9%), due to the increase in the number of Sonelgaz customers and their needs.
- Slight increase (0.8%) in the consumption of the "transport" sector to 15.4 Mtoe in 2019, driven by road fuels.
- Increase in the consumption of the "Industries and Construction" sector by 9.3%, to 11.4 Mtoe, driven by the sub-sectors of ISMME (steel, metal, mechanical and electrical industries) (41%), construction (84%) and building materials (+5%) (Ministry of energy 2020).

Details of final consumption by sector for both 2018 and 2019 are given in Table III- 1.

Table III- 1. Final energy consumption by sector.

Source: Ministry of energy 2020.

Unit: K toe	2018	2019
Industry, Building and civil engineering	10 450	11 424
Transport	15 281	15 405
Households and others	22 414	23 529

Moreover, the extensive use of oil and natural gas is associated with an impact on C02 emissions. As reported by the International Energy Agency (IEA), CO2 emissions have increased from 51.2 Mt in 1990 to 137.3 Mt in 2018, more than doubling (IEA 2018).

For decades, the country's economy has been based on these fossil fuel resources. In order to meet the growing energy demand of its population, the decreasing production of oil and natural gas, and to promote a clean environment, Algeria has increased its efforts to develop other alternative energies such as renewable energies. It plans to produce 20% of its energy from renewable sources by 2030. To achieve this goal, the country has adopted a number of options such as the development of solar, wind, hydroelectric, geothermal and biomass energy production capacity, as well as a progressive legislative framework for the renewable energy sector, the strengthening of renewable energy structures, the adoption of various financial and fiscal incentives, and cooperation with the European Union on non-renewable and renewable energy (Amri 2017).

III.2.3. Energy consumption in the residential sector

Worldwide, the increase in energy consumption is linked to population growth and mainly concerns the residential sector. At the same time, this growth puts increasing pressure on environmental pollution. Therefore, the residential energy sector can play a crucial role in reducing CO2 emissions, as it has a significant potential for energy savings. Today, thanks to several research studies, the residential energy sector has become essential to undertake rapid emission reductions (Nejat, Jomehzadeh et al. 2015, Pablo-Romero, P et al. 2017). This is explained by the fact that it accounts for about 21% of global energy consumption and 17% of global CO2 emissions (IEA 2019) and therefore has significant direct effects on the global environment. Thus, this energy sector has a vital role in responding to climate change in the main place where this issue is posed - cities.

In Algeria, the analysis of final energy consumption by sector shows that the residential sector is the largest consumer in the country, with 33% of total energy consumption, compared to the industry, transport sectors and including losses. According to the national energy balance for 2020, the final energy consumption of this sector amounts to 18,140 K toe, followed by the transport sector with a value of 15,405 K toe. Between 2010 and 2020, natural gas and electricity consumption increased from 4 346 (million m^3) and 11 757 (GWh) to 10 974 (million m^3) and 2 653 (GWh), respectively (Ministry of energy 2010, Ministry of energy 2020).
Regarding the link between the type of housing and energy consumption, one study from 2012 shows that in the residential sector, individual houses are the biggest consumers with a share of 95% against 5% for collective houses (figure III- 4) (Latreche and Sriti 2018).

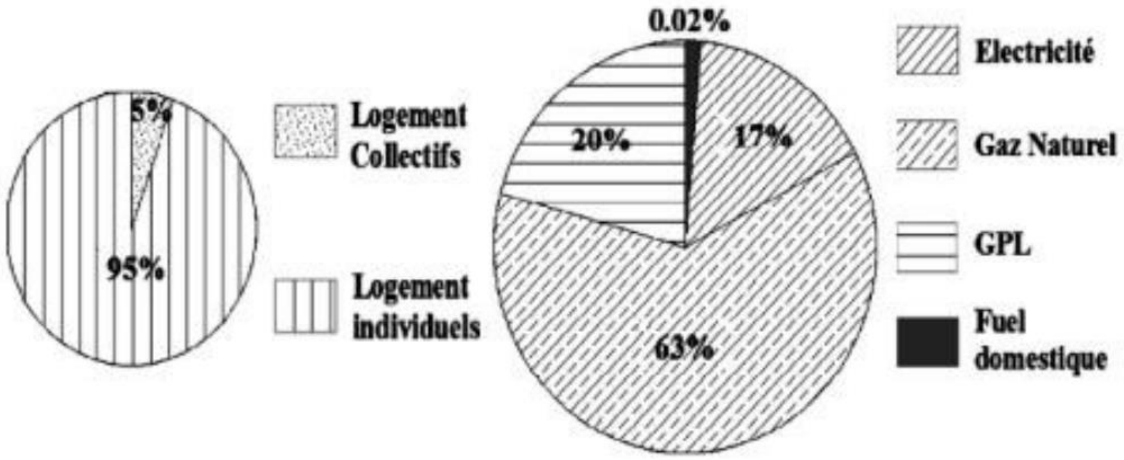


Figure III- 4. Distribution of residential energy consumption by energy and housing types in 2012.

Source: Latreche and Sriti 2018.

According to a prospective study by Ghedamsi et al, the total energy consumption of the Algerian residential sector will increase from 73 TWh in 2008 to 180 TWh in 2040, which represents an increase of 147% in energy demand in about 30 years (Ghedamsi, Settou et al. 2016). Moreover, the Algerian housing stock was estimated at 7.3 million housing in 2011 and 30% of them were built before 1977. Therefore, sustainable energy consumption in Algeria is directly linked to the improvement of the thermal performance of its existing and future housing stock. Then, more efficient housing stock requires not only the construction of low-energy buildings, but also the development of renovation solutions to reduce the energy needs of existing buildings (Kerfah, El Hassar et al. 2020).

III.3. Regulations and energy policy framework in Algeria

Over the last two decades, in order to provide global and sustainable solutions to environmental challenges and to the problems of preserving fossil energy resources, Algeria has initiated a green energy dynamic and has engaged in renewable energies. Its commitment is marked by the launch of an ambitious renewable energy and energy efficiency programme.

The following sections discuss the policy statements and commitment to sustainable energy improvement at national level.

III.3.1. Algerian Thermal Building Regulations (DTR C3-2 et 3-4)

In recent years, the Algerian government has adopted a policy to improve the management of energy resources. This policy is defined by law N°99-09 of 28 July 1999 relating to energy management and its application texts, including executive decree N°2000-90 of 24 April 2000 on thermal regulations for new buildings. In 1999, the Ministry of Housing and Urban Planning developed the first Algerian energy code for buildings. This document, which is presented in the form of two fascicles: one for winter DTR C3.2 and a second for summer DTR C3.4, aimed to reduce energy consumption for heating by at least 30% (DTR-C3.2 1997, Imessad, Kharchi et al. 2017).

After 16 years, an updated version of this regulation has been produced (DTR-C3.4 2016), containing the following main changes:

1. Consolidation of the two sets of regulations into one document.
2. Strengthening of the requirements.
3. Definition of a new zoning.

The DTR C3.2/4 is the current Algerian thermal regulation guide, however, the verification of a building's compliance with the DTR C3.2/4 must be done for the winter period and the summer period independently.

Verification of winter period

The DTR specifies that during the heating period, the heat losses by transmission through the walls must be lower than a reference value, which is defined in the following equation.

$D_T \leq 1.05\ D_{ref}$

$D_{ref} = a.\ S1 + b.S2 + c.S3 + d.S4 + e.S5$

a, b, c, d and e represent the heat transfer coefficients of the different walls (roof, floor, walls, door and windows respectively). S1, S2, S3, S4 and S5 represent the surface area of these walls (Imessad, Kharchi et al. 2017).

Verification of summer period

For the summer period, the heat gain through the opaque (APO) and glazed (AV) walls calculated at 15:00 in July (considered to be the hottest month of the year) must be below a limit called the Reference Heat Gain (RHG) (Imessad, Kharchi et al. 2017).

In terms of simulation and methods that facilitate energy calculations in buildings, the Algerian thermal regulation is accompanied by an application called RETA - Reglementation Thermique Algérienne. It is a free online graphical interface accessible via the web address (reta.cder.dz). The inputs of this software present the different components of a building, then the tool allows to perform the necessary thermal calculations in order to verify the conformity of the project with the thermal regulations (DTR C3-2 and DTR C3-4). Also, the user can dimension a heating system according to the thermal comfort requirements of the room (Imessad, Kharchi et al. 2017).

III.3.2. Energy efficiency development program to 2030

The law relating to energy management of 28 July 1999 presents the first guidelines for the framework and implementation of the national energy management policy, with regard to the design, development and implementation of energy management programs and actions, which must be carried out in consultation with the policy-makers in the sectors of activity such as companies in industry and the tertiary sector, building constructors, manufacturers, importers and sellers of equipment, local authorities and consumers. Following the guidelines of this law, the main lines of the national strategy for energy management were adopted in 2003. This strategy specifies the articulation of the institutional system aimed at ensuring a coherent implementation and an optimal use of the main instruments set up by the public power in favor of energy management, namely, the National Energy Management Program (PNME), the National Fund for Energy Conservation (FNME), the Intersectoral Committee for Energy Management (CIME), and the National Agency for the Promotion and Rationalization of the Use of Energy (APRUE)(Aprue2 2016) (figure III- 5).

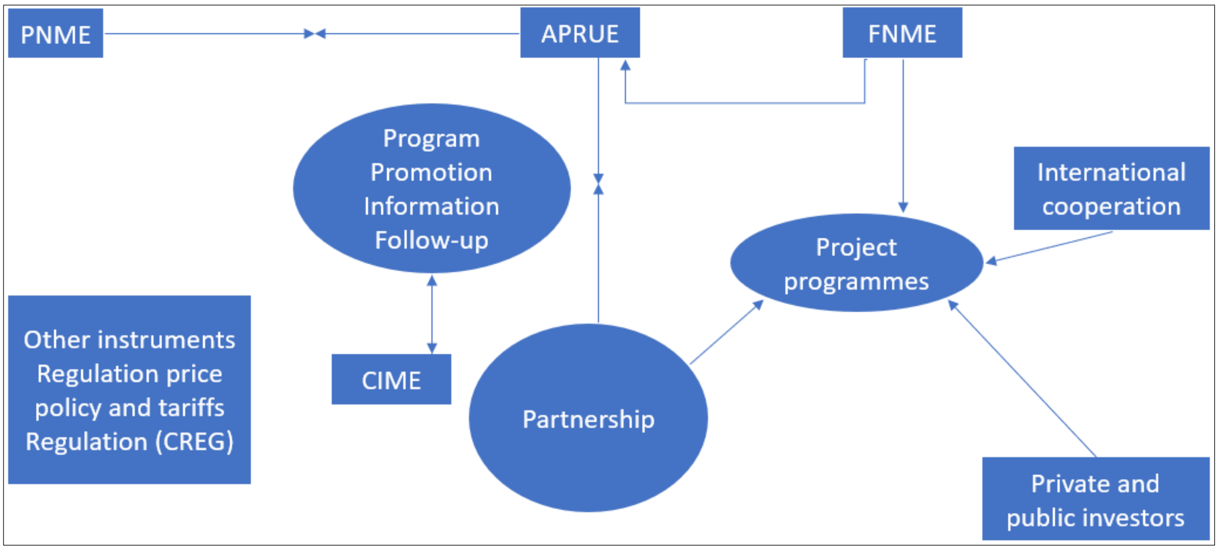


Figure III- 5. Scheme of the implementation of the NMEP 2007 /2011.

Source: APRUE 2011.

III.3.2.1. Main instruments in energy management and their interventions

III.3.2.1.1. The National Energy Management Program (PNME)

According to Article 2 of the Executive Decree n° 04-149 of 29 Rabie El Aouel 1425 corresponding to May 19, 2004, fixing the methods of development of the national program of energy management (PNME), this program constitutes the framework of implementation of the energy management at the national level. It is established under the responsibility of the minister in charge of energy and approved by the Government. It includes:

- The framework and perspectives of energy management.
- The evaluation of the potential and the definition of the objectives of energy management.
- The existing and future means of action to achieve the long-term objectives.
- A five-year action program (2004) (Aprue2 2016).

III.3.2.1.2. The National Fund for Energy Management (FNME)

The National Fund for Energy Management (FNME), approved by the Minister of Energy, is the specific public instrument for financial incentives for the energy management policy. The modalities of their monitoring and evaluation have been fixed by an inter-ministerial decree published in the Official Journal No. 19. Its aim is to promote the continuity of the means of energy policy, which is fed by an assigned tax and therefore independent of the State budget (Aprue2 2016).

FNME funding is admissible for the following areas:

Regulatory and institutional energy management supervision.

Education and sensitization in energy saving.

Development of research related to energy efficiency projects.

Discussion of implementation plans for long-term national energy efficiency strategies.

Assistance to operations aimed at improving energy efficiency through new energy technologies.

The activities of the institutions in charge of energy management promotion and coordination.

III.3.2.1.3. The Intersectoral Committee for Energy Management (CIME)

The Intersectoral Committee for Energy Management (CIME) is an advisory body to the Minister of Energy. It brings together energy management partners and facilitates consultation and development with and between public/private partners, making energy management a shared domain. It provides opinions on:

- The question of the evolution of the energy management policy and the means devoted to it,
- The work of developing, implementing, and monitoring the National Energy Management Program.

The CIME is made up of:

- A representative of the Ministries of the Interior, Finance, Energy, Environment, Industry, Housing and Urban Planning, Public Works, Transport, Agriculture, Trade, SMEs and SMIs, Water Resources, Higher Education and Scientific Research, National Education and Local Authorities national education and local authorities,
- A representative of the national chamber of commerce and industry A representative of the National Chamber of Commerce and Industry,
- Four (4) researchers representing universities and engineering Four (4) researchers representing universities and engineering schools,
- A representative of SONATRACH,
- A representative of SONELGAZ,
- A representative of the authority in charge of planning,
- The Director General of APRUE,
- Representatives of associations for the protection of the environment of the environment, consumers, the press club of energy, financing bodies energy press club, financing bodies, companies from the industry, energy sectors and any organization that can contribute to the that can contribute to energy management. energy management (Aprue2 2016).

III.3.2.1.4. The National Agency for the Promotion and Rationalization of the Use of Energy (APRUE)

The National Agency for the Promotion and Rationalization of Energy Use (APRUE) is an Algerian public industrial and commercial institution, created by presidential decree in 1985 and placed under the supervision of the Ministry of Energy and Mines.

According to the law n° 99- 09 of 28 July 1999 on energy management, the agency's task is explained by:

- The coordination and animation of the national policy of energy management.
- The implementation and monitoring of the National Energy Management Program (PNME).
- Raising awareness and disseminating information on energy management to different target groups (public, professionals, schools, etc.).
- Setting up sectoral programs and projects in partnership with the sectors concerned (industry, construction, transport, etc.).

APRUE represents an essential body in the orientations of the energy policy envisaged at the national level, which is translated into publications that dictate and show guidelines in terms of energy efficiency. Among these notable scientific publications, the following can be cited: Final Energy Consumption of Algeria - Key Figures: 2017, For an Eco-Energy Construction in Algeria, Methodological Guide of the Energy Audit, Guide of the Industrial Energy Audit Methodology EPS (Energy Potential Scan), and Guide on how to develop an action plan for sustainable energy (PAED) in local communities.

APRUE has also developed energy management and efficiency programs in the industrial and building sectors. In the building sector, one can distinguish the Eco-Bat, Eco-Lumiere, and Alsol programs.

a) Eco-BAT

As the building sector accounts for a large share of final energy consumption in Algeria, and with the aim of the need for energy efficiency measures in the building sector, the Agency for the Promotion and Rationalisation of Energy Use (APRUE) has initiated a program called "Eco-Bat" which will affect several wilayas and aims to gradually integrate energy efficiency measures in this sector, as well as specifically to the real evaluation of energy gains obtained by houses built according to energy efficiency standards and will proceed, in each region, to the comparison of housing having benefited from energy efficiency measures to the others.

In addition, the programme plays an essential role in mobilising the building industry around the energy efficiency dimension, in carrying out a demonstrative action proving the feasibility of introducing energy efficiency in Algeria, in contributing to the generalisation of good practices in the architectural design of housing and, finally, in promoting the application of regulatory standards. In the future, it aims to target a large majority of the Algerian housing stock (Bouamama 2013, APRUE 2019).

This programme has been reflected in the field by two projects:

The Eco-Bat1 project, which involves providing financial and technical support for the construction of 600 homes to optimise interior comfort by reducing energy consumption for heating and air conditioning.

And the Eco-Bat2 project, which consists of the insulation of 5,000 homes/year via support for 80% of the cost of insulation (wall, roof, double glazing) (Kamel DALI 2017).

III.3.3. Renewable energy and energy efficiency

Algeria, as a country committed to sustainable development, has embarked on a new era of energy in order to provide global and sustainable solutions to environmental challenges and the problems of preserving fossil energy resources. This is reflected in the launch of an ambitious program for the development of renewable energy, which was adopted by the government in February 2011, revised in May 2015 and made a national priority in February 2016. The adopted renewable energy program consists of installing around 22,000 MW of renewable energy capacity by 2030 for the domestic market, with the option of export as a strategic objective, market conditions permitting.

III.3.3.1. Renewable energy potential in Algeria

As regards the geographical location and the large area of Algeria, the country has a variation of climate, from north to south; mediterranean, cold semi-arid, hot semi-arid, cold desert, hot desert. This shows that the country has many advantages in terms of using renewable energy systems. This section deals with the potential of renewable energy in Algeria by giving an overview of renewable energy resources such as solar energy, wind energy, hydroelectricity, geothermal energy, and biomass (Himri, Malik et al. 2009).

III.3.3.1.1. Solar energy

Algeria has one of the highest solar potentials in the world. The duration of insolation over almost the entire national territory exceeds 2000 hours annually and can reach 3900 hours particularly in the Saharan region.

The energy received annually on a horizontal surface of 1m² is close to 3 KWh/m² in the North and exceeds 5.6 KWh/m² in the Deep South, which is suitable for solar energy applications like photovoltaic (Grid-connected, electrification of villages, water pumping.) or Concentrated Solar Power (CSP)(Stambouli 2011, Achour, Bouharkat et al. 2018). Figure III-6 and table III-2 show the details of this interesting potential.

Table III- 2. Solar potential in Algeria.

Source: Stambouli 2011.

Areas	Coastal area	High plains	Sahara
Surface (%)	4	10	86
Area (km2)	95.27	238.174	2.048.297
Mean daily sunshine duration (h)	7.26	8.22	9.59
Average duration of sunshine (h/year)	2650	3000	3500
Received average energy (kWh/m2 /year)	1700	1900	2650
Solar daily energy density (kWh/m2)	4.66	5.21	7.26

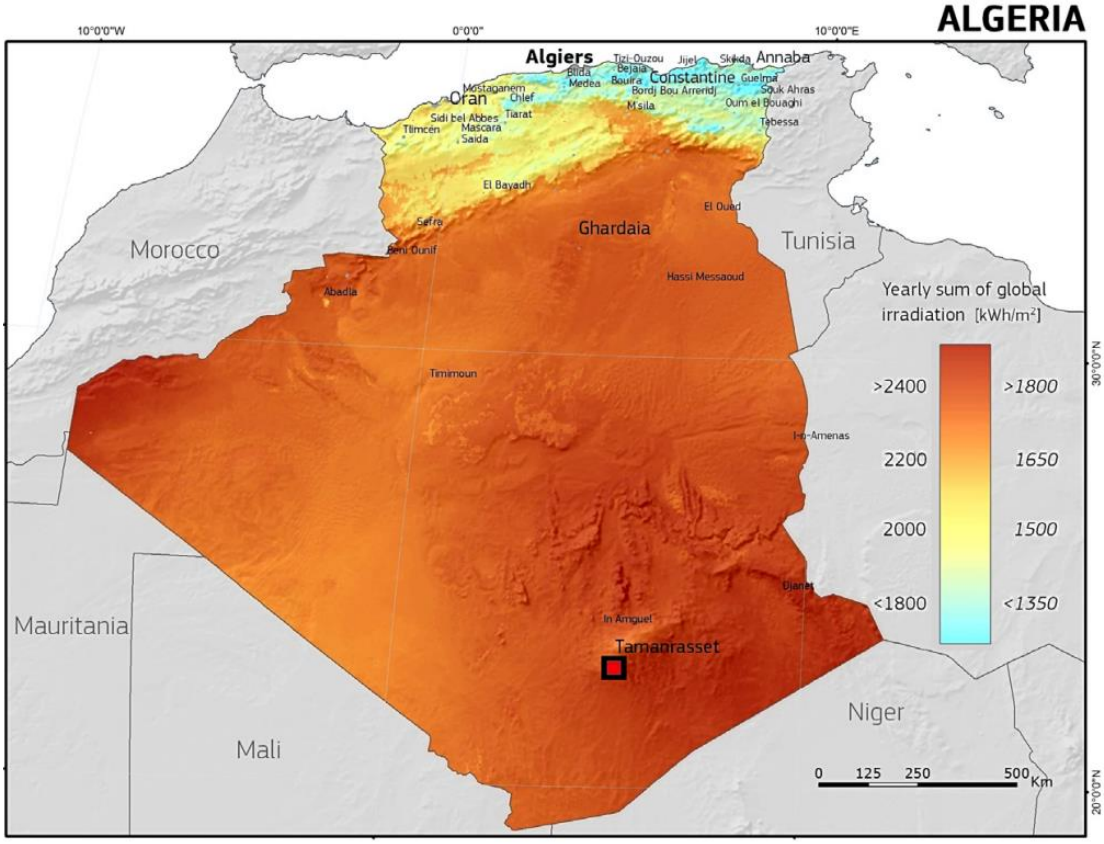


Figure III- 6. Solar potential in Algeria.

Source : Achour, Bouharkat et al. 2018.

III.3.3.1.2. Wind energy

Algeria is featured by a variation of the wind resource on the whole of its territory differs from one place to another (figure III- 7). Nearly 78% of Algeria's surface is characterized by wind speeds above 3 m/s with about 40% of these speeds exceeding 5 m/s, while the southern region is characterized by higher speeds (above 6 m/s) than the north (Bouraiou, Necaibia et al. 2020). A study by (Himri, Rehman et al. 2008) shows that wind farms with an installed capacity of 30 MW can be installed in Adrar, Timimoun and Tindouf, which if built can produce 98,832, 78,138 and 56,040 MWh of electricity per year. Another study assessed the wind power potential for five sites in Algeria using nine types of small and medium-sized wind turbines from five manufacturers. Most of these turbines can produce about 1,000-10,000 MWh of electricity per year at 60 m altitude and can easily meet the electricity needs for irrigation and domestic applications in rustic and arid regions (Ettoumi, Benzaoui et al. 2008). These results show that the country, and in particular the southwestern Sahara, is a favorable location for the use of wind energy, such as wind farms or hybrid systems.

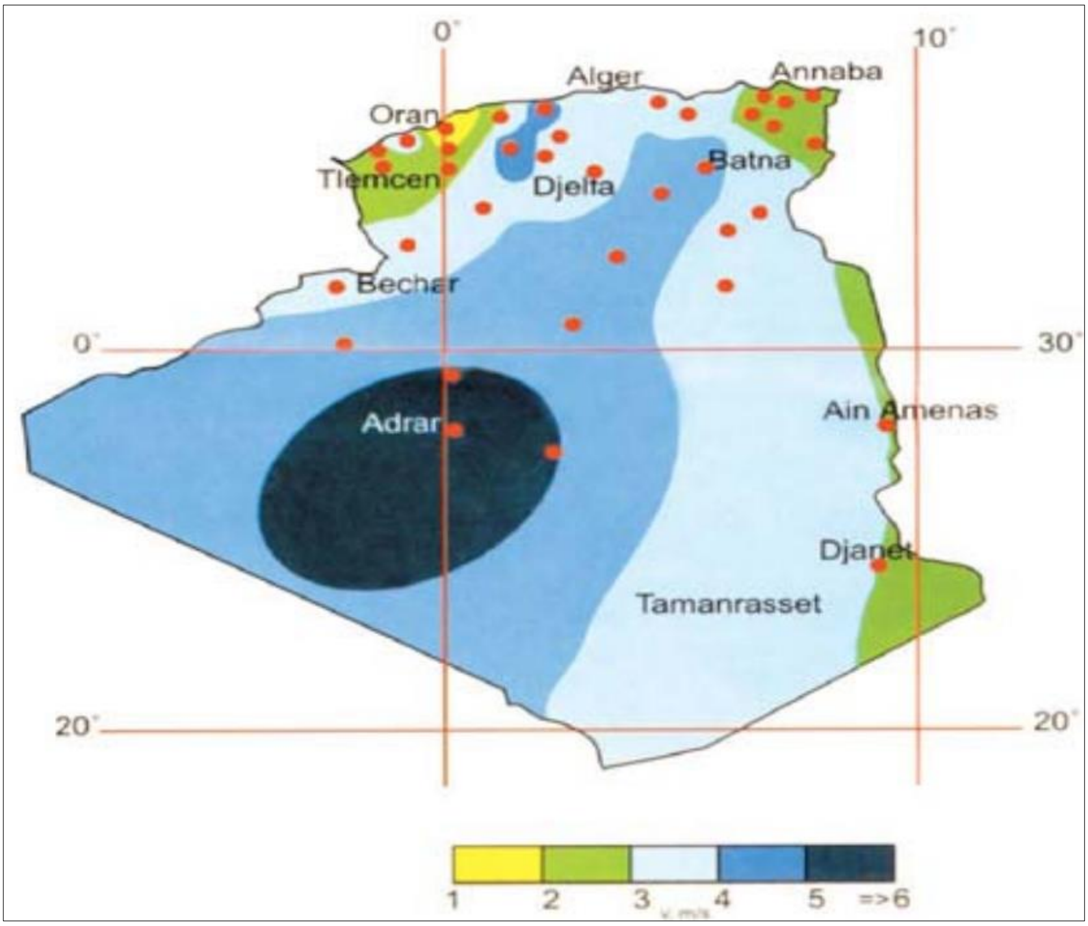


Figure III- 7. Wind chart of Algeria.

Source: Stambouli 2011.

III.3.3.1.3. Hydroelectricity

The overall amount of precipitation falling on the Algerian territory is estimated at 65 billion m^3, which is considered important, but its usefulness is considered low, mainly to produce hydroelectric energy, due to the concentration of rainfall in a limited area, limited rainy days, and high evaporation and rapid evacuation to the sea. Presently, the assessment of useful and renewable energy is about 25 billion cubic meters, of which about 2/3 are surface resources (Bouraiou, Necaibia et al. 2020).

103 sites of dams have been identified. More than 50 dams are currently operational. The share of these small-scale generation sites is about 5% and complements the generation of electricity from natural gas. The total capacity of 13 of them is 269,208 MW as shown in Table 8. The estimated total installed capacity of hydropower is 270 MW as detailed in Table III- 3, accounting for just 1% of total electricity generation (Stambouli 2011).

Table III- 3. Hydropower installed in Algeria.

Source: Hamiche, Stambouli et al. 2015.

Hydropower plant	Installed capacity
Darguina	71.5
Ighil Emda	24
Mansouria	100
Erraguene	16
Souk El Djemaa	8.085
Tizi Meden	4.458
Ighzernchebel	2.712
Ghrib	7.000
Gouriet	6.425
Bouhanifia	5.700
Oued Fodda	15.600
Beni Behde	3.500
Tessala	4.228
Total	269.208

III.3.3.1.4. Geothermal energy

Regarding geothermal energy in Algeria, studies reveal that existing geothermal resources such as thermal springs and wells are only used for space heating. Over the entire surface of the country, more than two hundred (200) thermal springs have been inventoried in the northern part, about one third (33%) of which have temperatures above 45 °C. The highest temperatures recorded are 98 °C in the Guelma province at Hammam El Maskhoutin and 118 °C in the Biskra province. The Albian sandstone reservoir in southern Algeria has an average water temperature of 57 °C. There are non-electrical applications of geothermal heat, however a project has been considered for the installation of a small power plant in the Bouhadjar area, eastern Algeria (Stambouli 2011, Bouraiou, Necaibia et al. 2020).

III.3.3.1.5. Biomass

In Algeria, the biomass potential is 3.7 MTOE from forests and 1.33 MTOE per year from agricultural and urban waste, which are adequate to produce biomass energy, but this potential is not yet exploited and used (Himri, Malik et al. 2009).

Biomass can be burned directly or converted into solid, gaseous, and liquid fuels using conversion technologies such as fermentation to produce alcohols, bacterial digestion to produce biogas and gasification to produce a substitute for natural gas. Numerous studies have shown that biomass in Algeria can be used to meet a variety of energy needs, including electricity generation, residential heating, and process heat for facilities (Himri, Malik et al. 2009). Bennouna and Kehal highlight the role of wastewater treatment plants and the potential they may have for biogas production in Algeria (Bennouna and Kehal 2001). Kaidi and Touzi suggest producing ethyl alcohol from date waste rich in fermentable sugars (60%) (Kaidi and Touzi 2001). A prospective study shows the feasibility of producing electricity by 2 MW modals that can reach a peak of 6 MW from the Oued Smar dump in Algiers (Hattabi 2004).

III.3.3.2. Algerian renewable energy development programme

At the stage of this renewable energy programme, the Algerian state aims not only to exploit efficiently these renewable energy resources, citing the photovoltaic and wind energy sectors by integrating biomass, cogeneration, geothermal energy and, beyond 2021, solar thermal energy, in order to make up for the energy deficit, but also to move towards a sustainable reflection of the environment, to boost a new model of economic growth, and to become a major player in the production of clean energy in the medium and long term.

The plan aims to achieve 37% of installed capacity by 2030 and 27% of electricity production for national consumption will be of renewable origin.

Knowing that the national potential in renewable energies is strongly dominated by solar energy, the latter is considered the great fruit of renewable sources, and which will be a lever for economic and social development, particularly through the establishment of industries that create wealth and jobs.

The renewable energy programme is marked by phase of realisation and type of energy during the period 2015 to 2030.

First phase 2015 - 2020: This phase includes the realisation of a power of 4010 MW, between photovoltaic and wind, as well as 515 MW, between biomass, cogeneration and geothermal.

Second phase 2021 - 2030: Continuing the first phase and following the development of the electrical interconnection between the North and the Sahara, which will allow the installation of large renewable energy plants in the regions of In Salah, Adrar, Timimoune and Bechar and their integration in the national energy system (Ministry of energy n, d).

Table III- 4 illustrates the structure of the programme by type of energy and by phase of completion.

Table III- 4. Algerian national renewable energy development program over 2015-2030

Source: Ministry of energy n, d.

Unit : MW	1st phase 2015e2020	2nd phase 2021e2030	TOTAL
Photovoltaic	3 000	10 575	13 575
Wind	1 010	4 000	5 010
CSP	-	2000	2 000
Cogeneration	150	250	400
Biomass	360	640	1 000
Geothermal	5	10	15
TOTAL	4 525	17 475	22 000

In this programme, Algeria also aims to develop a real renewable energy industry associated with a training and knowledge capitalisation project, which will eventually allow the use of local Algerian engineering and project managers. From a global point of view, the programme will be a great opportunity for the economic (creation of several thousand direct and indirect jobs) and environmental sectors.

III.3.3.3. National Energy Efficiency Program

the Algerian government has adopted a new national energy efficiency program (2016-2030) in order to mitigate the strong growth in consumption driven, in particular, by the domestic sector with the construction of new housing, the construction of public utility infrastructure and the revival of industry.

2.1.1.1.Energy Efficiency Action Plan

This programme has been mapped out by an action plan to have a good implementation of the programme, the plan is intended for different sectors that have a significant impact on energy demand, mainly building, transport and industry (Ministry of energy n, d).

a) Building sector

Given that the building sector is the largest energy consumer in the country, the energy efficiency programme aims to encourage the implementation of innovative practices and technologies around the thermal insulation of existing and new buildings. Also, the availability of efficient equipment and appliances on the local market to users, notably solar water heaters and energy saving lamps: the objective being to improve the indoor comfort of housing by using less energy.

The programme seeks to save more than 30 million TOE by 2030, distributed as follows:

- Thermal insulation: the objective is to reach a cumulative gain evaluated at more than 7 million TOE.
- Solar water heating: the objective is to achieve energy savings of more than 2 million TOE;
- Low-energy light bulbs (LBC): the expected energy savings by 2030 are estimated at nearly 20 million TOE.
- Public lighting: the objective is to achieve energy savings of nearly one million TOE by 2030 and to reduce the energy bill of communities.

b) Transport sector

In this sector, the programme is intended to promote the most available and least polluting fuels, namely LPG and NG, the objective being to improve the structure of the fuel offer and to contribute to reducing the share of diesel, in addition to the beneficial effects on health and the environment. This would result in a saving of more than 16 million TOE by 2030.

c) Industrial sector

Energy efficiency is applied to energy sobriety in this sector targeting the mode and type of industrial production. For this sector, more than 30 million TOE will be saved via:

- The generalised use of energy audits and control of industrial processes which will make it possible to identify substantial energy saving potentials and to recommend corrective action plans.
- The promotion of operations to reduce the over-consumption of industrial processes, through State support for the financing of these operations (CDER 2015, Ministry of energy n, d).

III.4. Energy improvement studies in the residential sector in Algeria

First, taking a regard on the use of renewable energies in the housing sector, the application remains timid and limited. In all cities of the country, almost all the houses are supplied by the grid, with a few exceptions in the case of owners and in certain projects such as Rural electrification by solar PV in the Algerian south, this project concerns about 906 houses in eighteen (18) villages in the great south (provinces of Adrar, Illizi, Tindouf and Tamanrasset) (Bouraiou, Necaibia et al. 2020).

Opening the discussion on the studies carried out in the field of energy improvement in the residential sector, it is interesting to mention first of all that Algeria has several climates. The National Centre for Integrated Building Studies and Research (CNERIB) and the thermal regulation (DTR C3- 2) for residential buildings define six different climate zones in Algeria Zone (A): in the north of Algeria, comprising the coastal zone; Zone (B): which lies to the south of Zone (A), including the plain behind the coastal area; Zone (C): which lies to the south of Zone (B), covering the highlands; Zone (D): which lies to the south of Algeria, covering the desert; and climatic zones (B′) and (D′), which comprise sub-zones within the main zones (B) and (D), respectively (DTR-C3.2 1997). This climatic diversity has therefore led to a number of research and studies that take into account very different case studies on energy improvement in the residential sector.

These energy improvement studies can be limited to the study of factors (such microclimate and shape of buildings) influencing energy demand and consumption status in housing case studies (Semache, Hamidat et al. 2015, Missoum, Hamidat et al. 2016, Tibermacine and Zemmouri 2017, Maachi, Mokhtari et al. 2019, Kerfah, El Hassar et al. 2020, Afaifia, Djiar et al. 2021, Kaihoul, Sriti et al. 2021, Kaihoul, Sriti et al. 2021), in addition, they can be further extended to studied the application of renewable energies such as photovoltaic or solar thermal collectors (Missoum, Hamidat et al. 2014, Maouedj, Mammeri et al. 2015, Sami-Mecheri, Semmar et al. 2015, Laib, Hamidat et al. 2018, Sami, Semmar et al. 2018, Mokhtara, Negrou et al. 2021). Moreover, many studies in this field have used the concept of optimisation in various manners (thermal insulation, algorithms, design ....) to reduce energy consumption in housing (Ali-Toudert and Weidhaus 2017, Derradji, Imessad et al. 2017, Imessad, Kharchi et al. 2017, Moussaoui, Cherrared et al. 2018, Boukli Hacene, Chabane Sari et al. 2020, Amraoui, Sriti et al. 2021).

In addition, it is worth mentioning a predictive study by (Ghedamsi, Settou et al. 2016) which tends to model and forecast energy consumption in the Algerian residential sector, this study used a bottom-up approach where the results show that final energy consumption has increased from 73.23 TWh in 2008 to 179.78 TWh in 2040, while cooking, heating and hot water are the main energy consumers in the Algerian residential sector.

III.5. The recent national energy improvement situation and realization

The current proportion of renewables is not very significant in the total energy balance, but in recent years an ambitious development programme has been put in place, with specific laws and decrees to use renewable energies to produce electricity. In the total territory of Algeria, natural gas and electricity consumption are the most demanded energies, for natural gas, the country has a large reserve of this resource and its replacement by renewable energies is not very targeted, unlike electricity where this energy is intended to be produced in a renewable way (Bouraiou, Necaibia et al. 2020). Table III- 5 provides an overview of the evolution of electricity production in recent years.

Table III- 5. Evolution of the renewable and conventional produced electricity energy (1980-2018)

Source: Bouraiou, Necaibia et al. 2020.

Production by type of equipment	Steam Turbine	Gas Turbine	Combined Cycle	Hydraulic	Diesel	Wind	Photovoltaic	Total (GWh)
1980	3621	2223	_	251	125	_	_	6220
1990	8397	6704	_	135	216	_	_	15452
2005	16624	15679	386	555	281	_	_	33525
2006	14558	16463	3419	218	264	_	_	34922
2007	14142	17011	5321	226	250	_	_	36950
2008	13384	20339	5704	277	283	_	_	39987
2009	11857	19940	10318	342	313	_	_	42770
2010	9692	19564	15341	173	403	_	_	45173
2011	9654	22055	15701	378	464	_	_	48252
2012	9422	24075	18623	389	416	_	_	52925
2013	9582	17400	27685	98	227	_	_	54992
2014	10221	20211	28444	193	248	1	1	59319
2015	10227	26970	26122	145	276	19	14	63773
2016	11511	24441	29664	72	281	264		70997
2017	9992	30752	29204	56	314	579		76017
2018	10682	36580	28244	117	374	666		76663

The realization in terms of renewable energy project is mainly in the central and southern part of the country, as the Society of Electricity and Renewable Energy (SKTM) is responsible for renewable energy plants, this company manages several projects, one of them is grid-connected plants based on renewable energy, this project has been realized, table III- 6 presents its details (23 PV plants and 01 wind farm), it aims to produce energy from its commissioning date to June 2017 (Bakir 2017). There is also a remarkable achievement in Bir Rebaa (province of Ouargla), where a new 10 MW photovoltaic power plant made up of 31,320 photovoltaic panels spread over an area of 20 ha was inaugurated in November 2018. This project was established in the framework of a partnership between the Algerian and Italian oil companies Sonatrach and Eni (Bouraiou, Necaibia et al. 2020).

Table III- 6. The installed capacity and produced energy from the date of commissioning to June 2017.

Source: Bouraiou, Necaibia et al. 2020.

Central		Surface (Hectare)	Installed capacity (MW)	Production at June 2017 (GWH)	date of commissioning
Location	Province				
			PIAT		
Kabertene (Wind)	Adrar	33	10.2	51.579	2014
Adrar city	Adrar	40	20	59.585	2015
Kabertene (PV)	Adrar	6	3	9.584	2015
In Salah	Tamanrasset	10	5	12.328	2016
Timimoune	Adrar	18	9	23.8222	2016
Reggan	Adrar	10	5	12.221	2016
Zaouiat Kounta	Adrar	12	6	15.213	2016
Aoulef	Adrar	10	5	12.557	2016
			RIS		
Tamnrasset	Tamnrasset	26	13	36.410	2015
Djanet	Illizi	6	3	10.729	2015
Tindouf	Tindouf	18	9	6.376	2015
			RIN		
Oued Nechou PV	Ghardaia	5	1.1	4.593	2014
Serdret Leghzel	Naama	32	20	40.715	2016
Oued El Kebrit	Souk Ahras	20	15	28.900	2016
Ain Skhouna	Saida	60	30	14.213	2016
Ain El Bel 1 and 2	Djelfa	120	53	25.134	2016 and 2017
Telagh	Sidi Bel Abbes	30	12	7.417	2016

Lekhneg 1 and 2	Laghouat	120	60	53,576	2016 and 2017
Labioh Sidi chikh	El Bayadh	40	23	19.146	2016
El Hadjira	Ouargla	60	30	9.738	2017
Ain El Melh	M’Sila	40	20	16.473	2017
Oued El Ma	Batna		2		2017
Total SKTM (RE)		354.3		470.318	

According to the dataset, the first construction of RE-based power plants (PV and wind managed by SKTM) started in 2014. The generation capacity from this year increased from 1.1 MW to 354.3 MW in 2018 (PV: 344.1 MW and wind: 10.2 MW). As for wind power, the only wind farm was built in the province of Adrar in 2014 and can produce 10.2 MW. The capacity of hydroelectric power is not significant with a production of 228 MW since 2008. With regard to concentrated central solar power, there is a 150 MW hybrid solar power plant in Hassi R'Mel (Laghouat province), of which 25 MW is solar thermal (CSP), commissioned in July 2011. In addition, another 10 MW photovoltaic plant was installed in 2018 and is managed by GSA. The geothermal energy is not used for energy production actually and is considered only to be used for heating the thermals. Therefore, in terms of national achievements in renewable energy, the state and progress are low and need more impetus (Bouraiou, Necaibia et al. 2020).

With regard to the implementation report of the first phase of the National Energy Efficiency Programme (Ministry of energy n, d), the State has completed the following projects:

- Thermal insulation of 600 new homes: 160 homes.
- Thermal insulation of existing buildings: thermal insulation of 620 m².
- Installation of individual and collective thermal water heaters: 407 units.
- Replacement of mercury lamps with sodium lamps "Public lighting": 10,000 lamps.
- Conversion of passenger cars (PCs) to LPGc: 9,100 kits converted.
- Installation of LPGc kits for vehicles in captive fleets: 48 kits were installed.
- Feasibility studies: 08 studies were carried out.
- Energy audits: 33 operations were carried out.
- Investment grants: 18 operations were carried out.

Today a new boost is given to this axis, in June 23, 2020 the state has created the Ministry of Energy Transition and Renewable Energies (MTEER), this new ministry has the objective to elaborate a roadmap of the energy transition which is articulated on many axes, essentially; achieving energy savings with the first objective of gradually reaching 10% energy savings per year; implementation of the renewable energy development programme for electricity production and self-consumption; development of the national energy model; development of the national energy model; drafting of the law on energy transition (Ministere de la transition energetique et des energies renouvelables 2021). In the sphere of renewable energies, this ministry has worked to put in place the favourable technical and financial conditions for the realisation of the renewable energy development programme, the one adopted by the government in February 2020.

III.6. Conclusion

In terms of energy performance in the residential sector, until now, the corpus of legislation and regulations remains basic and elementary, this is due to the fact that, on the one hand, the application of energy efficiency strategies set are done on a small percentage of housing in comparison with the huge building stock, on the other hand, these strategies do not reflect the best energy performance expected as a key for adaptation and mitigation of climate change.

Moreover, as far as renewable energies are concerned, Algeria is in a better position to exploit these resources and achieve self-sufficiency in energy consumption. The strategies and plans fixed by the legislation and regulation in this axis are compatible to answer the energy stake, the projects carried out especially the exploitation of solar energy in the southern part are remarkable, except that the northern part of the country which knew a big energy consumption remains energy-consuming, this necessitates a clear engagement to take advantage of the renewable energetic resources of the northern part, which know a strong urbanization and a high energy demand.

Chapitre IV

Environment study

IV.1. Introduction

This chapter presents the study environment. The city of Constantine as an object of this study is presented and discussed in four sections; first, a historical overview of the city of Constantine was given to show its interesting site. Secondly, a climatic study of the city of Constantine was carried out from a global and Algerian climatic point of view, and then the climatic specificities of the city were studied. In addition, an epistemological study and a classification containing the type of habitat in the city of Constantine with examples was discussed, this chapter was further elaborated to discuss the type of individual habitat in the city.

Finally, the last part of the chapter aims to show the four selected urban residential forms in the city of Constantine as targeted case studies for the urban energy study.

IV.2. City of Constantine Object of study

IV.2.1. Presentation and historical overview of the city of Constantine

Constantine is one of the oldest cities in Africa located in the north-east of Algeria, 80 km from the Mediterranean coast with a rich and varied history, most of the archaeologists and researchers cannot yet predict a common date on the first foundation which is hard to specify the origin of the city, others suggest that its roots go back to late prehistoric times, around 3000 BC. Before, it was Cirta, the capital of the kingdom of the Numidian king Massinissa. It was then destroyed during an insurrection, then rebuilt by Constantine in 311, to whom the city owes its name (Selougha and Wilkinson 1984, ENCYCLOPEDIE de L'AFN 2006, Constantine d'hier et d'aujourd'hui 2016).

After that it was occupied by the Vandals around 431. In the Middle Ages, it was dominated by the Byzantines and several dynasties such as the Fatimids, Zirids and Almohads. Around 1521, the city lived through the arrival of the Ottomans. During this occupation, the architecture and the urban planning of the city had scientific, cultural and religious specificity, especially in the Salah Bey period 1770-1792. Today, these specificities can be found in the old medina of Constantine (Selougha and Wilkinson 1984).

In 1837 the city experienced the arrival of French colonisation, until 1962 the architecture and town planning of the city underwent notable interventions, Haussmannian town planning and modern architecture were the new characterisation of the city, but until now the city maintains its origins of Muslim civilisations in the Medina (FOUZIA 2017).

Since independence in 1962 until the beginning of 1968, the metropolis of Constantine did not encounter any major changes, after which the post-colonial and post-modern era was marked by Algerian development policies in the urban, industrial and educational sectors, such as the Great Mosque and the Emir Abdelkader University in 1976, the Mentouri Constantine University in 1969 and the ZHUN from 1975. It was during this period that urban densification began to reach its peak (Salah Chaouche 2013).

At the end of the 20th century and the beginning of the 21st century, Constantine, like other metropolises, tried to modernise itself on the urban level by extending and creating a new city, Ali Mendjli, this city ex nihilo aims to decongest the city of Constantine (Merdji 2010).

Today, Constantine is the third most densely populated city in the country, and it is known as the eastern capital of Algeria (l'Office National des Statistiques 2008), it is characterized by a rapid urbanization where a new housing and equipment programs are currently under building process. Also, on a global scale, the giant transrhumel bridge is one of the public projects and artworks that characterise the city with its futuristic design. Inaugurated in 2014, this giant viaduct with a length of 1,119 m, represents a touch of modernity in the urban configuration of Constantine (Hanifa 2017, DIABI and LAZRI 2018).

IV.2.2. Climate study

IV.2.2.1. Global and Algerian climate

Climate is the presentation of the average weather conditions at a site during a long period (30 years or more), worldwide, there are many different types of climates. The determination of the type of the climate is in important task for any physical studies, especially those related to energy on the earth. Wladimir Koppen around 1900 developed a climate classification system for the earth, which is widely used to present the climate of a site (Kottek, Grieser et al. 2006). In World Map of Köppen-Geiger climate classification (figure IV- 1) the climates are divided into five principal climate groups (*A- tropical, B- dry, C- temperate, D- continental*, and *E- polar*), subsequently, each groupe is divided based on seasonal precipitation and temperature patterns.

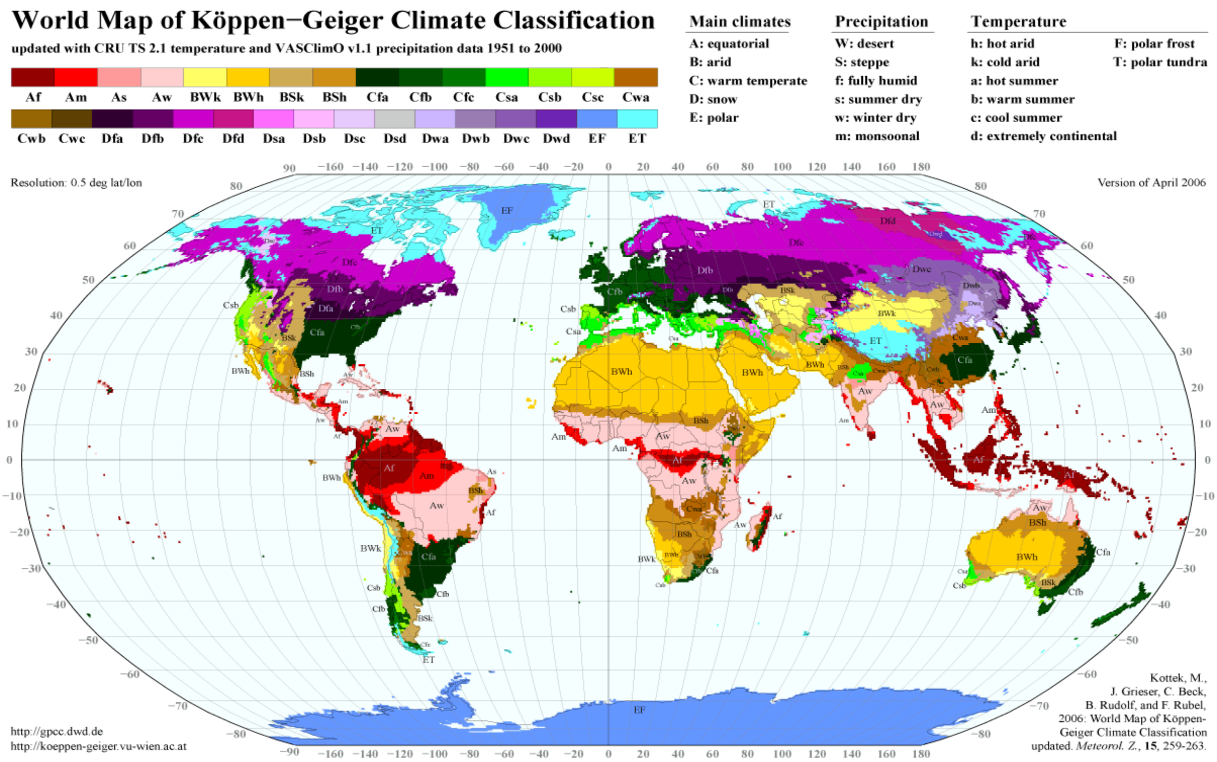


Figure IV- 1. World Map of Köppen-Geiger climate classification.

Source: Kottek, Grieser et al. 2006.

Algeria has a large surface area in North Africa and a variety of climates, on the northern fringe it is a Mediterranean climate with hot and dry summers, humid and cold winters, on the centre and the high plateaus of the country the climate is semi-arid, going southwards through the Saharan Atlas chain the climate becomes desert (Météo Algérie n,d,)

According to Koppen classification, the north part of algeria has a Csa type of climate, then a group of regions from east to west in the midelle of the country have a semi-arid climate (hot: BSk and cold: BSh). The rest of the regions in the south have a desert climate (BWh and BWk) (Kottek, Grieser et al. 2006).

IV.2.2.2. Climate study of the city of Constantine

IV.2.2.2.1. Location

Constantine is located in the north-east of Algeria (Figure IV- 2) (36.17 North and 07.23 East) with an altitude of about 694 m above sea level, this altitude varies from one point to another, it is 493 m at El-Menia the lowest bridge, it can reach 820 on the side of Jebel Ouahch. It is known as the eastern capital of Algeria located between the Tellian Atlas and Saharan Atlas mountain ranges (Benlatreche 2006, Bourbia and Boucheriba 2010).

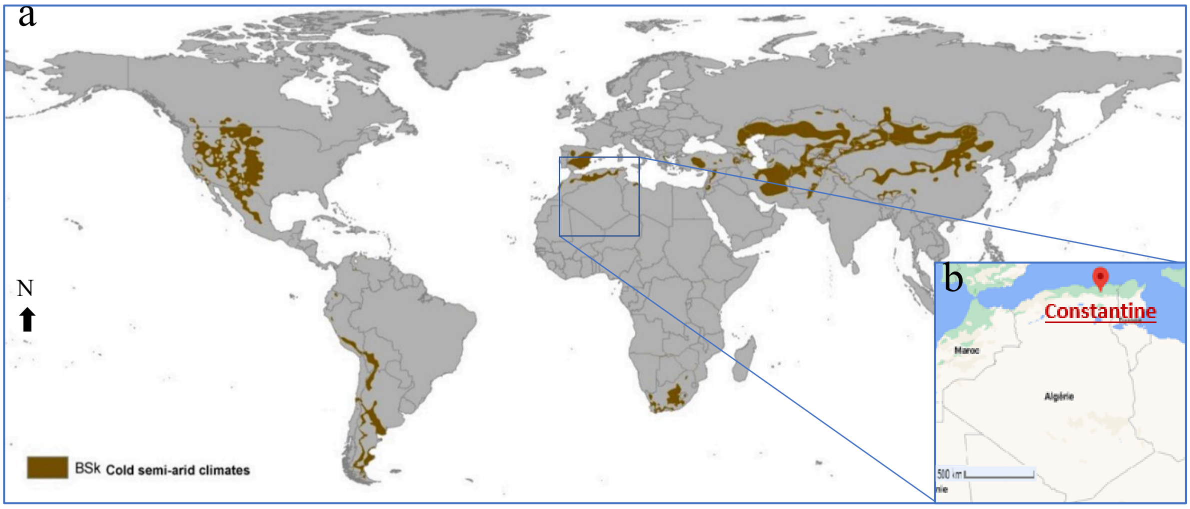


Figure IV- 2. Cold semi-arid climate regions worldwide according to Köppen World Map (a) (BSk) and the location of the city of Constantine (b).

Source: Mahar, Verbeeck et al. 2020, and Google map.

IV.2.2.2.2. Climate interpretation

The interpretation of the climatic data was done using climatic data from previous climate research on the city of Constantine (Benharkat 2006, Benlatreche 2006, Kottek, Grieser et al. 2006, Bourbia and Boucheriba 2010), on the world climate websites (GLOBAL WIND ATLAS n,d), as well as the Meteonorm software (Annex 1) Which is widely used reference weather data generator.

The city has a cold semi-arid climate, as shown in figure IV- 2, this type of climate characterizes a limited region world widely, it can be found in south Europe, north and south Africa, some big cities in Asia and north America. The city of Constantine features a cold and humid in winter, with maximum temperatures reaching 17 °C, hot and dry in summer with an average maximum temperature of 36 °C. The annual average humidity is around 67%.

IV.2.2.2.3. Air temperature :

Figure IV- 3 shows that temperatures rise and peak to reaches 40°C in July and August, which are the hottest months. Considering that April and May are comfortable periods where the average temperature is between 12 and 18°C, the period from June to September represents the hot and dry period, while the cold and wet period is from October to March.

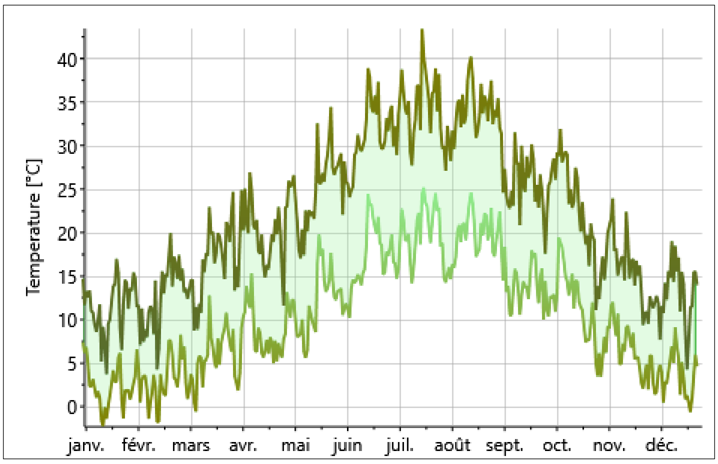


Figure IV- 3. Monthly air temperature for the city of Constantine.

Source: Meteonorm 7.

IV.2.2.2.4. Relative humidity:

The annual average humidity is around 67% and ranges from: a maximum of 80% in the month of December, January, and a of minimum of 44% in July.

IV.2.2.2.5. Precipitation

Annual rainfall amount to 500 mm, the rainiest months are: November, January and December where the rainfall reaches 60 mm (figure IV- 4).

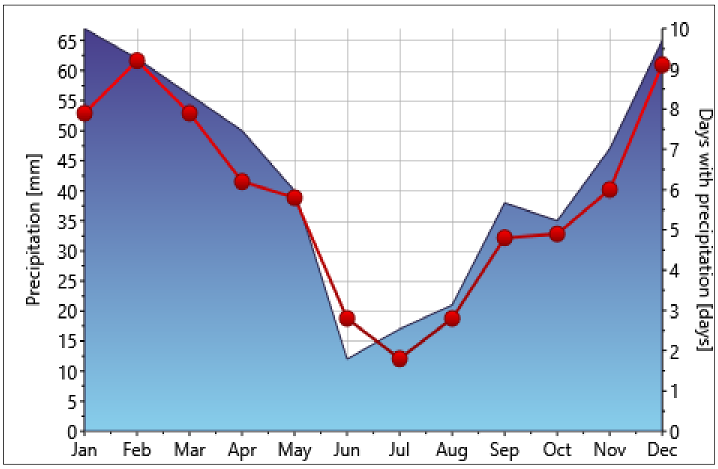


Figure IV- 4. Monthly precipitation for the city of Constantine.

Source: Meteonorm 7.

IV.2.2.2.6. Wind:

The average wind speed in Constantine varies between 2.1 and 2.5 m/s, with maximum average wind speeds recorded during the cold period, in the months of February, March and April, reaching 4 m/s at a height of 10 m during some days, while minimum values are recorded during the months of September and October. The most important wind direction in the city is from the northwest and west (figure IV- 5).

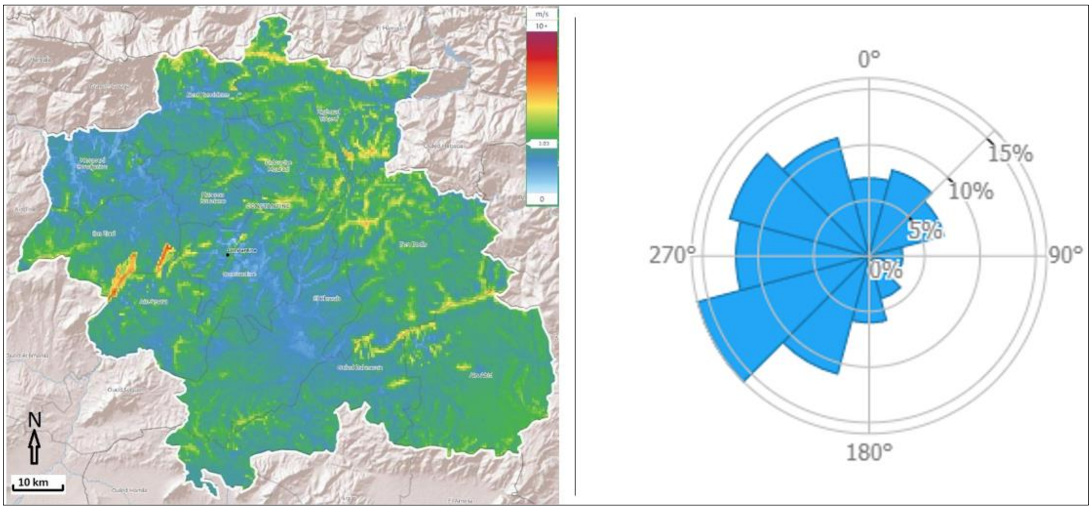


Figure IV- 5. Wind map (left) and wind speed rose (right) of the city of Constantine.

Source: GLOBAL-WIND-ATLAS.

IV.2.2.2.7. Insolation

The city has a high solar radiation intensity with long periods of sunny and clear skies during the day. In the summer months, the amount of sunshine during the year is very high, averaging 2882 hours per year, which represents one third of the year. The sunshine exceeds 10 hours per day, and in July the city receives more than 300 hours of sunshine. In winter, it varies between 5 and 6 hours, with the month of January having the least amount of sunshine with an average duration of 157 hours. As shown in figure IV- 6, global solar irradiation can exceed 7.5 Kwh/m² during the hot season and is less important during the cold season with an average of 2.5 Kwh/m².

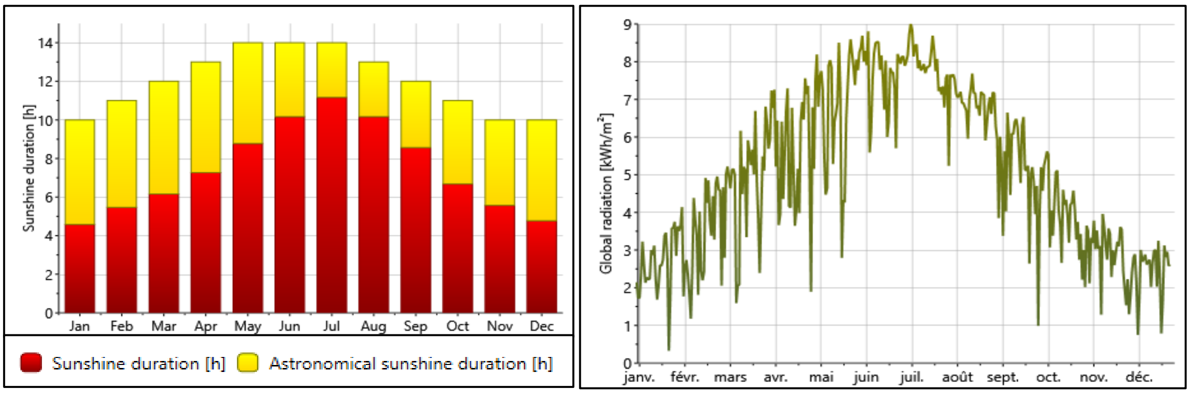


Figure IV- 6. Monthly Sunshine duration (left) and globale solar irradiation (right) for the city of Constantine.

Source : Meteonorm 7.

The variability of long and shortwave radiation over the earth is related to cloud cover and therefore affects other parameters such as the energy on the earth (Sanchez-Lorenzo, Calbó et al. 2012). Analysing Constantine, the overall luminance is higher, reaching 36 kilolux during the warm season, when the sky is clear, and the cloud cover is lower. From December, January, February to April, the cloud cover is higher, and the global luminance tends to be lower, with an average of 16 kilolux, due to the overcast sky (figure IV- 7).

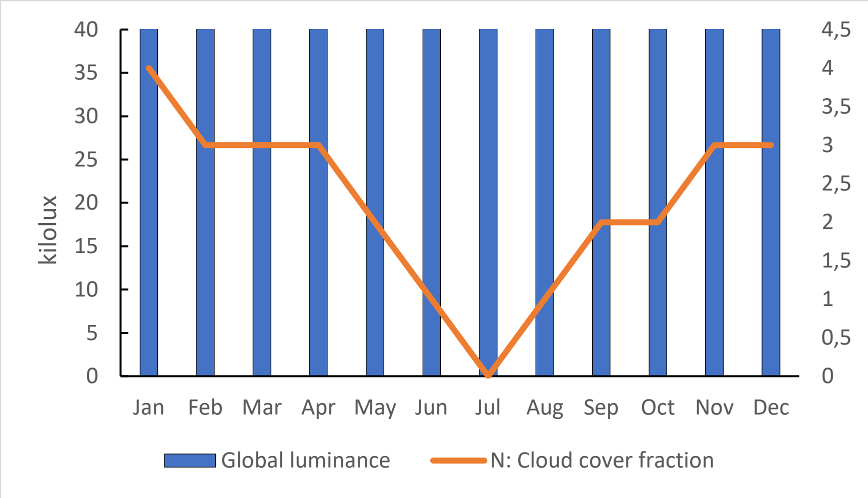


Figure IV- 7. Average monthly Global luminance and cloud cover for the city of Constantine (period 1991-2010).

Source: ONM.

IV.2.3. Urban housing study in the city of Constantine

IV.2.3.1. First survey: Type of housing in Constantine

Chronologically, in the city of Constantine, several types of habitats can be distinguished: the traditional type, the colonial type, the post-colonial type, and the recent type. Basically, there are several types of habitats in Constantine, figure IV- 8 presents a map of the type of habitat in the city of Constantine (BELMALLEM 2014).

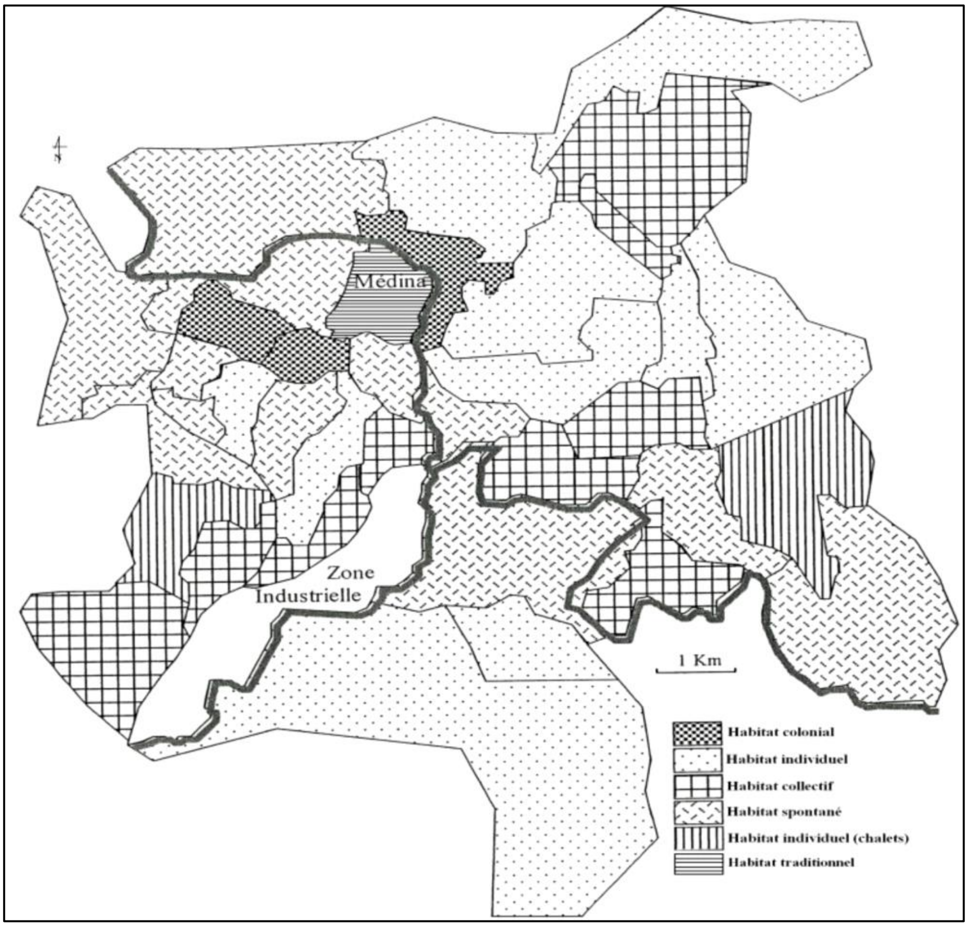


Figure IV- 8. Type of housing in the city of Constantine

Source: BELMALLEM 2014.

IV.2.3.1.1. Traditional housing

The traditional housing is mainly located in the old town of Constantine, the examination of the architectural and urban specificities of these housing fabrics reveals the characteristics of the Arab-Muslim habitat located in the Medina of Constantine, which is characterised by a very dense tree-structure organised according to Islamic planning (Selougha and Wilkinson 1984). The high density is explained by the concept of multi-semi-detached houses where traffic is channelled through curved passages to dead ends or alleys (FOUZIA 2017).

The house of the pre-colonial medina has the shape of a parallelepiped with a central courtyard, or several courtyards framed by porticoes (figure IV- 9) (Merdji 2010).

According to Abdelhafid Selougha in his Master of Philosophy at Newcastle University on Typology of housing in Constantine, there are four types of traditional houses (the L-form; the U-form; the □-form (one courtyard) and the □□-form (two courtyard)). The building materials are often local, walls and foundations of solid stone, beams of wood and roofing of Roman tiles (Selougha and Wilkinson 1984).

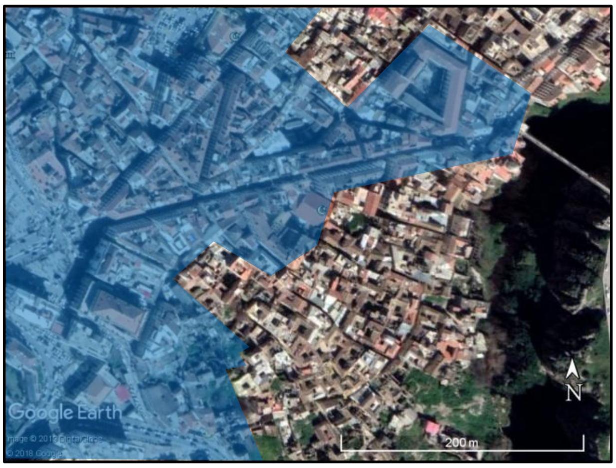


Figure IV- 9. Traditional housing in the old city of Constantine.

Source: Google map.

IV.2.3.1.2. Colonial urban social housing

The intervention of French Haussmannian urbanism outside the medina has allowed the creation of colonial social housing (figure IV- 10), these houses are aligned, its plans are almost the same all along the layout. the ground is made up of four straight rows of blocks to give a regular almost rectangular shape, the housing of each block is stacked on top of each other. The height does not exceed four levels, the building system is mainly based on stone masonry for the foundations and load-bearing walls, iron beams allow for several floors, and the roofs are mostly double-pitched and tiled (Selougha and Wilkinson 1984).

Figure IV- 10. Colonial urban social housing in the Pyramid Place in the city of Constantine.

Source: Google map.

IV.2.3.1.3. Traditional Europeanised housing (hybrid)

This type of housing is at the origin of the French Haussmannian urban and architectural intervention on the traditional fabric of the city through the demolition, opening and reconstruction of traditional houses (figure IV- 11), which aims to accommodate the French population with its Western tradition(Laid 2018).

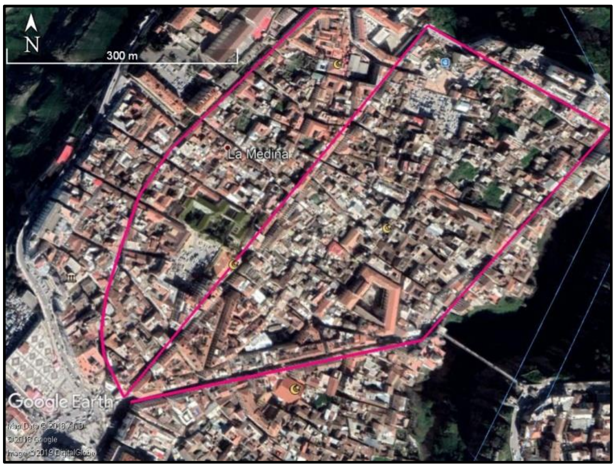


Figure IV- 11. Traditional Europeanised housing in the old city of Constantine.

Source: Google map.

IV.2.3.1.4. Medium-sized buildings (H.B.M. Habitat a bon marché/ Low-cost housing)

This type of housing was taken over by the HBM office, two main reasons were behind these buildings, one is the appearance of concrete, which was widely used in Paris by August Perret. Another reason was the large increase in the Algerian and French population. These buildings are characterised by two urban forms, a linear form, with the blocks arranged side by side on both sides of the road and the height varying between three and four floors. The other urban form is a group of blocks, whose heights vary between seven and eight storeys, as well as the site conditions of the constructions (figure IV- 12).

The structure and construction system of the two forms is very similar, it is mainly characterized using reinforced concrete for foundations, beams, slabs, stairwells and retaining walls against the slopes (Selougha and Wilkinson 1984).

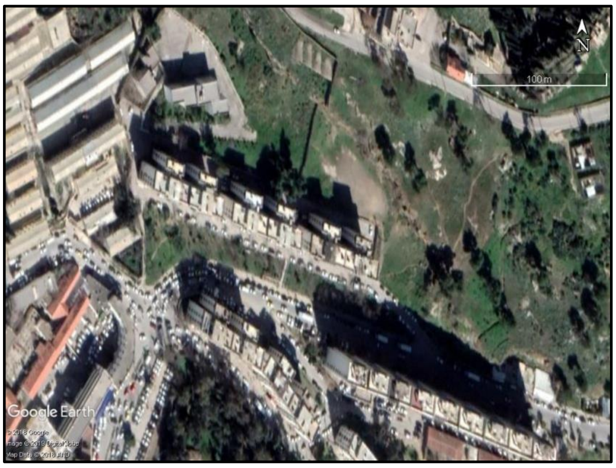


Figure IV- 12. Medium-sized buildings houses of the district Gaillard in the city of Constantine.

Source: Google map.

IV.2.3.1.5. Housing moderate rents for linear planning (H.L.M)

To overcome the natural mountainous and rocky constraints of the city of Constantine, French planning developed the linear concept in the layout of buildings. Starting with the modern movement, whose construction on stilts allows the development of building design even on difficult sites. Long avenues, boulevards and linear roads characterise the planning of these dwellings. The blocks are placed on both sides of the road, in the city centre, near the city centre, they are multi-storey, the height varies from eight to thirteen floors. The building form follows the physical morphology of the street (figure IV- 13).

The structure of these dwellings is a reinforced concrete frame with solid slabs, the masonry is hollow brick, fired brick and cement. The foundations are often piles or reinforced concrete bearing walls (Selougha and Wilkinson 1984, Laid 2018).

Figure IV- 13. Housing moderate rents in district of Coudia at the city of Constantine.

Source: Google map.

IV.2.3.1.6. Dormitory cities (resettlement)

From the 1950s onwards, and with the growth of the European and Algerian urban population, modern French urban planners introduced suburban dormitory cities. These dormitories take two forms, dormitories built for Europeans such as the City Bir (figure IV-14), and others for Muslims, both of which are developed on several floors forming different urban figures that depend on the site. The construction system of both types is based on reinforced concrete pile foundations with load-bearing walls, the upper structure consists of a reinforced concrete frame, slab and beams and a concrete block and hollow brick. (Selougha and Wilkinson 1984).

Figure IV- 14. Dormitory buildings at the district of Bir in the city of Constantine.

Source: Google map.

IV.2.3.1.7. European and Muslim individual housing

European and Muslim individual housing are a subdivision built during the period 1945-1961, on low density residential suburban areas.

This type of housing is divided into two models (figure IV- 15), the one for Europeans and the one for Muslims. The european model is characterised by the semi-detached villa type. The urban plan of the villas is designed based on a uniform subdivision, with rows divided into equal areas, no more than ten, surrounded by a winding road to give access to the units, and then each area is divided into two plots. The buildings of Sidi Mabrouk Supérieur present a part of these villas. The construction system includes a reinforced concrete frame, cement block, hollow brick, wood and even stone (Selougha and Wilkinson 1984).

The Muslim model presents the concept of resettlement in separate areas, to meet the expectations of the Muslim family and easy military control. This model was of houses tightly packed together forming four corner yards, on the basic concept of a housing estate, the rows of houses are parallel surrounded with a street, as well as pierced by other streets that intersect on a small communal area, as shown in the urban plan of the City of Muriers. The building system consists of a reinforced concrete structure with cement concrete filling and a roof slab in-situ system (Selougha and Wilkinson 1984).

Figure IV- 15. European type (left; Sidi Mabrouk Supérieur district) and Muslim type (right; City of Muriers) of individual housing in the city of Constantine.

Source: Google map.

IV.2.3.1.8. Resettlement buildings 1963-1969

Because of the imposed development of the housing areas accelerated by the lack of development of industrial areas or social facilities, the housing estates have taken on the expression of residential resettlement estates. Most of their buildings are unfinished works left by the French. At the level of Constantine, these resettlement cities are determined by a modern urban configuration, characterised by blocks of flats, car parks, access roads, pedestrian crossings, green areas, as well as other small social facilities added later. The buildings are characterised by two types of multi-storey buildings of between five and six storeys; the first type is of medium height and linear, such as the buildings of Fadilla Saadane in Belle Vue, and the second type are towers, such as the buildings of the Bousquet houses in Sidi Mabrouk (figure IV- 16). The structure and the slabs are made of reinforced concrete, as well as the reinforcement of the structure by load-bearing walls (Selougha and Wilkinson 1984).

Figure IV- 16. Resettlement buildings of Fadilla Saadane houses in Belle Vue district (left) and Bousquet houses in Sidi Mabrouk (right) in the city of Constantine.

Source: Google map.

IV.2.3.1.9. Collective housing (ZHUN: The new urban housing zones)

The new urban housing zones is a programme launched in 1974, this programme introduces the concept of zoning for the realisation of new housings responding to the housing crisis, two types of dwellings programmed by the ZHUNs: the type of dense collective housing and the type of self-built housing. In Constantine, from the launch of the ZHUN programme to the present day, the collective housing type looks like a real challenge to respond to the need to house the population of Constantine. The district of 5 Juillet 1962 and the district Serkina are the first achievements of this programme in the city of Constantine (figure IV- 17). The buildings are characterised by their height, the first realisations having heights of four to six floors, while the prefabrication of reinforced concrete panels allows heights of more than eight floors (Laid 2018).

Figure IV- 17. New urban housing zones of the 5 Juillet 1962 district in the city of Constantine.

Source: Google map.

IV.2.3.1.10. Transit housing (chalets)

During the post-colonial period, the rural exodus, the victims of the ruined districts and the disaster-stricken population increased the housing crisis, the need for housing was necessary especially in the metropolitan cities. In Constantine, the state tried to respond to this need by constructing a new type of housing that was not expensive and did not take much time to complete. This type of housing is the prefabricated chalets or transit housing which coincides with the resettlement cities of the colonial period, the objective of which is to temporarily house the inhabitants who are waiting for the allocation of non-provisional housing in the process of being programmed or built. The construction of these transit cities still exists, and others have existed since the first birth of these cities such as the EL GAMMAS city (figure IV- 18). These housing estates are organised with a high density and a large arrangement of chalets, of which each chalet has a small garden. These chalets are built with a metal frame with a prefabricated filling of sandwich panels covered with a skin against humidity. The foundations are made of a concrete platform (Selougha and Wilkinson 1984, Merdji 2010).

Figure IV- 18. Transit housing of El Gammas city in the city of Constantine.

Source: Google map.

IV.2.3.1.11. Self-built housing (ZHUN: The new urban housing zones)

In the 1970s, the housing crisis in Algeria reached an important threshold due to the inability of the Algerian state to respond to the need for housing. After the first four-year plan, this response became obvious and urgent due to the growth of precarious housing and shanty towns, which allowed for the release of land through the municipalization of land and the launching of ZHUN programmes, by the 1974 decree and the 1977 programme respectively, which allowed for the birth of self-built housing (Alkama 1995, Merdji 2010).

At the level of self-built housing, there are two components, the planned category and the informal (unplanned) category.

a) Planned self-build housing

This type of housing first appeared in Algeria during the colonial period, in the early 1940s, in the form of land parcelling for this type of housing and other French colonial equipment (Picard 1989, Alkama 1995).

Then it was the programme launched in 1977 within the framework of the realization of the new urban housing zones ZHUN which allowed the birth of the residential allotments, as well as the appearance of the law n° 90-25 of November 18, 1990, relating to land orientation which made it possible to privilege the private development of the allotments and not to make it any more an affair of state, which generated the creation of multiple residential subdivisions (BOUKHABLA 2015).

The metropolis of Constantine has known many achievements of this type of housing (figure IV- 19), citing; Géric housing estate, Ain El Bey housing estate .... etc. The urban fabric of this type of housing is planned in advance through an urban development procedure, according to the concepts of zoning and parcelling, of which the subdivision is defined by the operation of creating a parcel of land, which is a set of batteries of regular blocks generally, so that each block is divided into parcels of which the heights of the constructions should not exceed 3 levels (r+2), and the intervention of development on subdivisions housing requires a subdivision permit approved by the responsible services (DUAC) (BOUKHABLA 2015). The self-build is characterised by a post and beam construction system with hollow body floors and compression slab, as well as masonry and hollow brick.

Figure IV- 19. Planned self-build housing of Géric housing estate in the city of Constantine.

Source: Google map.

b) Unplanned self-built housing

The construction of these dwellings does not take into account the urban regulations and they are developed in a chaotic way and in a marginal situation. The causes of the lack of respect for alignment and the parcelling out of land create alleys and impasses which structure a dense urban configuration through their intersections, the state of construction of most of these dwellings is almost unfinished, the height varies between one to four levels with a construction system in post, beam and hollow body slab, as well as the masonry is in brick or breeze block (Selougha and Wilkinson 1984, BELMALLEM 2014, BOUKHABLA 2015).

In the city of Constantine many of these constructions types are found (figure IV- 20), the Ben Chergui housing estate or Elbir district is a real example of unplanned housing.

Figure IV- 20. Unplanned self-build housing of El Bir district in the city of Constantine.

Source: Google map.

IV.2.3.1.12. Non-conventional housing (Gourbi or shanty towns)

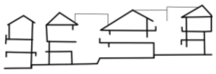
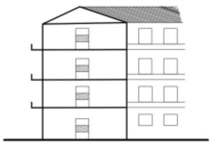
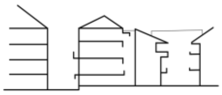
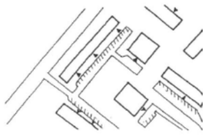
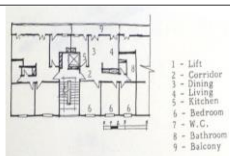
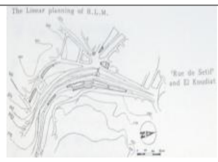
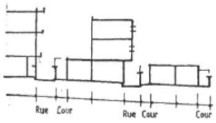
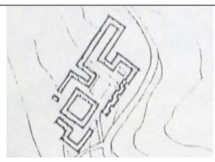
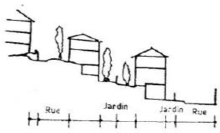
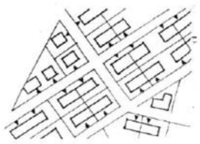
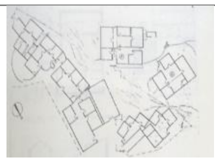
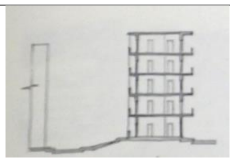
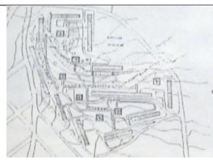
As early as the 1930s, this type of housing began to appear around the city of Constantine as small satellite entities (Merdji 2010). The main reason for the appearance of these dwellings was rural migration, especially in the early 1950s during the war.

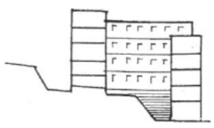
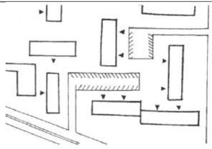
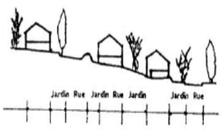
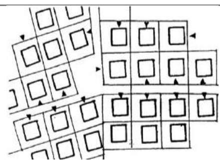
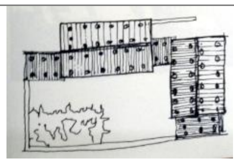
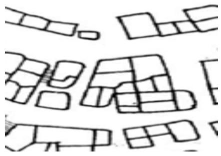
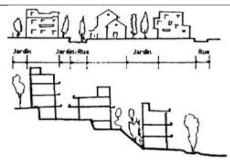
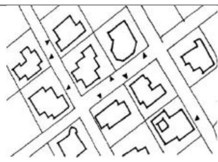
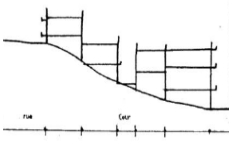
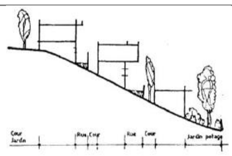
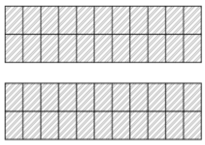
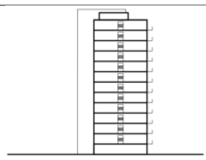
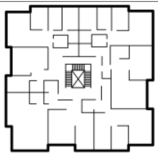
These temporary shelters are called Gourbi or shanty towns and are classified as precarious, marginal, disorderly, spontaneous, unhealthy. Their forms are irregular uneven envelopes, the building materials are of great variety, constructed of mud, iron or any indigenous material in a deformed manner. (Selougha and Wilkinson 1984).

In order to have an overview, table IV- 1 presents all types of housing in Constantine in a chronological and updated manner.

Table IV- 1. Simplified forms of housing types in Constantine

Source: Thesis author, Selougha and Wilkinson 1984, Bourbia and Boucheriba 2010, Laid 2018.

Period	Types of housing	Architectural form	Urban form
Pre-colonial period (before 1837)	Traditional housing		
First colonial period (1837-1944)	Colonial urban social housing		
	Traditional Europeanised housing (hybrid)		
	Medium-sized buildings (H.B.M)		
Last colonial period (1945-1962)	Housing moderate rents for linear planning (HLM)		
	Dormitory cities		
	European individual housing		
	Non-conventional housing (Gourbi)		
Post-colonial period (1963-1969)	Resettlement buildings		

Period from 1970 until today	Collective housing (ZHUN)		
	Transit housing (chalets)		
	Non-conventional housing (Gourbi or shanty towns)		
	Individual housing (communal housing estates)		
	Self-built housing (Planned and unplanned self-build housing)		
			
	Promotional tower block		

IV.2.3.2. Second survey: Type of individual housing in Constantine

This survey concerns individual houses in the city of Constantine, focusing on self-built housing fabrics for the final determination of the urban samples of the targeted study. For this purpose, the identification of individual houses was done on the map of Constantine based on an orthophoto-graphic study.

The city of Constantine has an area of 231.6 km², where the urban area represents 34% of this area with a surface of 77.9 km².

Figure IV- 21 and Annex 2 show the identification of individual houses and their architectural and urban properties for each individual housing district in the city. Table IV- 2 shows the area of the city, the urbanised area and the area occupied by individual houses.

It can be seen that the area occupied by individual houses has a small portion of the urbanised area with a value of 19%. In this stage, planned and unplanned housing occupy the largest part of the urbanised area with a percentage of 60% and 31%, respectively. Prefabricated housing covers 8% of this total area, while traditional housing forms a small part of this area with 1%.

Table IV- 2. Different zone area in the city of Constantine.

Zone	Area m²
Planned habitat	8918942
Unplanned habitat	4594627
Prefabricated habitat	1159450
Traditional housing	107335
All induvidual houses	14780354
Urbanized area	77892268
Constantine city	231600000

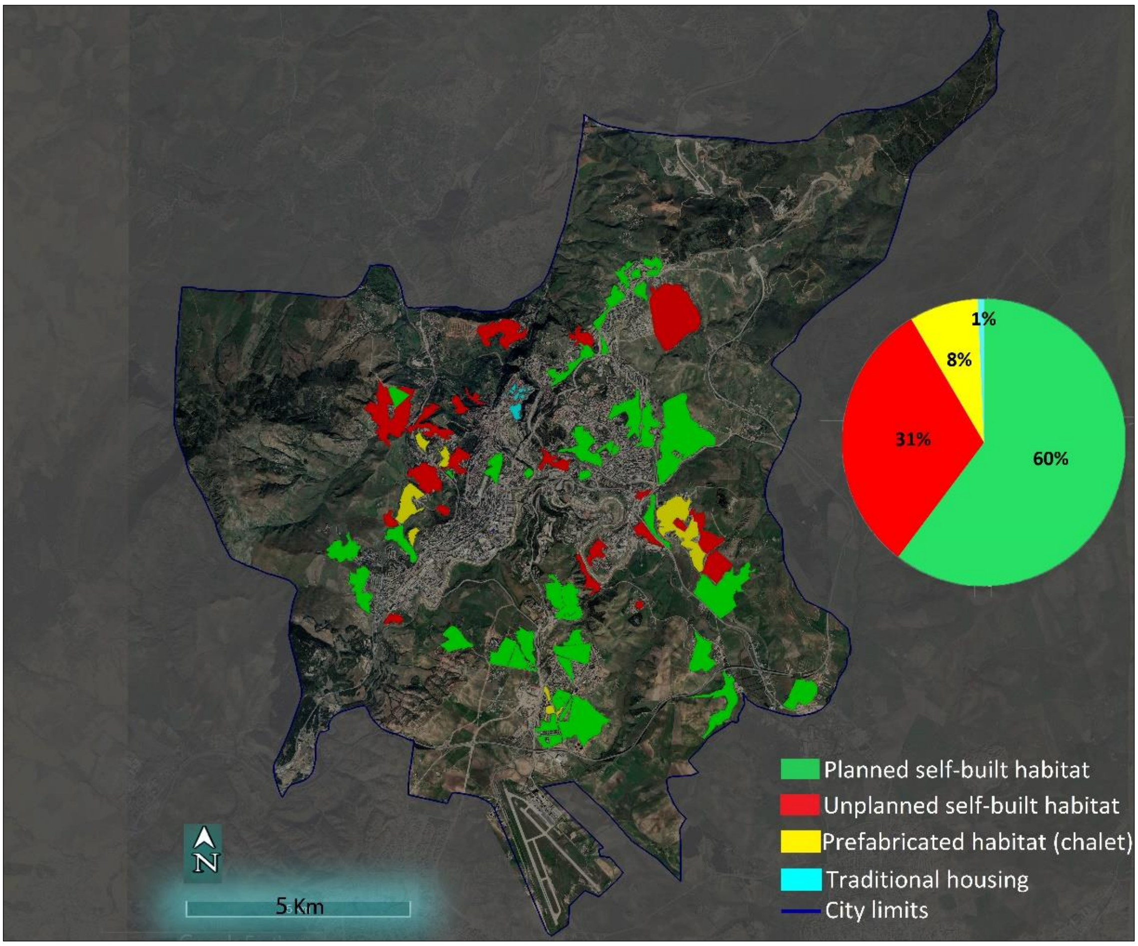


Figure IV- 21. Map of individual housing types in the city of Constantine.

Source: Google Earth and thesis author.

IV.3. Choice and overview of the urban case studies

Our study focuses on the individual housing subdivisions in the city of Constantine, the choice of residential urban case studies was performed after an analysis of individual dwellings based on the construction year, the type of individual house in the city, the shape of the neighbourhoods, the urban density, the area, the construction type, the building shapes, the height, the construction type, as well as other spaces (traffic, green space). These potential indicators were then examined in depth for a more detailed characterisation of urban forms. As show the figureIV- 22, the four selected urban forms are the residential subdivisions of
Ain El Bey 1st Tranche (Case A) situated in the south part of the city near to the aerport, Djbel El Ouihch (case B) located in the north part of the city, Villat Boudiaf (Case C) and Nedjma district (case D) situated in the west part of the city.

Figure IV- 22. The city of Constantine and the four identified case studies

Source: thesis author. Photos taken on; 10th, 11th 12th and 13th September 2019.

IV.4. Conclusion

Constantine is a city with a cold-semi-arid climate characterised by a cold, wet winter and a hot, dry summer. Furthermore, the city has experienced a different and interesting historical development in the built environment, especially in the residential area. The above epistemological work shows that the city has a variety of housing types depending on citizenship and urban applications over the decades. This variation in seasons and built environment makes the city a particular and attractive site of study in multi-disciplines. The final part of this chapter provides a very useful demonstration and overview of the types of individual housing in the city, this part has been further developed to highlight the selection of the most interesting urban areas for individual housing as case studies for the whole thesis.

Chapter V

Material and methodology

V.1. Introduction

The definition of the methodology path of the studies is an essential task to chain the way between the state of the art and the main part of the study carried out. This chapter gives a comprehensive overview on the methods and tools used in the conduction of the study.

Considering the introduction as the first section in this chapter, the second section treats the screening of the case studies by the identification of their typo-morphological properties in several scales, including the urban, building and envelope scales. These characteristics are one of the main elements of this study, their elaboration is made to better use them to understand the energy behaviour of urban forms. The third section presents data on current energy demand and its description across urban forms. Next, the section on urban building energy modelling is presented, it explains the criteria for the selection of Citysim as an urban building energy modelling tool capable to meet the study specifications. The section also deals with an in-depth explanation of its features and uses. The fifth section consists of modelling the present and future climate models used in the study, as well as determining the heating and cooling season in the both climate scenarios. The next part concerns the improvement of energy in urban forms, it takes into account and as an important topic the explanation and assessment of different solar techniques whose advantages can be used in urban residential areas. The seventh and eighth sections provide two important studies that consist of the impact of urban form factors on energy consumption and assessed solar potential, and renewable energy application, respectively. In the second, photovoltaic technology is chosen as the appropriate renewable energy application for the case studies.

The last section of this chapter aims to perform the calibration of the energy model in order to provide more precision to the study.

V.2. Screening of the case studies

V.2.1. The determination of the typo-morphological factors of the cases

The identification of urban typo-morphological factors reveals the characterization of each case study, to this end, the determination of these factors at the urban forms was performed at three scales.

a. Urban form scale.

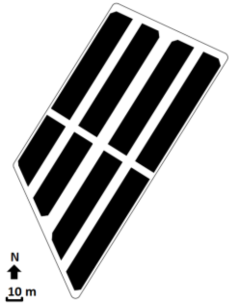
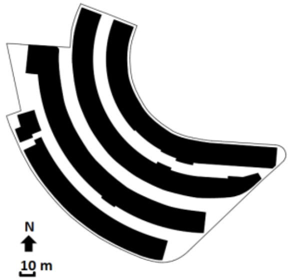
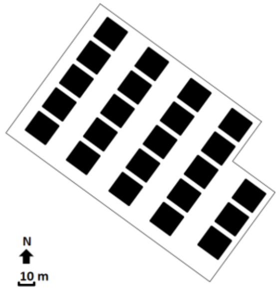
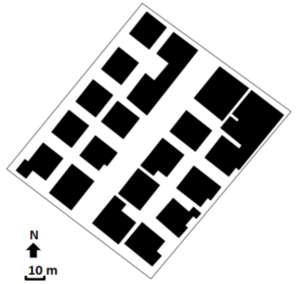
b. Building scale.

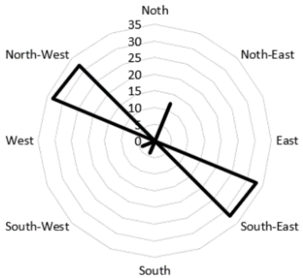
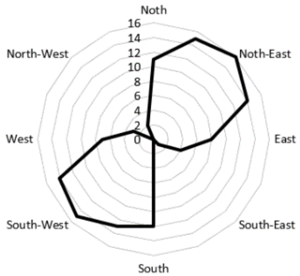
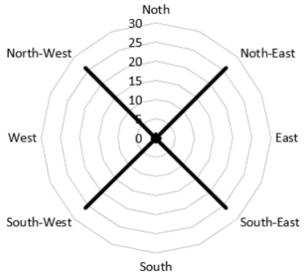
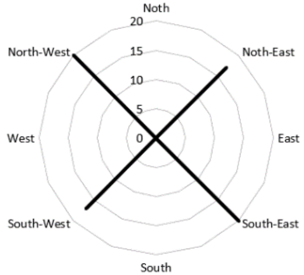
c. Envelope scale.

And to further illustrate this determination factors, Table V- 1 summarizes all the typo-morphological factors according to the above scales.

The geometric and the typo-morphological factors of the buildings were taken and calculated from the urban Master Plans of the city of Constantine, namely, plans directeurs d'aménagement et d'urbanisme: PDAU 1989, Revised in 2015, soil use plan of the four areas namely: plan d'occupation des sol, POS, and other municipal technical map and plans, i.e. district plan, building height, type of users. The use of other useful information is also taken into account, such as orthophotos and identification areas on maps, i.e. green surfaces, trees, type of surface. Furthermore, the other typo-morphological factors such as (complexity, compactness....) were calculated according to its definition (chapter 1, Section I.2.2.1.). The characteristics of the buildings, including thermal envelope and glazing characteristics, were taken from the document of thermal regulation of residential buildings in Algeria (Centre National d'Etudes et de Recherches Intégrées du Bâtiment, 2011; DTR-C3.2, 1997; DTR-C3.4, 2016)

Table V- 1. Typo-morphological factors for the urban forms.

Scale	Typo-morphological factors				
					
					
Urban	Area of the study zone [m²]	16973	22943	11675	6474
	Site coverage	0,6	0,6	0,3	0,4
	Number of building volumes in the urban area	52	66	23	20
	Density (mass index) [m^3/m^2]	7,89	7,49	2,42	2,27
	Ground occupation coefficient COS	2,34	2,24	0,78	0,82
	Surface of the all the building	34104,5	39061,02	14085,2	8103,86
	Compactness [m^2/m^3]	0,254	0,227	0,497	0,558

	Complexity [m²/m²]	1,38	1,09	0,88	0,79
	Orientation of the longitudinal axis.	N-O_S-E	N-E_S-O	N-O_S-E	N-O_S-E
	Façade orientation (16 selected orientations) (Orientation rose).				
	The width of the street [m]	6	11,5	16	10
	Green space [m²]	683	2 243	2 111	729,6
	Contiguity	0,3445	0,4744	0	0,0094
	Aspect ratio H / W	2,151473716	1,081016585	0,463365964	0,514785831
Building	Volume [m³]	133916,33	171976,28	28306,1	18368.97
	Floors area [m²]	39872,23	51341,96	9131	5350,94
	Façades area [m²]	23556,5	25187,13	10267,2	5144,29
	Roof area [m²]	10466	13873,89	3818	3092,52
	Façades area + Roof area [m²]	34022,5	39061,02	14085,2	8236,81
	Max Height / Min Height (m)	17.30 / 7.1	17.80 / 4	9,3	7.62 / 4.82

	Mean building height (MeH) – building height weighted by footprint area [m]	12,9088423	12,43169073	7,413855422	5,147858305
	Standard deviation of building height StH [m]	3,4495	5,2742	0	2,5273
	Standard deviation of building footprint area StF [m²]	54,856	31,3069	0	48,8921
	Mean outdoor distance MOD [m]	4,27	4,71	10	5,18
	Length [m]	16	16.5	13	11,5
	Width [m]	12,7	12.2	12	10,5
	Number of inhabitants	305	369	103	91
	Human density	0,0173	0,016	0,0088	0,0139
	Year of construction	1989 – Today	1989 – Today	1990-2000	1900-1920
Envelop	Wall material	Cement mortar + Hollow brick 15cm + empty spacing (air) 5cm + Hollow brick 10cm + plaster.	Cement mortar + Hollow brick 15cm + empty spacing (air) 5cm + Hollow brick 10cm + plaster.	Cement mortar + Hollow brick 15cm + empty spacing (air) 5cm + Hollow brick 10cm + plaster.	lime mortar+ cut stone 50 cm + plaster.
	Roof material	Plaster + houdi (hollow blocks) + Reinforced Concrete + mortar screed and coating (Granito)	Plaster + houdi (hollow blocks) + Reinforced Concrete + mortar screed and coating (Granito)	Plaster + houdi (hollow blocks) + Reinforced Concrete + mortar screed and coating (Granito)	roof tiles+ glass wool

Floor material	mortar screed and coating (Granito) + Reinforced Concrete + houdi (hollow blocks)	mortar screed and coating (Granito) + Reinforced Concrete + houdi (hollow blocks)	mortar screed and coating (Granito) + Reinforced Concrete + houdi (hollow blocks)	roof tiles+ glass wool + wood+ plasterboard
U value wall [w/m²k]	1,4	1,4	1,4	2,3
U value roof [w/m²k]	3.95	3.95	3.95	
Ratio glazing	0,2	0.18/0.13	0.1/0.12	0,2
Transmittance of glazing	2,25	2,25	2,25	2,25
Solar factor of the glazing	0,95	0,95	0,95	1
Façade albedo	0,2	0,3	0,25	0,2
Roof albedo	0.2 / 0.3	0.2 / 0.3	0,3	0,3
Ground albedo	0,2	0,2	0,2	0,2

Basing on table (V- 1) of the typo-morphological factors of the cases, and for more suitable detail to the study, a descriptive analysis of the cases touching the architectural, urban, socio-economic, and energy consumption parameters, is presented in next sections.

V.2.1.1. Case study A

Ain El Bey 1st Tranche is characterized by a trapezoidal urban form and presents a continuously aligned pavilions built after 1989. It includes 52 houses where the buildings are attached and aligned facing the northwest-southeast axis, the area is characterized by high site coverage, high density, medium building height and small width street. The district has a high inhabitants density with a medium social class. The envelope of the building of case A shares similar U (heat transmission coefficient) values as cases B and C since their envelope contains the same type of wall from the same epoch. The buildings have a high glazing ratio as case D compared to the other cases, but the glazing ratio of 0.2 is considered to be limited in terms of energy benefit from the natural environment (light, heat gain, ventilation) whereas a recommended ratio may be 40% in an exposed wall (ASHRAE, 2010).

V.2.1.2. Case study B

Djbel El Ouihch is a curvature urban form with a continuous pavilion of buildings attached around a curve, built on a slope in 1989, the area contains 66 buildings, and shares the same characteristics of the urban form A with high density, strong site coverage and small width street but it differs by the curvature of the attached buildings. As case study A, the district has a high inhabitants density but its social class is less wealthy than those in urban form A. As cases A and C, this case has its same heat transmission coefficient, which is calculated as 1,4 w/m²k for the walls and 3.95 w/m²k for the roofs, unlike the glazing ration of the buildings which is differs by its medium value regarding the two cases A and C.

V.2.1.3. Case study C

Villat Boudiaf is an irregular rectangle urban form with a missing part, it is composed of modern discontinuous pavilions built in 1990, including 23 houses, the area is characterised by low density, medium height, open street and detached cubic aligned building. The density of inhabitants is low and its social class is the richest one regarding the other case studies. The glazing ratio of this case is much lower than the other three cases, and the thermal transmittance of the building envelope is more efficient than Case D but similar to Cases A and B.

V.2.1.4. Case study D

Nedjma district is a rectangular urban form characterised by a traditional discontinuous pavilion with 20 individual houses built in 1920. The area has a low density, medium height, open street and detached cubic aligned building. The district contains high inhabitants' density from a middle-social class. This case has the lowest value of thermal transmittance and the highest glazing ratio among the previous cases.

V.3. Energy demand data

An estimate of local energy demand is required to perform the calibration of the buildings' energy model. For this purpose, the energy consumption data for the four urban forms was obtained from the East Algerian region Electricity and Gas Distribution Company, Constantine Distribution Division, Commercial Relations Division: Belle Vue Agency source for case A, El Kantara Agency source for case B and C, Sidi Mabrouk Agency source for case D. For other energy needs such as consumption appliances, the value of each annual consumption household was estimated as an average values (table V- 2) taking account the data from the East Algerian region Electricity and Gas Distribution Company and from the study of Ghedamsi et al (Ghedamsi et al., 2016) that deal with the "*Modeling and forecasting of energy consumption for residential buildings in Algeria using bottom-up approach.",* It ought to be mentioned that, in Constantine as elsewhere in the country, heating and cooking are usually provided by gas (central heating boilers or gas heater, gas stoves, boiler for domestic hot water) whilst electricity is mostly used for lighting, air conditioning and household appliances (lamps, air conditioners, electric stove, refrigerator, etc.) (DTR-C3.2, 1997; DTR-C3.4, 2016; Nadia, 2017).

Table V- 2. Average annual energy consumption of appliances for the case studies.

	Average annual consumption per household (kWh/year)	Ownership rate (%)
Lighting	233,6	100
Refrigeration	353	100
Freezer	478	100
TV	278	100
Pc	365	100
Clothes washer	653	100
Microwaves	109	100
Ironer	103	100
Hot water	1074	100
Cooking	7925	100

The calculation of indoor lighting use is based on the analysis of simulated hourly shortwave radiation data, where during the time from 7 :00 to 18 :00 the light is on if the solar irradiance is 0W/m². In addition, during nighttime 5 hours was considered for lighting on. Influence of the season and the building type are considered when calculating the electricity demand for lighting (Le Guen et al., 2018).

Table V- 3 summarizes all the obtained data from the companies, the first part of the data shows the Energy Use Intensity (EUI) of gas and electricity in each urban form as demonstrated in figure equation V- 1, second part of the data presents the heating and cooling needs per m^3 as showed in equation V- 2.

The energy use intensity is defined as:

$$\text{EUI} = \frac{EU}{FR} \qquad \textit{Eq. V- 1}$$

where EUI represents the energy use intensity (KWh/m²), EU is the energy consumption in the case studies (KWh), FR is the floor area of case studies buildings (m²) (Zhong et al., 2021).

The energy need per volume is defined as:

$$\text{ENv} = \frac{EN}{Vl} \qquad \textit{Eq. V- 2}$$

where ENv represents the energy need per volume (KWh/m^3), EN is the heating or cooling needs of the case studies (KWh), Vl is the volume of case studies buildings (m^3).

Table V- 3. The energy use intensity and the energy demand of the cases studies.

Urban form		A	B	C	D
EUI (kWh/m²/)	Gas kWh/m²/year	2.23	1.39	7.52	9.19
	Electric kWh/m²/year	3.66	5.21	19.15	7.41
Energy need (kWh/m^3)	Heating kWh/m^3/year	22.01	12.80	34.88	54.31
	Cooling kWh/m^3/year	3.07	4.53	20.63	7.76

The determination of the intensity of energy use (EUI) and energy requirement per volume (Env) from an original source is carried out to develop a comparative energy analysis between the case studies, also, to examine the impact of urban form factors on energy behaviour and to calibrate the energy simulation model for further accuracy in conducting the study.

V.4. Urban building energy modelling

V.4.1. Criteria for selecting the software

From all the urban building energy model tools (Chapiter 2 section 4), CitySim Pro is chosen for the simulation of this study (Kämpf, 2009). CitySim Pro is developed at the Solar Energy and Building Physics Laboratory of the École Polytechnique Fédérale de Lausanne (EPFL) by doctor Jérôme Kämpf. It is an urban building energy modelling and simulation tool adequate for the study of energy behaviour of the buildings at the neighborhood scale (Vázquez-Canteli et al., 2019). Citysim is used widely for radiation and energy studies at the urban scale (Mauree et al., 2017; Mohajeri et al., 2019; Perera et al., 2018) and occupants' behaviour on the building energy demand (Haldi & Robinson, 2011). A study was carried out by Walter and Kämpf (Walter & Kämpf, 2015) on the validation of the output and the radiation model of Citysim, where the results show an important precision and accuracy of the software. The criteria for selecting the software are its use in different urban energy studies (Le Guen, Mosca et al. 2018, Perera, Coccolo et al. 2018) and the ability of the simulation tool to respond to the study specifications. The software is known as an urban building modelling energy tool (Johari et al., 2020), and its advantage is not only the simulation of energy needs and energy production but also the ability to take into account urban energy performance parameters, including solar inter-reflection and shading in urban areas.

CitySim is in fact developed on a simple resistor-capacitor network to model the thermal behaviour of buildings, this advantage allows to model a whole district at the unique time. Furthermore, it provides a more realistic scene to modelling the irradiation exchange between external surfaces. It uses a simplified radiosity algorithm for the definition of shortwave and longwave radiation, in addition, temperatures and source view factor are considered during the radiosity simulation.

V.4.2. Definition of software parameters (input and output)

Citysim, like any other simulation tool, needs inputs to run the simulation parameters. Figure V- 1 shows all the sections contained in the graphical interface of the software.

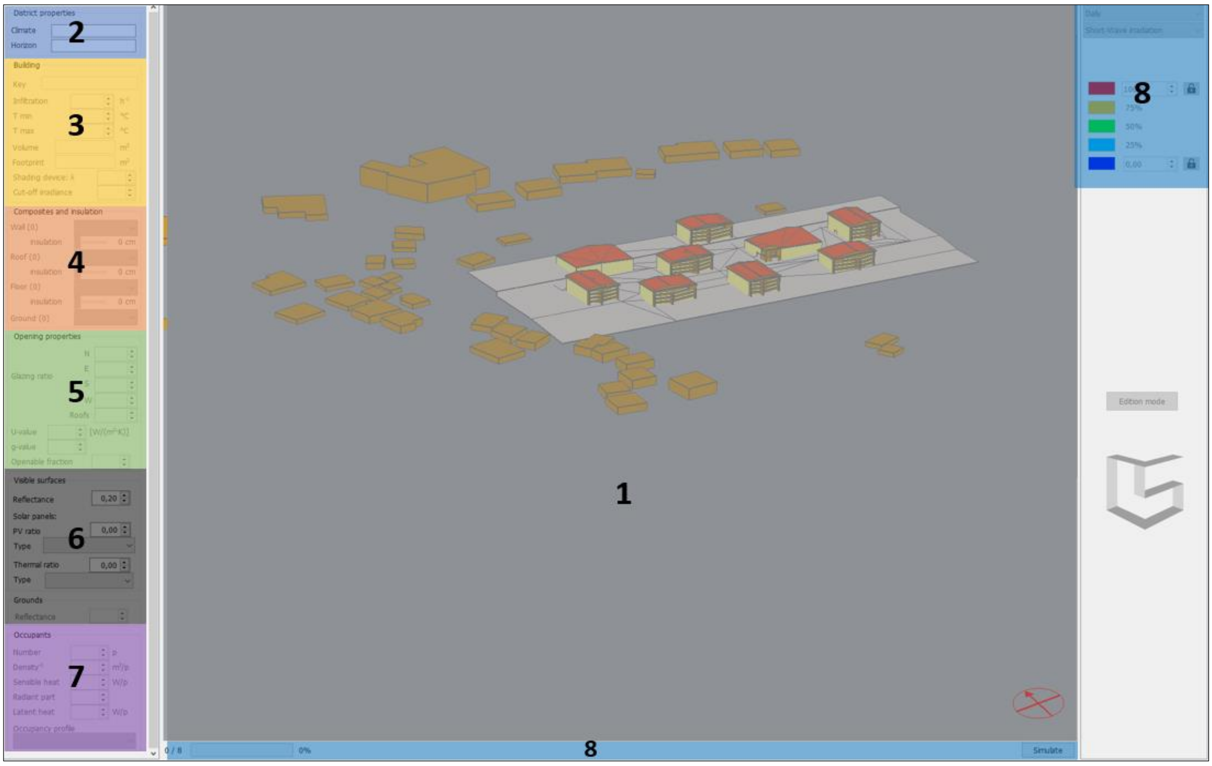


Figure V 1. The graphical interface of Citysim pro software.

The main window of Citysim is divided in a bunch of sections.

Section 1; Scene to display the 3D model of the case studies, where an appropriate 3D model must be imported, Citysim supports geometrical model designed by third party software that must be defined as dxf format file. The 3D model is subject to specific properties, where each surface is defined by a layer for each building in the 3D modelling tool.

Section 2 to section 7; contains all the definition of the input data, in section 2 the location data, the meteorological data in (cli) file format and the horizon of the selected region must be inserted. Weather data must be an hourly data during a selected year, and it is composed by several information as solar irradiance, wind speed and direction, temperatures…

Section 3 is devoted to defining the main properties of the building such as the value of air change per hour ($^{-}$h), the minimum temperature permitted inside the building (°C), the maximum temperature permitted inside the building (°C), the shading device representing the smooth transition between the open and closed states of the blinds, and the cut-off irradiance (W/m²).

Section 4 contains the composites and insulations of the envelope properties, like the thickness and the layers of the walls, the floors, and the roofs. The software allows to modify the composites or creating new one by redefining its materials and the physical properties of the materials (thermal conductivity, specific heat, density, and color) in the XML file of the library of the software by using some programs that allow this complicate task such Notepad++ (Annex 5). In this section we can also define the ground properties by its composite, modify it or create a new one as the same way of the previous task.

Section 5 is dedicated for the opening properties, and it allows to define the opening properties of the building such as glazing ration in each façade of the building, thermal transmittance heat (U) and glazing transmittance (g).

Section 6 helps to manipulate the visible surfaces and to define each characterization of the surface, and whether it is used as a renewable energy (PV or ST) with the appropriate specifics of that energy or not.

Section 7 deals with information about occupants and their behaviour, as well as the occupancy profil.

After completing all those sections, the simulation scene is now composed properly and the next step is to launch the simulation from section 8, this same section contains simulation and results showed colored as an average in the 3D scene.

The outputs can be exported to as an csv format file on an hourly basis, and it provides:

- *Ta (°C) the indoor air temperature.*
- *Heating the ideal heating needs to reach the heating set point temperature.*
- *Cooling the ideal cooling needs to reach the cooling set point temperature.*
- *Qi the internal gains comprising occupants, appliances and solar heat gains.*
- *Qs (Chen et al.) the satisfied heating (positive) or cooling (negative) needs.*
- *VdotVent (m^3/h) the natural ventilation flow rate by window openings.*
- *HeatStockTemperature (°C) the temperature of the heat tank.*
- *DHWStock Temperature (°C) the temperature of the domestic hot water tank (if applicable).*
- *ColdStockTemperature (°C) the temperature of the cold tank.*
- *MachinePower (W) the power necessary for the energy conversion system to provide heating or cooling.*
- *FuelConsumption (MJ) the energy consumed by the energy conversion system in terms of fuel.*
- *ElectricConsumption (kWh) the energy consumed by the energy conversion system in terms of electricity deduced by the photovoltaics (PV) production.*
- *SolarThermalProduction (J) the energy provided to the heat stock by solar thermal panels.*

- *Illuminance in the surface.*

Regarding the four urban form case studies, the 3D modelling was made in the SketchUp software with level of detail 2 (LOD 2) (Biljecki, 2017) for the building envelope. The existing ground slope was imported from Google earth into SketchUp to facilitate the export of the model into CitySim Pro software. Figure V- 2 shows the four modelled case studies in the graphical interface of Citysim.

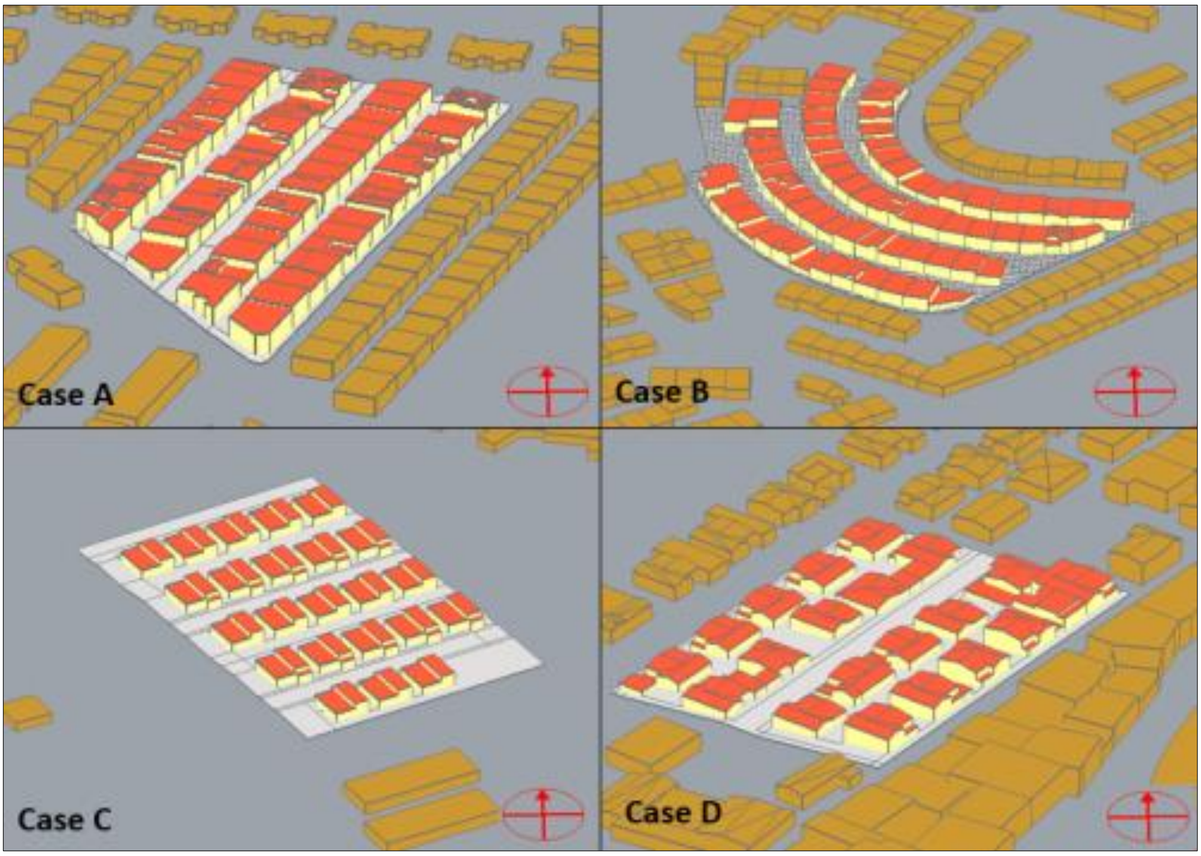


Figure V 2. Representation of urban forms in CitySim.

V.5. Model calibration

For each of the urban forms, the calibration of the Citysim model was made through the matching of the estimated energy demand against actual consumption. In a number of important research studies, it is mentioned that the energy profile of buildings is influenced by a several significant factors such as the local climatic conditions, the properties of the building envelope, the type of energy systems installed, and the most important factor was the energy consumption behaviour as well the activities of the occupants (Chen et al., 2015; Page et al., 2007). For instance, Hub et al found that a relevant difference in total energy consumption in the same type of building is observed and attributed to occupancy rates and thermal behavioural preferences of the occupants (Hub, 2015). In other research, even using detailed and accurate energy simulation software, the effects of differences can be important (Martinaitis et al., 2015).

Taking into account the occupant factor in the calibration procedures, it is also necessary to note that in this study, the differences found before the calibration procedure between the modelled energy demand and the actual energy consumption are in fact expected because of the use of Meteonorm's climate data, where its data presents average climate data and does not reflect the present weather during the measurement period, furthermore, the internal gains caused by appliances and occupants are not identified for certain periods such as weekends and holidays (Walter & Kämpf, 2015).

The heating and cooling needs are identified in the Citysim software according to the indoor temperature, when the indoor temperature changes outside the identified comfortable temperature, the energy demand starts to take a value. Respectively, the heating or cooling demand starts to take a value when the minimum or maximum indoor temperature falls outside the comfortable temperature range. This temperature range is often considered to be [18, 25] °C (World Health Organization, 1990, 2018), however, it is influenced by the social and health conditions of the building occupants (Delzendeh et al., 2017; Haldi & Robinson, 2011).

Therefore, the calibration procedure is based on the adjustment of the temperature setpoint pairs for each urban form through a method of applying a set of simulation tests, this method is used to minimize the differences between the modelled and actual energy consumption for each case study. The procedure for adjusting the temperature setpoint pairs starts by using the recommended range of Tmin (18.0°C) and Tmax (25.0°C) to achieve the lowest percentage modelling error, where the heating and cooling requirements are directly linked to the parameters Tmin and Tmax, respectively.

V.6. Climate modelling data

V.6.1. Present and future climate modelling

Meteonorm is considered a useful meteorological data set, generating output based on satellite data for radiation and ground stations for other meteorological parameters. It is widely used to provide meteorological files (typical meteorological years, TMY) for current and future climate studies for a range of different climate scenarios based on greenhouse gas emissions and aerosol concentration, from the period 2010 through to 2200 (Remund et al., 2010).

In the current work, meteonorm is used to generate meteorological data for present (2020) and future (2050) climate studies, the reference file was based on IPCC AR4 - A2 scenario (Intergovernmental Panel on Climate Change), which correspond to an economic scenario with a radiative forcing of 4.5 W/m² and a CO2 concentration of 850 ppm in 2100, which can be categorized as a severe impact scenario.

Figure V- 3 shows significant differences between current and future ambient temperatures, where temperatures in 2050 are expected to be higher than present temperatures throughout the whole year, with maximum temperatures in 2050 in August instead of 2020 in July. Concerning solar radiation and as shown in figure V- 4, the differences are less significant than those detected in the ambient temperatures, the amount of solar radiation is expected to increase during the cold season but decrease during the summer months for the future climate, other studies have been done in other regional climate modelling show the same scenario (Soares et al., 2019).

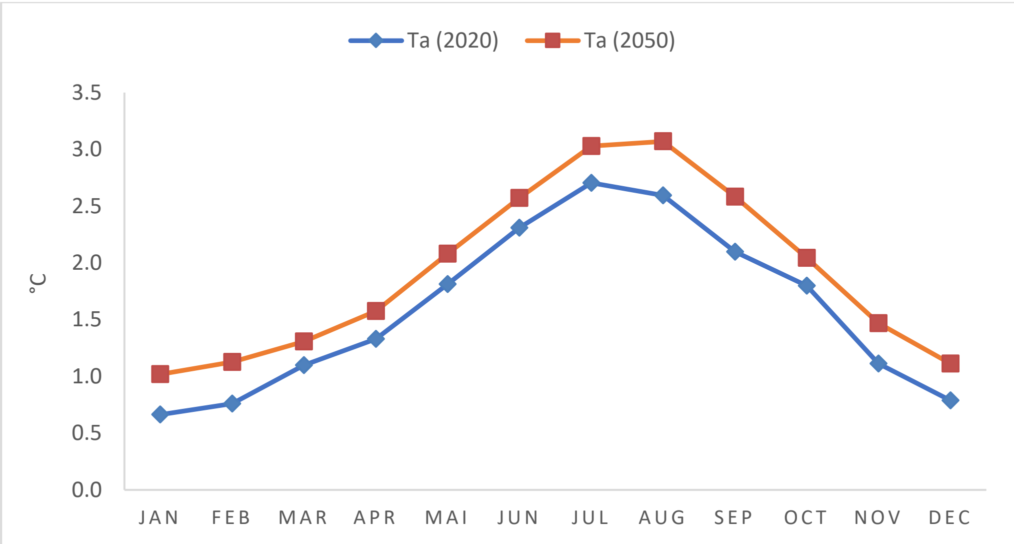


Figure V 3. Ambient temperature in the present and future climate.

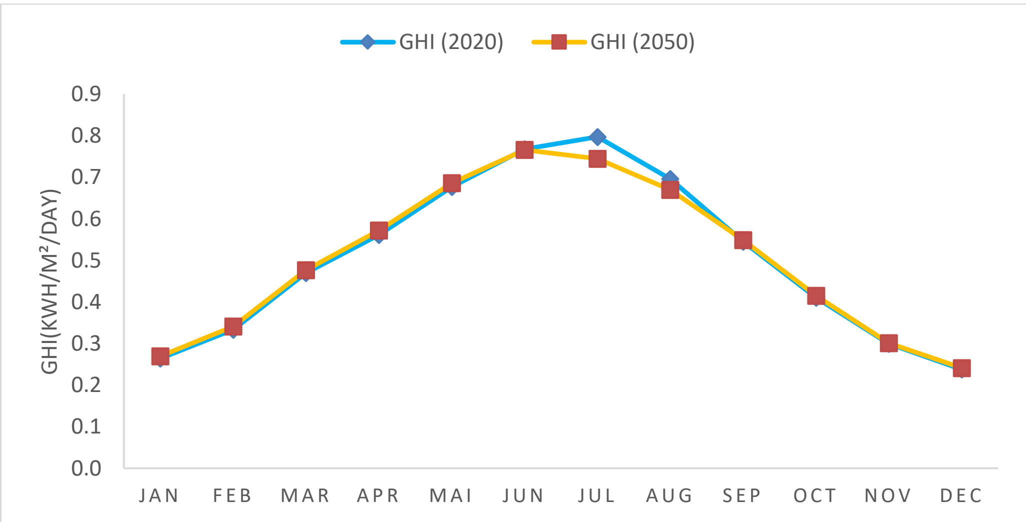


Figure V 4. Global solar irradiation in the present and future climate.

For both simulation climate scenarios (present and future), all properties of the study cases, such as materials, are considered unchanged in both situations, only the meteorological data are updated.

V.6.2. Heating and cooling degree-days

The determination of the heating and cooling seasons presents an important parameter to understand the energy behaviour of the building, The degree-day method is strongly recommended to answer the question of how to calculate heating and cooling seasons (Dias et al., 2020; Sargent et al., 2011). This method allows to measure the number of degrees of required heating or cooling comparing the mean daily temperature with base temperature, where T base = 18.3 °C according to reference (ASHRAE, 2013). Respectively, equations V-3 and V- 4 determine the calculation procedure of the heating and cooling degree-days.

$$\mathrm{HDD} = \sum_{\mathrm{i=1}}^{\mathrm{day}} (\mathrm{T\ base} - \mathrm{Ti}) \qquad \textit{Eq. V- 3}$$

$$\mathrm{CDD} = \sum_{\mathrm{i=1}}^{\mathrm{day}} (\mathrm{Ti} - \mathrm{T\ base}) \qquad \textit{Eq. V- 4}$$

Where Ti is the average between daily maximum and minimum temperature, and T base = 18.3 °C is the recommended base temperature in buildings (ASHRAE, 2013).

The definition of heating and cooling seasons is derived by comparing the two periods, the heating season is determined when the heating degree days (HDD) are superior to the cooling degree days (CDD), and vice versa for cooling.

V.7. Energy improvement at the case studies

Adequate exposure of buildings to solar radiation, or in other words, good insolation of buildings, allows natural light and solar heat gain, especially during the heating season, as part of a passive strategy. Furthermore, this well exposed building to the sun facilitates the use of active solar technologies such as photovoltaic or thermal panels, resulting in an effective hybrid solar strategy to meet the buildings' energy demand.

In order to assess the potential of the different solar techniques in the urban cases including passive and renewable (photovoltaic and thermal solar) techniques. First, an irradiation and illuminance threshold has been defined according to the type of solar technique. This threshold represents the minimum amount of radiation required for an appropriate energy production or use by these solar techniques. This method is given by professor Raphael Compagnon, and it has been widely used in the research of the last twenties years. This technic allows to assess the four solar technics comprising; solar heat gain, daylight, photovoltaic and thermal solar

potentials, were the technical and economic factors has been taken into consideration in the threshold calculation process. Each process of the threshold calculation is given in the next section according to the required solar technic.
Subsequently, the amount of irradiance and illuminance were examined using Citysim on each surface of the building envelope of the case studies.
Lastly, a comparison of the irradiance and illuminance of the case studies with the threshold required for each solar technique is made to determine the appropriate surfaces for the application of each solar technique.

V.7.1. Irradiation threshold for assessing solar heat gain

Solar heat gain is crucial during the heating season, and the most important part of the building envelope to utilize it, is the windows. According to Compagnon, in order to quantify the solar heat potential and achieve an energy balance between solar heat gain and loss during the heating season, an overall solar irradiance threshold is calculated ($G_{passive\text{-}threshold}$) using equation V- 5.

$$G_{passive-threshold} = \frac{24\,DD\,U}{1000\,g\,n} \qquad \textit{Eq. V- 5}$$

Where **DD (°F)** is the degree-days for the heating season, **U-value (W/m² K)** is the thermal transmittance, **g-value** presents the total solar energy transmittance, and **η** is a reduction factor of the total solar gains regarding the building behaviour and occupants. For our study, the glazing thermal transmittance is taken as (U=1.3 W m^{-2}), the glazing solar transmittance is taken as (g=0.75), the reduction factor is fixed to 0.7, and the degree-days for the present and the future heating season is assumed for the study as 3150 °F and 2017°F, respectively,

$$G_{Present-passive-threshold}\left(\frac{KWh}{m^2}\right) = \frac{24 * 3150 * 1.3}{1000 * 0.75 * 0.7}$$

Then the result of passive thresholds is:

$$G_{Future-passive-threshold}\left(\frac{KWh}{m^2}\right) = 119{,}87$$

V.7.2. Illuminance threshold for assessing daylight

For the determination of the minimum required illuminance threshold, first, we use the assumption of the illuminance of the working plane $\mathbf{E_w}$ as a function of the average external vertical illuminance $\mathbf{E_o}$ that illuminates the façades.

$$\mathrm{Ew}(lx) = CU\ Eo \qquad Eq.\ V\text{- }6$$

Where CU is the coefficient of using daylight, which is used to take in consideration the construction parameters (e.g., room sizes, glazing ratio and luminous transmittance, indoor surface reflectance). Secondly, the value of this coefficient has been calculated for vertical openings windows as CU = 0.05. in addition, the inside average illuminance for workplane is assumed to be Ew= 500lx. From the above settings the illuminance of the outside vertical surfaces in building is defined as:

$$\mathrm{E}_{\mathrm{threshold}}(lx) = \frac{Ew}{CU} = 10\ 000\ lx \qquad Eq.\ V\text{- }7$$

V.7.3. Irradiation threshold for assessing photovoltaic system integration

It is known that the integration of photovoltaic systems can be done on the roof as well as on the façade, however, the roof has a better insolation than the façade. For this reason and according to the references (Compagnon, 2004; Compagnon & Raydan, 2000), in the current study, a threshold of **$G_{threshold\text{-}pv}$ = 800 kWh m^{-2}** is defined as the minimum amount for the integration of the photovoltaic system on the façade, and the amount of **$G_{threshold\text{-}pv}$ = 1000 kWh m^{-2}** is defined as the threshold for the integration of the photovoltaic system on the roof.

V.7.4. Irradiation threshold for assessing thermal solar technology system integration

The efficiency of the integration of solar thermal collectors presents the same response as the photovoltaic system, where both of their energy production depends on the amount of the insolation, so an annual irradiation of **$G_{threshold\text{-}st}$ = 600 kWh m^{-2}** is defined as the suitable threshold for installing solar thermal collectors in roofs, and for the façades, this threshold is considered as **$G_{threshold\text{-}st}$ = 400 kWh m^{-2}.**

In order to summarize these defined thresholds, table V- 4 sets out all these thresholds according to their integration

Table V- 4. Summary of defined threshold values

Solar energy	Period and energy source	Façade	Roof
Passive solar heat (kWh m^{-2})	Heating season solar irradiation	187	/
Daylighting (lx)	During illuminance hours (8-18h)	10000	/
Photovoltaic system (kWh m^{-2})	Annual solar irradiation	800	1000
Solar thermal collectors system (kWh m^{-2})	Annual solar irradiation	400	600

V.8. Impact of urban form factors on energy consumption and solar potential

In order to check the correlation between the case study urban form factors, solar potential and energy demand, a bilateral Pearson correlation was performed. This method is used to test the interdependence between the two urban form factors as a variable and to express the strength of the association between the variables. The strong positive correlation means that these factor variables can exert the same impact on solar potential or energy behaviourt is used to help optimise the repetition of much of the work by taking the most relevant factors whose influence on solar potential or energy behaviour needs to be studied. For the two variables containing the values $\{(x_1, y_1), \dots.., (x_i, y_i)\}$ consisting of n variables, the mathematical formula of pearson correlation is built as follow:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad Eq.\ \ V\text{-}8$$

Where:

n is number of pairs or size,

x_i, y_i are the values of the two variables indexed with i,

$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ is the mean of first variable and $\bar{y}$ is the same presenting the second variable.

The value in pearson correlation varies between -1 and 1, where the former refers to a strong negative correlation while the latter leads to a strong positive correlation. And the closer you get to 0, the more the correlation starts to reduce.

V.9. Renewable energy application

After carrying out the threshold analysis of the different solar techniques, a simulation application of the active solar renewable energy for the photovoltaic integration system is performed, the choice was made based on a set of arguments.

Photovoltaic energy is environmentally friendly, as it produces electricity without harmful greenhouse gas emissions.

Photovoltaic panels have an incredibly long lifespan, providing electricity for up to 30 years.

The efficiency of the photovoltaic system is most apparent in summer, when more electricity is needed for cooling.

The energy produced by the photovoltaic system in the form of electricity can cover the total energy demand of the buildings for cooling, lighting, electrical appliances as well as heating (heat pump).

At the urban scale, electricity generated by PV technology is less complicated than that generated by ST technologies, where the latter requires the collection of sunlight and its transformation into stored heat, then converted into electricity.

The energy demand results for the future scenario show an increase in cooling and a decrease in heating, which requires more electricity generation. PV technology can offer additional energy for this problem.

V.9.1. PV modelling

Due to the high solar potential of the roofs of the buildings against the façades (Vulkan et al., 2018) in the four urban forms, these areas are suitable for the installation of photovoltaic (PV) systems and the achievement of relevant PV production. On each building's rooftops a designed photovoltaic system of 20 m² is installed. This installation size is determined as a compromise between the surface area required for efficient photovoltaic electricity production, comparable to the electricity consumption of each building, as well as the costs.

For maximum PV production, PV panels are oriented with an azimuth of 180º (towards the south direction) with an inclination of about 32° for maximal production (annex 4). The required PV installation is adequate for flat roofs, where orientation and inclination can be manipulated, however some of the case study buildings have sloping roofs, as illustrated in figure V- 5. Referring to annex 4, the data indicates that the production is higher in summer than in winter, with long production hours and a high amount during summer days. Moreover, using a PV system with an installation capacity of 1 KWp with optimal orientation and inclination in a small house, it allows an average production of almost 1500MWh of photovoltaic power per year and the inclined surfaces can receive almost 2000 KWh/m² per year of irradiation.

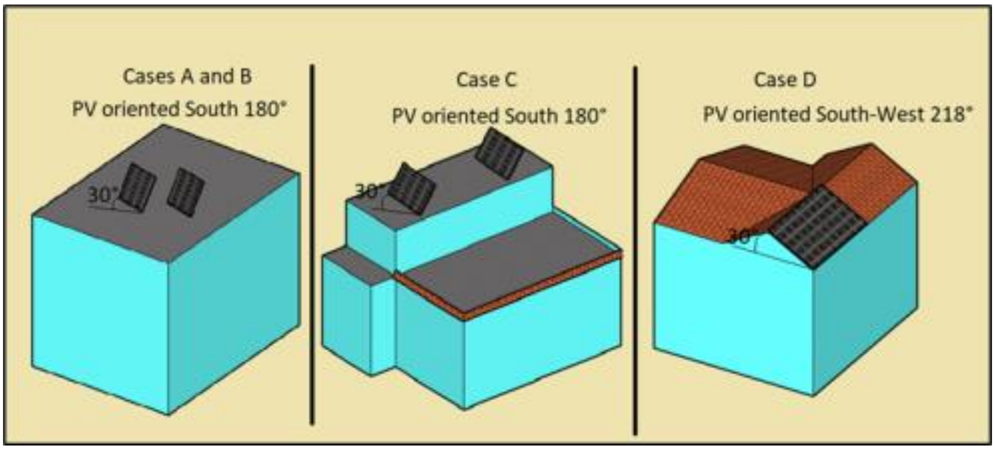


Figure V 5. Examples of designed rooftop PV system for different rooftop layouts.

For more comprehensive application of the PV system in the buildings of the case studies, the photovoltaic installations are designed with the 335 W Jinko solar modules, featuring a conversion efficiency of 17.26%, which is supposed to be typical for this type of operation.

The appropriate settings of the Jinko solar module parameters required as inputs to the Citysim modelling are shown in Table 4 and given as inputs in appendix 3 (JINKOSOLAR, 2018).

The utility of installing a PV system to solve the energy problem is twofold. On the one hand, the energy produced in the form of electricity reduces the energy demand of buildings by consuming locally. On the other hand, PV panels cast a shadow on building surfaces during the day, which reduces solar gains, especially during the cooling season, when these are not appropriate for indoor comfort.

In our case, the software cannot model both the effects of the PV system for electricity production and the cast of shadow on the building surfaces. For this reason, and in order to properly model the impact of rooftop PV systems, it is necessary to run three models for each case study.

1. Reference model refers to the basic simulated urban form; the results (heating, cooling, electricity, and DHW) correspond to the no-PV models.
2. Shadow layer model refers to the simulated urban form where the PV panel is a shadow layer affecting the energy demand in the building (no PV generation).
3. Roof PV layer with generation model refers to the simulated urban form where the PV panel is a roof layer generating electricity (unrealistic building energy demand).

Therefore, the heating and cooling needs can be estimated from model 2 and the photovoltaic electricity production from model 3.

Table V- 5. Specifications of the PV module used in the simulations.

Source: JINKOSOLAR 2018.

Module type	JKM335M-72H-V	The PV module
Cell type	Polycrystalline silicon	
Maximum Power (Pmax)	335 Wp	
Maximum Power Voltage (Vmp)	38.0 V	
Operating temperature (C°)	-40 ℃ +85 ℃	
Temperature Coefficient of Voc	-0.14918 V/K	
Nominal operating cell temperature (NOCT)	45±2℃	
Module area (m²)	1.94	
Tref	25	

V.10. Conclusion

This chapter has produced a general explanation for the methodology of the entire study and presents the techniques and tools used for each stage in order to understand the results obtained in the following chapter.

The whole process consists of examining the properties of each urban form in order to analyse its influences on the energy behaviour (demand and benefits of solar energy) of the case studies, this analysis is carried out using current and future climate scenarios. In addition, an assessment of the application of photovoltaic energy has been explained. Moreover, the work was subjected to a calibration procedure for more accurate results.

Chapter VI

Results and discussions

VI.1. Introduction

Worldwide, the assessment of solar potential and energy consumption within the urban form is a field of study that is of interest to many researchers, but the study of the impact of urban form indicators on the development of energy consumption and solar potential over the years is a research gap in this field, especially with the future climate change scenario.

In this context, this chapter focuses on the main part of the impact of urban form factors on energy consumption and solar potential of urban forms during the present and future climate.

The first part of this chapter deals with the selection of urban form factors that exert a significant influence on energy behaviour and solar irradiation received. In the course of the study, sections are based on mathematical approaches such as Pearson correlation or linear regression models and 3D simulated models to thoroughly understand the relationships between the study components.

After performing the energy calibration model, a comparative study of the energy behaviour due to the variation of the urban form factor is carried out. Then, the study was driven to evaluate the different solar techniques at the urban scale using the method described in Chapter V section 7 while the following section focuses on the impact of the urban form factors on the solar irradiation in both climates. The last part of the chapter presents the application of renewable energy, using rooftop PV systems, testing the benefits of these systems in the city of Constantine, in Algeria, in different urban forms.

VI.2. The correlation study between the urban form factors

In this section, we have systematically performed the Pearson correlation between each of the two urban factors of the four case studies. The results presented in table VI- 1 and figure VI- 1 show that most of the urban form indicators (site coverage, number of buildings, floor area ratio, complexity, contiguity, height to width ratio (H/W), mean building height and standard deviation of building height) have a strong positive correlation among themselves and with density.

In addition, the analysis shows a strong negative correlation between density and compactness, between density and mean outdoor distance, and between density and street width.

The correlation between compactness and mean outdoor distance gives a positive correlation of 0.551. The correlation of the standard deviation of building footprint area with the other indicators does not indicate an interesting correlation except with site coverage (0.641) and standard deviation of building height (0.604). The mean outdoor distance and the street width features a negative correlation with all other indicators varying between strong (such as with standard deviation of building footprint area) and weak (such as with mean building height), the correlation between both gives a strong positive r-value of 0.869.

Table VI- 1. Pearson correlation results for the urban form indicators of the case studies.

	Den	Sco	NB	Far	Com	Cex	Cgt	H / W	MeH	StH	StF	MOD	WtS
Den	**1**	**0.957**	**0.951**	**1.000**	-0.984	**0.909**	**0.962**	**0.857**	**0.972**	**0.790**	0.446	-0.666	-0,614
Sco		**1**	**0.914**	**0.961**	-0.909	**0.816**	**0.943**	**0.797**	**0.864**	**0.912**	**0.641**	-0.848	-0,733
NB			**1**	**0.952**	-0.977	**0.748**	**0.997**	**0.657**	**0.934**	**0.848**	0.278	-0.594	-0,403
Far				**1**	-0.982	**0.906**	**0.964**	**0.855**	**0.969**	**0.797**	0.455	-0.675	-0,62
Com					**1**	-0.863	-0.975	-0.781	-0.988	-0.757	-0.286	0.551	0,463
Cex						**1**	**0.763**	**0.984**	**0.912**	0.509	0.456	-0.528	-0,692
Cgt							**1**	**0.685**	**0.929**	**0.877**	0.353	-0.654	-0,469
H / W								**1**	**0.832**	0.485	0.581	-0.592	-0,797
MeH									**1**	**0.655**	0.244	-0.473	-0,458
StH										**1**	**0.604**	-0.874	-0,578
StF											**1**	-0.915	-0,952
MOD												**1**	**0,869**
WtS													**1**

The strong positive correlation between the urban form indicators means that they display a similar impact on the energy behaviour and solar potential of the urban case studies (and vice versa for the strong negative correlation). These results are similar to those explored for the city of London (Chatzipoulka et al., 2016).

In this perspective, and to build a precise study of the impact of typo-morphological factors of urban forms on solar potential and energy demand, the study is carried out based on the analysis of the influence of density (Den), compactness (Com), mean outdoor distance (MOD), the standard deviation of building footprint area (StF) as well as the thermal transmittance (U) of the envelope of the buildings case studies on energy consumption and solar potential.

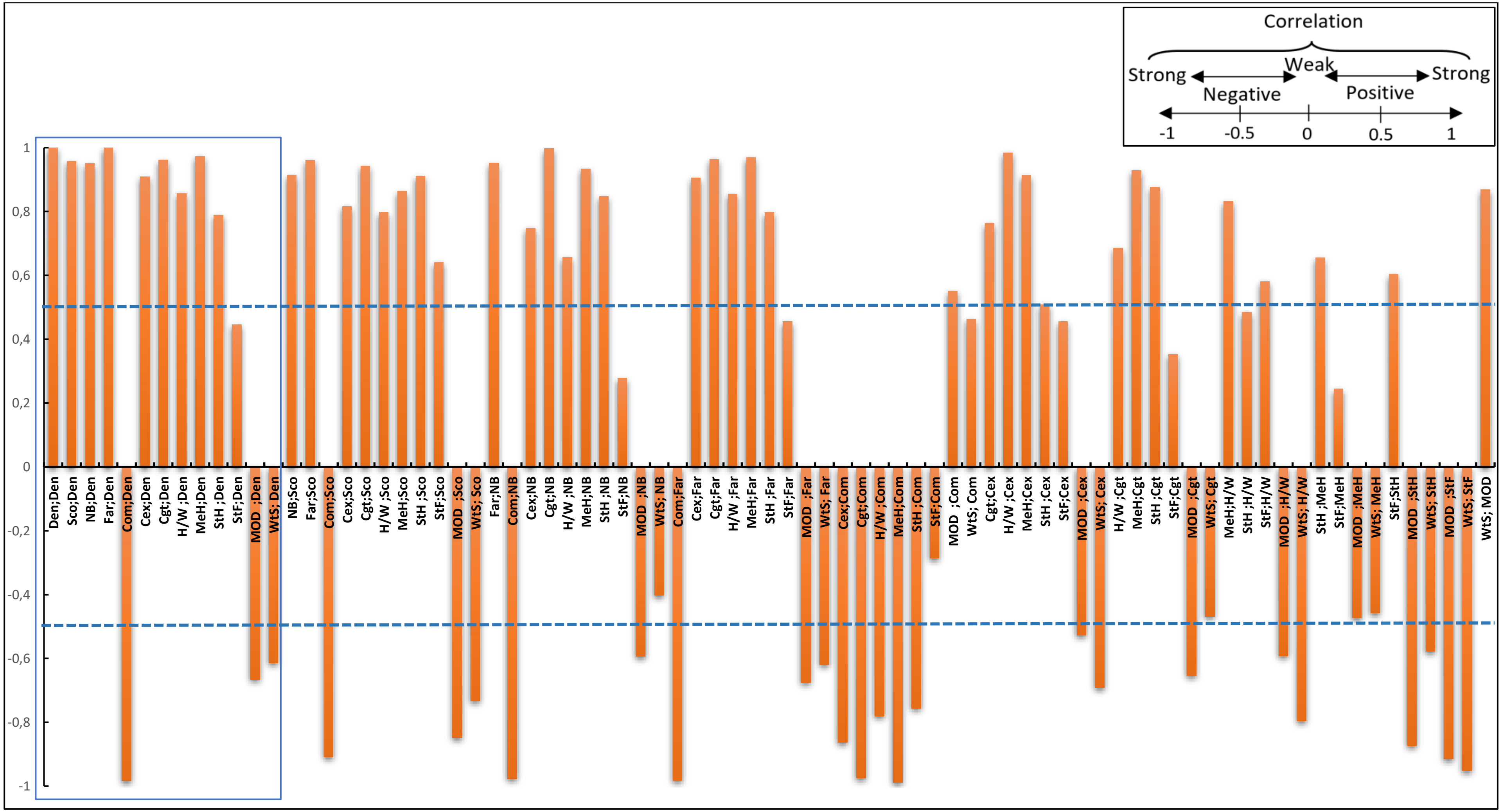


Figure VI- 1. Grouped histogram presents the Pearson correlation results for the urban form indicators of the case studies.

VI.3. Heating and cooling seasons

As explained in chapter V section 6.2, the method of heating and cooling degree-days was used to identify the warm and cold seasons. The results are shown in figure VI- 2. We can observe that, for Constantine's present climate, the heating season is from October 18th to May 20th and the cooling season corresponds to the remaining 150 days of the year. For the future climate, there is a shortening of the heating season and an extension of the cooling season by a few weeks; the latter extends from October 25th to April 30th.

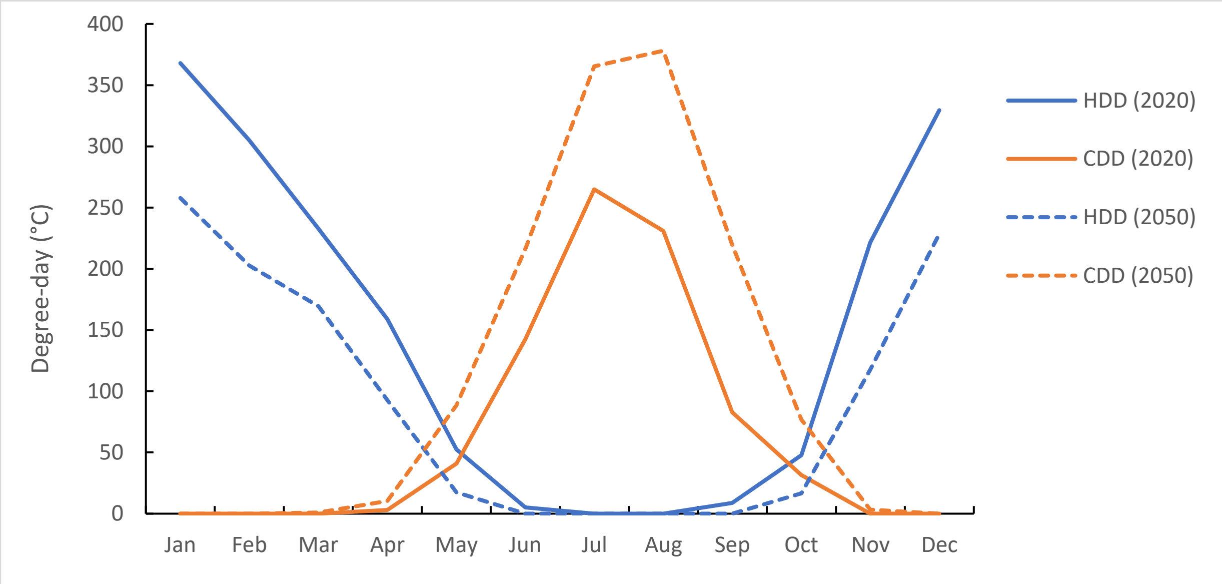


Figure VI- 2. Heating and cooling degree-day for present and future climate in the city of Constantine.

VI.4. Calibration energy model of the urban form

In this section we seek to explain the results and the application of the model calibration procedure. To understand the adjusting temperatures explained in chapter V section 5, the procedure for each urban form is illustrated in figures VI- 3, VI- 4, VI- 5, and VI- 6. Annexee 5 summarizes this adjusting and the modelling error for each point in the simulation test.

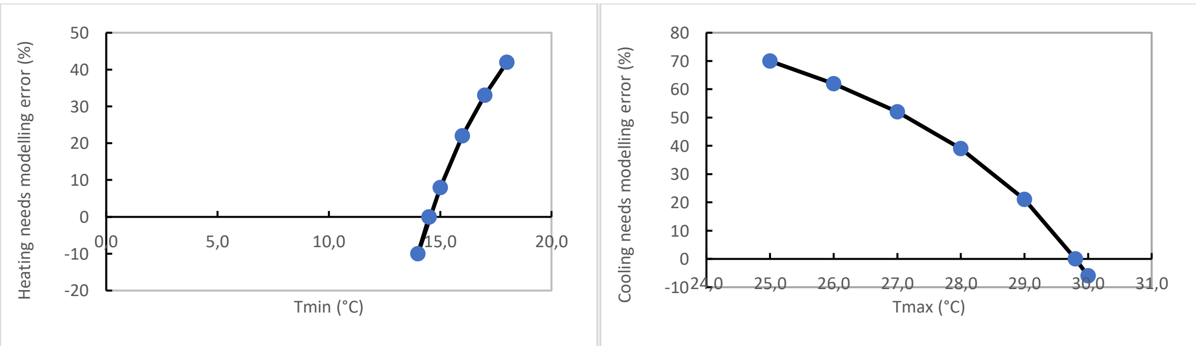


Figure VI- 3. Heating and cooling needs modelling error using the adjusting of minimum and maximum temperature, respectively, in urban form A.

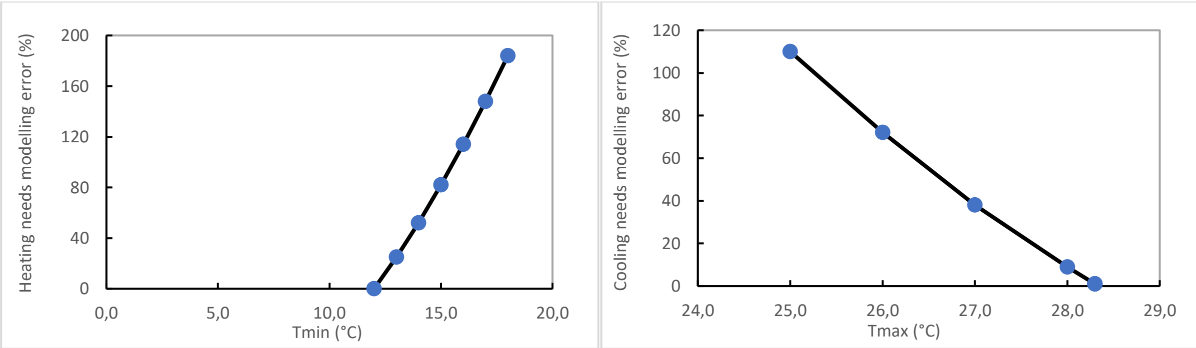


Figure VI- 4. Heating and cooling needs modelling error using the adjusting of minimum and maximum temperature, respectively, in urban form B.

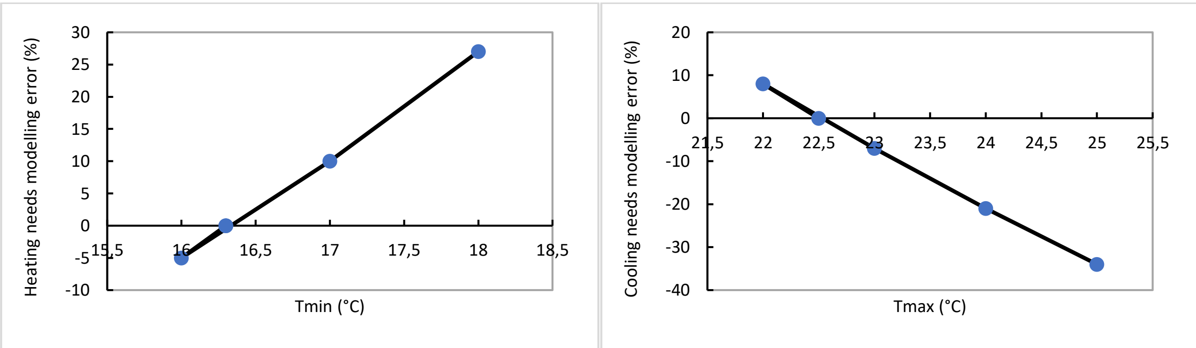


Figure VI- 5. Heating and cooling needs modelling error using the adjusting of minimum and maximum temperature, respectively, in urban form C.

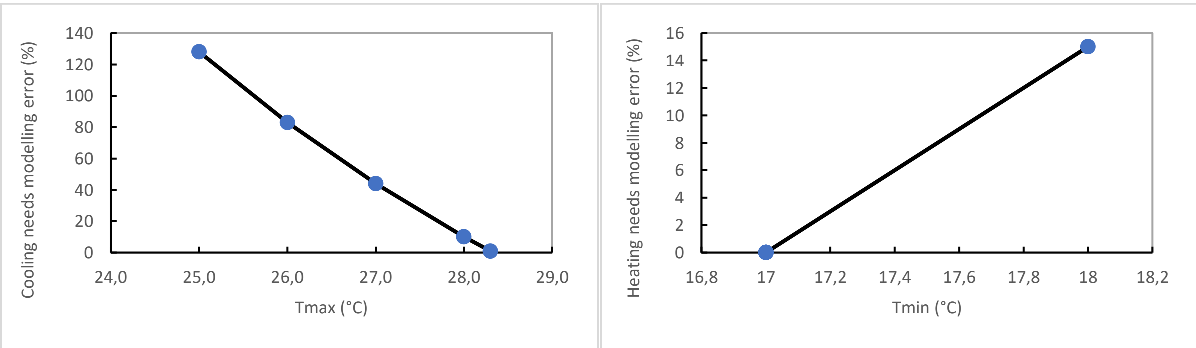


Figure VI- 6. Heating and cooling needs modelling error using the adjusting of minimum and maximum temperature, respectively, in urban form D

Interpreting the above figures VI- 3, VI- 4, VI- 5, and VI- 6, it can be seen that to perform the heating calibration, the temperature adjustment starts to decrease from 18°C to 14.5, 12, 16.3, and 17°C in the urban forms A, B, C, D, respectively. On the other hand, the cooling calibration procedure shows an increase in temperature adjustment from 25°C to 29.8, 28.3, and 28.3°C, in the three cases A, B, D, respectively. An exception was found in case C where the temperature adjustment is adjusted to 22.5 °C. Table VI- 2 and annexe 5 show the adjusted modelled indoor temperature for the estimated heating and cooling needs for the four urban forms, the differences in the adjustment of the temperature setpoint pairs between the modelled and estimated demand ranging from [0% to 1%].

Table VI- 2. Modelled indoor temperature range, estimated heating and cooling needs (kWh/year/m3) and modelling error.

Urban form	T_{min} (°C)	T_{max} (°C)	Estimated heating needs (kWh/year/m^3)	Estimated cooling needs (kWh/year/m^3)	Heating needs modelling error (%)	Cooling needs modelling error (%)
A	14.5	29.8	22.01	3.07	0	0
B	12.0	28.3	12.8	4.53	1	1
C	16.3	22.5	34.88	20.63	0	0
D	17.0	28.3	54.31	7.76	0	1

The value of the adjusted temperature for the calibration explains the energy behavior of each urban form from two perspectives: from a heating perspective, whenever the setting drops from 18°C to a lower temperature, less heating is used during the heating season; from a cooling perspective, whenever the urban form has a higher set temperature, there is less need for cooling.

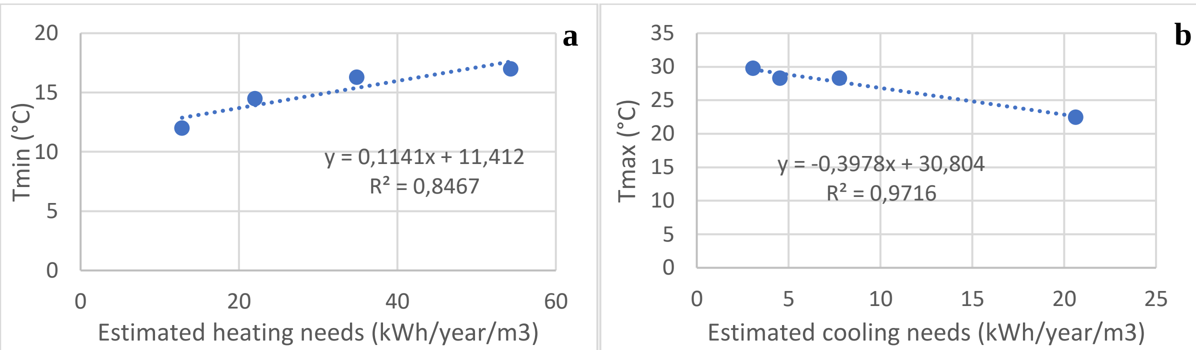


Figure VI- 7. Linear regression models for adjusted minimum temperatures (Tmin) and estimated heating need (a). And for adjusted maximum temperatures (Tmax) and estimated cooling need (b).

It is interesting to note that in all four case studies, the lower the minimum temperature, the more the urban form is suggested to have low heating needs, even under uncomfortable indoor conditions (Figure VI- 7 a). Case B has this favorable profile requiring a low heating need. Furthermore, the lower the maximum temperature, the more the urban forms are suggested to have high cooling needs (Figure VI- 7 b). These results suggest an intensive use of air conditioning in the wealthiest district (urban form C), with a much lower cooling threshold temperature compared to other areas.

In general, cases A and B present a favorable profile in terms of heating and cooling needs compared to the other two urban forms C and D, according to the figure VI- 7 above, one can see that energy demand follows the perceived wealth of each neighborhood, with higher consumption in urban forms C and D, followed by urban forms A and B.

VI.5. Energy improvement at the case studies by assessing energy demand and the potential of solar techniques

VI.5.1. Energy analysis for the case studies (Present/Future)

The buildings in the different urban forms show a clear variation in the intensity of energy use and heating and cooling needs (Figure VI- 8). The range of energy intensity follows the range of heating and cooling needs, where heating needs are linked to gas consumption and electricity is the main source for cooling needs (besides lighting and other household uses). Urban forms A and B, with their compact form of building and small size of streets, have lower heating and cooling needs than the detached buildings in areas C and D. Regarding the heating need only, case B features the lowest value of 13 kWh/m^3/year, followed by cases A, C and the highest value of case D with 54.3 KWh/m3.year. These differences in the ranking of heating needs do not match the differences in the ranking of cooling needs, for which case A presents the lowest value of 3.1 KWh/m3.year, followed by cases B and D with 4.6 and 7.8 KWh/m3.year, respectively. The urban form C requires a high cooling need of 20.6 KWh/m3.year.

From this point of view, and without pointing the explanation to the behaviour of the occupants, it can be argued that cases C and D do not have a high solar gain during the cold season and high-density areas, such as cases A and B, shadows cast by surrounding bildings decrease cooling needs in the cooling season. To better understand the causes of these energy differences, the following sections discuss the impact of urban form indicators on energy consumption in the four urban forms.

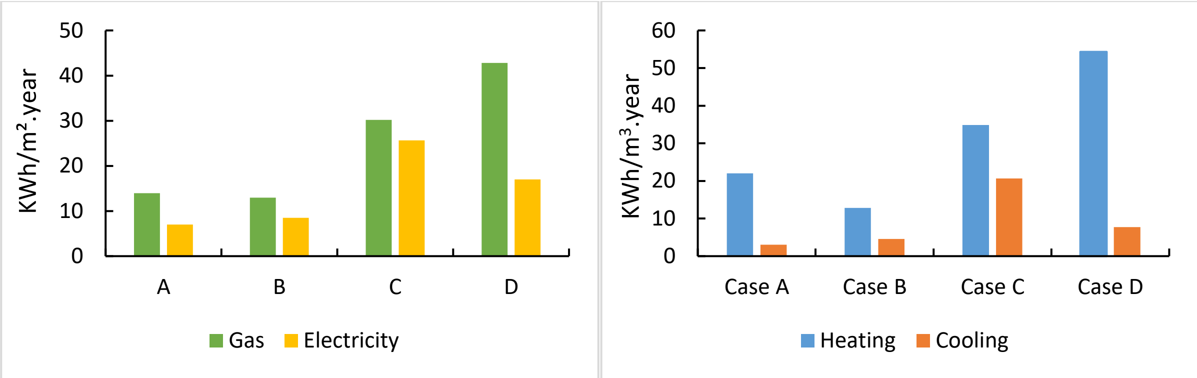


Figure VI- 8. The energy use intensity of the four case studies. The heating and cooling demand of the four case studies.

The future climate characteristics, as discussed in chapter V section 6.1, result in a profile of milder winters and hot summers, which will lead to reduced heating needs in the cold season but higher cooling needs in the hot season, as shown in Table VI- 3 and Figures VI- 9, VI- 10, and VI- 11. During the cold season, the decrease in heating needs varies between -40% in urban form D and -62% in urban form B. On the other hand, during the hot season, the increase in cooling needs varies between +34% for urban form C and +56% for all urban forms.

Regarding the heating needs, the significant change in urban form B results from increased solar gains in winter due to its curved alignment. The increase in cooling requirements during the summer is more pronounced for all urban forms, the three urban forms A, B and D have an increase of more than 50%. The exception was found in urban form C, characterized by compact and detached buildings form, which achieved the highest resilience with an increase of less than 35%.

Table VI- 3. Effect of future climate on heating and cooling needs.

	Heating needs ($kWh/year/m^3$)		**Cooling needs ($kWh/year/m^3$)**	
	2020	2050	2020	2050
A	22	11.2	3.1	7.4
B	13	4.9	4.6	9.8
C	34.9	20.2	20.6	31.1
D	54.3	32.5	7.8	17.5

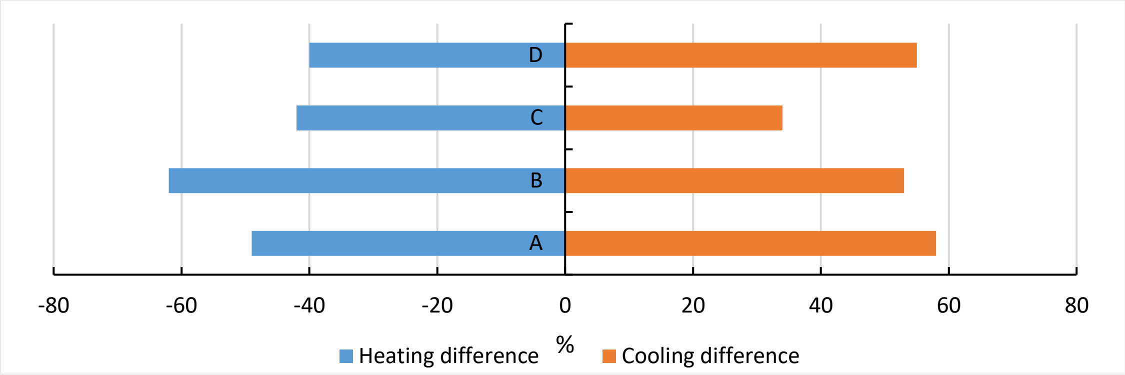


Figure VI- 9. The heating and cooling demand of the four case studies in the future climate.

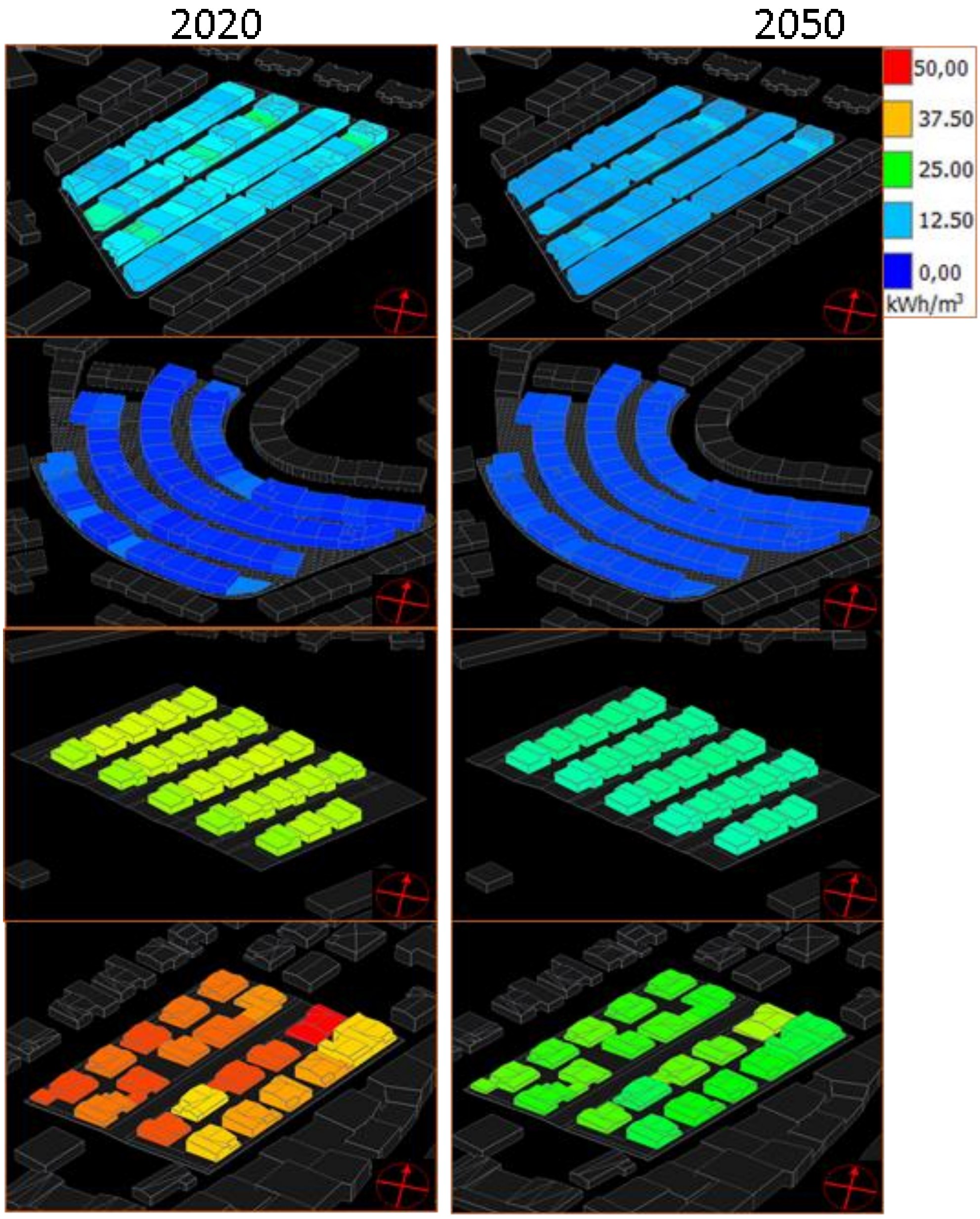


Figure VI- 10. The present and future heating needs of the four case studies

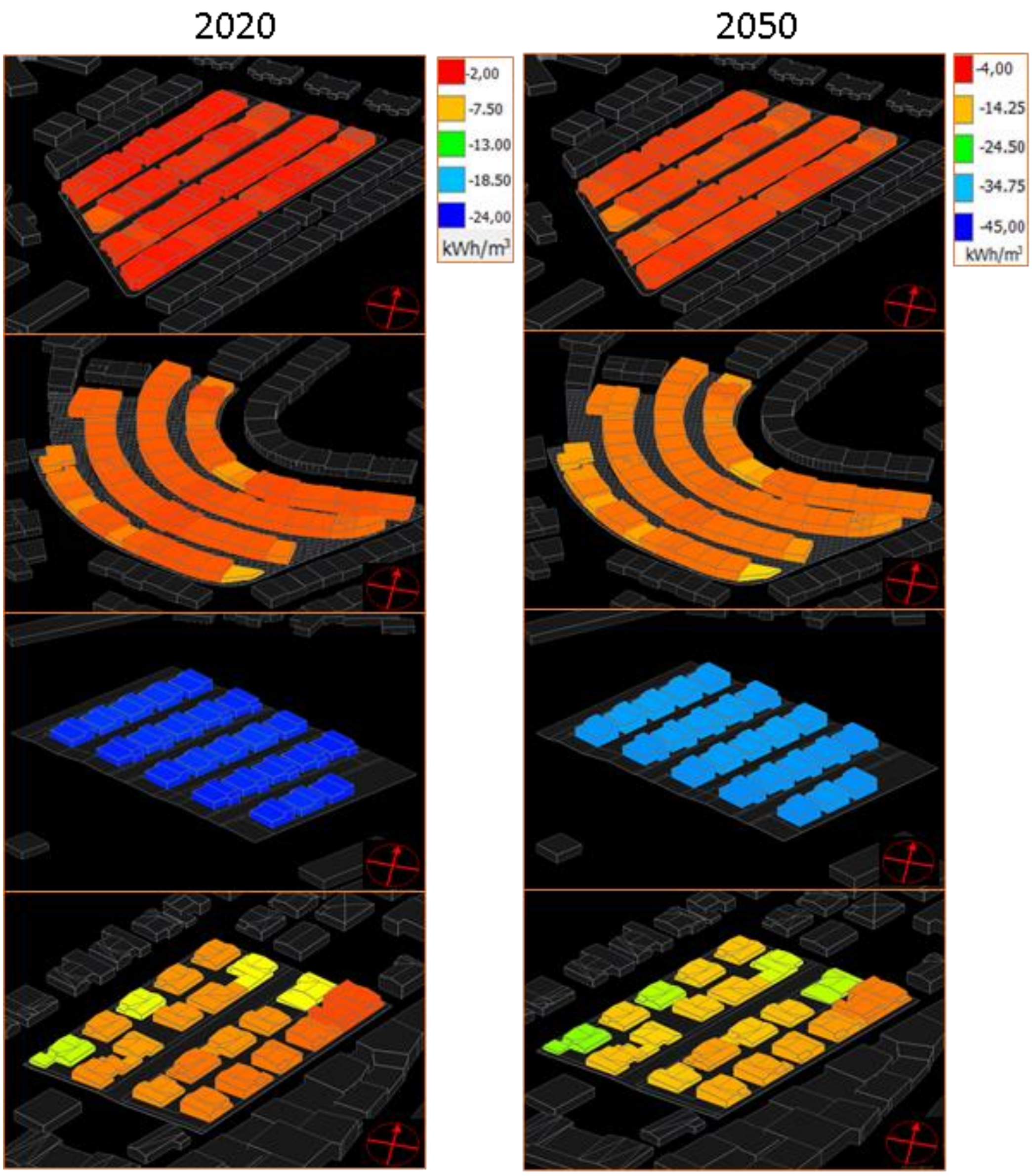


Figure VI- 11. The present and future cooling needs of the four case studies.

VI.5.2. Impact of urban form indicators on energy demand

To demonstrate the impact of the selected urban form factors (density, compactness, standard deviation of building floor area, mean outdoor distance, and thermal transmittance (U) of the building envelope) on the energy demand (heating and cooling needs) in the present and future scenarios, a correlation study was carried out, firstly, with a combined plot (fig. IV- 12) showing the heating and cooling demand (bars) and the urban form indicator (curve).

In a second step and for further analysis, a linear regression analysis is performed between urban form factors with heating and cooling needs., as well as between the urban form factors and the differences in heating and cooling needs extracted in the future.

In the two scenarios, there is a strong anticorrelation between the density and the heating and cooling needs, with low heating and cooling needs for high density in urban forms A and B, and high energy needs for the lower density of urban forms C and D (Figure VI- 12). Referring to the linear regression (figure VI- 13), the relationship is higher with R^2 being particularly high for heating needs in the current (0.756) and future (0.770) scenario, for cooling needs, the relationship in the current climate is not higher (0.548) in comparison to the future climate (0.709). Following the relationship between density and the differences in heating and cooling needs between the two scenarios (figure VI- 14), it is found that density has a strong correlation with the differences in heating needs (0.662) than with the differences in cooling needs (0.334). These results show that density has a strong impact on heating and cooling requirements in both present and future scenarios and that its impact is more noticeable on gaps in heating needs than on cooling needs over the years.

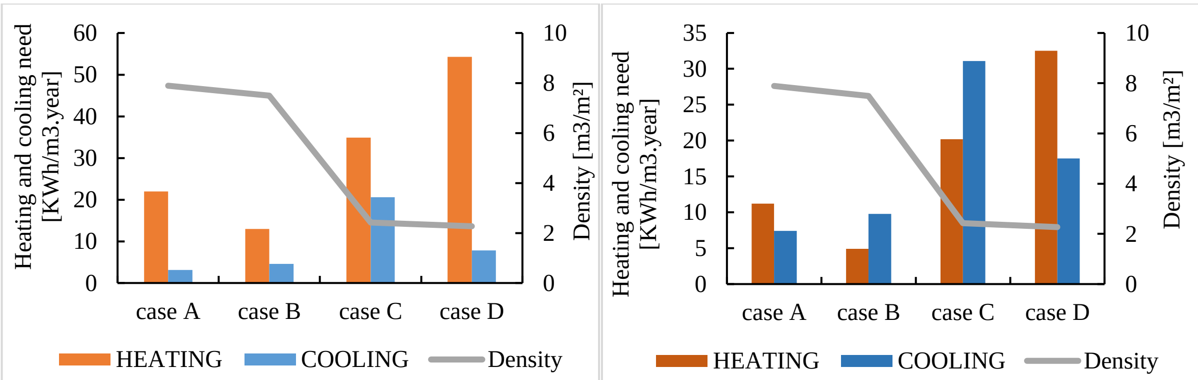


Figure VI- 12. Present (left) and future (right) heating and the cooling needs, and density of the four case studies.

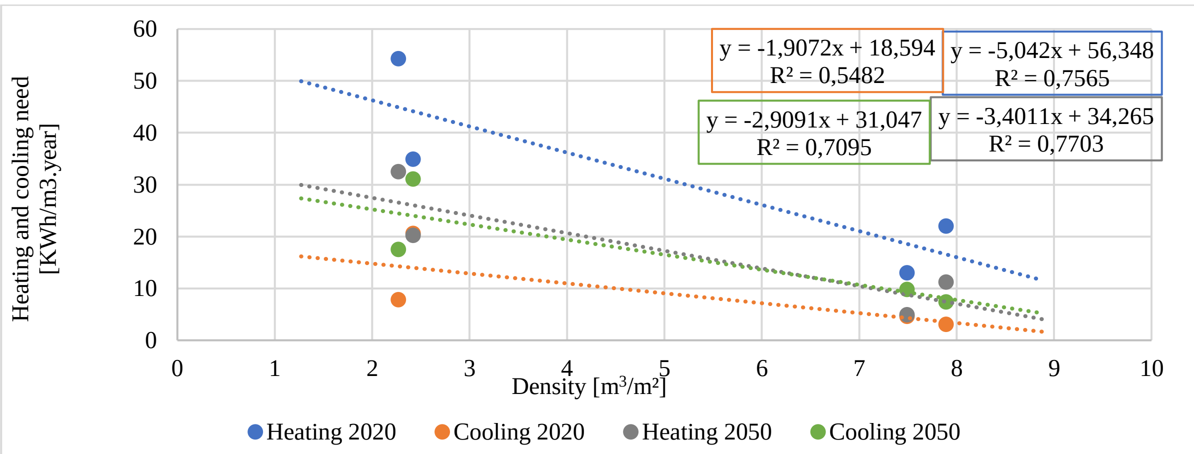


Figure VI- 13. Linear regression models for the density and the heating and cooling needs of the 4 case studies.

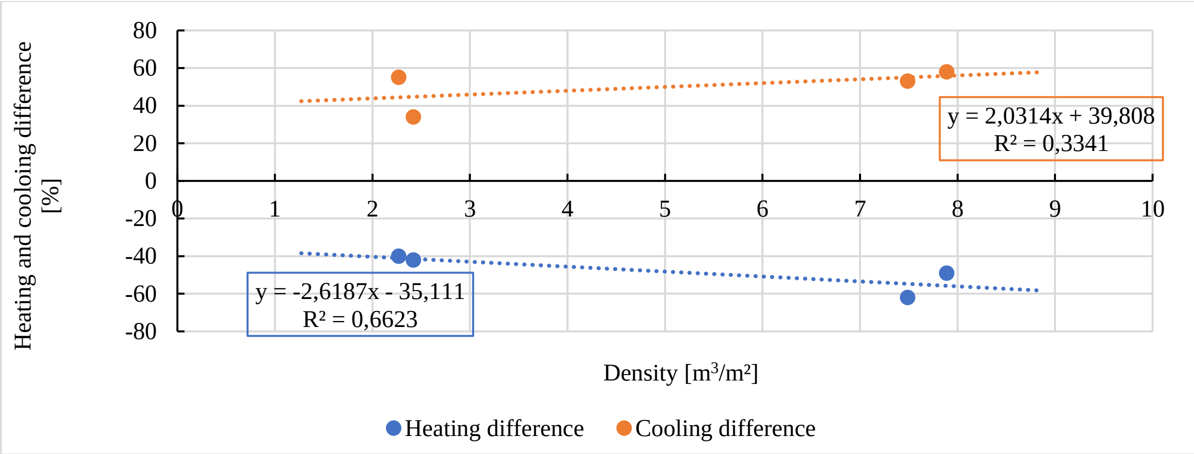


Figure VI- 14. Linear regression models for the density and the difference of heating and cooling needs between the present and the future climate scenario of the four case studies.

The correlation study between compactness and heating and cooling needs shows an opposite relationship with density (Figure VI- 15), in the present and future climates: the more compact the urban forms (C and D) the higher are the heating and cooling needs, and vice versa. For the linear regression models for compactness with heating and cooling needs (Figure VI- 16), the result shows a strong relationship between compactness and heating needs in both scenarios, with an R^2 of 0.884 and 0.886, respectively, while the relationship with cooling needs is weaker in both climates. The linear regression models for the compactness and the heating and cooling need gaps in the future display high relationship between compactness and the heating need gap (Figure VI- 17), in contrast to the weak relationship with the cooling need gap. This acknowledges that the impact of compactness is important in energy, and it is more pronounced with the development of heating needs through the years.

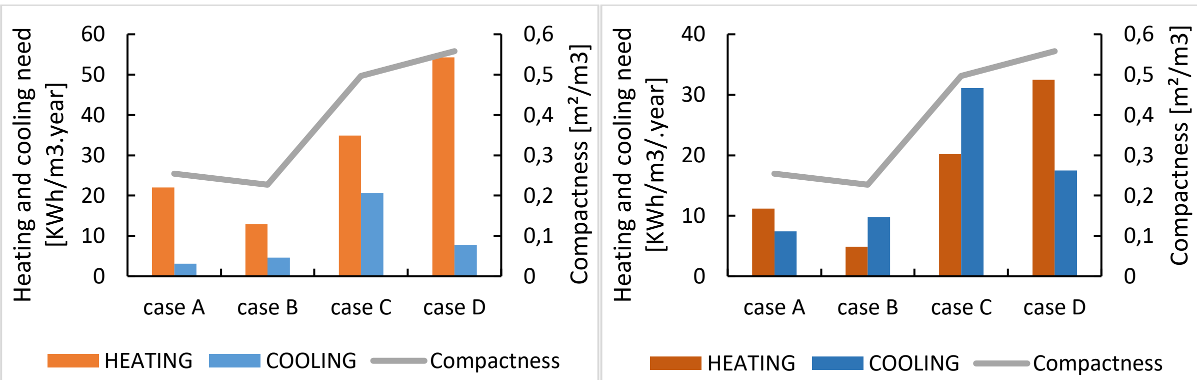


Figure VI- 15. Present (left), future (right) heating and cooling needs as well compactness of the 4 case studies.

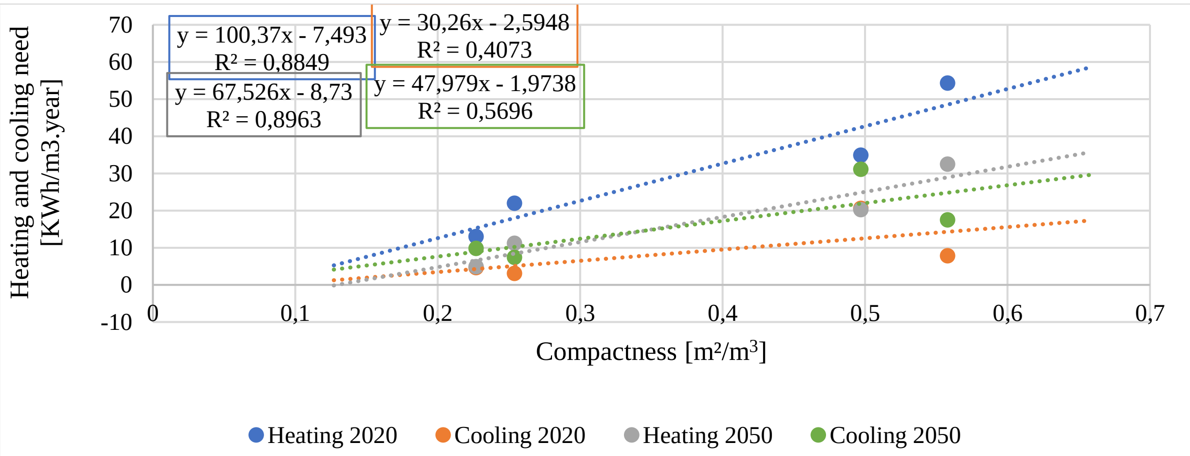


Figure VI- 16. Linear regression models for the compactness and the heating and cooling needs of the 4 case studies.

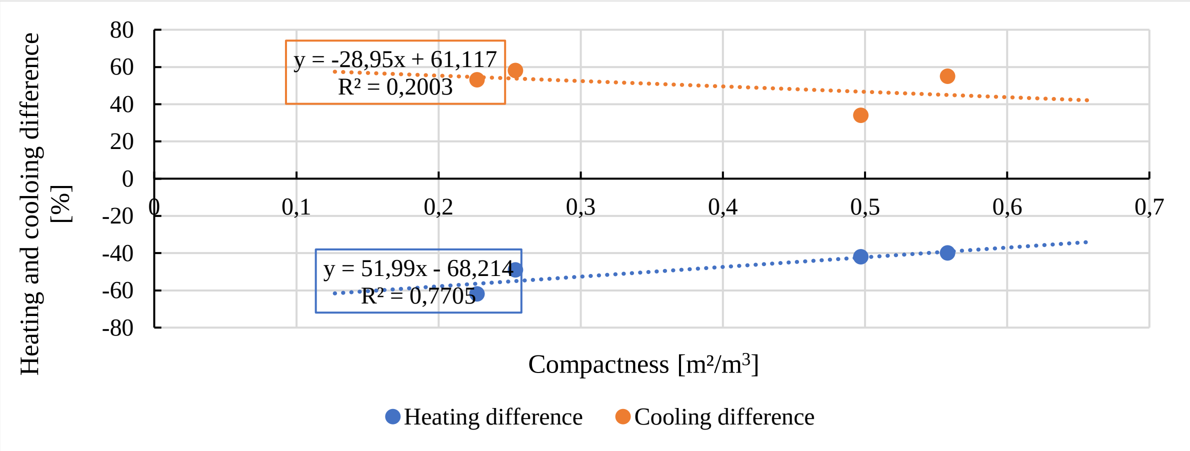


Figure VI- 17. Linear regression models for the compactness and the difference of heating and cooling needs between the present and the future climate scenario of the 4 case studies.

The results presented in figure VI- 18 do not indicate a clear dialogue between the standard deviation of the building footprint area and the heating and cooling needs. It can be seen that a high standard deviation of the footprint corresponds to low cooling needs (urban forms A, B and D), and high cooling needs reflect a low or zero standard deviation of the footprint (urban form C). For the linear regression models, figure VI- 19 shows a high relationship between the standard deviation of the building footprint and the cooling needs in both climates. Unlike, the relationship between this urban form factor and heating needs is very weak. Furthermore, when examining the linear regression models for the standard deviation of the building footprint area and the changes in the development of heating and cooling needs over years (figure VI- 20), the relationship of the model is high with the second change where R^2 is 0.937 compared to the first change in heating needs where R^2 is 0.008.

Thus, the standard deviation of building floor area, appears to have a strong impact on energy needs, particularly on cooling needs.

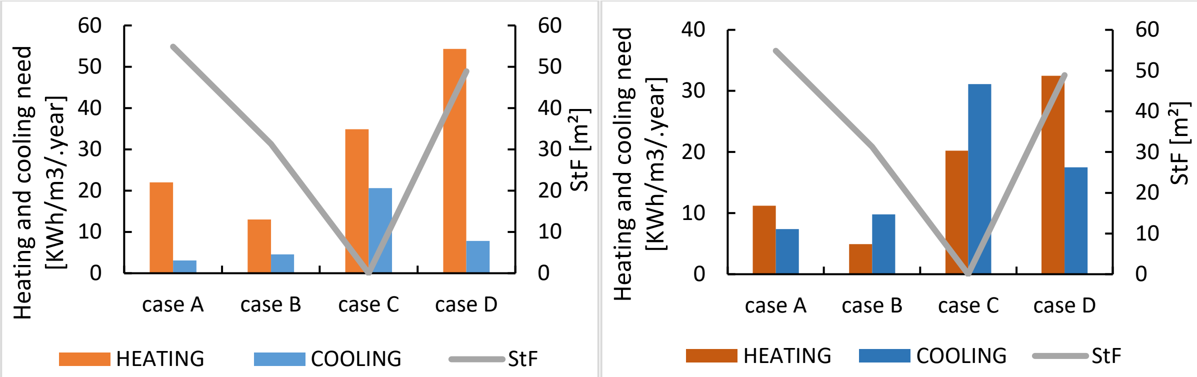


Figure VI- 18. Present (left), future (right) heating and the cooling needs as well standard deviation of building footprint area of the 4 case studies.

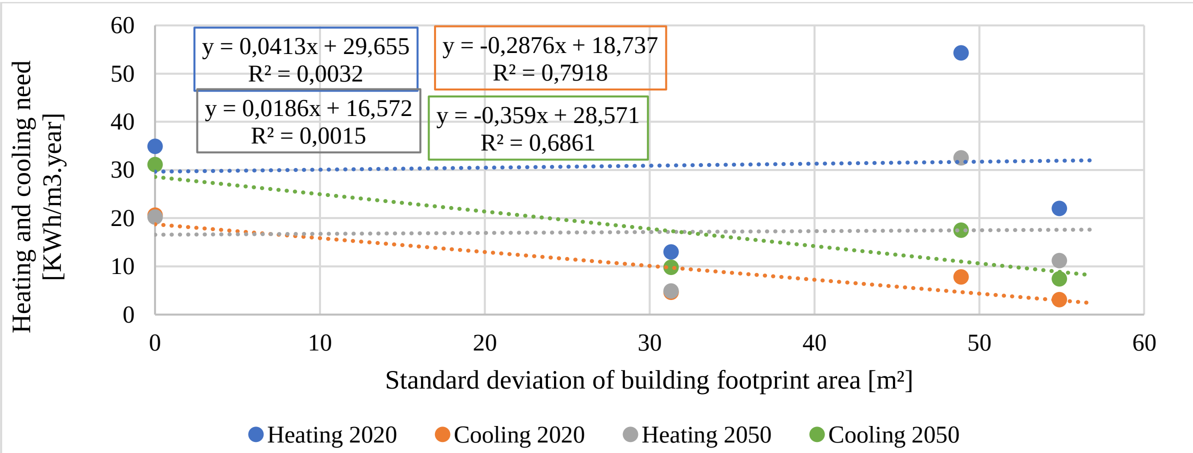


Figure VI- 19. Linear regression models for the standard deviation of building footprint area and the heating and cooling needs of the 4 case studies.

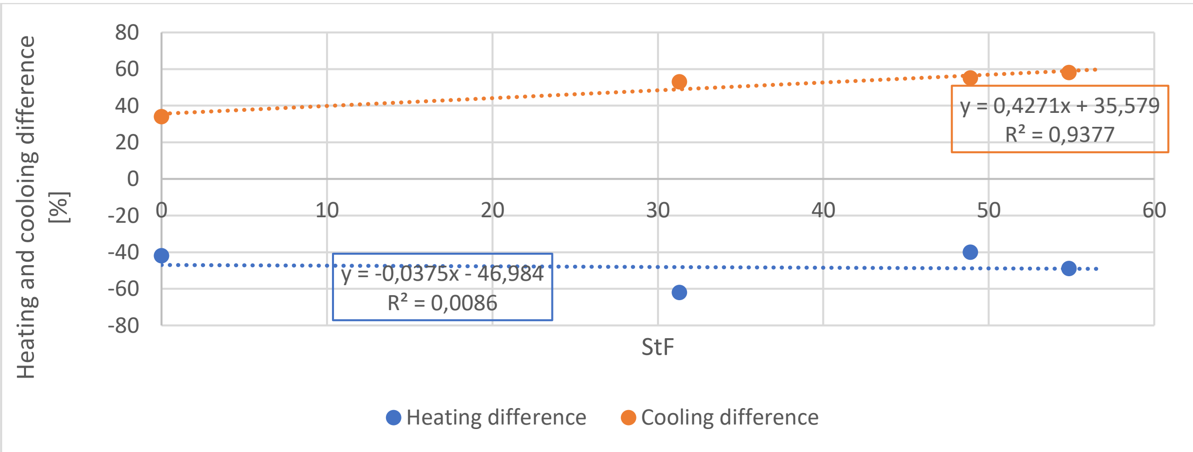


Figure VI- 20. Linear regression models for the standard deviation of building footprint area and the difference of heating and cooling needs between the present and the future climate scenario of the 4 case studies.

Figure VI- 21 shows an understandable correlation between the mean outdoor distance and the cooling needs. In the present and future climate, the low cooling needs in urban forms A, B and D are reflected in a low value of the mean outdoor distance, case C with its high cooling needs has a high value of the mean outdoor distance. This understandable correlation with cooling needs is not the same for heating needs. Figure VI- 22 follow the same former discussed result, a high relationship is presented with cooling needs in both climates where R^2 is 0.987 and 0.921, respectively, while the relationship is very low with heating needs. For the linear regression models for the average outdoor distance and the difference between heating and cooling needs (figure VI- 23), the respective values are 0.975 and 0.219, thus the mean outdoor distance has a significant impact on the cooling needs and its increases over the years.

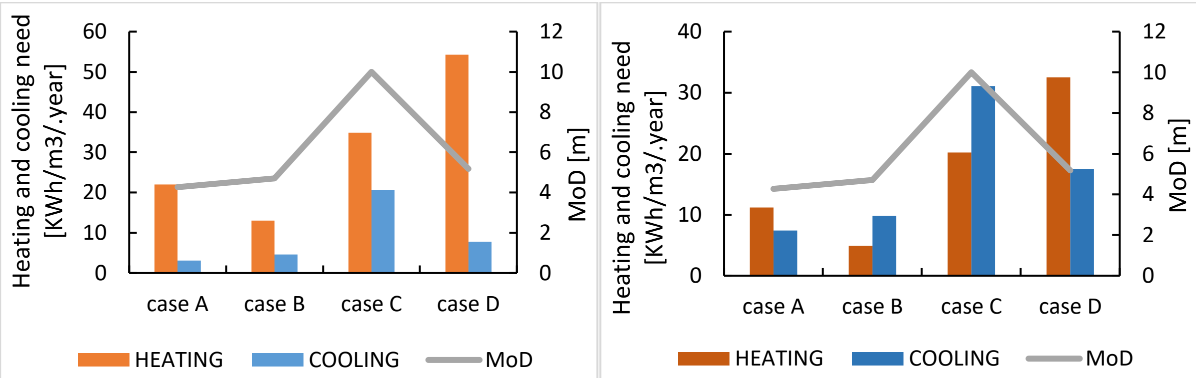


Figure VI- 21. Present (left), future (right) heating and the cooling needs as well mean outdoor distance of the 4 case studies.

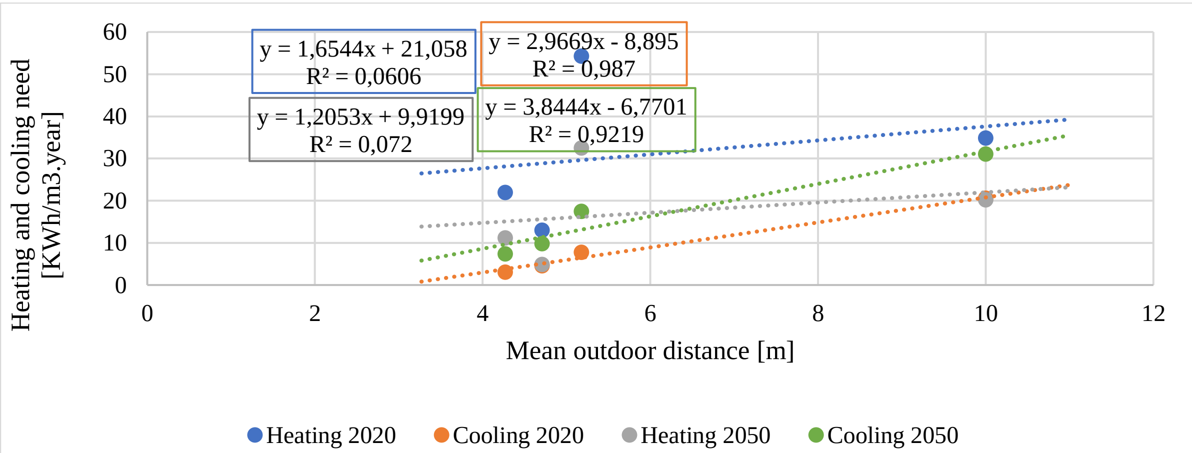


Figure VI- 22. Linear regression models for the mean outdoor distance and the heating and cooling needs of the 4 case studies.

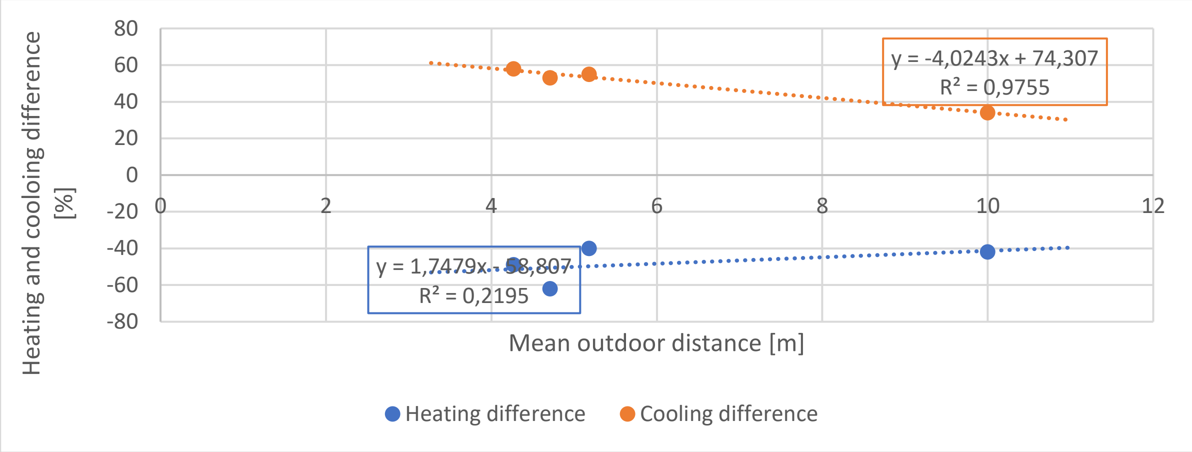


Figure VI- 23. Linear regression models for the mean outdoor distance and the difference of heating and cooling needs, in the present and the future climate scenario of the 4 case studies.

Concerning the impact of the thermal transmittance (U) of the building envelope on the energy needs, figure VI- 24 indicates a low value of thermal transmittance matched with low heating and cooling needs (urban forms A, B and C) and a high U-value with high energy needs in both climate scenarios, the exception being in the present climate with the cooling needs of urban form C. The linear regression models in figure VI- 25 show a high and low relationship of the U-value with heating and cooling needs, respectively, in both climates. The correlation with the differences in heating and cooling needs appears to be weak, with the R^2 (0.305) of the first linear regression being higher than the R^2 (0.094) of the second linear regression. The thermal transmittances (U-value) is an important factor of the envelope of a building strongly affect its energy performance, in all the parts of the building (wall, roof, window, and floor) it controls heat losses and gains from the outdoor environment, and the energy needs of the heating, ventilation, and air conditioning system (Bienvenido-Huertas et al., 2019), referring to figure VI- 26, the results show a clear impact on the heating and cooling needs confirmed by the precedente literature studies (Rodrigues et al., 2019; Teni et al., 2019), but the result presented in figure VI- 26 leads to explain that the U-value has not much impact on the decrease of the heating needs and the increase of the cooling needs over the years. It is important to note that the degradation of thermal transmittance over the years due to ageing or other influences is not considered, as this may introduce a magnitude in the analysis and results.

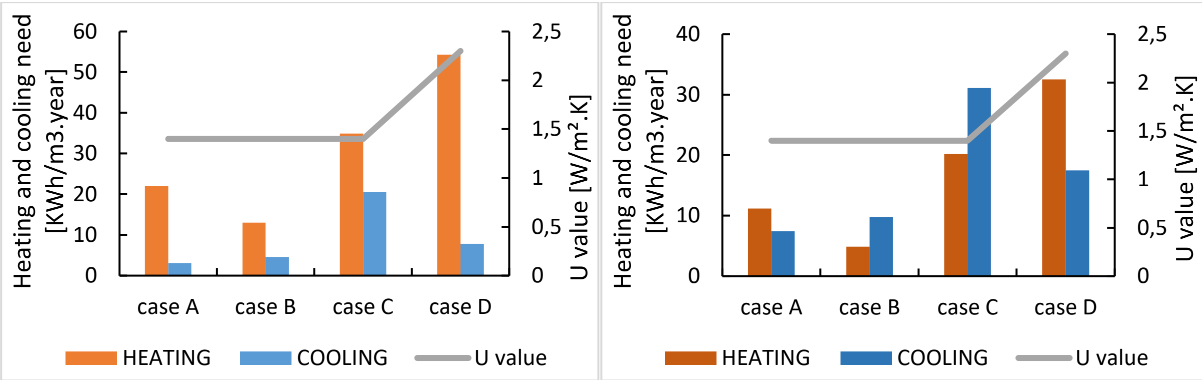


Figure VI- 24. Present (left) and future (right) heating and cooling needs and thermal transmittance (U) of the building envelope of the 4 case studies.

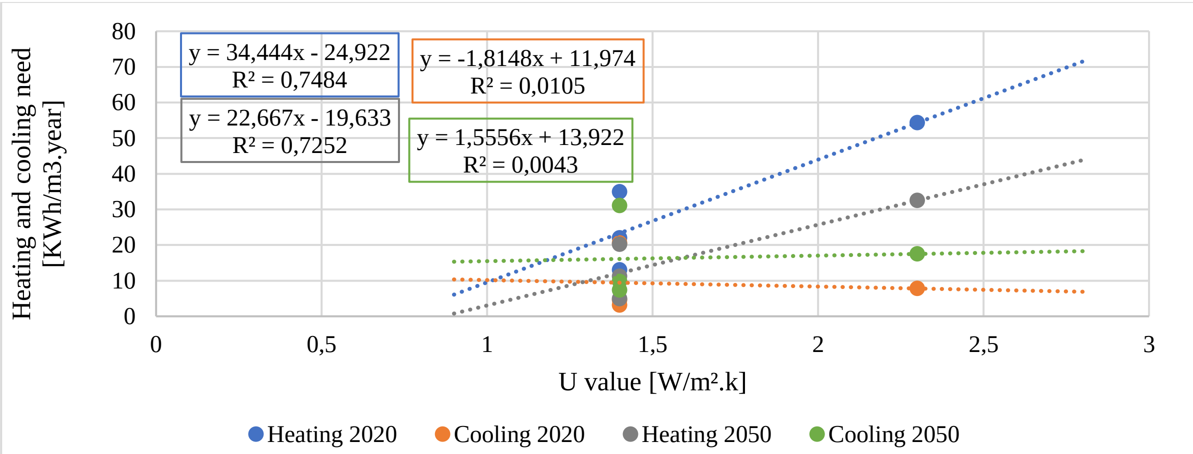


Figure VI- 25. Linear regression models for the thermal transmittance (U) of the building envelope and the heating and cooling needs of the 4 case studies.

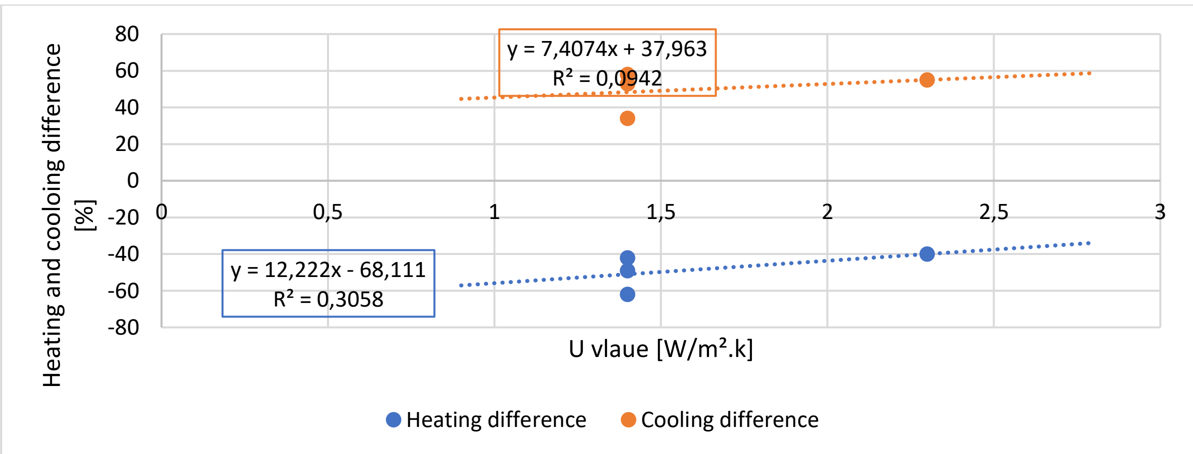


Figure VI- 26. Linear regression models for the thermal transmittance (U) of the building envelope and the difference of heating and cooling needs between the present and the future climate scenario of the 4 case studies.

VI.6. Assessing the potential of solar techniques

VI.6.1. Solar potential in the present and future climate

Solar irradiation availability on façades and roofs are affected by shadow cast and mainly related to the urban form factors (Chatzipoulka et al., 2016), these factors exert different magnitude of impact on solar availability, the openness of the urban form to the sky vault allows to countify the availability of solar irradiation on buildings (Chatzipoulka & Nikolopoulou, 2018; Chatzipoulka et al., 2020).

As mentioned in section 6.1 of Chapter V, in figure V- 4, the amount of solar irradiation is expected to increase during the cold season but decrease during the summer months for the future climate, other studies have been carried out in other regional climate modelling show the same scenario (Soares et al., 2019). To further investigate these differences, a comparative study of the effect of the future climate on the average yearly solar irradiation of façades and roofs is illustrated in table VI- 4, the results display practically no difference between the current and future average solar irradiations of the façades, on the other hand a remarkable difference is found between the current and future solar irradiations of the roofs, urban forms A and D feature an increase of 10% and16%, respectively, while the average solar irradiations of the roofs decrease by 6% in urban form B and by 17% in urban form C.

In the present climate, the results indicate that the mean solar irradiation on the roofs is high, almost 45% than the mean solar irradiations on the façades in all the cases, except in case C where it is 12%. On the other hand, the future climate still records a lower mean solar irradiation of the façades than that of the roofs by 35% to 50% in the three urban forms A, B and D. Unexpectedly, the mean solar irradiation of the roofs is lower than that of the façades in the urban form C by 6%. This difference is due to the importance of the shadow cast in this urban form compared to the others.

Comparing the mean solar irradiation (W/m²) in the four urban forms, in the facades the values are closre to each other, with urban form B having the highest mean solar irradiation due to its large street width and its adequate slope in the north-east and south-west directions, allowing the solar irradiation to reach the high facade surfaces. For roofs, urban forms A, B and D have the highest value (1400 kWh/m²) while urban form C gets 800 kWh/m². In the future climate, the tilted roofs of urban form D allow the highest solar irradiation (1600 kWh/m²) followed by urban forms A and B.

Table VI- 4. Effect of future climate façade and roof mean solar irradiation (W/m²)

	Façade mean solar irradiation (W/m²)			Roof mean solar irradiation (W/m²)		
	2020	**2050**	**Differences (%)**	**2020**	**2050**	**Differences (%)**
Case A	794934	797863	0	1417454	1576930	+10
Case B	837076	844540	+1	1415880	1329234	-6
Case C	715352	717904	0	809411	672617	-17
Case D	754446	753938	0	1446213	1676984	+16

VI.6.2. Irradiation threshold for assessing passive solar techniques in façades during heating season

This section provides the whole application of the irradiation threshold to evaluate passive solar techniques in all urban forms. The calculated threshold (chapter V section 7.1) during the heating season was assumed to be 187 kWh/m² in the current climate scenario and 120 kWh/m² in the future climate scenario.

Table VI- 5. The appropriate potential of passive solar techniques in façades of urban form A.

A		Total area	Area with suggested threshold	Adequate potential of passive solar techniques
Façades area m².	Present climate	23556,5	9772,25	41%
	Future climate	23556,5	12874,32	55%

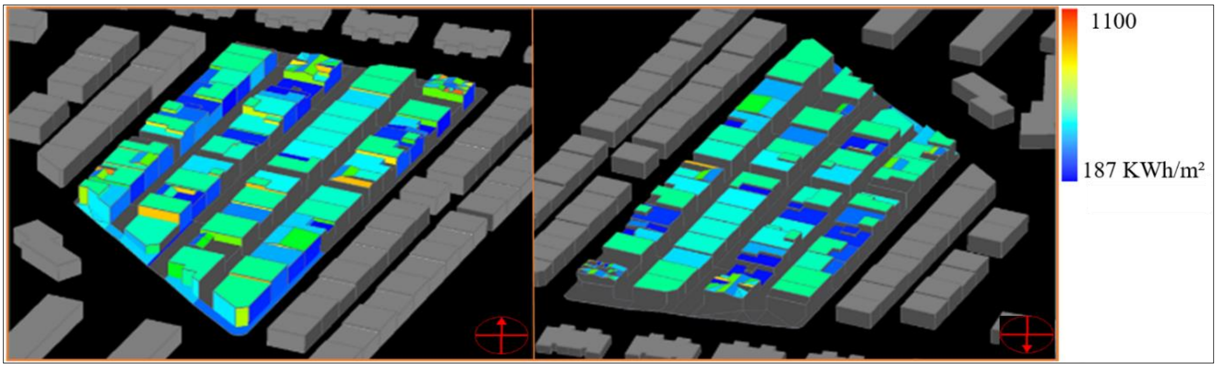


Figure VI- 27. Present (2020) passive solar availability in façades applying a threshold of 187 kWh/m² for urban form A, South view (left) and north view(right).

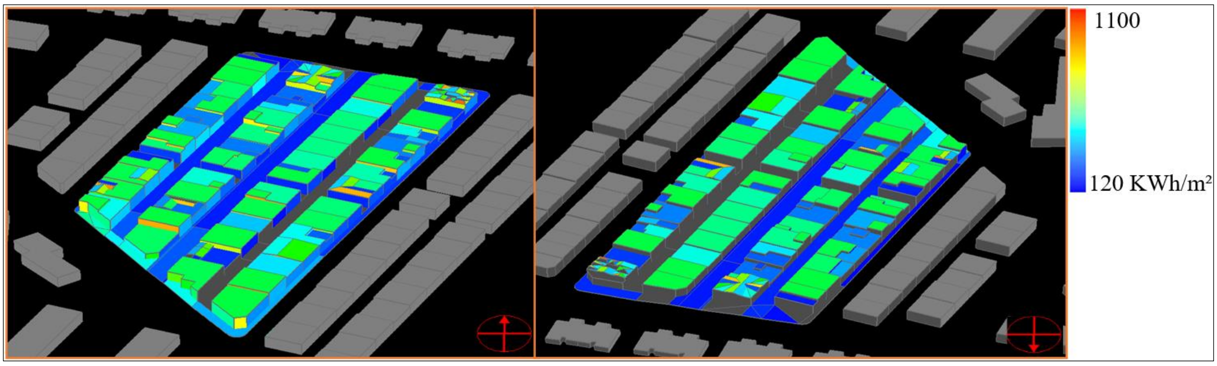


Figure VI- 28. Future (2050) passive solar availability in façades applying a threshold of 120 kWh/m² for urban form A, South view (left) and north view(right).

Table VI- 6. Adequate potential of passive solar techniques in façades of urban form B.

B		Total area	Area with suggested threshold	Adequate potential of passive solar techniques
Façades area m².	Present climate	25187,13	14381,74	57%
	Future climate	25187,13	17195,89	68%

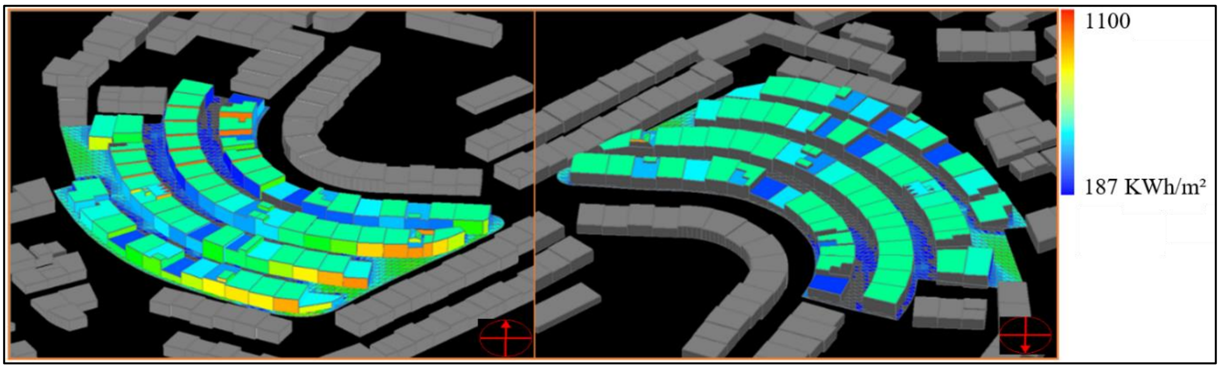


Figure VI- 29. Present (2020) passive solar availability in façades applying a threshold of 187 kWh/m² for urban form B, South view (left) and north view(right).

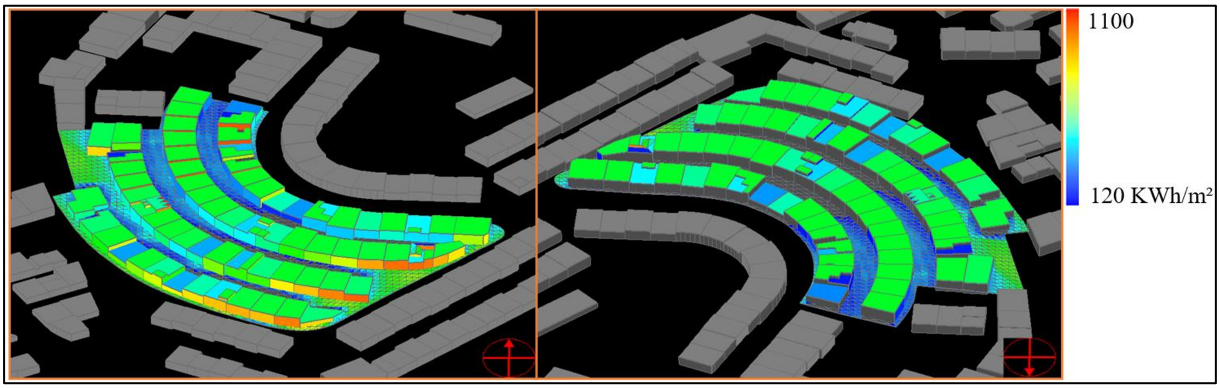


Figure VI- 30. Future (2050) passive solar availability in façades applying a threshold of 120 kWh/m² for urban form B, South view (left) and north view(right).

Table VI- 7. Adequate potential of passive solar techniques in façades of urban form C.

C		**Total area**	**Area with suggested threshold**	**Adequate potential of passive solar techniques**
Façades area m².	Present climate	10267,2	3682,8	36%
	Future climate	10267,2	5133,6	50%

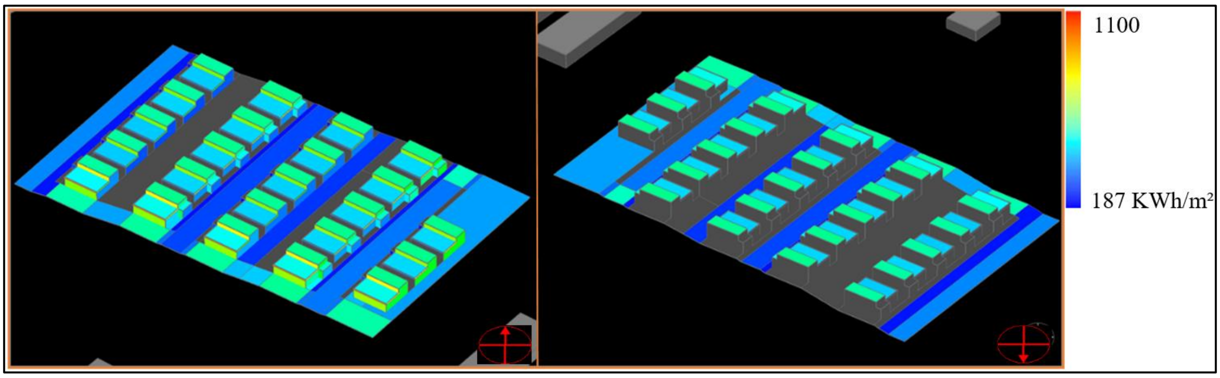


Figure VI- 31. Present (2020) passive solar availability in façades applying a threshold of 187 kWh/m² for urban form C, South view (left) and north view(right).

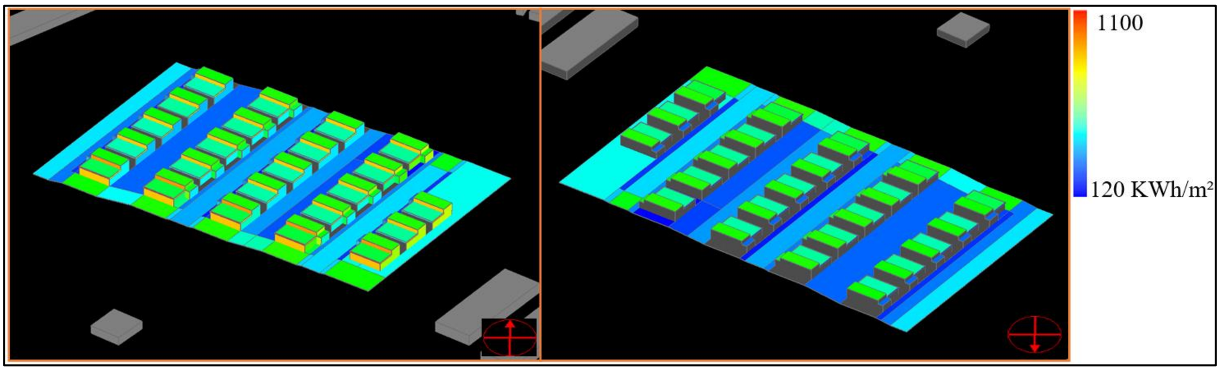


Figure VI- 32. Future (2050) passive solar availability in façades applying a threshold of 120 kWh/m² for urban form C, South view (left) and north view(right).

Table VI- 8. Adequate potential of passive solar techniques in façades of urban form D.

D		**Total area**	**Area with suggested threshold**	**Adequate potential of passive solar techniques**
Façades area m².	Present climate	5144,29	1487,78	29%
	Future climate	5144,29	2239,73	44%

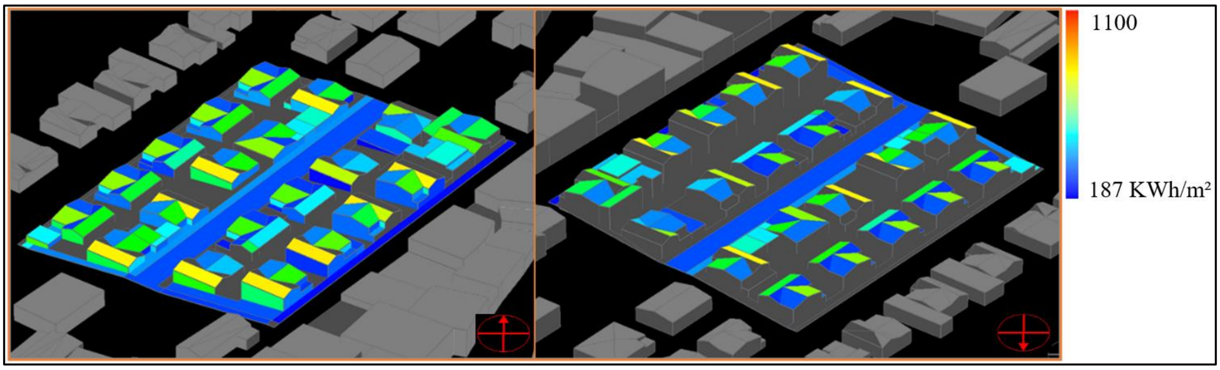


Figure VI- 33. Present (2020) passive solar availability in façades applying a threshold of 187 kWh/m² for urban form D, South view (left) and north view(right).

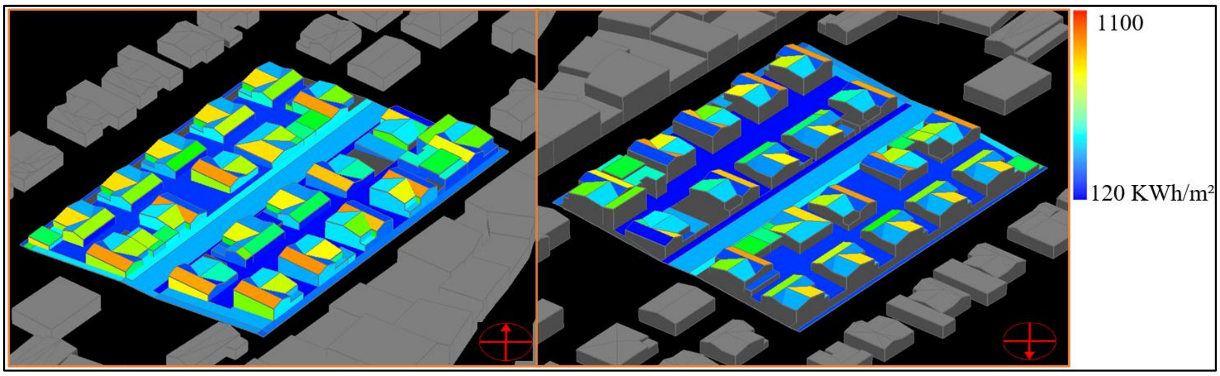


Figure VI- 34. Future (2050) passive solar availability in façades applying a threshold of 120 kWh/m² for urban form D, South view (left) and north view(right).

VI.6.3. Illuminance threshold for assessing daylight

This part deals with the evaluation of daylighting in the four urban forms in the present and future climates. By applying an illuminance threshold of 1000 Lx (chapter V section 7.2) for the façades, the simulated result in this part shows the adequate façade area for the required daylight potential.

Table VI- 9. Adequate potential of daylight (Illuminance) in façade of urban form A.

A		Total area	Area with suggested threshold	Adequate potential of daylight
Façades area m².	Present	23556,5	4916,61	21%
	Future	23556,5	2228,52	9%

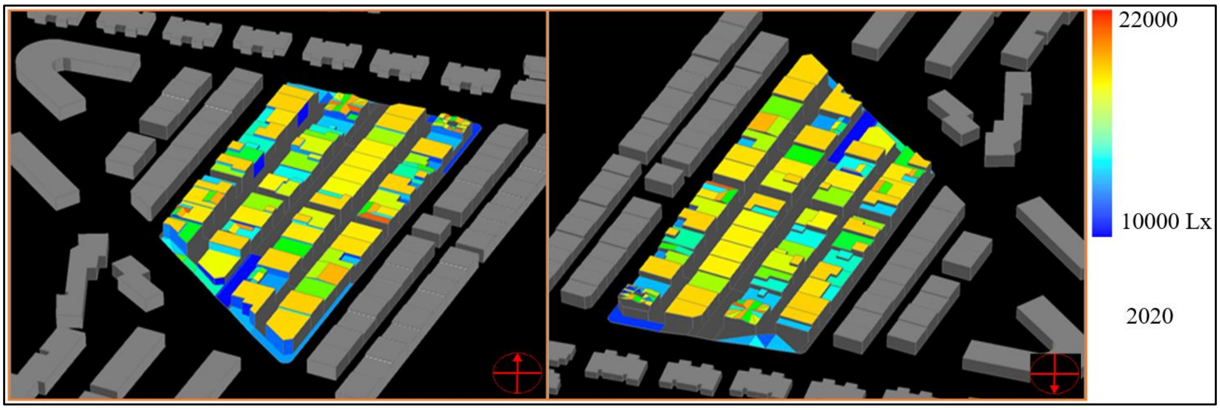


Figure VI- 35. Present daylight availability applying a threshold of 1000 Lx for urban form A, South view (left) and north view(right).

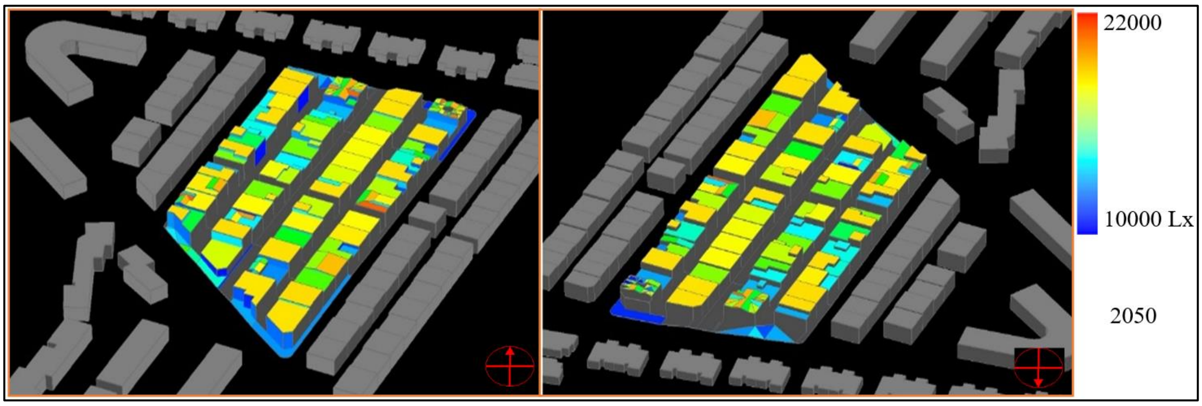


Figure VI- 36. Future daylight availability applying a threshold of 1000 Lx for urban form A, South view (left) and north view(right).

Table VI- 10. Adequate potential of daylight in façades of urban form B.

B		Total area	Area with suggested threshold	Adequate potential of daylight
Façades area m².	Present	25187,13	10848,05	43%
	Future	25187,13	8487,15	34%

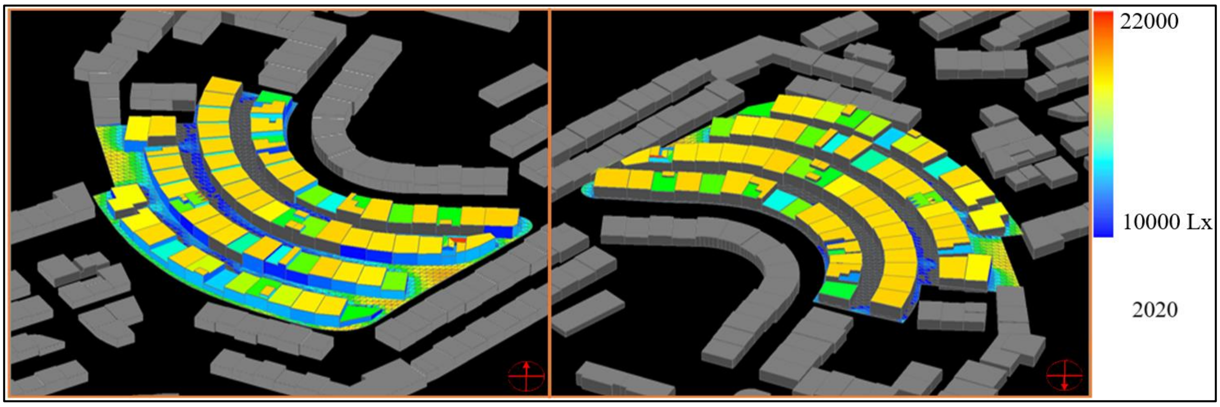


Figure VI- 37. Present daylight availability applying a threshold of 1000 Lx for urban form B, South view (left) and north view (right).

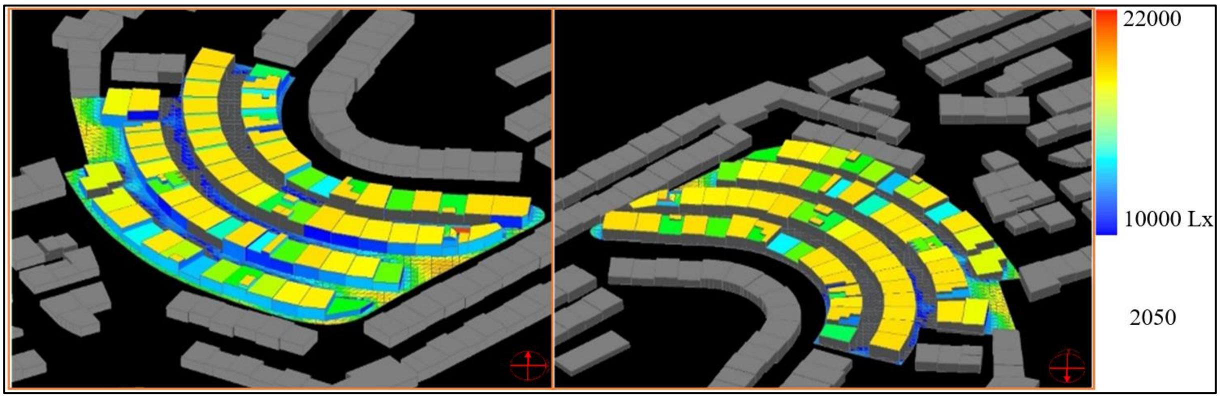


Figure VI- 38. Future daylight availability applying a threshold of 1000 Lx for urban form B, South view (left) and north view (right).

Table VI- 11. Adequate potential of daylight in façades of urban form C.

C		Total area	Area with suggested threshold	Adequate potential of daylight
Façades area m².	Present	10267,2	2318,8	23%
	Future	10267,2	2328,1	23%

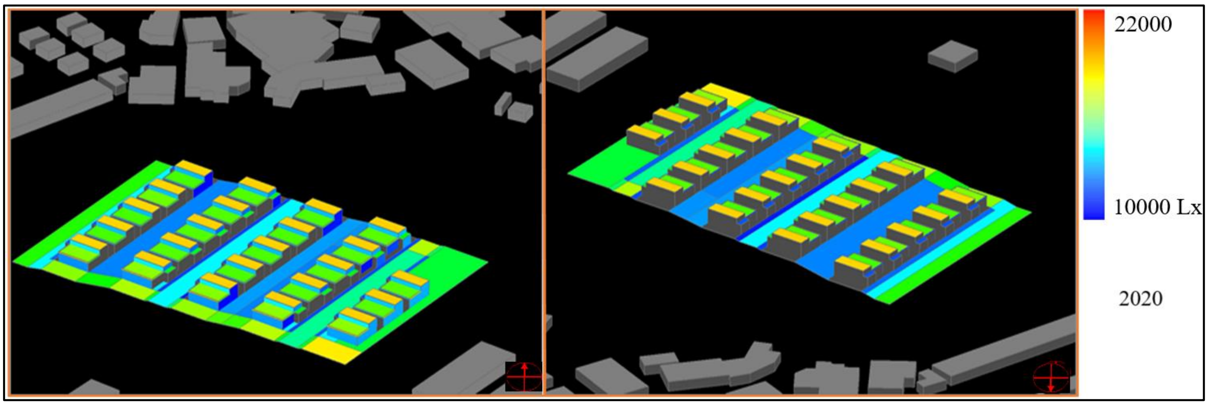


Figure VI- 39. Present daylight availability applying a threshold of 1000 Lx for urban form C, South view (left) and north view (right).

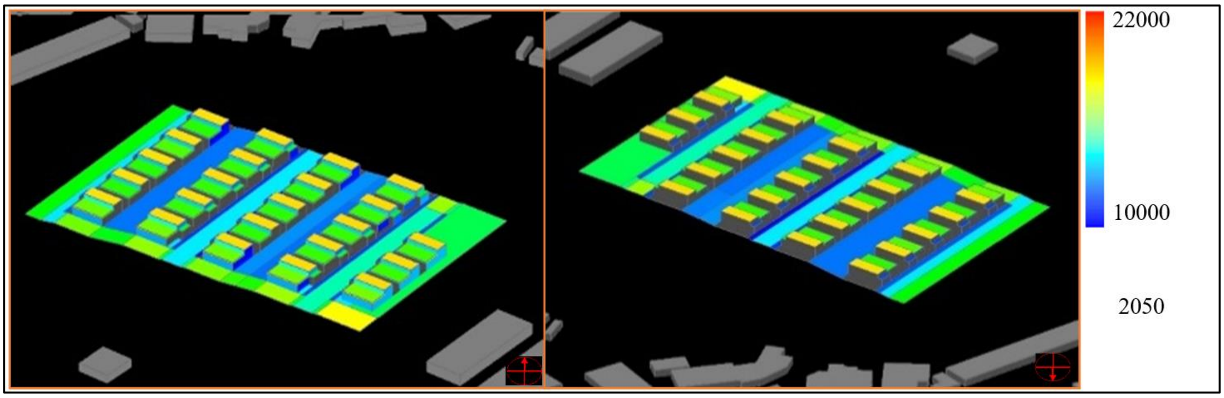


Figure VI- 40. Future daylight availability applying a threshold of 1000 Lx for urban form C, South view (left) and north view(right).

Table VI- 12. Adequate potential of daylight in façades of urban form D.

D		Total area	Area with suggested threshold	Adequate potential of daylight
Façades area m².	Present	5144,29	626,9	12%
	Future	5144,29	445,17	9%

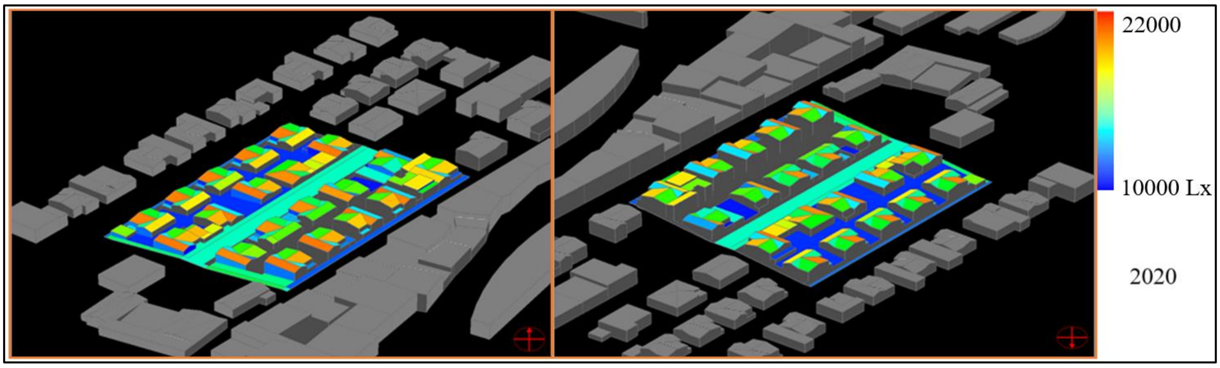


Figure VI- 41. Present daylight availability applying a threshold of 1000 Lx for urban form D, South view (left) and north view (right).

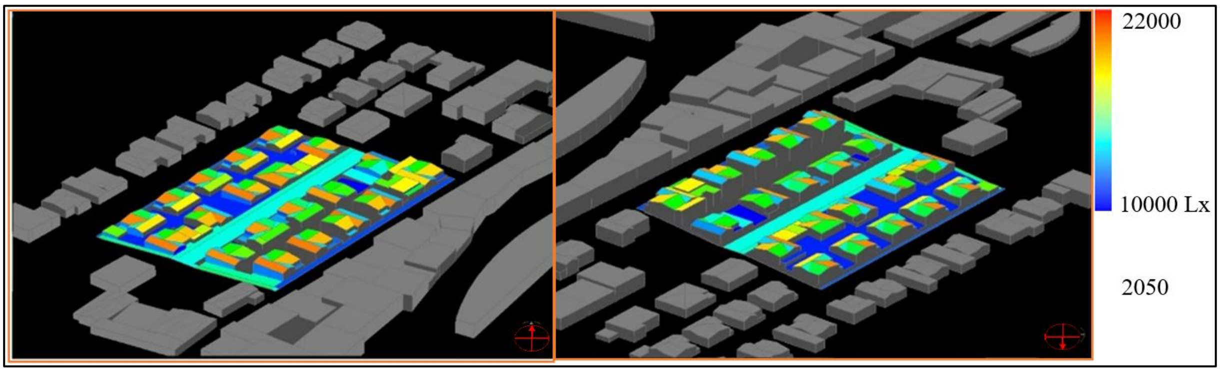


Figure VI- 42. Future daylight availability applying a threshold of 1000 Lx for urban form D, South view (left) and north view (right).

VI.6.4. Irradiation threshold for assessing photovoltaic system integration

In this section, the tables and figures below present the evaluation of the irradiation threshold for photovoltaic technology. As in current and future climates, a threshold of 1000 KWh/m² is set to assess the feasibility of photovoltaic technology on roofs. To assess the feasibility of photovoltaic technology on the façade, the threshold applied is 600 KWh/m² (chapter V section 7.4).

Table VI- 13. Adequate potential for PV systems in façades and roofs of urban form A.

A		Total area	Area with suggested threshold	Potential for PV systems
Surface of the all the building		34104,5	24045,53	71%
Façades area m².	Present	23556,5	13635,51	58%
	Future	23556,5	10236,75	43%
Roof area m².	Present	10466	10410,02	99%
	Future	10466	10318,9	99%

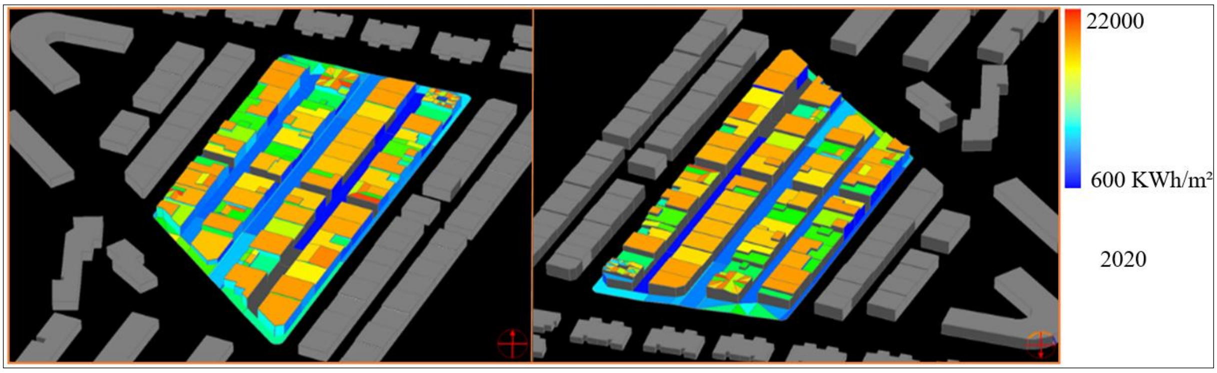


Figure VI- 43. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form A, South view (left) and north view(right) in the present climate.

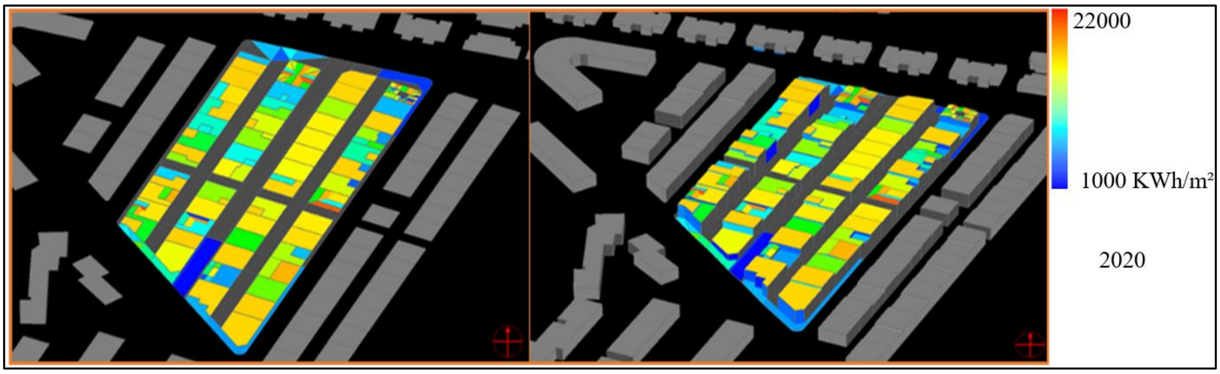


Figure VI- 44. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form A, top view (left) and south view(right) in the present climate.

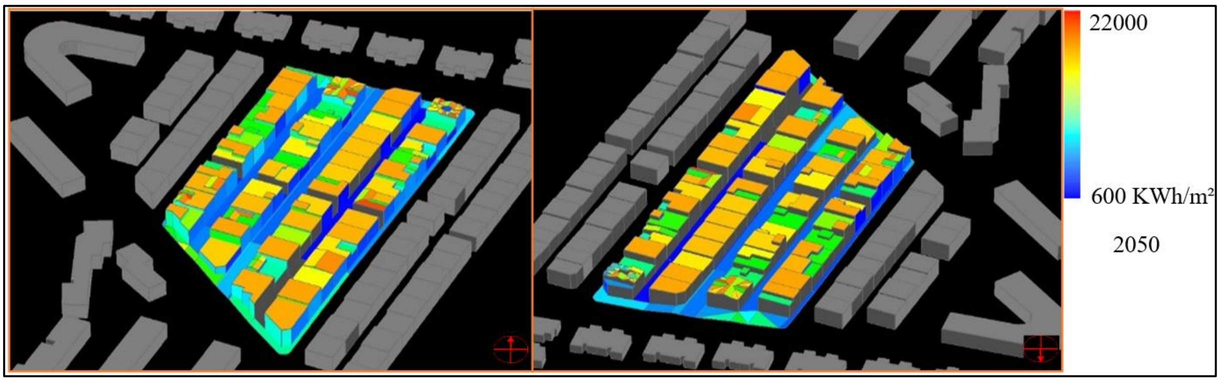


Figure VI- 45. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form A, South view (left) and north view(right) in the future climate.

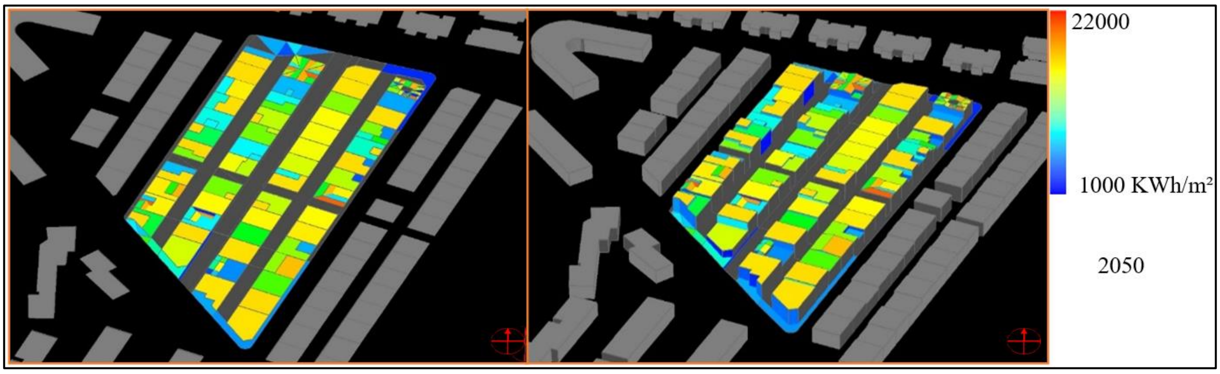


Figure VI- 46. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form A, top view (left) and south view (right) in the future climate.

Table VI- 14.Adequate potential for PV systems in façades and roofs of urban form B.

B		Total area	Area with suggested threshold	Potential for PV systems
Surface of the all the building		39061,02	31436,04	80%
Façades area m².	Present	25187,13	17668,16	70%
	Future	25187,13	14014,8	56%
Roof area m².	Present	13873,89	13767,88	99%
	Future	13873,89	13767,88	99%

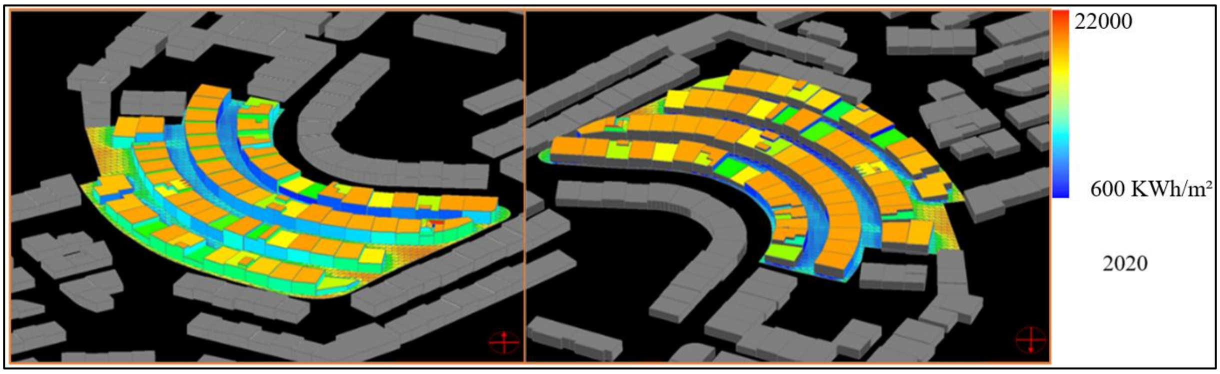


Figure VI- 47. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form B, South view (left) and north view(right) in the present climate.

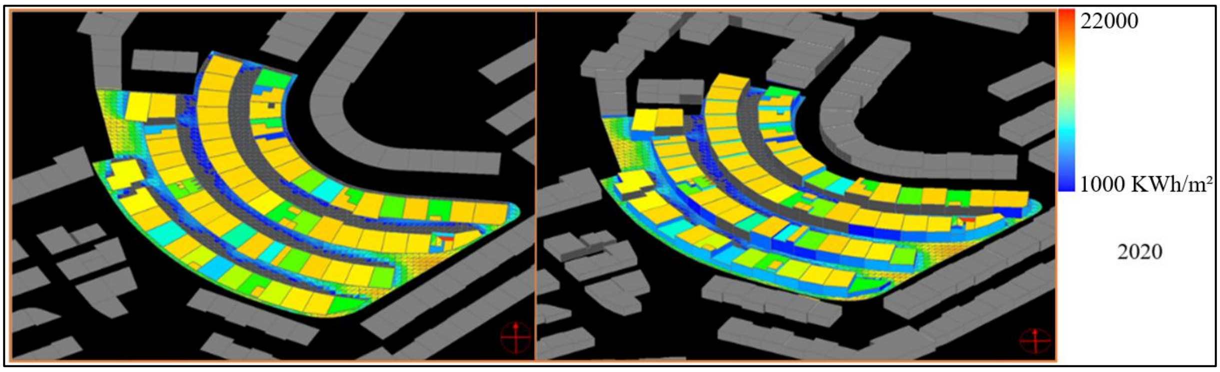


Figure VI- 48. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form B, top view (left) and south view(right) in the present climate.

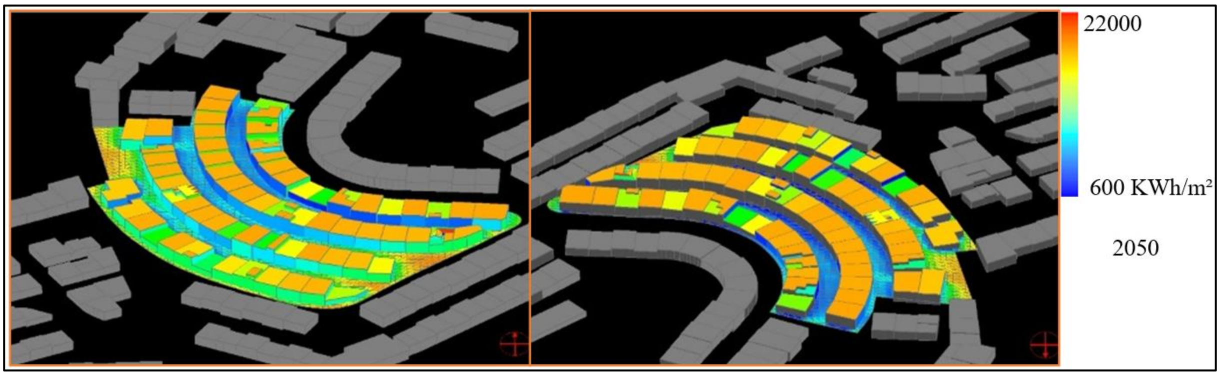


Figure VI- 49. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form B, South view (left) and north view(right) in the future climate.

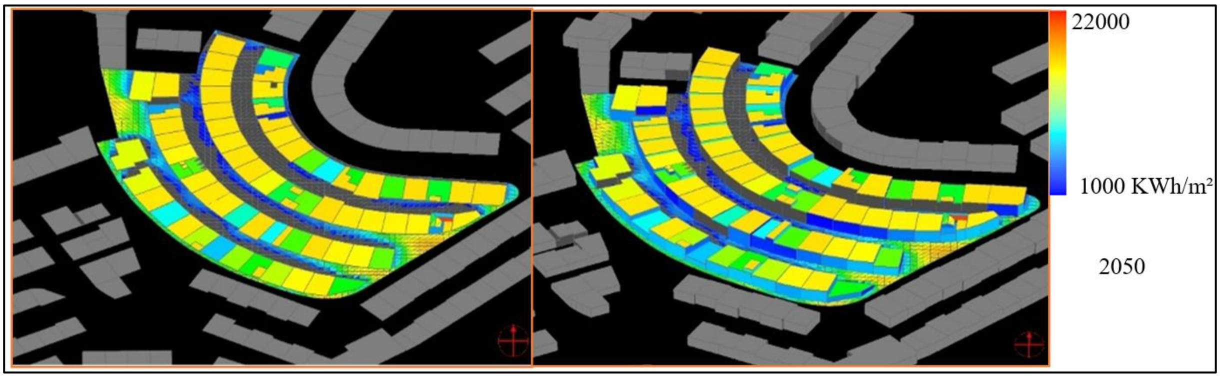


Figure VI- 50. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form B, top view (left) and south view(right) in the future climate.

Table VI- 15. Adequate potential for PV systems in façades and roof of urban form C.

C		Total area	Area with suggested threshold	Potential for PV systems
Surface of the all the building		14085,2	9686,3	69%
Façades area m².	Present	10267,2	5868,3	57%
	Future	10267,2	5793,9	56%
Roof area m².	Present	3818	3818	100%
	Future	3818	3818	100%

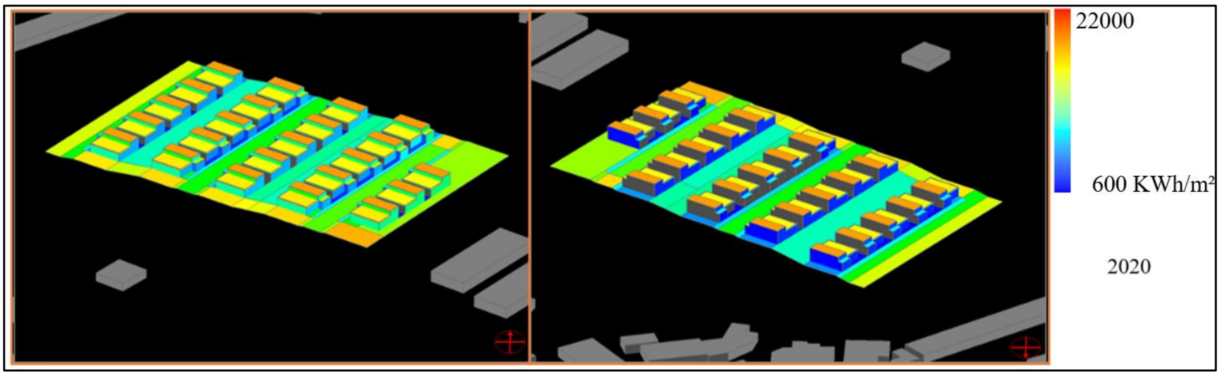


Figure VI- 51. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form C, South view (left) and north view(right) in the present climate.

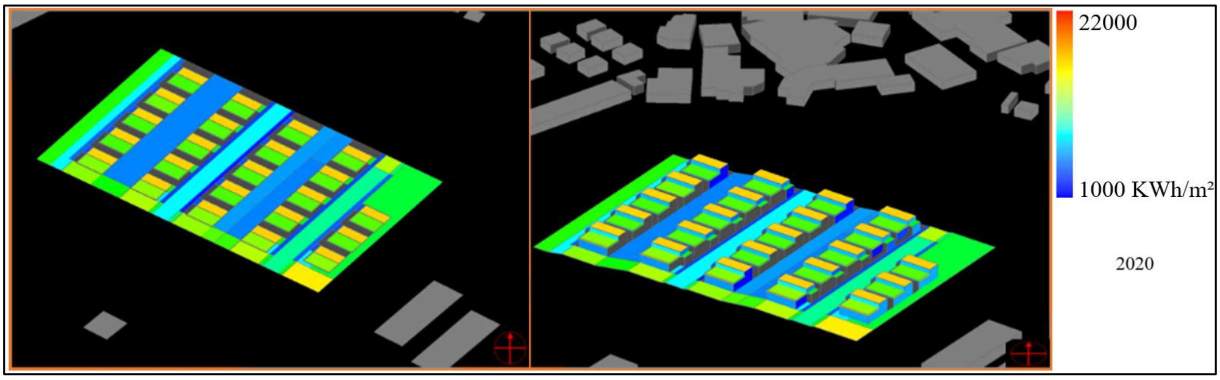


Figure VI- 52. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form C, top view (left) and south view(right) in the present climate.

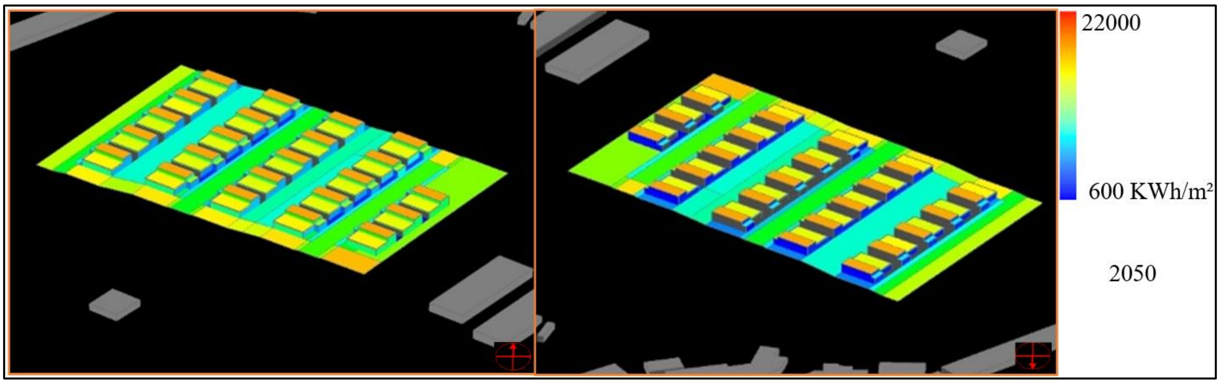


Figure VI- 53. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form C, South view (left) and north view(right) in the future climate.

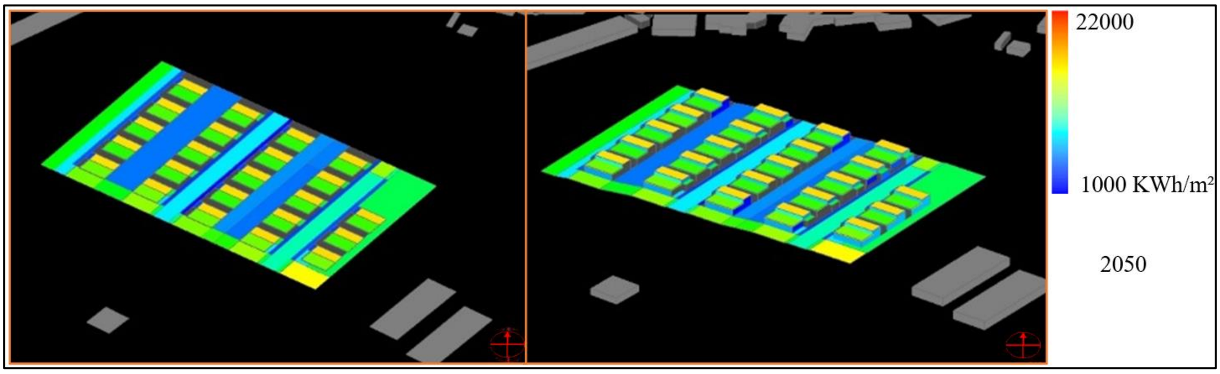


Figure VI- 54. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form C, top view (left) and south view(right) in the future climate.

Table VI- 16. Adequate potential for PV systems in façades and roofs of urban form D.

D		Total area	Area with suggested threshold	Potential for PV systems
Surface of the all the building		8103,86	6480,81	80%
Façades area m².	Present	5144,29	3423,27	67%
	Future	5144,29	3267,25	64%
Roof area m².	Present	3092,52	3057,54	99%
	Future	3092,52	3043,63	98%

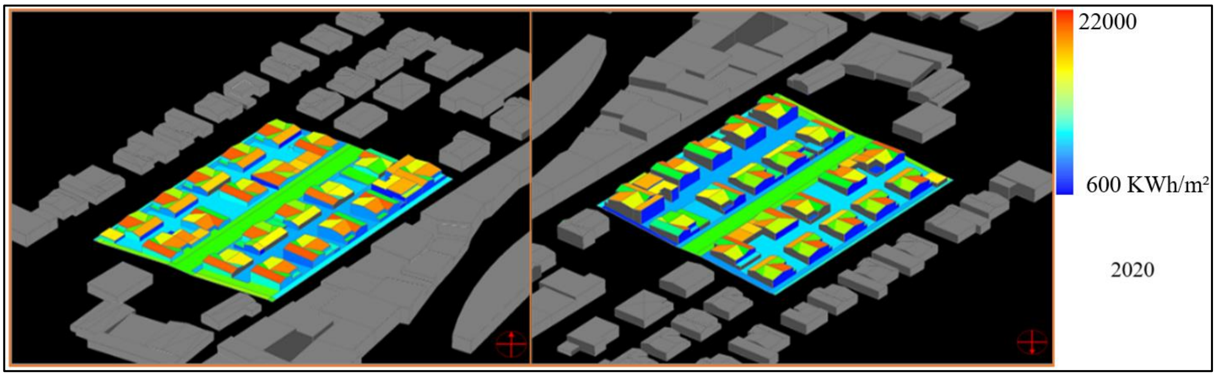


Figure VI- 55. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form D, South view (left) and north view(right) in the present climate.

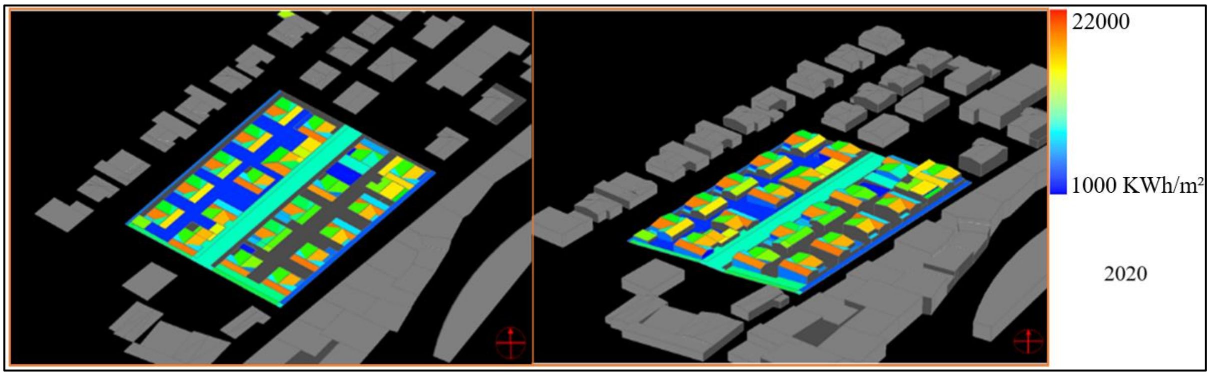


Figure VI- 56. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form D, top view (left) and south view(right) in the present climate.

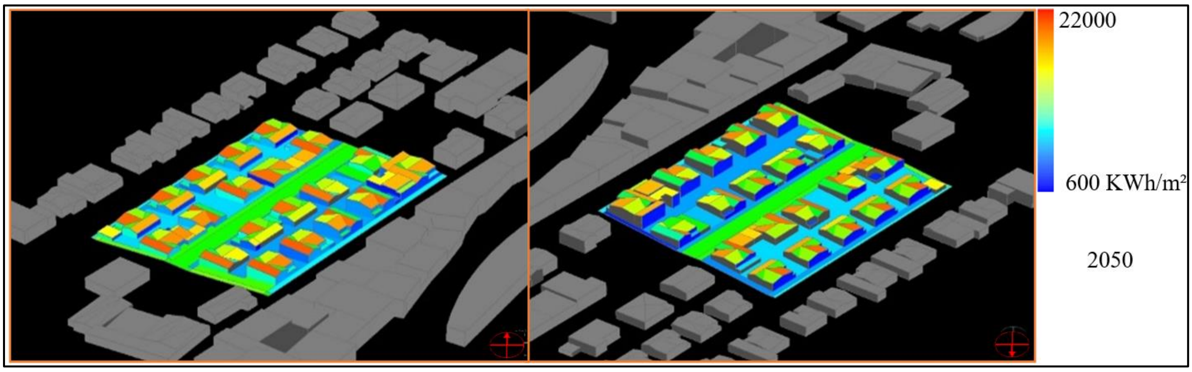


Figure VI- 57. Adequate PV solar potential availability on façades applying a threshold of 600 kWh/m² for urban form D, South view (left) and north view(right) in the future climate.

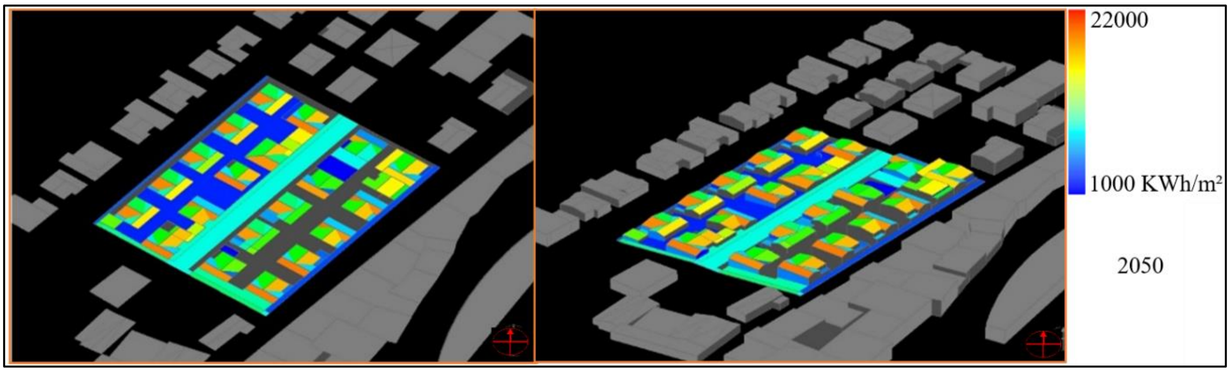


Figure VI- 58. Adequate PV solar potential availability on roofs applying a threshold of 1000 kWh/m² for urban form D, top view (left) and south view(right) in the future climate.

VI.6.5. Irradiation threshold for assessing thermal solar technology system integration

Following the evaluation of the different solar techniques, this section covers the evaluation of the irradiation threshold for solar thermal collector technology in current and future climates. The assessment consists of applying a threshold of 600 kWh/m² and 400 KWh/m² (chapter V section 7.4) to evaluate the potential of roof and façade solar thermal collectors, respectively.

Table VI- 17. Adequate potential for ST collectors in façades and roofs of urban form A.

A		Total area	Area with suggested threshold	Potential for ST systems
Surface of the all the building		34104,5	30578,92	90%
Façades area m².	Present	23556,5	20128,84	85%
	Future	23556,5	17306,2	73%
Roof area m².	Present	10466	10450,08	100%
	Future	10466	10408,43	99%

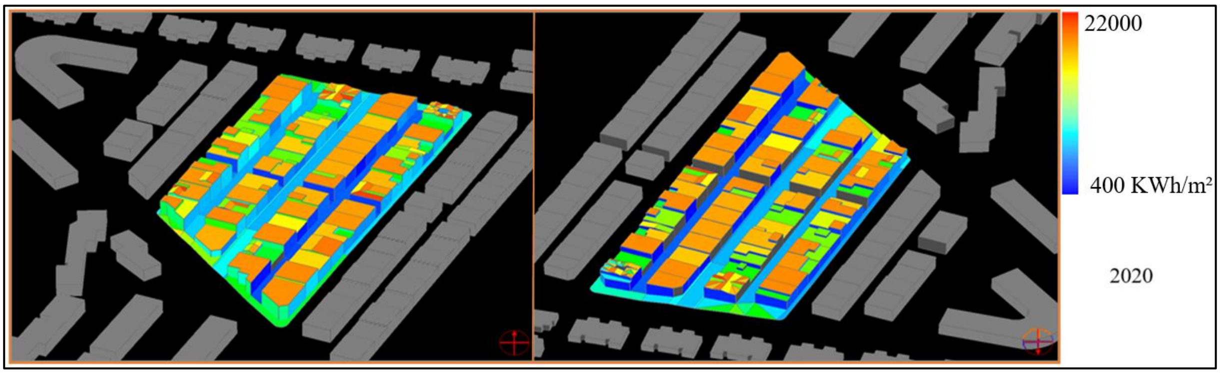


Figure VI- 59. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form A, South view (left) and north view(right) in the present climate.

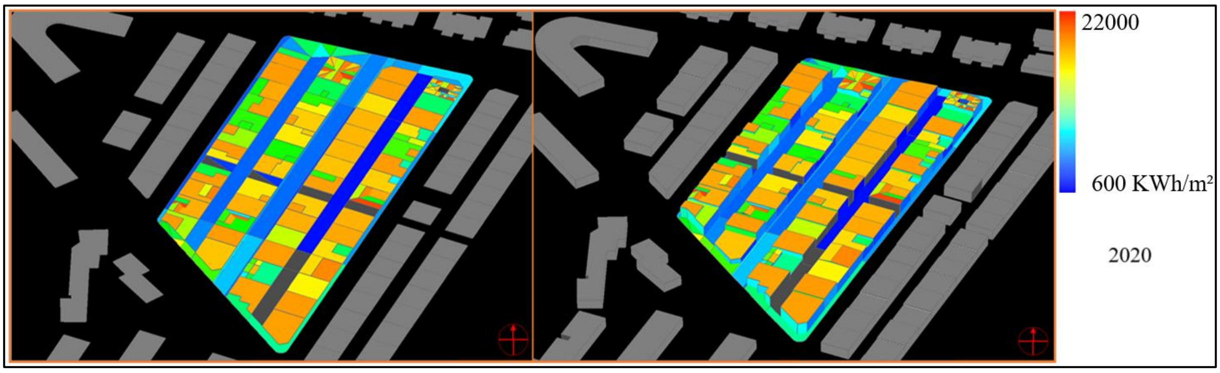


Figure VI- 60. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form A, top view (left) and south view(right) in the present climate.

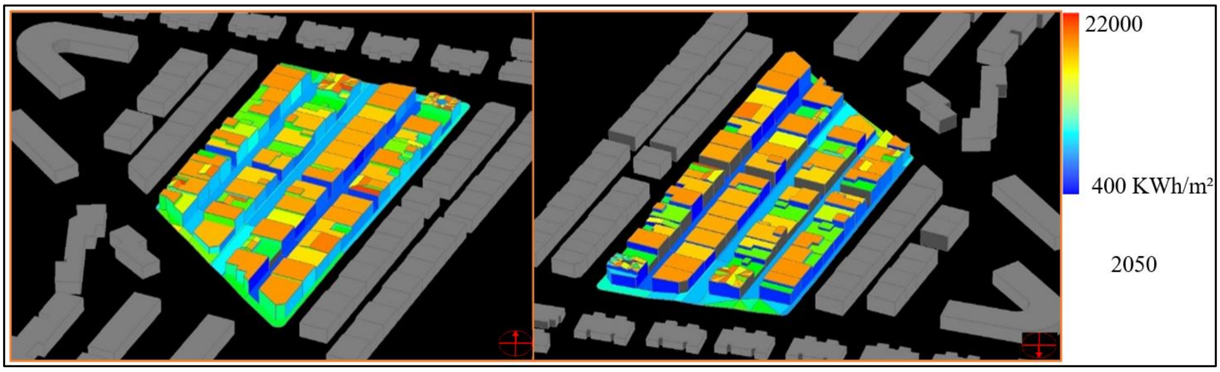


Figure VI- 61. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form A, South view (left) and north view(right) in the future climate.

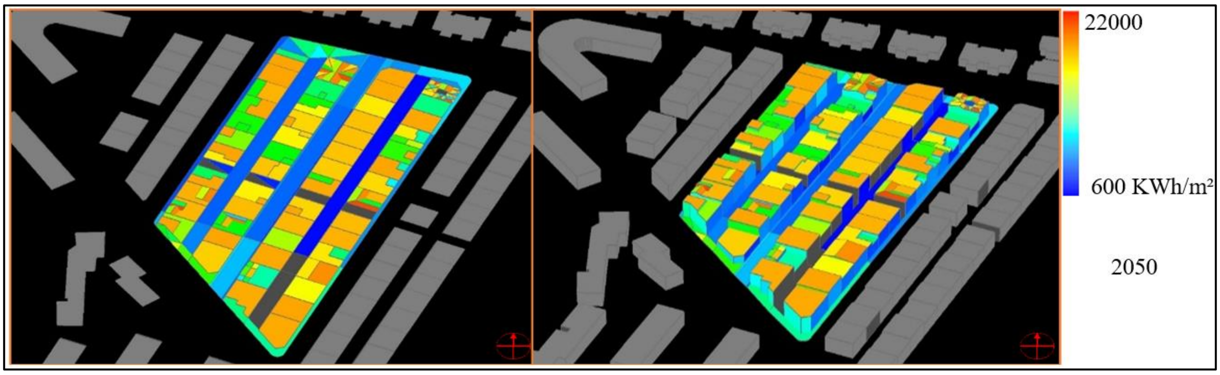


Figure VI- 62. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form A, top view (left) and south view(right) in the future climate.

Table VI- 18. Determining the appropriate potential for ST collectors in façades and roofs of urban form B.

B		Total area	Area with suggested threshold	Potential for ST systems
Surface of the all the building		39061,02	34854,35	89%
Façades area m².	Present	25187,13	20994,89	83%
	Future	25187,13	17302,53	69%
Roof area m².	Present	13873,89	13859,46	100%
	Future	13873,89	13859,46	100%

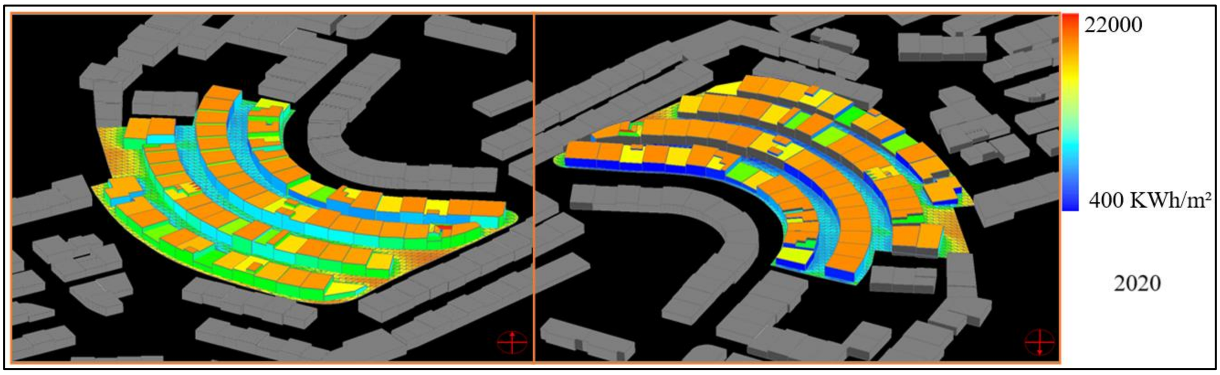


Figure VI- 63. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form B, South view (left) and north view(right) in the future climate.

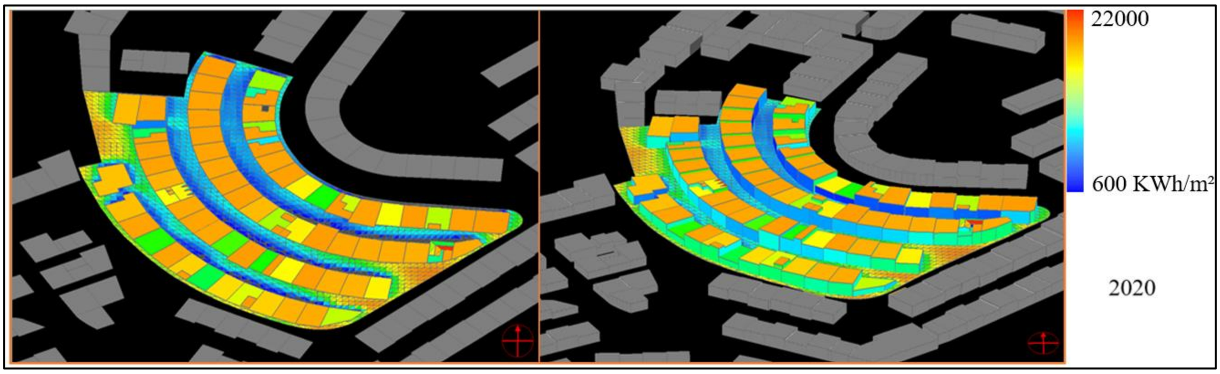


Figure VI- 64. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form B, top view (left) and south view(right) in the present climate.

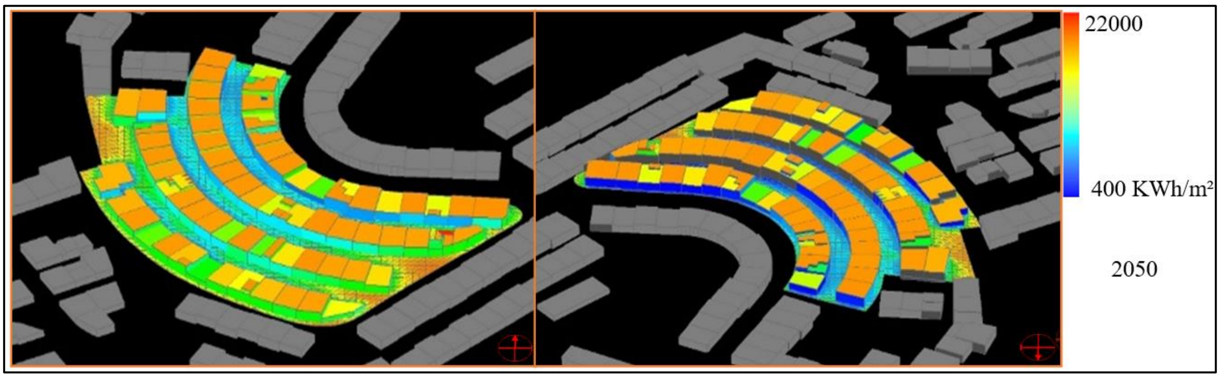


Figure VI- 65. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form B, South view (left) and north view(right) in the future climate.

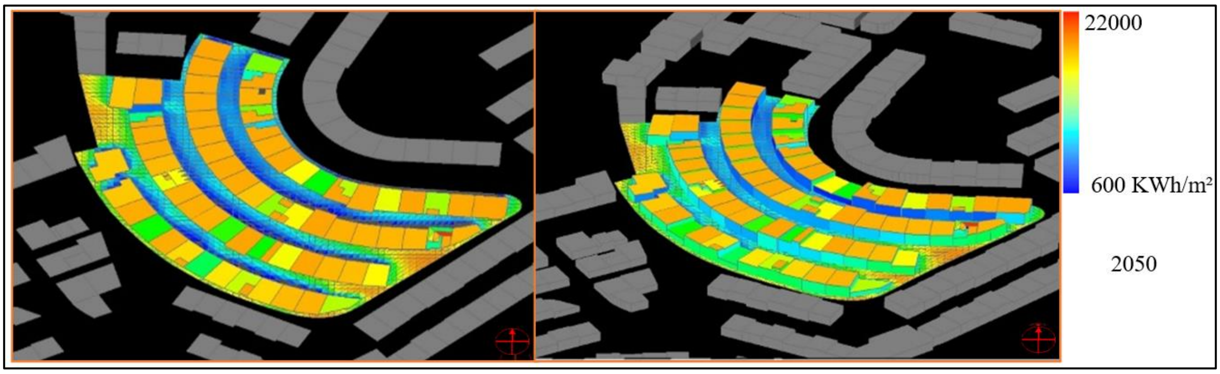


Figure VI- 66. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form B, top view (left) and south view(right) in the future climate.

Table VI- 19. Adequate potential for ST collectors in façades and roofs of urban form C.

C		Total area	Area with suggested threshold	Potential for ST systems
Surface of the all the building		14085,2	11363,4	81%
Façades area m².	Present	10267,2	7545,4	73%
	Future	10267,2	6373,6	62%
Roof area m².	Present	3818	3818	100%
	Future	3818	3818	100%

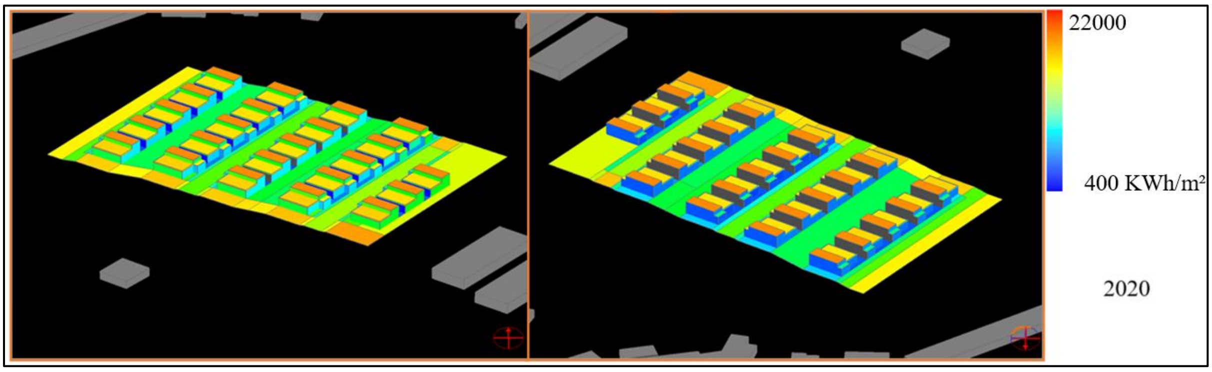


Figure VI- 67. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form C, South view (left) and north view(right) in the present climate.

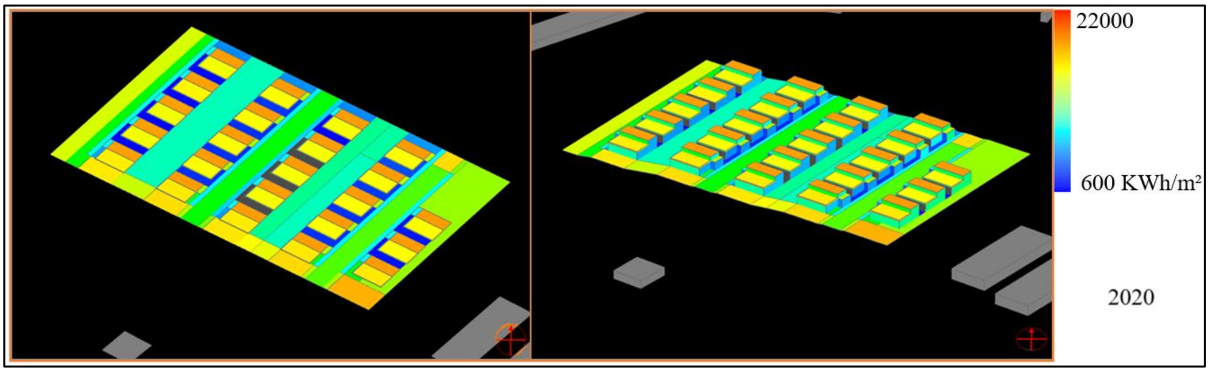


Figure VI- 68. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form C, top view (left) and south view(right) in the present climate.

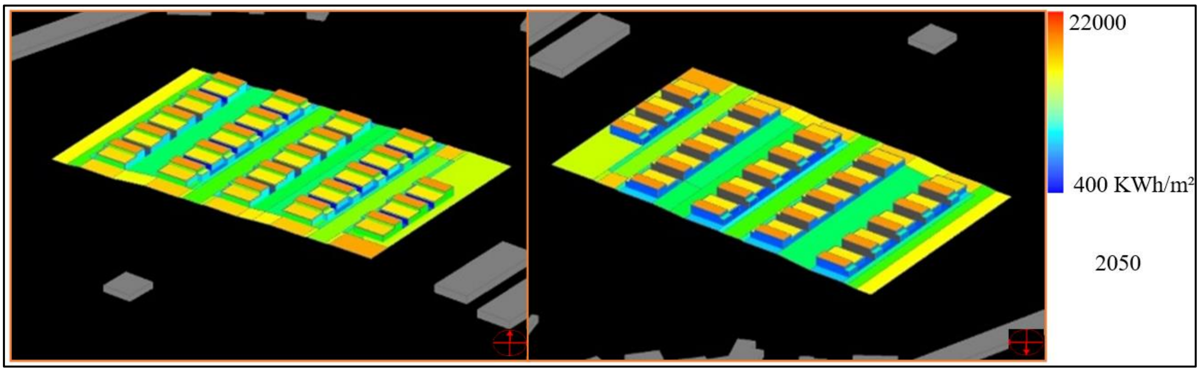


Figure VI- 69. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form C, South view (left) and north view(right) in the future climate.

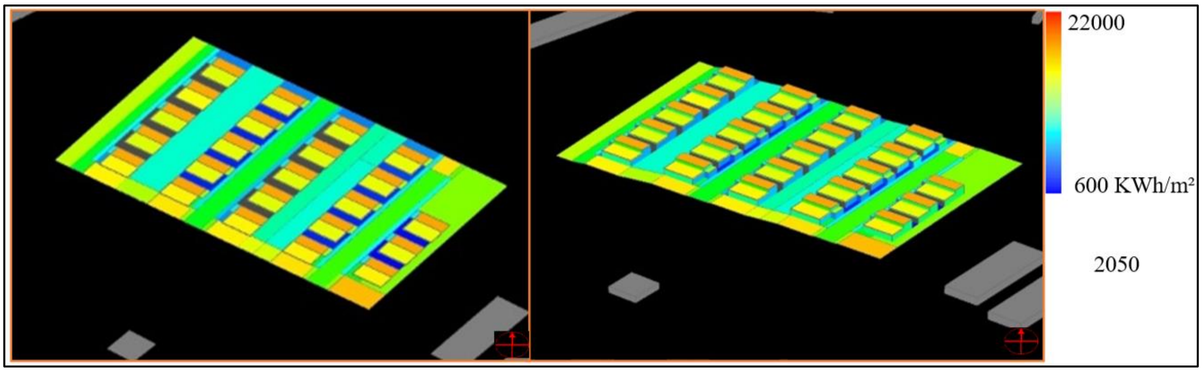


Figure VI- 70. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form C, top view (left) and south view(right) in the future climate.

Table VI- 20. Determining the appropriate potential for ST collectors in façades and roofs of urban form D.

D		Total area	Area with suggested threshold	Potential for ST systems
Surface of the all the building		8103,86	7347,17	91%
Façades area m².	Present	5144,29	4254,65	83%
	Future	5144,29	4178,75	81%
Roof area m².	Present	3092,52	3092,52	100%
	Future	3092,52	3092,52	100%

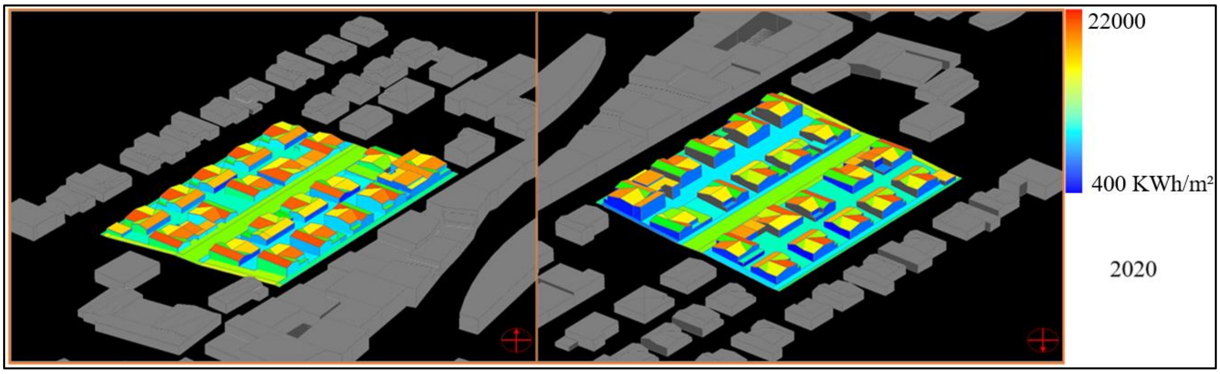


Figure VI- 71. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form D, South view (left) and north view(right) in the present climate.

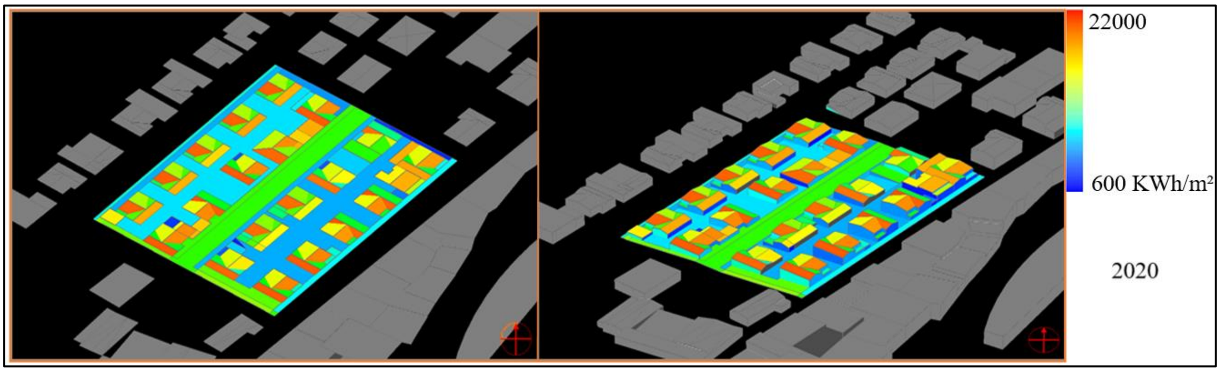


Figure VI- 72. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form D, top view (left) and south view(right) in the present climate.

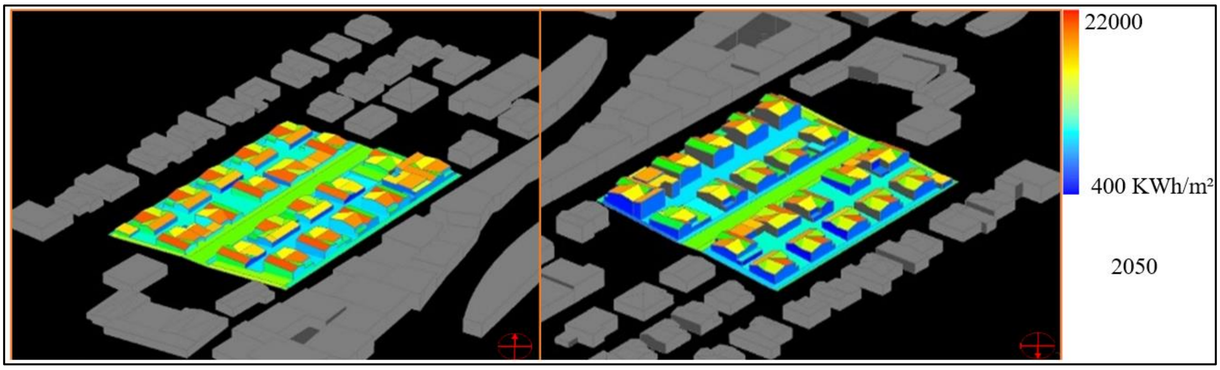


Figure VI- 73. Adequate ST potential availability on façades applying a threshold of 400 kWh/m² for urban form D, South view (left) and north view(right) in the future climate.

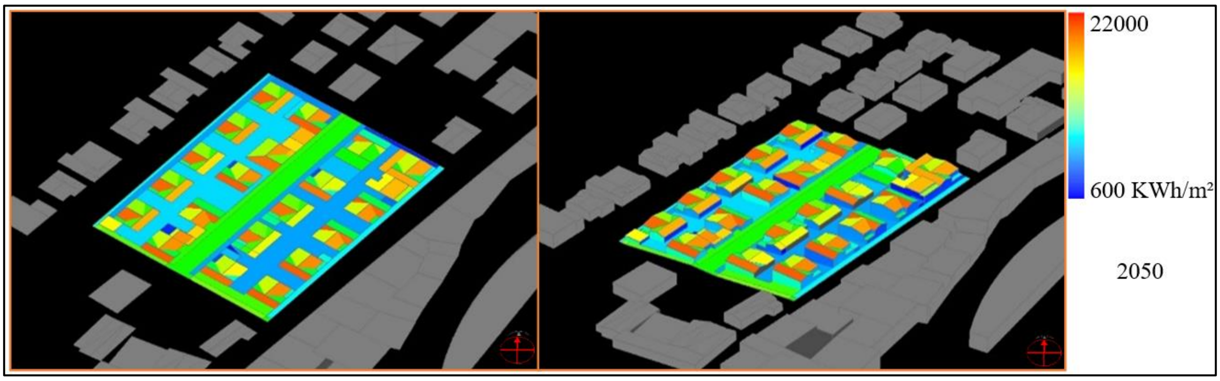


Figure VI- 74. Adequate ST potential availability on roofs applying a threshold of 600 kWh/m² for urban form D, top view (left) and south view(right) in the future climate.

Table VI- 21 gives a comprehensive comparative analysis of the different potentials of solar techniques in the current and future climate in all urban forms. The evaluation shows that the area of façades suitable for passive solar techniques varies between 29% (urban form D) and 57% (urban form B) during the current heating season, for the future heating season, an increase of about 11% to 15% of the appropriate area of passive solar techniques in all urban forms is found due to the high temperature during the future climate. By examining figures VI- 27, 28, 29, 30, 31, 32, 33, and 34, it can be seen that only the south-east, south and south-west façades receive the required passive solar heat gains, in both climates, and in some façades area with the same orientations where the street width is small, the façade area does not receive the adequate passive solar gain. Also, the results indicate that the façades of urban form B are performing better in terms of passive solar techniques against the other urban forms during the heating season in both climates.

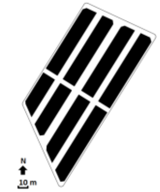
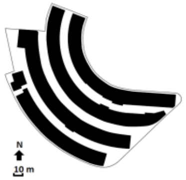
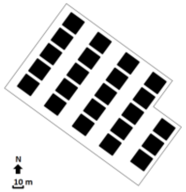
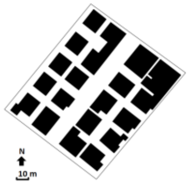
Regarding the potential daylight area in the facades, the results displayed in table VI- 21 indicate that the potential is less than 50% in all urban forms, ranging from 12% to 43%. Referring to figures VI- 35, 36, 37, 38, 39, 40, 41, and 42, the behavior is the same as the passive solar gain, the facade areas oriented in the azimuth from west to south-east do not receive the required amount of illumination, due to the significant shadowing and unfavorable orientations for certain areas (west, north and east). In contrast to the passive solar gain, the illuminance in the future climate is expected to decrease, which means a decrease of the potential facade areas varying between 0% and 12% in all the urban forms, the decrease in urban forms with detached buildings (urban form C (0%) and D (3%)) is lower than those with attached buildings (urban form A (12%) and B (10%)). The small decrease in daylight potential in detached buildings indicates that the low density and aspect of detached houses preserve a high amount of daylight and are not significantly affected by climate change, whereas for all urban forms, urban form B as in the passive solar gain potential, it has the adequate high daylight potential compared to the other urban forms.

Under the current climate, the assessment of the adequate potential of solar PV technologies shows a difference in facades compared to roofs. On the one hand, the area of the adequate potential of solar PV technologies in facades varies between 57% and 70% in the four urban forms. These percentages reduce in the future climate to a range of 43% to 64%, the drop is significant in the high-density urban forms (urban forms A and B) by almost 15% and less important in the urban forms with isolated buildings (C and D) by almost 2%. Urban form B has the highest fraction with the adequate potential of solar PV technologies on the façades in the future climate, while in the future climate urban form D has the highest fraction. This helps to explain that in the future climate, high density (figures VI- 43, 45, 47, and 49) shows a considerable decrease in the potential of solar PV technologies on the facades and that low-density neighborhoods with detached buildings (figures VI- 51, 53, 54, and 56) maintain a high amount of the adequate potential of solar PV technologies on the facade. On the other hand, the roofs in all urban forms reach the ultimate adequate potential of solar PV technologies by about 99% and do not exhibit any significant differences in both climates (figures VI- 44, 46, 48, 50, 52, 54, 56, and 58).

When it comes to the adequate surface of solar thermal collectors by applying the required thresholds, the same behavior of the PV assessment is experienced in facades and roofs. According to table VI- 21 and when applying a threshold of 400 kWh/m², the percentage of adequate facade area for solar thermal collectors is above 70% in all urban forms, reaching almost 84% in urban forms A, B and D during the present climate, in the future climate and the same facade areas, the adequate areas decrease significantly in urban forms A, B and C by a range of 11% to 14%, and urban form D experiences a slight decrease of 2%. Referring to figures VI- 59, 61, 63, 65, 67, 69, 71, and 73 north-facing facades and facade areas located in small street width do not receive high solar irradiation (400 kWh/m² or more) for a favorable solar thermal production.

As illustrated in figures VI- 60, 62, 64, 66, 68, 70, 72, 74, and table VI- 21, the adequate potential of rooftop solar thermal collectors shows the best results with 100% under the current and future climate.

Table VI- 21. Comparison of the solar potential of the four urban forms for the city of Constantine.

Urban form	**Plan**	**Façade annual solar irradiation (kWh/m²)**		**Roof annual solar irradiation (kWh/m²)**		**Adequate potential of passive solar techniques (%)**		**Adequate potential of daylight (%)**		**Adequate potential of active solar techniques (PV) (%)**				**Adequate potential of active solar techniques (ST) (%)**			
		Present	Future	Present	Future	Present	Future	Present	Future	Present		Future		Present		Future	
										Façade	Roof	Façade	Roof	Façade	Roof	Façade	Roof
A		795	798	1417	1577	41	55	21	9	58	**99**	43	**99**	**85**	**100**	**73**	**99**
B		837	845	1416	1329	57	68	43	34	70	**99**	56	**99**	**83**	**100**	69	**100**
C		715	718	809	673	36	50	23	23	57	**100**	56	**100**	**73**	**100**	62	**100**
D		754	754	1446	1677	29	44	12	9	67	**99**	64	**98**	**83**	**100**	**81**	**100**

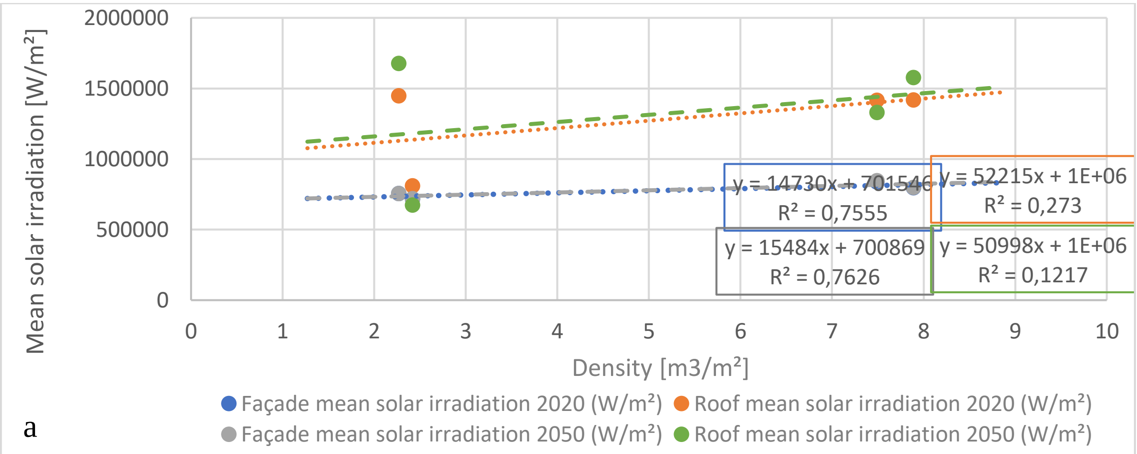
VI.7. Impact of urban form indicators on solar potential

In this section, the relationship between the selected urban form factors (density, compactness, standard deviation of building footprint area, mean outdoor distance) and the mean solar irradiation is studied, during different periods (yearly, heating season and cooling season), under the present and the future climate scenarios.

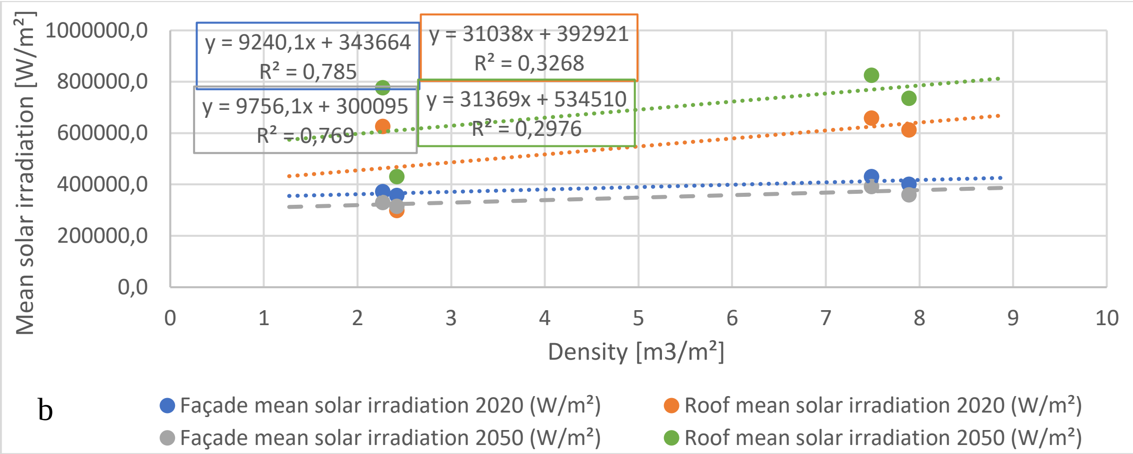
Figure VI- 75 demonstrates the linear regression models between density and mean solar irradiation. In general, it is observed that the correlation between density and mean façade solar irradiation is stronger than the correlation between density and mean roof solar irradiation, among the three periods (annual, heating and cooling season), the relationship between density and mean roof solar irradiation is weak. Moreover, the density correlates better with the mean facade solar irradiation, the correlation coefficients for heating season are lower than those for cooling season and the whole year, during these two periods a strong correlation is seen (|r| > 0.755) under the current and future climates.

This result indicates that solar altitude angles over the year affect the relationship between geometry and solar availability, during the heating season with lower solar altitude angles the relationship gets weaker, and the strength of this relationship becomes more pronounced during the cooling season with high solar angles.

Yearly



Heating season



Cooling season

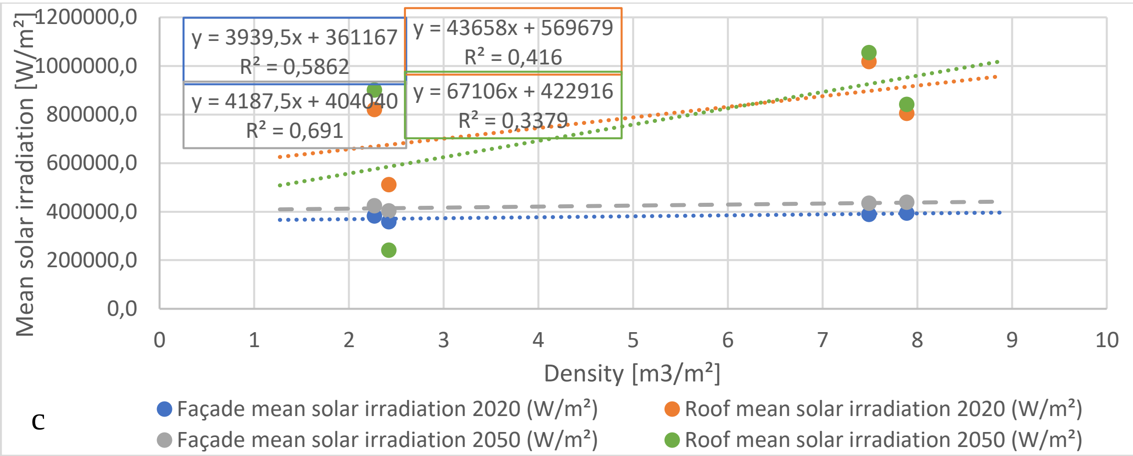
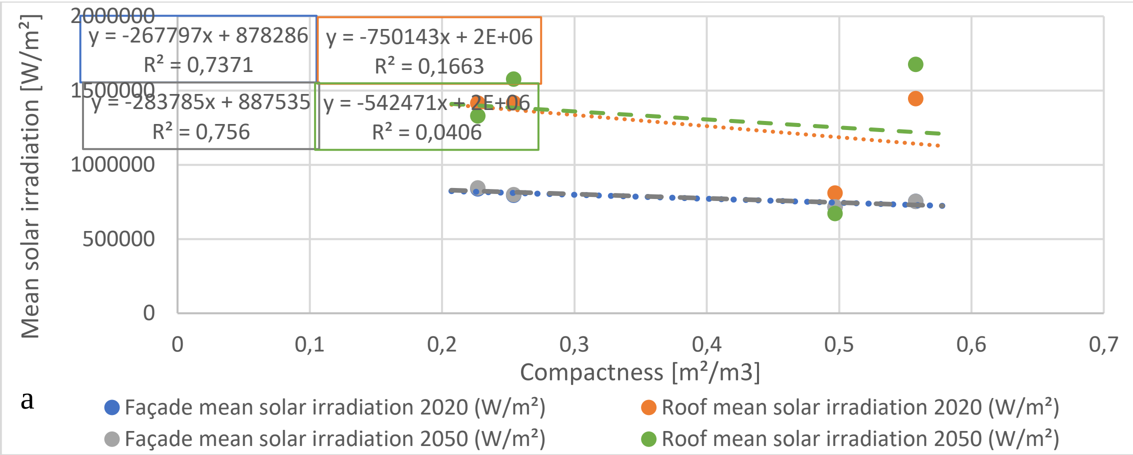


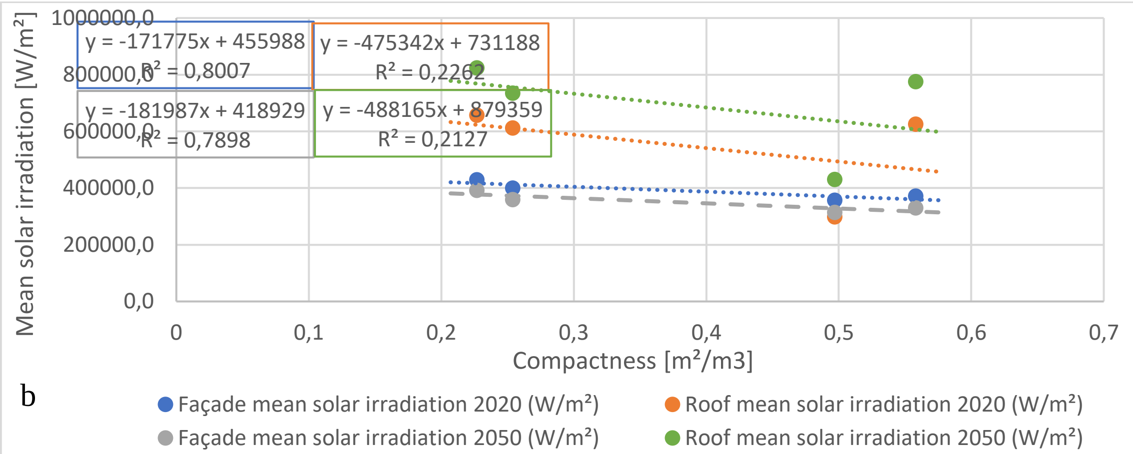
Figure VI- 75. Linear regression models for density and façades mean solar irradiation of the four case studies, over the entire year (a), in the heating season (b), and in the colling season (c).

Examining the linear regression models between compactness and mean solar irradiation (Figure VI- 76), the correlation with mean solar irradiation of façades is stronger than that with mean solar irradiation of roofs. During the heating season as well as during the whole year, the correlation coefficients between compactness and mean façade solar irradiation of are strong (|r| > 0. 730) in both climates, the correlation of compactness and density with mean solar irradiation, respectively, features a similar result in the three periods.

Yearly



Heating season



Cooling season

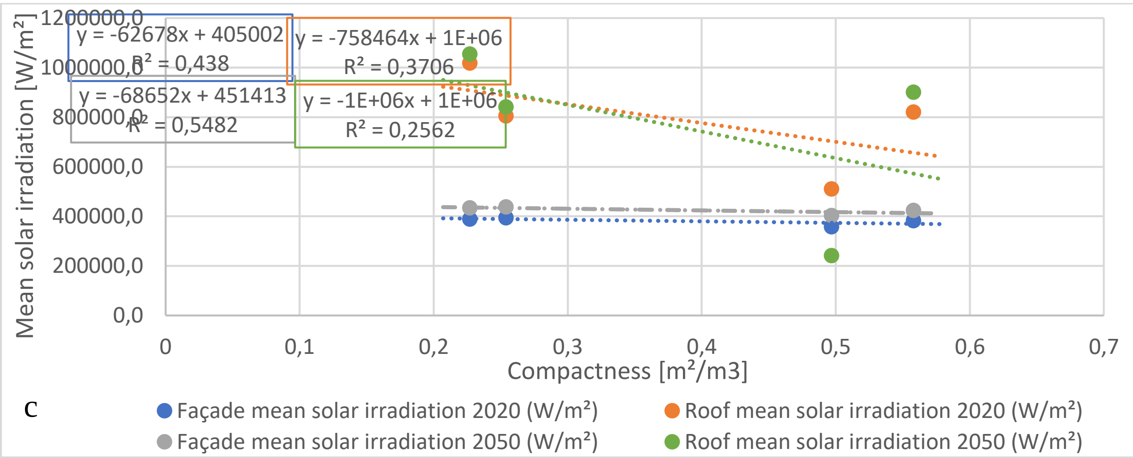
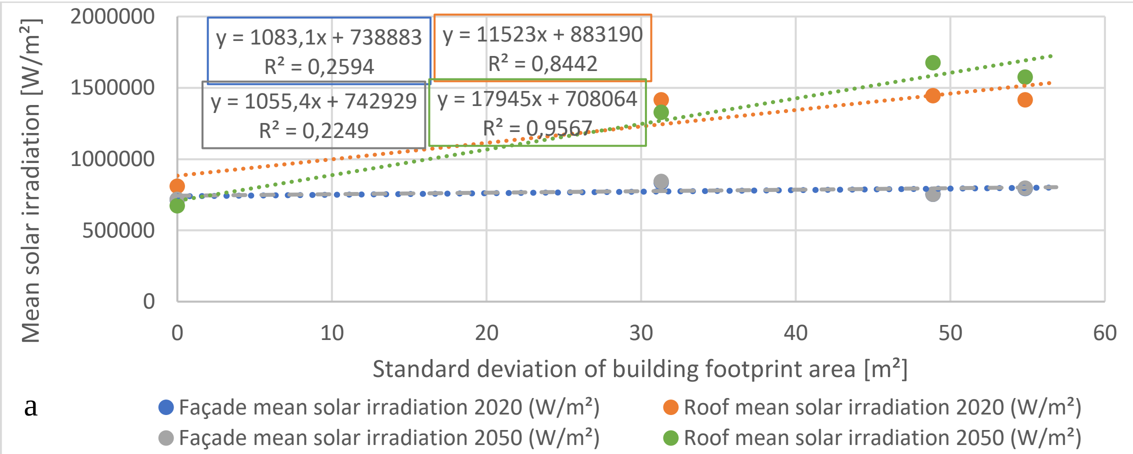


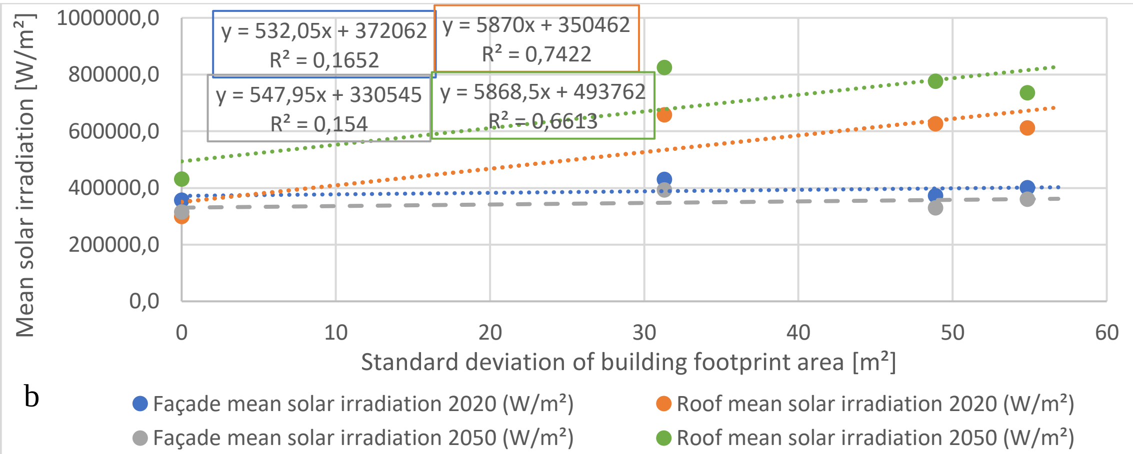
Figure VI- 76. Linear regression models for compactness and façades mean solar irradiation of the four case studies, over the entire year (a), in the heating season (b), and in the colling season (c).

Following the impact assessment of the urban form indicators on mean solar irradiation, the linear regression models between the standard deviation of building footprint area and mean solar irradiation (figure VI- 77) display a strong relationship with those of the roofs versus the façades during the year and the heating season. Considering the whole year, the correlation coefficient (|r| > 0. 844) is significant. However, in both periods of the year, the correlation between the standard deviation of building footprint area and the mean solar irradiation of the façades is weak during the heating season, and differently from the results obtained for density and compactness, the correlation coefficient is strong during the cooling season. It is interesting to note that during the heating season, the relationship between the standard deviation of building footprint area and mean roofs solar irradiation appears also important.

Yearly



Heating season



Cooling season

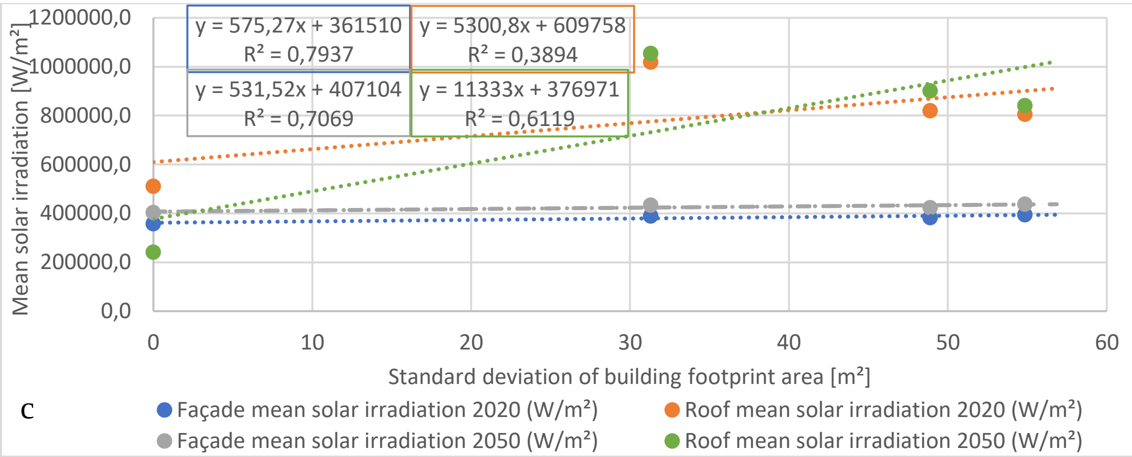
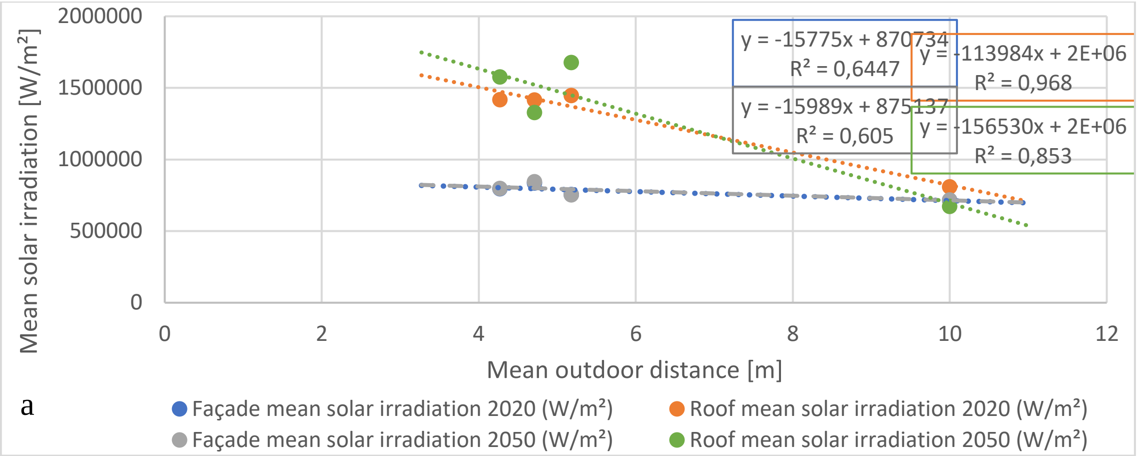


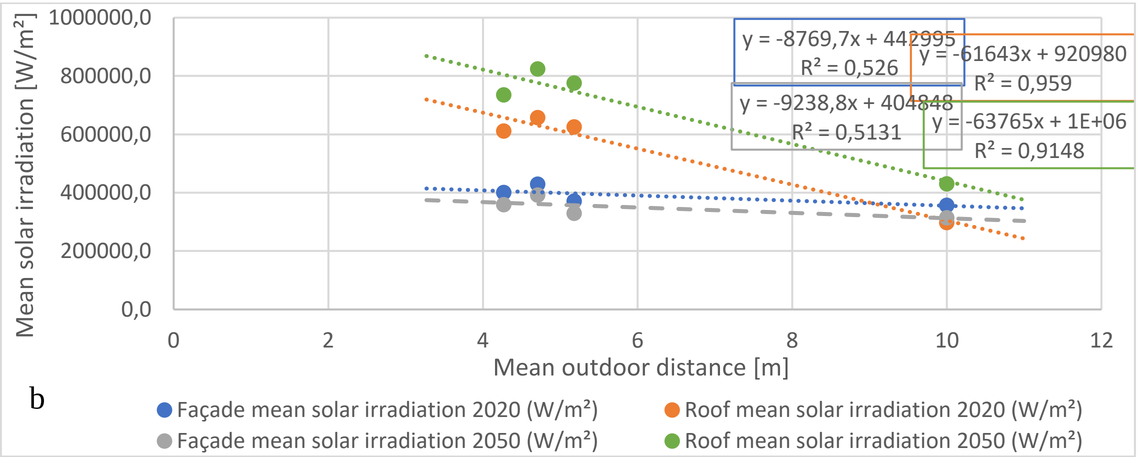
Figure VI- 77. Linear regression models for Standard deviation of building footprint and façades mean solar irradiation of the four case studies, over the entire year (a), in the heating season (b), and in the colling season (c).

By analyzing figure VI- 78, the linear regression models between the mean outdoor distance and the mean solar irradiation show a different result against the three correlations of density, compactness and standard deviation of building footprint area with the mean solar irradiation. The relationship between the mean outdoor distance and the mean roof solar irradiation is significant compared to the relationship of the urban form indicator with the mean solar irradiation of the façades in all periods. On the one hand, considering the three periods in both climates, the correlation coefficient between mean outdoor distance and mean roof solar irradiation is $|r| > 0.764$, while in the whole year and the heating season, this correlation coefficient is more pronounced where $|r| > 0.853$. On the other hand, if we examine the relationship between the average external distance and the average solar irradiation of the façades in the present and future climates, the relationship is very significant during the cooling season period with $|r| > 0.931$ compared to the other two periods.

Yearly



Heating season



Cooling season

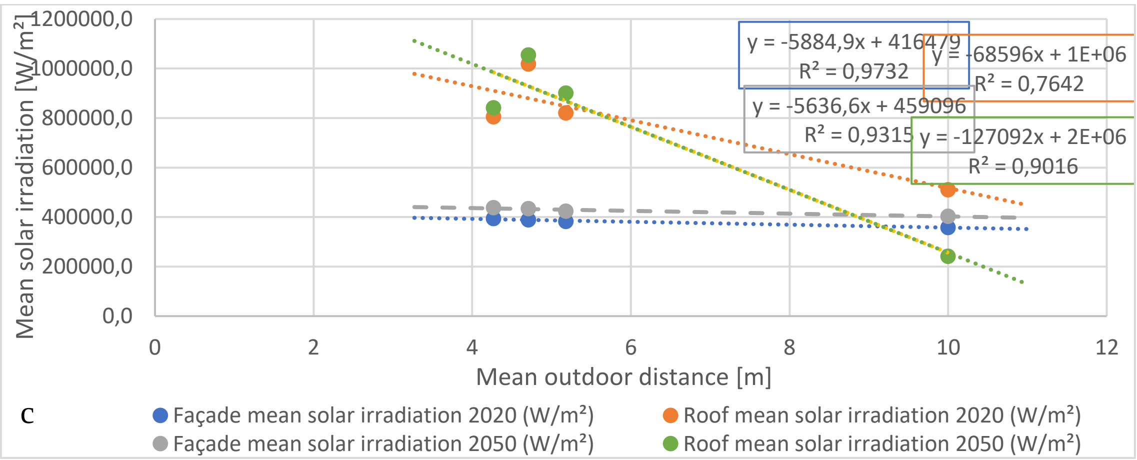


Figure VI- 78. Linear regression models for Mean outdoor distance and façades mean solar irradiation of the four case studies, over the entire year (a), in the heating season (b), and in the colling season (c).

VI.8. Renewable energy application

VI.8.1. PV rooftops in the present climate

Figure VI- 79 displays the annual solar irradiation on all building surfaces of the urban forms, referring to the data presented by the solar atlas platform in annexe 4, this result confirms those of the solar atlas which indicates that the maximum solar irradiation received in a well-exposed surface can reach 2000 kWh/m² per year. Figure VI-79 shows that all roofs of the buildings in the study areas are well exposed to solar irradiation.

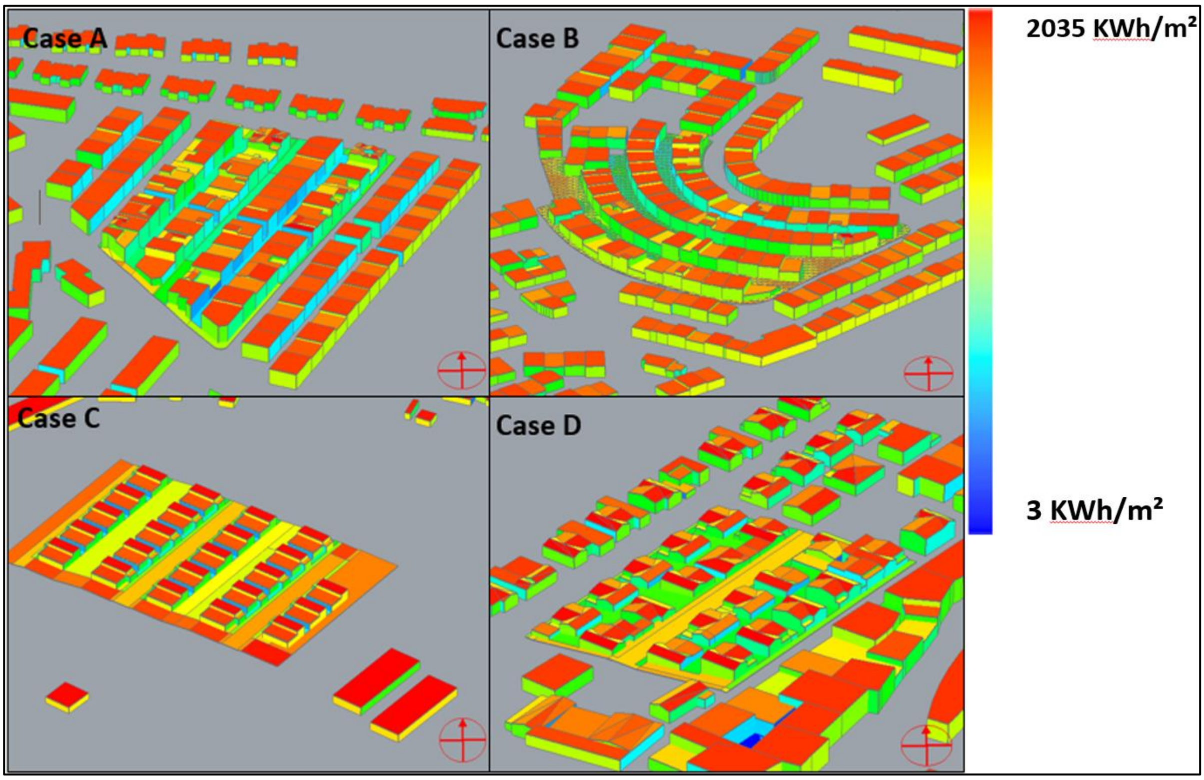


Figure VI- 79. Yearly solar irradiation in all urban form areas (kWh/m²/year).

Next, the study of solar electricity generation from 20m² rooftop photovoltaic systems is carried out. Table VI- 22 presents the PV generation in the four urban forms and its impact on the heating and cooling needs of the buildings as well electricity demand.

Table VI- 22. PV generation (per unit area of PV area) and its impact on heating and cooling needs and electricity demand (per unit of volume of the building) in the present climate.

Urban form	**PV Generation (PV area) kWh/year/m²**	**Additional heating needs kWh/year/m³**	**Additional cooling needs kWh/year/m³**	**Net change in electricity demand**	
				self-consumption kWh/year/m³	net metering kWh/year/m³
A	326.6	22.0	3.1	0.6	0.0
B	321.9	13.0	4.6	1.0	0.0
C	323.2	34.9	20.6	4.3	0.7
D	315.3	54.3	7.8	1.1	0.0

The most rooftops in urban forms A, B and C are generally flat and therefore allow the installation of PV systems with the optimal inclination and orientation, leading to maximum PV production during the year. The roofs of urban form D are mostly inclined 30° to the southwest, which results in a slightly lower PV production than the other urban forms. In addition, it is interesting to note that the electricity production of a southwest-facing PV module in the northern hemisphere will be at its maximum later in the day, which is more practical for self-consumption for cooling or other uses during the afternoons which are warmer than the mornings (Hsieh et al., 2013; Velik, 2013).
Looking at the impact of installing PV models on the roof, we found that during the cold season, the shading of the PV system on the roof leads to a slight increase in heating needs, this increase depends on the urban form and is between 1 and 2%. During the warm season, the impact is more noticeable, leading to a decrease in cooling needs of 4 to 8%, depending on the urban form. This decrease is less pronounced in urban form C and more significant in urban form A. This effect is explained by the fact that the roofs of urban form A are larger and attached, so the impact of the shadowing of 20 m² of PV panels in the attached continuous roofs is greater during the day than in the detached buildings. A large shadow in the buildings does not allow direct sunlight on the external surfaces of the building, resulting a slight increase in heating demand in winter and a slight decrease in cooling demand in summer.

Based on Table VI- 22, the net electricity consumption is defined assuming self-consumption of the solar PV electricity production, with the electricity produced by solar PV being used during its production. Nevertheless, in a net metering system (or by using a locally installed battery storage system), it is possible to use electricity in an unsynchronized manner. It is important to note that for simplicity, no efficiency losses are considered in the study.

It is clearly shown that all urban forms have high electricity consumption during the cooling season, especially in July. On the one hand, using a local storage system, solar electricity production can eliminate a considerable part of the electricity consumption in all urban forms. It is also interesting to note that urban forms A, B, and D display excess electricity production. On the other hand, considering a self-consumption model without a storage system, the solar PV electricity production during the cooling season is well matched to the cooling needs. This favourable situation enables the decrease of the electricity consumption which varies between 28% and 36% in urban forms A, B, and C, and about 58% in urban form D.

Reflecting on the findings, it has been shown that a relatively small PV rooftop area can eliminate a large part of the electricity demand of urban residential forms. Therefore, since a larger area of roofs is available for the installation of more PV systems, and in opposition to other urban areas in different regions (Ayompe et al., 2011; Mondol et al., 2005), it is not necessary to take into account other areas in buildings, such as façades, which are less appropriate for PV production due to their lower efficiency and higher cost per unit of energy generated.

VI.8.2. PV rooftops in the future climate

Indicatively and as shown in figures V- 3, and 4, chapter V section 6.1, the future climate is characterized by a decrease in solar irradiation during the warm season and a high temperature during the entire year. Concerning PV production, this leads to a slight decrease in PV production, as the increase of solar irradiation in the wintertime is compensated by the decrease in PV conversion efficiency due to the increase in module's temperature (Soares et al., 2019).

As for the results of the 20 m² rooftop PV systems in the future climate projection, table 9 provides the results of this model. The results reveal a decrease in PV production, by a percentage of 2% for urban forms A, B and D and 3% for urban form C. Furthermore, in the future climate, the impact of PV modules on the magnitude of the variation in heating and cooling needs due to rooftop shading is comparable to the current climate.

Table VI- 23. PV generation (per unit area of PV area) and its impact on heating and cooling needs and electricity demand (per unit of volume of the building) in the future climate.

Urban form	**PV Generation (PV area) kWh/year/m²**	**Additional heating needs kWh/year/m^3**	**Additional cooling needs kWh/year/m^3**	**Net change in electricity demand**	
				self-consumption kWh/year/m^3	net metering kWh/year/m^3
A	320.0	11.2	7.4	2.1	0.2
B	311.1	4.9	9.8	2.9	1.1
C	317.1	20.2	31.1	8.3	4.9
D	308.1	32.5	17.5	4.0	0

Figure VI- 80 shows that the future seasonal PV production is higher in winter and lower in summer compared to the current climate. The decrease in PV production during the future cooling season will reduce the benefit of the 20 m² rooftop PV system on electricity demand, it is interesting to point out that only in the urban form D the solar PV production can cover the electricity demand.

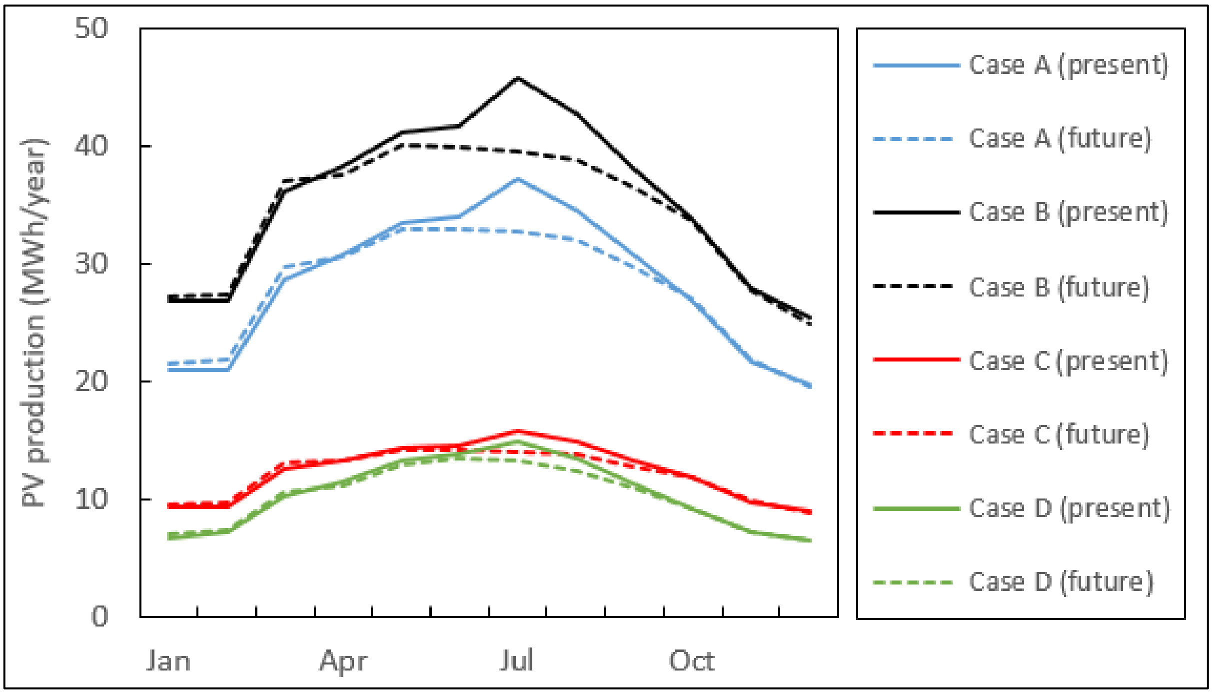


Figure VI- 80. Annual present (solid lines) and future (dashed lines) PV production of urban forms A (blue), B (black), C (red) and D (green).

As the roofs of the urban forms allow the installation of more PV systems, the results suggest extending the PV area to 30 m². Following the same steps above, the orientation of the PV modules is still south (180°) for all but the urban form D, with a southwest orientation (218°).

Comparing the results of 30 m² of PV roofs in table VI- 24 with the PV system in the current climate, one can see an increase in PV production above 30%. The proposed 30 m² PV system can eliminate all the electricity demand of the urban forms, but this is not realized for urban form C which has high cooling needs.

Table VI- 24. PV generation of 30 m²/building (per unit area of PV area) and its impact on heating and cooling needs and electricity demand (per unit of volume of the building) in 2050 climate.

Urban form	**PV Generation (PV area) kWh/year/m²**	**Additional heating needs kWh/year/m³**	**Additional cooling needs kWh/year/m³**	**Net change in electricity demand**	
				self-consumption kWh/year/m³	net metering kWh/year/m³
A	475.9	11.2	7.4	1.9	0.0
B	475.5	4.9	9.8	2.6	0.0
C	470.4	20.2	31.1	7.6	2.4
D	464.8	32.5	17.5	3.2	0.0

VI.8.3. Replacing gas consumption for heating needs with PV electricity

The increase in photovoltaic generation and the decrease in heating needs in winter discussed above can eventually lead to the option of converting the heating needs from gas to electricity. This option takes into account the fact that heating is provided by heat pumps using a coefficient of performance (COP = 3). For this purpose, the analysis is carried out during the future cold season.

As shown in figure VI- 81 and considering the day of January 13th, 2050, selected because it features the highest heating needs and the lowest solar irradiation during the year, the PV generation would provide enough electricity to satisfy the heating needs during the day, but it necessitates consumption of electricity from the grid for heating during the night for all urban forms.

As many householders would in practice not keep heat pumps powered during sleeping hours, the demand for electricity from the grid for heating would be expected to be much lower than the values estimated in table VI- 25.

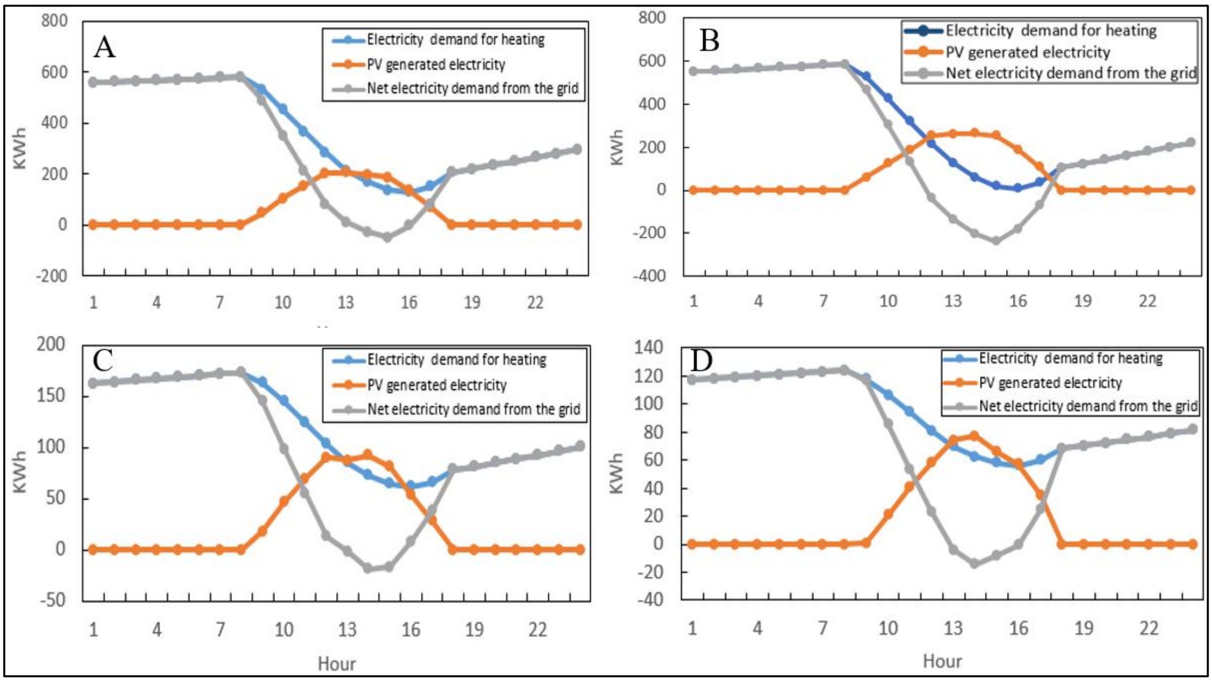


Figure VI- 81. Hourly electricity demand for heating needs (blue line) assuming COP=3, PV generation (orange line) and net electricity demand from the grid (grey line) for January 13th, 2050, considering 30 m^2 of PV per building for all urban forms.

Table VI- 25. Electricity demand from the grid for electric heating during the heating season, assuming 30m² of PV in 2050.

Urban form	**Electricity demand for heating (KWh/building)**	**PV generated electricity in the heating season (KWh/building)**	**Electricity demand from the grid for heating (KWh/building)**	**% of heating needs to be supplied by the PV**
A	9536.2	4374.0	5162,2	46%
B	4238.9	4398.7	0	100%
C	8227.4	4353.0	3874.4	53%
D	7939.2	4034.9	3904.3	51%

According to table VI- 25 and during the heating season, solar PV generation can supply approximately half (46% to 53%) of the electricity demand for heating in urban forms A, C and D. It should be highlighted that due to the specificity of urban form B, which is convenient for low energy demand, solar PV generation can eliminate all the electricity required by heat pumps to heat the buildings.

VI.9. Conclusion

Chapter VI presented the essence and results of the different studies undertaken for the objective of researching the impact of urban form on energy consumption and solar access, case of individual housing estates in Constantine.

In a first step, using the Pearson correlation method, the selection of urban form factors that exert a significant influence on energy behaviors and solar irradiation received in the buildings was carried out. Results reveal that these urban form factors are density (Den), compactness (Com), mean outside distance (MOD), standard deviation of the building footprint area (StF) and thermal transmittance (U) of the building urban form envelope. The energy model was calibrated using real energy data consumption, featuring a high accuracy regarding the performance of a model error (between 0 and 1% for all urban forms). Next, the comparison of the energy behavior of each urban form in the present and future climate shows a clear variation in the intensity of energy use and the heating and cooling needs for the different urban forms.

In both present and future climates, the high-density urban forms (A and B) show a low energy demand compared to the low-density urban forms (C and D). Moreover, in the future climate, cooling needs are expected to increase severely, between 34% and 58% depending on the urban form, in contrast to the heating need which shows a considerable decrease of more than 40% for all urban forms.

The study of the impact of the urban form factors on energy demand shows a high relationship between density and heating and cooling needs in both climates, with low heating and cooling needs matching with high density in urban forms A and B, and low density of urban forms C and D matching with high heating and cooling needs.

As far as compactness is concerned, the relationship between the urban form factor and the heating and cooling needs shows a strong and opposite relationship to that found in density, urban forms (C and D) with high energy needs show high compactness, and in contrast for urban forms A and B, the correlation between compactness and the differences in heating and cooling needs shows a high relationship between compactness and the difference in heating needs, and a low relationship with the difference in cooling needs. In another correlation study, the high standard deviation of building floor area corresponds to low cooling needs (urban forms A, B and D), and exhibits no match with heating needs. On the other hand, the changes in cooling requirements over the 30 years are strongly linked to the standard deviation of the floor area of the buildings. For the average outdoor distance, the modelling results show a significant impact on the cooling needs and their increase over the years. Furthermore, low heat transmission values correspond to low heating and cooling needs (urban forms A, B and C) and vice versa in urban form D, in comparison with the above urban form factors, the U-value did not show a high impact on the decrease of heating needs and the increase of cooling needs over the years.

The second objective of this chapter focuses on the evaluation of the potential of solar techniques in urban forms. The results indicate that there are no relevant differences between the present and future average solar irradiation of facades, while the average solar irradiation of roofs in the future climate increases by 10-17% in urban forms A, C and D depending on the urban form, and decreases by 6% in urban form B. Furthermore, the average solar irradiation differs in facades and roofs by more than 35% for roofs across the two climates.

Based on the method of applying a threshold to evaluate the different solar techniques described in chapter V section 7, the results for the four solar techniques (passive solar, daylight, PV and ST) feature interesting results. Applying an irradiation threshold of 187 kWh/m² and 120 kWh/m² in the current and future climate, respectively, reveals that the façade area suitable for passive solar techniques varies between 29% and 57% of the total façade area of the urban form depending on the urban form, and these fractions increase in the future projection from 11% to 15% depending on the urban form. In the present climate, the favourable façade area for the required illuminance threshold (10000Lx) presents 12% to 43% of the total façade area. The future scenario shows a decrease of these fractions in all urban forms, except urban form C which keeps the same present fraction.

In the present climate, the evaluation of the active solar techniques in facades by applying solar irradiation thresholds of 600 kWh/m² and 400 kWh/m² for the PV technique and the solar thermal collectors, respectively, demonstrates an adequate area that exceeds 50% of the total façade area in all urban forms; these fractions decrease in the future climate for both applications. However, for roofs, using thresholds of 1000 kWh/m² for the suitability of PV and 600 kWh/m² for the suitability of solar thermal, the results point to a appropriate roof area of about 99% of the total roof area in both climates.

The last part of the chapter presents the application of rooftop PV system in all urban forms, the results indicate that 20 m² of rooftop PV system generation in each building in the current climate can eliminate a considerable part of the electricity consumption in a self-consumption scheme, in addition, these results will be more favourable when using a storage system. Regarding the future projection, the increase in cooling needs requires more electricity demand, which reduces the impact of 20 m² of PV system generation on electricity supply and suggests increasing the size of the PV system. 30 m² of PV roof generation can cover the electricity consumption in urban forms A, B, and D and eliminate a large part in urban form C. The excess PV generation in the urban forms gives the possibility to use a heat pump for heating and gas substitution for more environmental sustainability. It is also interesting to note that the shading of the PV panels on the roofs allows for a slight increase in heating needs and a slight decrease in cooling needs in all urban forms.

General conclusion and perspectives

GENERAL CONCLUSION AND PERSPECTIVES

The main aim of this doctoral thesis was to promote a sustainable urban built environment by investigating the energy behaviour, potential uses of solar radiation, and influence of urban form factors in urban areas considering the context of climate change. The study focuses on the case of residential housing subdivisions in Algeria, in the metropolis of Constantine. A city known for its historical urban development, its widespread urbanization, and its different urban morphologies. The four urban forms selected are the residential subdivisions of Ain El Bey 1st Tranche (urban form A), Djbel El Ouihch (urban form B), Villat Boudiaf (urban form C), and district Nedjma (urban form D). These selected urban residential samples were chosen after an analysis of the individual housing subdivisions in the town of Constantine based on the surface area, the shape of the neighborhoods, the urban density, the shape of the buildings, the type of individual house in the city, the height, and the type of construction.

Overall, the thesis starts with a general introduction which contains: a context study that presents a global and local opening of the thesis topic; a problematic that highlights the logical links between the terms of the study object, as well as showing the importance of the study issues at the scale of the chosen case study; objectives section which defines the points reached by the thesis; and hypothesis section which sets out the ideas that guide the scientific research, pave the way for discoveries, and which are verified in the last section of this part. The main body is composed of two parts. The first part contains three chapters, deals with the literature review, and presents the main studies that are relevant to the topic of the thesis. The second part in turn contains three chapters, which present practical work on the study of energy at the level of the urban case study.

After a reminder of the main objective and structure of the thesis, the following sections offer a retrospective of the main axes and milestones linked to the sub-objectives of the research, as well as an extracted answer to the issues raised at the beginning. At the end the sections verify the hypotheses, give a scientific position on the studied research, present future research tracks as well as the limits of this research.

In the scientific field, there is a great deal of research into the impact of an interaction between two objects [natural phenomenon and matter (for example between radiation and a building) or natural phenomenon and several sensitive matters between them (between wind and several buildings)]. These studies require a thorough analysis of the object's structure, in particular the matter from which the other natural phenomenon is experienced. This makes it possible to know which components of the structure and to what extent have an influence on the existing results. Once this stage has been completed, suggestions for optimising, reducing, or improving the impact can be reformulated. For this purpose, the first objective of this study was to determine the different scales and factors that structure the urban form, and then to extract the most influential urban form factors on energy demand and solar access. Going through chapter one, urban form shows three scales (urban form, building and envelope scale) which are in turn broken down into several factors. Then, by performing a mathematical analysis in the first part of chapter six, the most influential factors were found to be: density (Den), compactness (Com), mean outdoor distance (MOD), standard deviation of building footprint area (StF) as well as the thermal transmittance (U) of the envelope of the buildings case studies. The latter has an impact only on energy consumption, while in terms of solar access at the urban scale, it is not considered.

On the issues of climate change and energy in urban areas, chapters two and three show that governments around the world are addressing these issues through new policies for sustainable environments and the reinforcement of renewable energy use, such as solar technologies. In addition, the sections in these chapters deal with techniques applied in the urban environment for climate change adaptation and mitigation, as well as for ensuring high energy efficiency, which is achieved by intervening in the urban form that was the reason for the problem, and which can then be transformed into a solution. The intervention can be carried out in existing or new buildings. It includes the adoption of passive and active strategies in the design of buildings. Solar energy is considered as the most promising renewable energy, because of its many techniques (PV, St, passive solar heat, daylight) that can be combined between the two strategies, especially to develop the current and future exploration on clean energy efficient building types such as BAPV, BIPV and ZEB, where solar energy is the main energy supplier for these buildings.

In the same chapters, mainly the third one and concerning Algeria, this government has tried with some of its policies and strategies to achieve a clean energy transition and to respond slightly to climate change issues. The country has many cities, such as the city of Constantine, which have a high energy consumption (natural gas and electricity) in the residential sector, mainly individual housing, this energy is derived from non-renewable sources. At this stage, within the framework of the present and future climate scenario, the second objective consists in examining the energy behaviour and the amount of solar irradiation of the four urban residential forms in the city of Constantine. Through chapters four, five and six, the long line of study starts with the identification of the environment study in its entirety, from the point of view of the climate to the point of view of the type of residential building, at this point, the research shows that Constantine has a cold semi-arid climate, while the 30-year projection shows that this climate will experience an increase in the total ambient temperature throughout the year, for solar irradiation, a slight increase during the cold season as well as a decrease during the summer months were perceived. Regarding the types of housing, as the city has experienced a different historical urban development, it was found that it has several types of housing. In the same line, projecting the conclusion light in the results of the case studies and giving a place to the third objective, which targets the study of the impact of urban form factors on energy behavior, solar irradiation and on the evolution of the latter two components over the years in the selected urban areas, the results show that on the one hand, the urban forms had a different energy demand explained by a wide range of heating and cooling needs, per unit of volume of the building, that differ by a factor of 2 and 6, respectively, between urban forms. For future climate, the heating decreased significantly, and the cooling known a high increase in all urban forms. The difference in energy need is a function of the differences in urban form configuration, precisely the impact of urban form factors. A low energy need corresponds to high density, low compactness, high standard deviation of the footprint area of buildings, high mean outdoor distance, and low U-value. In the context of climate change up to 2050, the change in energy demand is mainly caused by the high temperature and solar irradiation difference of the future climate, the decrease in heating is strongly correlated to the values of density and compactness, while the increase in cooling is strongly correlated to the high standard deviation of the building footprint area and the mean outdoor distance.

On the other hand, the amount of solar irradiation was found to be high and comparable in all urban forms, while in dense urban forms, façades receive a lower amount compared to low density forms. Moreover, the average solar irradiation differs between façades and roofs by more than 35% for roofs in both climates.

Following the study line of the thesis, the evaluation of solar techniques including passive solar, daylight, photovoltaic and solar thermal was carried out. Passive solar techniques show a reduced present average potential in the façades of all urban forms. Due to the high temperature in the future climate, this potential tends to increase. The same conclusion can be drawn for the assessment of the daylighting potential of the façades, except that in the future climate the potential decreases, significantly in the dense areas. The evaluation of PV and ST in façades shows an acceptable useful potential in the current climate, in the future climate the same reduction behaviour in both techniques is perceived. For roofs, in all urban forms, both techniques reach the ultimate adequate potential and do not show significant differences in both climates.

In the same context, the fourth objective aims to test the application of renewable solar energy in urban forms, as the solar potential of roofs is important, the use of a photovoltaic system is applied. Therefore, the results show that a small rooftop PV system in the case studies can eliminate a considerable part of the electricity consumption in a self-consumption scheme, moreover, these results will be more favourable by using a storage system.

Among all the results, a conspicuous one was in the urban form B, which is distinguished by its continuous curvature that could improve solar gains during the winter months, and by its attached dense buildings that have low energy consumption. From this point of view, this urban form is the most appropriate to minimise energy needs.

By concatenating the previous achievements with the first declarative ideas, it is interesting in this section to open a window for the hypothesis.

- Hypothesis one: **Impact of urban form on energy demand and solar access will accentuate in future climate, and the energy gap presents a connection with typo morphological factors.**

Chapter six, in its evaluations and results, gives an answer and a return to this hypothesis. It shows that the urban form factors have a declarative impact on energy demand and solar energy access in the present climate. Due to the change of the future climate, the impact of the urban form factors increases or decreases according to these factors, the difference of decrease and increase of heating and cooling in urban forms in the future climate, respectively, show clearly the impact of the urban form characterisation on energy demand, solar energy access as well as the energy gap in the course of years.

- Hypothesis two: **A small area of PV system (20 m²) per building would satisfy electricity demand in the present climate and for next 30 years, and the PV could trigger the replacement of gas with electricity to satisfy heating needs in the heating season.**

This hypothesis has likewise been analysed in the context of the thesis. The results show that there is significant solar potential on rooftops. A small PV area (20 m²) can meet most of the electricity needs for all urban forms. The results indicate that as heating needs decrease in future climates, the increase in PV capacity will allow the use of solar heat pumps to supply the heating needs of buildings during the heating season. It demonstrates that PV could satisfy about half or all the heating needs, depending on the urban form, thus contributing to the complete decarbonisation of heating and cooling needs.

- Hypothesis three: **The built environment in Algeria, mainly subdivision housing, presents a compromised environment and is considered unsuitable for solar techniques and in terms of energy efficiency.**

The results from the literature review or the practical work of the thesis indicate that these housing are high energy consumers, which proves the lack of energy efficiency. However, the results show that these housing units are adapted to solar techniques mainly the active technique, which invalidates the second part of the hypothesis.

This study performed on a real housing in Constantine which may give a future vision for Algerian energy decision makers on how energy consumption could be in one of the most energy consuming sectors in the context of climate change, furthermore, encouraging the use of microgeneration renewable energy in the building sector such as photovoltaic systems can lead to a clean energy transition, especially in cities with a significant solar potential. Furthermore, intervention on reducing energy consumption in existing buildings may require the previous strategy, but with a prior assessment of the solar potential, moreover, in the construction of new urban forms, the use of methods to predict energy consumption and microgeneration renewable energy production for the detailed urban scale like UBEM will be more useful.

Research limitations

With regard to the calibration procedure, it should be noted that Meteonorm, in producing typical meteorological years, it does not reflect the real time during a given period. Similarly, for some periods during weekends or holidays, internal gains due to appliances and occupants are not identified.

The building energy modelling procedure has certain limitations as well, because of the required simplified urban representation and modelling design simplifications of Citysim. Citysim is not able to evaluate in full the complexity of the urban microclimate, ignoring the effect of reflected irradiation from the ground or neighbouring buildings, and using simplified anisotropic diffusion irradiation and solar transposition models. Furthermore, heat transfer modelling simplifies zoning and HVAC systems.

It is also important to note that the conversion efficiency of the PV is considered to be constant over the lifetime of the system, hence the effect of ageing on the PV efficiency is neglected.

Development perspectives

The application of this study can be extended to other type of urban forms in other sectors and/or cities, this will help to give guidelines on how energy consumption and production could change due to climate change.

In the same previous perspective, the application of energy optimisation to the urban form in terms of energy consumption or production with a future climate projection can be an interesting line of research, firstly, it will lead to high energy efficiency and effective strategies for climate change adaptation and mitigation, secondly, it can be achieved by mathematical approaches directly or via the in-depth use of a visual programming language for design and optimisation.

Filling in some of the points in this study, it is interesting to extend the study using a tool or combination of tools (such as Citysim and Envi-met) to fully assess the complexity of the urban microclimate (thermal fluctuation, tree effect .....), which will help to study the realisation work with more and more precision, furthermore, the assessment of the impact of the active solar techniques on the microclimate of the urban form is a point that has not been clearly covered before.

The assessment procedure adopted for energy generation from PV technology as a renewable energy application allows the assessment to be extended to other microgeneration renewable energy systems such as solar thermal collectors and micro wind turbines.

As the UBEM tool used in this study allows for a high-quality energy study at the Urban scale, other scales larger or smaller than the studied urban forms can be explored, this will allow to obtain more results that will help urban planners, architects, engineers and policymakers in the decision phases of construction or in the consideration of energy in existing buildings.

Bibliographic references

BIBLIOGRAPHY

BOOK

ASHRAE. (2010). IES Standard 90.1-2010: Energy Standard for Buildings Except Low-rise Residential Buildings: Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning.

ASHRAE. (2013). Handbook, Fundamentals (SI Edition) (Vol. Inc): American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Baker, N., & Steemers, K. (2003). Energy and environment in architecture: a technical design guide: Taylor & Francis.

Bednar, T. (2020). Determination of total energy transmittance of glazing systems at the building site: CRC Press.

Council, S. B. I. J. S. B. I. C. E. (2004). Green building guidelines: Meeting the demand for lowenergy, resource efficient homes. Washington, DC: Sustainable Buildings Industry Council.

De Herde, A., & Liébard, A. (2005). Traité d'architecture et d'urbanisme bioclimatiques: concevoir, édifier et aménager avec le développement durable.

Dempsey, N., Brown, C., Raman, S., Porta, S., Jenks, M., Jones, C., & Bramley, G. (2010). Elements of urban form. In Dimensions of the sustainable city (pp. 21-51): Springer.

Ebinger, J. O. (2011). Climate impacts on energy systems: key issues for energy sector adaptation: World Bank Publications.

Goulding, J. R., Lewis, J. O., & Steemers, T. C. (1992). Energy in architecture: the European passive solar handbook (Vol. 13446): Trafalgar Square Publishing.

Houghton, J. T., Meira Filho, L., Bruce, J. P., Lee, H., Callander, B. A., Harris, N., & Haites, E. (1995). Climate change 1994: radiative forcing of climate change and an evaluation of the IPCC 1992 IS92 emission scenarios: Cambridge University Press.

Hughes, S., Chu, E. K., & Mason, S. G. (2020). Climate Change and Cities: Springer.

Hyde, R. (2012). Bioclimatic housing: innovative designs for warm climates: Routledge.

Johnson, T. E. (1981). Solar architecture: the direct gain approach: Massachusetts Institute of Technology.

Morvaj, Z. (2012). Energy Efficiency: A Bridge to Low Carbon Economy: BoD–Books on Demand.

Oliveira, V., Barke, M., Ünlü, T., Conzen, M., Cataldi, G., Marzot, N., . . . Strappa, G. (2018). Teaching urban morphology: Springer.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., . . . Dasgupta, P. (2014). Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change: Ipcc.

Patrick Bacry, H. H.-F., Patricia Maire, DorineMorel, Géard Petit, Nivole Tien-Nikolaev, Magali Rouquier, Dominique Vaquié and Christophe Andreau,. (1995). Dictionnaire de la langue française (Claude Kannas Ed. Vol. 4): Larousse.

Rosenzweig, C., Solecki, W. D., Romero-Lankao, P., Mehrotra, S., Dhakal, S., & Ibrahim, S. A. (2018). Climate change and cities: Second assessment report of the urban climate change research network: Cambridge University Press.

Salah Chaouche, M. B. (2013). Une promenade patrimoniale maghrébine à travers le temps: connaître le passé pour construire l'avenir (B. éditions Ed. 2013 ed.).

Santamouris, M. (2013). Thermal balance in the urban environment. In Energy and Climate in the Urban Built Environment (pp. 47-55): Routledge.

Staffell, I., Brett, D. J., Brandon, N. P., & Hawkes, A. D. (2015). Domestic microgeneration: renewable and distributed energy technologies, policies and economics: Routledge.

Steane, M. A., & Steemers, K. (2004). Environmental diversity in Architecture: Routledge.

World Health Organization. (2018). WHO housing and health guidelines.

Catalogue

JINKOSOLAR, 2018. CheetahPerc JKM315-335M-60-V-A2-EN.ai, in: JINKOSOLAR

Conference paper

Amraoui, K., Sriti, L., Di Turi, S., Ruggiero, F., & Kaihoul, A. (2021). Exploring building's envelope thermal behavior of the neo-vernacular residential architecture in a hot and dry climate region of Algeria. Paper presented at the Building Simulation.

Araji, M. (2019). Surface-to-volume ratio: How building geometry impacts solar energy production and heat gain through envelopes. Paper presented at the IOP Conference Series: Earth and Environmental Science.

Compagnon, R., & Raydan, D. (2000). Irradiance and illuminance distributions in urban areas. Paper presented at the Proceedings of PLEA.

Danielski, I., Fröling, M., & Joelsson, A. (2012). The impact of the shape factor on final energy demand in residential buildings in nordic climates. Paper presented at the World Renewable Energy Forum, WREF 2012, Including World Renewable Energy Congress XII and Colorado Renewable Energy Society (CRES) Annual Conference; Denver, CO; 13 May 2012through17 May 2012; Code94564.

Felkner, J., Brown, J. D., Vazquez-Canteli, J. R., & Nagy, Z. (2019). Urban densification and housing typology for climate change mitigation. Paper presented at the Journal of Physics: Conference Series.

Jamaludin, A. A., Inangda, N., Ariffin, A. R. M., & Hussein, H. (2011). Energy performance: A comparison of four different multi-residential building designs and forms in the equatorial region. Paper presented at the 2011 IEEE Conference on Clean Energy and Technology (CET).

Laksmiyanti, D., & Salisnanda, R. (2019). Atrium Form and Thermal Performance of Middle-Rise Wide Span Building in Tropics. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Mohammed, A., Mustapha, A., & Mu'azu, N. (2011). Energy efficient buildings as a tool for ensuring sustainability in the building industry. Paper presented at the 2011 International Conference on Multimedia Technology.

Montavon, M., Scartezzini, J.-L., & Compagnon, R. (2004). Comparison of the solar energy utilisation potential of different urban environments. Paper presented at the PLEA 2004 Conference.

O'Brien, C. M. (2019). [Floor Area Ratio Requirements].

Page, J., Robinson, D., & Scartezzini, J.-L. (2007). Stochastic simulation of occupant presence and behaviour in buildings. Paper presented at the Proc. Tenth Int. IBPSA Conf: Building Simulation.

Peri, G., Foresta, F., Inzerillo, L., & Rizzo, G. (2013). Environmentally assessing buildings characterized by complex shape and innovative materials. Paper presented at the Advanced Materials Research.

Raven, J., Stone, B., Mills, G., Towers, J., Katzschner, L., Leone, M., . . . Lee10, J. (2016). The Assessment Report for Climate Change in Cities (ARC3-2) Urban Planning and Design. Paper presented at the International Conference on Sustainable Infrastructure Shenzhen, China.

Raynaud, D. (1999). Forme urbaine: une notion exemplaire du point de vue de l'épistémologie des sciences sociales. Paper presented at the Ph. Boudon, éd., Langages singuliers et partagés de l'urbain (Actes du Colloque LOUEST, CNRS UMR 7544).

Robinson, D., Haldi, F., Leroux, P., Perez, D., Rasheed, A., & Wilke, U. (2009). CitySim: Comprehensive micro-simulation of resource flows for sustainable urban planning. Paper presented at the Proceedings of the Eleventh International IBPSA Conference.

Sargent, J. A., Niemasz, J., & Reinhart, C. F. (2011). Shaderade: combining Rhinoceros and Energyplus for the design of static exterior shading devices. Paper presented at the Proceedings of Building Simulation.

Walter, E., & Kämpf, J. H. (2015). A verification of CitySim results using the BESTEST and monitored consumption values. Paper presented at the Proceedings of the 2nd Building Simulation Applications conference.

Wang, Z., Yang, R., & Wang, L. (2010). Multi-agent control system with intelligent optimization for smart and energy-efficient buildings. Paper presented at the IECON 2010-36th annual conference on IEEE industrial electronics society.

Geniric

Birkhoff, G. (1933). Aesthetic Measure. Cambridge, Massachusetts Harvard. In: University Press.

Sgroi, A. (2011). Morfología Urbana: Forma Urbana: Paisaje Urbano. In: La Plata: Universidad Nacional de La Plata.

Steadman, p., Hamilton, i., Godoy-shimizu, d., Shayesteh, h., & Evans, s. (2017). High-Rise Buildings: Energy and Density [Online]. UCL Energy Institute Home. In.

Articles

Abanda, F., & Byers, L. (2016). An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling). Energy, 97, 517-527.

Achour, L., Bouharkat, M., & Behar, O. (2018). Performance assessment of an integrated solar combined cycle in the southern of Algeria. Energy Reports, 4, 207-217.

Adolphe, L. (2001). A simplified model of urban morphology: application to an analysis of the environmental performance of cities. Environment planning B: planning design, 28(2), 183-200.

Afaifia, M., Djiar, K. A., Bich-Ngoc, N., & Teller, J. (2021). An energy consumption model for the Algerian residential building's stock, based on a triangular approach: Geographic Information System (GIS), regression analysis and hierarchical cluster analysis. Sustainable Cities Society, 74, 103191.

Afiq, W., Azwadi, C. N., & Saqr, K. (2012). Effects of buildings aspect ratio, wind speed and wind direction on flow structure and pollutant dispersion in symmetric street canyons: a review. International Journal of Mechanical Materials Engineering

7(2), 158-165.

Ahmad, M. W., Mourshed, M., & Rezgui, Y. (2017). Trees vs Neurons: Comparison between random forest and ANN for high-resolution prediction of building energy consumption. Energy and Buildings, 147, 77-89. doi:https://doi.org/10.1016/j.enbuild.2017.04.038

Ali-Toudert, F., & Weidhaus, J. (2017). Numerical assessment and optimization of a low-energy residential building for Mediterranean and Saharan climates using a pilot project in Algeria. Renewable energy, 101, 327-346.

Amri, F. (2017). The relationship amongst energy consumption (renewable and non-renewable), and GDP in Algeria. Renewable sustainable energy reviews, 76, 62-71.

Anderson, W. P., Kanaroglou, P. S., & Miller, E. J. (1996). Urban form, energy and the environment: a review of issues, evidence and policy. Urban studies, 33(1), 7-35.

Angel, S., Parent, J., Civco, D. L., Blei, A., & Potere, D. (2011). The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. Progress in Planning, 75(2), 53-107.

Ayompe, L., Duffy, A., McCormack, S., & Conlon, M. (2011). Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. Energy conversion and management, 52(2), 816-825. doi:https://doi.org/10.1016/j.enconman.2010.08.007

Bakar, N. N. A., Hassan, M. Y., Abdullah, H., Rahman, H. A., Abdullah, M. P., Hussin, F., & Bandi, M. (2015). Energy efficiency index as an indicator for measuring building energy performance: A review. Renewable sustainable energy reviews, 44, 1-11.

BELMALLEM, S. C. (2014). L'HABITAT INFORMEL DANS LA VILLE DE CONSTANTINE: ETALEMENT URBAIN ET INEGALITES SOCIO-SPATIALES. Sciences Technologie. D, Sciences de la terre, 9-19.

Benmatti, N. A. (1982). L'Habitat du tiers-monde (cas de l'Algérie).

Bennouna, M., & Kehal, S. (2001). Production de méthane à partir des boues des stations d'épuration des eaux usées: potentiel existant en Algérie. Revues des Energies Renouvelables: Production et Valorisation-Biomasse, 29-36.

Berardi, U., & Jafarpur, P. (2020). Assessing the impact of climate change on building heating and cooling energy demand in Canada. Renewable and Sustainable Energy Reviews, 121, 109681. doi:https://doi.org/10.1016/j.rser.2019.109681

Bergamini, K. (2019). Urban Landscape/Urban Form. The Wiley Blackwell Encyclopedia of Urban and Regional Studies, 1-10. doi: https://doi.org/10.1002/9781118568446.eurs0375

Bienvenido-Huertas, D., Moyano, J., Marín, D., & Fresco-Contreras, R. (2019). Review of in situ methods for assessing the thermal transmittance of walls. Renewable Sustainable Energy Reviews, 102, 356-371.

Biljecki, F. (2017). Level of detail in 3D city models.

Biyik, E., Araz, M., Hepbasli, A., Shahrestani, M., Yao, R., Shao, L., . . . Rico, E. (2017). A key review of building integrated photovoltaic (BIPV) systems. Engineering science technology, an international journal, 20(3), 833-858.

Boissonade, J., Méquignon, M., & Mignot, J.-P. (2016). Habitat durable: approches critiques. Sciences de la société(98), 3-13.

Boukli Hacene, M., Chabane Sari, N. J. I., & Environment, B. (2020). Energy efficient design optimization of a bioclimatic house. Indoor Built Environment, 29(2), 270-285.

Bouraiou, A., Necaibia, A., Boutasseta, N., Mekhilef, S., Dabou, R., Ziane, A., . . . Touaba, O. (2020). Status of renewable energy potential and utilization in Algeria. Journal of Cleaner Production, 246, 119011. doi:https://doi.org/10.1016/j.jclepro.2019.119011

Bourbia, F., & Boucheriba, F. (2010). Impact of street design on urban microclimate for semi arid climate (Constantine). Renewable energy, 35(2), 343-347. doi:https://doi.org/10.1016/j.renene.2009.07.017

Bourne, L. S. (1982). Urban spatial structure: an introductory essay on concepts and criteria. Internal Structure of the City, 45.

Bruun Jørgensen, O., Croce, S., Dahlberg, J., Delmas, A., Florio, P., Garde, F., . . . Kappel, K. (2018). Lesson Learned from Case Studies of Solar Energy in Urban Planning. IEA SHC Task 51/Report C3.

Chatzipoulka, C., Compagnon, R., & Nikolopoulou, M. (2016). Urban geometry and solar availability on façades and ground of real urban forms: using London as a case study. Solar Energy, 138, 53-66. doi:https://doi.org/10.1016/j.renene.2013.02.013

Chatzipoulka, C., & Nikolopoulou, M. (2018). Urban geometry, SVF and insolation of open spaces: London and Paris. Building Research & Information, 46(8), 881-898. doi:https://doi.org/10.1080/09613218.2018.1463015

Chatzipoulka, C., Steemers, K., & Nikolopoulou, M. (2020). Density and coverage values as indicators of thermal diversity in open spaces: Comparative analysis of London and Paris based on sun and wind shadow maps. Cities, 100, 102645.

Cheekatamarla, P. K. (2021). Decarbonization of Residential Building Energy Supply: Impact of Cogeneration System Performance on Energy, Environment, and Economics. Energies, 14(9), 2538.

Chen, S., Yang, W., Yoshino, H., Levine, M. D., Newhouse, K., & Hinge, A. (2015). Definition of occupant behavior in residential buildings and its application to behavior analysis in case studies. Energy and Buildings, 104, 1-13. doi:https://doi.org/10.1016/j.enbuild.2015.06.075

Chen, S., Zhang, G., Xia, X., Setunge, S., & Shi, L. (2020). A review of internal and external influencing factors on energy efficiency design of buildings. Energy buildings, 216, 109944.

Codoban, N., & Kennedy, C. A. (2008). Metabolism of neighborhoods. Journal of urban planning development, 134(1), 21-31.

Compagnon, R. (2004). Solar and daylight availability in the urban fabric. Energy buildings, 36(4), 321-328.

Conzen, M. R. G. (1960). Alnwick, Northumberland: a study in town-plan analysis. Transactions Papers(27), iii-122.

Cubasch, U., D. Wuebbles, D. Chen, M.C. Facchini, D. Frame, N. Mahowald, & Winther, J.-G. (2013). Introduction in: Climate Change : The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Davis, W., Frederick, C. M., & Valois, K. K. (2003). Building a representation of aspect ratio. Journal of Vision, 3(12), 13-13.

de Lemos Martins, T. A., Adolphe, L., Bastos, L. E. G., & de Lemos Martins, M. A. (2016). Sensitivity analysis of urban morphology factors regarding solar energy potential of buildings in a Brazilian tropical context. Solar Energy, 137, 11-24. doi:https://doi.org/10.1016/j.solener.2016.0

de Lemos Martins, T. A., Faraut, S., & Adolphe, L. (2019). Influence of context-sensitive urban and architectural design factors on the energy demand of buildings in Toulouse, France. Energy buildings, 190, 262-278.

Debbage, N., & Shepherd, J. M. (2015). The urban heat island effect and city contiguity. Computers, Environment Urban Systems, 54, 181-194.

Delzendeh, E., Wu, S., Lee, A., & Zhou, Y. (2017). The impact of occupants' behaviours on building energy analysis: A research review. Renewable and Sustainable Energy Reviews, 80, 1061-1071. doi:https://doi.org/10.1016/j.enbuild.2019.02.019

Derradji, L., Imessad, K., Amara, M., & Errebai, F. B. (2017). A study on residential energy requirement and the effect of the glazing on the optimum insulation thickness. Applied Thermal Engineering, 112, 975-985.

Dias, J. B., Soares, P. M., & da Graça, G. C. (2020). The shape of days to come: Effects of climate change on low energy buildings. Building and Environment, 181, 107125. doi:https://doi.org/10.1016/j.buildenv.2020.107125

Eshraghi, J., Narjabadifam, N., Mirkhani, N., Khosroshahi, S. S., & Ashjaee, M. (2014). A comprehensive feasibility study of applying solar energy to design a zero energy building for a typical home in Tehran. Energy buildings, 72, 329-339.

Ettoumi, F. Y., Benzaoui, M. L., & Bouzergui, N. (2008). Comparative simulation of wind park design and siting in Algeria. Renewable energy, 33(10), 2333-2338.

Ewing, R., & Rong, F. (2008). The impact of urban form on US residential energy use. Housing policy debate, 19(1), 1-30.

Fallahtafti, R., & Mahdavinejad, M. (2015). Optimisation of building shape and orientation for better energy efficient architecture. International Journal of Energy Sector Management.

Filion, P. (2012). Evolving suburban form: dispersion or recentralization? Urban Morphology, 16(2), 101.

Fouad, A. O. (2007). Morphologie urbaine et confort thermique dans les espaces publics: étude comparative entre trois tissus urbains de la ville de Québec.

Gadsden, S., Rylatt, M., & Lomas, K. (2003). Putting solar energy on the urban map: a new GIS-based approach for dwellings. Solar Energy, 74(5), 397-407.

Gerlak, A. K., Weston, J., McMahan, B., Murray, R. L., & Mills-Novoa, M. (2018). Climate risk management and the electricity sector. Climate risk management, 19, 12-22.

Gernaat, D. E., de Boer, H. S., Daioglou, V., Yalew, S. G., Müller, C., & van Vuuren, D. P. (2021). Climate change impacts on renewable energy supply. Nature Climate Change, 11(2), 119-125.

Ghedamsi, R., Settou, N., Gouareh, A., Khamouli, A., Saifi, N., Recioui, B., & Dokkar, B. (2016). Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach. Energy and Buildings, 121, 309-317. doi:https://doi.org/10.1016/j.enbuild.2015.12.030

Ghosh, A. (2020). Potential of building integrated and attached/applied photovoltaic (BIPV/BAPV) for adaptive less energy-hungry building's skin: A comprehensive Review. Journal of Cleaner Production, 123343.

Ghosh, S., & Vale, R. (2006). The potential for solar energy use in a New Zealand residential neighbourhood: a case study considering the effect on CO2 emissions and the possible benefits of changing roof form. Australasian Journal of Environmental Management, 13(4), 216-225.

Gi, K., Sano, F., Hayashi, A., Tomoda, T., & Akimoto, K. (2018). A global analysis of residential heating and cooling service demand and cost-effective energy consumption under different climate change scenarios up to 2050. Mitigation and adaptation strategies for global change, 23(1), 51-79. doi:https://doi.org/10.1007/s11027-016-9728-6

Gong, F.-Y., Zeng, Z.-C., Zhang, F., Li, X., Ng, E., & Norford, L. K. (2018). Mapping sky, tree, and building view factors of street canyons in a high-density urban environment. Building Environment, 134, 155-167.

Greening, B., & Azapagic, A. (2013). Environmental impacts of micro-wind turbines and their potential to contribute to UK climate change targets. Energy, 59, 454-466.

Gros, A., Bozonnet, E., Inard, C., & Musy, M. (2016). Simulation tools to assess microclimate and building energy–A case study on the design of a new district. Energy buildings, 114, 112-122.

Guan, L. (2009). Preparation of future weather data to study the impact of climate change on buildings. Building Environment, 44(4), 793-800.

Güneralp, B., Zhou, Y., Ürge-Vorsatz, D., Gupta, M., Yu, S., Patel, P. L., . . . Seto, K. C. (2017). Global scenarios of urban density and its impacts on building energy use through 2050. Proceedings of the National Academy of Sciences, 114(34), 8945-8950.

Hachem, C., Fazio, P., & Athienitis, A. (2013). Solar optimized residential neighborhoods: Evaluation and design methodology. Solar Energy, 95, 42-64.

Haldi, F., & Robinson, D. (2011). The impact of occupants' behaviour on building energy demand. Journal of Building Performance Simulation, 4(4), 323-338. doi:https://doi.org/10.1080/19401493.2011.558213

Hamiche, A. M., Stambouli, A. B., & Flazi, S. (2015). A review on the water and energy sectors in Algeria: Current forecasts, scenario and sustainability issues. Renewable sustainable energy reviews, 41, 261-276.

He, X., Li, Y., Wang, X., Chen, L., Yu, B., Zhang, Y., & Miao, S. (2019). High-resolution dataset of urban canopy parameters for Beijing and its application to the integrated WRF/Urban modelling system. Journal of Cleaner Production, 208, 373-383.

Hekkenberg, M., Moll, H., & Uiterkamp, A. S. (2009). Dynamic temperature dependence patterns in future energy demand models in the context of climate change. Energy, 34(11), 1797-1806.

Himri, Y., Malik, A. S., Stambouli, A. B., Himri, S., & Draoui, B. (2009). Review and use of the Algerian renewable energy for sustainable development. Renewable

sustainable energy reviews, 13(6-7), 1584-1591.

Himri, Y., Rehman, S., Draoui, B., & Himri, S. (2008). Wind power potential assessment for three locations in Algeria. Renewable Sustainable Energy Reviews 12(9), 2495-2504.

Holmer, B., Postgård, U., & Eriksson, M. (2001). Sky view factors in forest canopies calculated with IDRISI. Theoretical Applied Climatology, 68(1), 33-40.

Hong, T., Chen, Y., Luo, X., Luo, N., & Lee, S. H. (2020). Ten questions on urban building energy modeling. Building Environment, 168, 106508.

Hong, Y., Ezeh, C., Deng, W., Hong, S., Peng, Z., & Tang, Y. (2020). Correlation between building characteristics and associated energy consumption: Prototyping low-rise office buildings in Shanghai. Energy buildings, 217, 109959.

Hsieh, C.-M., Chen, Y.-A., Tan, H., & Lo, P.-F. (2013). Potential for installing photovoltaic systems on vertical and horizontal building surfaces in urban areas. Solar Energy, 93, 312-321. doi:https://doi.org/10.1016/j.solener.2013.04.021

Hub. (2015). Post-occupancy Evaluation, Rowner Research Project Phase Two. Zero Carbon HUB.

Hui, S. C. (2001). Low energy building design in high density urban cities. Renewable energy, 24(3-4), 627-640.

IEA. (2019). 2019 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and constructi on sector. UN Enviroment programme, 224.

Imessad, K., Kharchi, R., Bouchaib, S., Chenak, A., Hakem, S., Hamidat, A., . . . Sahnoune, F. (2017). Mise en application de la nouvelle réglementation thermique algérienne du bâtiment. Revue des Energies Renouvelables, 20(4), 591-597.

Intergovernmental Pane On Climate Change. (2007). Climate change 2007: The physical science basis. Agenda, 6(07), 333.

IPCC, C. C. (2014). Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 1454.

Iqbal, M. J., & Quamar, J. (2011). Measuring temperature variability of five major cities of Pakistan. Arabian Journal of Geosciences, 4(3), 595-606.

Jackson, T. L., Feddema, J. J., Oleson, K. W., Bonan, G. B., & Bauer, J. T. (2010). Parameterization of urban characteristics for global climate modeling. Annals of the Association of American Geographers, 100(4), 848-865.

Jankovic, A., Podrascanin, Z., & Djurdjevic, V. (2019). Future climate change impacts on residential heating and cooling degree days in Serbia. Idojaras (Budapest, 1905), 123, 351-370. doi:https://doi.org/10.28974/idojaras.2019.3.6

Johari, F., Peronato, G., Sadeghian, P., Zhao, X., & Widén, J. (2020). Urban building energy modeling: State of the art and future prospects. Renewable and Sustainable Energy Reviews, 128, 109902. doi:https://doi.org/10.1016/j.rser.2020.109902

Kaidi, F., & Touzi, A. (2001). Production de bioalcool à partir des déchets de dattes. Revue des Energies Renouvelables, NS: Biomasse Production et Valorisation, 75-78.

Kaihoul, A., Sriti, L., Amraoui, K., Di Turi, S., & Ruggiero, F. (2021). The effect of climate-responsive design on thermal and energy performance: A simulation based study in the hot-dry Algerian South region. Journal of Building Engineering, 43, 103023.

Kamal, M. A. (2013). Le Corbusier’s solar shading strategy for tropical environment: A sustainable approach. Journal of Architectural/Planning Research Studies, 10(1), 19-26.

Kanters, J., & Horvat, M. (2012). Solar energy as a design parameter in urban planning. Energy Procedia, 30, 1143-1152. doi:https://doi.org/10.1016/j.egypro.2012.11.127

Kanters, J., & Wall, M. (2016). A planning process map for solar buildings in urban environments. Renewable and Sustainable Energy Reviews, 57, 173-185. doi:https://doi.org/10.1016/j.rser.2015.12.073

Kerfah, I. K., El Hassar, S. M. K., Rouleau, J., Gosselin, L., & Larabi, A. (2020). Analysis of strategies to reduce thermal discomfort and natural gas consumption during heating season in Algerian residential dwellings.

Kheiri, F. (2018). A review on optimization methods applied in energy-efficient building geometry and envelope design. Renewable sustainable energy reviews, 92, 897-920.

Knowles, R. L. (1981). Sun rhythm form.

Ko, Y. (2013). Urban form and residential energy use: A review of design principles and research findings. Journal of planning literature, 28(4), 327-351.

Kolokotroni, M., Davies, M., Croxford, B., Bhuiyan, S., & Mavrogianni, A. (2010). A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island: Case-study of London. Solar Energy, 84(12), 2246-2255.

Korolija, I., Marjanovic-Halburd, L., Zhang, Y., & Hanby, V. I. (2011). Influence of building parameters and HVAC systems coupling on building energy performance. Energy Buildings, 43(6), 1247-1253.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15(3), 259-263. doi:https://doi.org/10.1127/0941-2948/2006/0130

Kropf, K. (2014). Ambiguity in the definition of built form. Urban morphology, 18(1), 41-57.

Laib, I., Hamidat, A., Haddadi, M., Ramzan, N., & Olabi, A. G. (2018). Study and simulation of the energy performances of a grid-connected PV system supplying a residential house in north of Algeria. Energy, 152, 445-454.

Latreche, S., & Sriti, L. (2018). Optimisation énergétique d'un bâtiment résidentiel autoproduite à Biskra à travers ses caractéristiques matérielles. Journal of Renewable Energies, 21(3), 433-443.

Le Guen, M., Mosca, L., Perera, A. T. D., Coccolo, S., Mohajeri, N., & Scartezzini, J.-L. (2018). Improving the energy sustainability of a Swiss village through building renovation and renewable energy integration. Energy and Buildings, 158, 906-923. doi: https://doi.org/10.1016/j.enbuild.2017.10.057

Lévy, A. (2005). Formes urbaines et significations: revisiter la morphologie urbaine. Espaces et sociétés(3), 25-48.

Li, D. H., Yang, L., & Lam, J. C. (2012). Impact of climate change on energy use in the built environment in different climate zones–a review. Energy, 42(1), 103-112. doi:https://doi.org/10.1016/j.energy.2012.03.044

Li, Y., Schubert, S., Kropp, J. P., & Rybski, D. (2020). On the influence of density and morphology on the Urban Heat Island intensity. Nature communications, 11(1), 1-9.

Littlefair, P. (1998). Passive solar urban design: ensuring the penetration of solar energy into the city. Renewable Sustainable Energy Reviews, 2(3), 303-326.

Littlefair, P. (2001). Daylight, sunlight and solar gain in the urban environment. Solar Energy, 70(3), 177-185.

Lobaccaro, G., Croce, S., Lindkvist, C., Probst, M. M., Scognamiglio, A., Dahlberg, J., . . . Wall, M. (2019). A cross-country perspective on solar energy in urban planning: Lessons learned from international case studies. Renewable and Sustainable Energy Reviews, 108, 209-237. doi:https://doi.org/10.1016/j.rser.2019.03.041

Louf, R., & Barthelemy, M. (2014). A typology of street patterns. Journal of The Royal Society Interface, 11(101), 20140924.

Luo, Y., Zhang, L., Bozlar, M., Liu, Z., Guo, H., & Meggers, F. (2019). Active building envelope systems toward renewable and sustainable energy. Renewable sustainable energy reviews, 104, 470-491.

Maachi, I. N., Mokhtari, A., & Slimani, M. E.-A. (2019). The natural lighting for energy saving and visual comfort in collective housing: A case study in the Algerian building context. Journal of Building Engineering, 24, 100760.

Mahar, W. A., Verbeeck, G., Reiter, S., & Attia, S. (2020). Sensitivity Analysis of Passive Design Strategies for Residential Buildings in Cold Semi-Arid Climates. Sustainability, 12(3), 1091.

Manzano-Agugliaro, F., Montoya, F. G., Sabio-Ortega, A., & García-Cruz, A. (2015). Review of bioclimatic architecture strategies for achieving thermal comfort. Renewable sustainable energy reviews, 49, 736-755.

Maouedj, R., Mammeri, A., Draou, M., & Benyoucef, B. (2015). Techno-economic analysis of a standalone hybrid photovoltaic-wind system. Application in electrification of a house in Adrar region. Energy Procedia, 74, 1192-1204.

Mardaljevic, J., & Rylatt, M. (2003). Irradiation mapping of complex urban environments: an image-based approach. Energy buildings, 35(1), 27-35.

Marszal, A. J., & Heiselberg, P. (2009). Zero Energy Building (ZEB) definitions-A literature review. Proceedings joint actions climate change, 40, 8-10.

Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I., & Napolitano, A. (2011). Zero Energy Building–A review of definitions and calculation methodologies. Energy buildings, 43(4), 971-979.

Martinaitis, V., Zavadskas, E. K., Motuzienė, V., & Vilutienė, T. (2015). Importance of occupancy information when simulating energy demand of energy efficient house: A case study. Energy and Buildings, 101, 64-75. doi:https://doi.org/10.1016/j.enbuild.2015.04.031

Mauree, D., Coccolo, S., Kaempf, J., & Scartezzini, J.-L. (2017). Multi-scale modelling to evaluate building energy consumption at the neighbourhood scale. PloS one, 12(9). doi:https://doi.org/10.1371/journal.pone.0183437

Middel, A., Häb, K., Brazel, A. J., Martin, C. A., & Guhathakurta, S. (2014). Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones. Landscape urban planning, 122, 16-28.

Mirkovic, M., & Alawadi, K. (2017). The effect of urban density on energy consumption and solar gains: the study of Abu Dhabi's neighborhood. Energy Procedia, 143, 277-282.

Missoum, M., Hamidat, A., Imessad, K., Bensalem, S., & Khoudja, A. (2016). Impact of a grid-connected PV system application in a bioclimatic house toward the zero energy status in the north of Algeria. Energy buildings, 128, 370-383.

Missoum, M., Hamidat, A., & Loukarfi, L. (2014). Energy performance simulations of a grid-connected PV system supplying a residential house in the North-Western of Algeria. Energy Procedia, 50, 202-213.

Mitrašinović, A. M. (2021). Photovoltaics advancements for transition from renewable to clean energy. Energy, 237, 121510.

Mohajeri, N., Gudmundsson, A., Kunckler, T., Upadhyay, G., Assouline, D., Kämpf, J., & Scartezzini, J. (2019). A solar-based sustainable urban design: The effects of city-scale street-canyon geometry on solar access in Geneva, Switzerland. Applied Energy, 240, 173-190. doi:https://doi.org/10.1016/j.apenergy.2019.02.014

Mohajeri, N., Upadhyay, G., Gudmundsson, A., Assouline, D., Kämpf, J., & Scartezzini, J.-L. (2016). Effects of urban compactness on solar energy potential. Renewable energy, 93, 469-482. doi:https://doi.org/10.1016/j.renene.2016.02.053

Mokhtara, C., Negrou, B., Settou, N., Settou, B., & Samy, M. M. (2021). Design optimization of off-grid Hybrid Renewable Energy Systems considering the effects of building energy performance and climate change: Case study of Algeria. Energy, 219, 119605.

Mondol, J. D., Yohanis, Y., Smyth, M., & Norton, B. (2005). Long-term validated simulation of a building integrated photovoltaic system. Solar Energy, 78(2), 163-176. doi:https://doi.org/10.1016/j.solener.2004.04.021

Morganti, M., Salvati, A., Coch, H., & Cecere, C. (2017). Urban morphology indicators for solar energy analysis. Energy Procedia, 134, 807-814.

Moss, R. H., Babiker, M., Brinkman, S., Calvo, E., Carter, T., Edmonds, J. A., . . . Hibbard, K. (2008). Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies.

Moudon, A. V. (1997). Urban morphology as an emerging interdisciplinary field. Urban Morphology, 1(1), 3-10.

Moussaoui, F., Cherrared, M., Kacimi, M. A., Belarbi, R. J. S. C., & Society. (2018). A genetic algorithm to optimize consistency ratio in AHP method for energy performance assessment of residential buildings—Application of top-down and bottom-up approaches in Algerian case study. Sustainable Cities Society, 42, 622-636.

Muhaisen, A. S., & Gadi, M. B. (2006). Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate of Rome. Building Environment, 41(3), 245-253.

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. Energy building, 38(7), 905-913.

Nadia, N. (2017). La rehabilitation energetique dans les logements collectifs existants.

Nagaoka, A., Ota, Y., Sakai, K., Araki, K., Matsuo, H., Kadota, N., . . . Nishioka, K. (2021). Performance evaluation and spectrum-based analysis of a wall-mounted photovoltaic system for zero-energy building. Renewable energy, 174, 147-156.

Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Majid, M. Z. A. (2015). A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renewable sustainable energy reviews, 43, 843-862.

Nicholson, S. E. (1975). A pollution model for street-level air. Atmospheric Environment, 9(1), 19-31.

Nik, V. M., Perera, A., & Chen, D. (2021). Towards climate resilient urban energy systems: a review. National Science Review, 8(3), nwaa134.

Oh, J., Hong, T., Kim, H., An, J., Jeong, K., & Koo, C. (2017). Advanced strategies for net-zero energy building: Focused on the early phase and usage phase of a building's life cycle. Sustainability, 9(12), 2272.

Oke, T. (1988). Street design and urban canopy layer climate. Energy buildings, 11(1-3), 103-113.

Okeil, A. (2010). A holistic approach to energy efficient building forms. Energy buildings, 42(9), 1437-1444.

Omer, A. M. (2008). Energy, environment and sustainable development. Renewable sustainable energy reviews, 12(9), 2265-2300.

Osorio, B., McCullen, N., Walker, I., & Coley, D. (2017). Understanding the relationship between energy consumption and urban form. Athens Journal of Sciences, 4(2), 115-142.

Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Engineering, 3(1), 1167990.

Pablo-Romero, P, M. d., Pozo-Barajas, R., & Yñiguez, R. (2017). Global changes in residential energy consumption. Energy Policy, 101, 342-352.

Parameshwaran, R., Kalaiselvam, S., Harikrishnan, S., & Elayaperumal, A. (2012). Sustainable thermal energy storage technologies for buildings: a review. Renewable Sustainable Energy Reviews, 16(5), 2394-2433.

Parasonis, J., Keizikas, A., & Kalibatiene, D. (2012). The relationship between the shape of a building and its energy performance. Architectural Engineering Design Management, 8(4), 246-256.

Perera, A., Coccolo, S., Scartezzini, J.-L., & Mauree, D. (2018). Quantifying the impact of urban climate by extending the boundaries of urban energy system modeling. Applied Energy, 222, 847-860. doi:https://doi.org/10.1016/j.apenergy.2018.04.004

Picard, A. (1989). Lotissements et colonisation: Algérie, 1830-1970. Villes en Parallèle, 14(1), 214-237.

Poon, K. H., Kämpf, J., Tay, S., Wong, N., & Reindl, T. (2020). Parametric study of URBAN morphology on building solar energy potential in Singapore context. Urban Climate, 33, 100624. doi:https://doi.org/10.1016/j.uclim.2020.100624

Portier, C., Thigpen-Tart, K., Hess, J., Luber, G., Maslak, T., Radtke, M., . . . Dilworth, C. (2010). A human health perspective on climate change. Research Triangle Park, NC: Environmental Health Perspectives, National Institute of Environmental Health Sciences.

Rahaman, M. H., & Iqbal, M. T. (2019). A Comparison of Solar Photovoltaic and Solar Thermal Collector for Residential Water Heating and Space Heating System.

Rahman, M. I.-u. (2013). Climate change: a theoretical review. Interdisciplinary Description of Complex Systems: INDECS, 11(1), 1-13.

Randles, C., Russell, L., & Ramaswamy, V. (2004). Hygroscopic and optical properties of organic sea salt aerosol and consequences for climate forcing. Geophysical Research Letters, 31(16).

Ratti, C., Raydan, D., & Steemers, K. (2003). Building form and environmental performance: archetypes, analysis and an arid climate. Energy buildings, 35(1), 49-59.

Redweik, P., Catita, C., & Brito, M. (2013). Solar energy potential on roofs and facades in an urban landscape. Solar Energy, 97, 332-341.

Reinhart, C. F., & Davila, C. C. (2016). Urban building energy modeling–A review of a nascent field. Building and Environment, 97, 196-202. doi: https://doi.org/10.1016/j.buildenv.2015.12.001

Resch, E., Bohne, R. A., Kvamsdal, T., & Lohne, J. (2016). Impact of urban density and building height on energy use in cities. Energy Procedia, 96, 800-814.

Reyna, J. L., & Chester, M. V. (2017). Energy efficiency to reduce residential electricity and natural gas use under climate change. Nature communications, 8(1), 1-12. doi:https://doi.org/10.1038/ncomms14916

Rode, P., Burdett, R., Robazza, G., & Schofield, J. (2014). Cities and Energy: Urban Morphology and Heat Energy Demand Final Report. Cities,LSE Cities: London, UK.

Rodrigues, E., Fernandes, M. S., Gaspar, A. R., Gomes, Á., & Costa, J. (2019). Thermal transmittance effect on energy consumption of Mediterranean buildings with different thermal mass. Applied Energy, 252, 113437.

Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. Renewable sustainable energy reviews, 15(8), 3617-3631.

Salat, S., Bourdic, L., & Nowacki, C. (2010). Assessing urban complexity. International Journal of Sustainable Building Technology Urban Development, 1(2), 160-167.

Salvati, A., Kolokotroni, M., Kotopouleas, A., Watkins, R., Giridharan, R., & Nikolopoulou, M. (2020). Impact of urban albedo on microclimate: Computational investigation in London.

Sami-Mecheri, S., Semmar, D., & Hamid, A. (2015). Determination of the energetic needs of low Energy housing and integration of a solar water heating installation located in Algeria. Energy Procedia, 74, 854-863.

Sami, S., Semmar, D., Hamid, A., Mecheri, R., & Yaiche, M. (2018). Viability of integrating solar water heating systems into high energy performance housing in Algeria. Energy, 149, 354-363.

Sanaieian, H., Tenpierik, M., Van Den Linden, K., Seraj, F. M., & Shemrani, S. M. M. (2014). Review of the impact of urban block form on thermal performance, solar access and ventilation. Renewable sustainable energy reviews, 38, 551-560.

Sanchez-Lorenzo, A., Calbó, J., & Wild, M. (2012). Increasing cloud cover in the 20th century: review and new findings in Spain. Climate of the Past, 8(4), 1199-1212.

Sarralde, J. J., Quinn, D. J., Wiesmann, D., & Steemers, K. (2015). Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London. Renewable energy, 73, 10-17. doi:https://doi.org/10.1016/j.renene.2014.06.028

SBIA YASMINE, H. K. M. (2017). LE SECTEUR DE L'HABITAT EN ALGERIE : ETAT DES LIEUX. REVUE DES SCIENCES COMMERCIALES, Numéro Spécial 01.

Scartezzini, J.-L., Montavon, M., & Compagnon, R. (2002). Computer evaluation of the solar energy potential in an urban environment. EuroSun, Bologna.

Semache, A., Hamidat, A., & Benchatti, A. (2015). Impact study of the solar energy on the energy performances of the rural housing in Algeria. International Journal of Heat Technology, 33(4), 229-236.

Seo, H., & Suh, J. (2021). A Review of Smartphone Applications for Solar Photovoltaic Use: Current Status, Limitations, and Future Perspectives. Applied Sciences, 11(5), 2178.

Shukla, A. K., Sudhakar, K., & Baredar, P. (2017). Recent advancement in BIPV product technologies: A review. Energy buildings, 140, 188-195.

Silva, M., Oliveira, V., & Leal, V. (2017). Urban form and energy demand: A review of energy-relevant urban attributes. Journal of planning literature, 32(4), 346-365.

Siret, D. (2013). Rayonnement solaire et environnement urbain: de l'héliotropisme au désenchantement, histoire et enjeux d'une relation complexe. Développement durable et territoires. Économie, géographie, politique, droit, sociologie, 4(2).

Soares, P. M., Brito, M. C., & Careto, J. A. (2019). Persistence of the high solar potential in Africa in a changing climate. Environmental Research Letters, 14(12), 124036. doi:https://doi.org/10.1088/1748-9326/ab51a1

Solaun, K., & Cerdá, E. (2019). Climate change impacts on renewable energy generation. A review of quantitative projections. Renewable sustainable energy reviews, 116, 109415.

Stambouli, A. B. (2011). Promotion of renewable energies in Algeria: Strategies and perspectives. Renewable sustainable energy reviews, 15(2), 1169-1181.
Stephens, G. L., O'Brien, D., Webster, P. J., Pilewski, P., Kato, S., & Li, J. l. (2015). The albedo of Earth. Reviews of geophysics, 53(1), 141-163.
Strømann-Andersen, J., & Sattrup, P. A. (2011). The urban canyon and building energy use: Urban density versus daylight and passive solar gains. Energy buildings, 43(8).
Su, B. (2011). The impact of passive design factors on house energy efficiency. Architectural Science Review, 54(4), 270-276.
Suman, A. (2021). Role of renewable energy technologies in climate change adaptation and mitigation: A brief review from Nepal. Renewable sustainable energy reviews, 151, 111524.
Tang, B.-J., Guo, Y.-Y., Yu, B., & Harvey, L. D. (2021). Pathways for decarbonizing China's building sector under global warming thresholds. Applied Energy, 298, 117213.
Teni, M., Krstić, H., & Kosiński, P. (2019). Review and comparison of current experimental approaches for in-situ measurements of building walls thermal transmittance. Energy buildings, 203, 109417.
Thatcher, M. J. (2007). Modelling changes to electricity demand load duration curves as a consequence of predicted climate change for Australia. Energy, 32(9), 1647-1659.
Tibermacine, I., & Zemmouri, N. (2017). Effects of building typology on energy consumption in hot and arid regions. Energy Procedia, 139, 664-669.
Trepci, E., Maghelal, P., & Azar, E. (2020). Effect of densification and compactness on urban building energy consumption: Case of a Transit-Oriented Development in Dallas, TX. Sustainable Cities and Society, 56, 101987. doi:https://doi.org/10.1016/j.scs.2019.101987
Troup, L., Phillips, R., Eckelman, M. J., & Fannon, D. (2019). Effect of window-to-wall ratio on measured energy consumption in US office buildings. Energy buildings, 203, 109434.
Vallati, A., Vollaro, A. D. L., Golasi, I., Barchiesi, E., & Caranese, C. (2015). On the impact of urban micro climate on the energy consumption of buildings. Energy Procedia, 82, 506-511.
Van Esch, M., Looman, R., & de Bruin-Hordijk, G. (2012). The effects of urban and building design parameters on solar access to the urban canyon and the potential for direct passive solar heating strategies. Energy buildings, 47, 189-200.
Vartholomaios, A. (2015). The residential solar block envelope: A method for enabling the development of compact urban blocks with high passive solar potential. Energy and Buildings, 99, 303-312. doi:https://doi.org/10.1016/j.enbuild.2015.04.046
Vázquez-Canteli, J. R., Ulyanin, S., Kämpf, J., & Nagy, Z. (2019). Fusing TensorFlow with building energy simulation for intelligent energy management in smart cities. Sustainable cities and society, 45, 243-257. doi:https://doi.org/10.1016/j.scs.2018.11.021
Velik, R. (2013). East-south-west orientation of PV systems and neighbourhood energy exchange to maximize local photovoltaics energy consumption. Int. J. Renew. Energy Res, 4, 566-570.
Vulkan, A., Kloog, I., Dorman, M., & Erell, E. (2018). Modeling the potential for PV installation in residential buildings in dense urban areas. Energy buildings, 169, 97-109.
Wei, D., Hu, X., Chen, Y., Li, B., & Chen, H. (2021). An Investigation of the Quantitative Correlation between Urban Spatial Morphology Indicators and Block Wind Environment. Atmosphere, 12(2), 234.
Wei, R., Song, D., Wong, N. H., & Martin, M. (2016). Impact of urban morphology parameters on microclimate. Procedia Engineering, 169, 142-149.
Williams, K., Burton, E., & Jenks, M. (2000). Achieving sustainable urban form: an introduction. Achieving sustainable urban form, 2000, 1-5.
Wong, N. H., Jusuf, S. K., Syafii, N. I., Chen, Y., Hajadi, N., Sathyanarayanan, H., & Manickavasagam, Y. V. (2011). Evaluation of the impact of the surrounding urban morphology on building energy consumption. Solar Energy, 85(1), 57-71. doi:https://doi.org/10.1016/j.solener.2010.11.002
Xu, S., Li, Z., Zhang, C., Huang, Z., Tian, J., Luo, Y., & Du, H. (2020). A method of calculating urban-scale solar potential by evaluating and quantifying the relationship between urban block

typology and occlusion coefficient: A case study of Wuhan in Central China. Sustainable Cities and Society, 102451. doi:https://doi.org/10.1016/j.scs.2020.102451

Yaşa, E., & Ok, V. (2014). Evaluation of the effects of courtyard building shapes on solar heat gains and energy efficiency according to different climatic regions. Energy buildings, 73, 192-199.

Yüksek, I., & Karadayi, T. T. (2017). Energy-efficient building design in the context of building life cycle. Energy Efficient Buildings, 93-123.

Zhang, J., Xu, L., Shabunko, V., Tay, S. E. R., Sun, H., Lau, S. S. Y., & Reindl, T. (2019). Impact of urban block typology on building solar potential and energy use efficiency in tropical high-density city. Applied Energy, 240, 513-533. doi:https://doi.org/10.1016/j.apenergy.2019.02.033

Zhang, X., Ai, T., Stoter, J., Kraak, M.-J., & Molenaar, M. (2013). Building pattern recognition in topographic data: examples on collinear and curvilinear alignments. Geoinformatica, 17(1), 1-33.

Zhang, X., Chen, Z., Yue, Y., Qi, X., & Zhang, C. H. (2019). Fusion of Remote Sensing and Internet Data to Calculate Urban Floor Area Ratio. Sustainability, 11(12), 3382.

Zhong, X., Hu, M., Deetman, S., Rodrigues, J. F., Lin, H.-X., Tukker, A., & Behrens, P. (2021). The evolution and future perspectives of energy intensity in the global building sector 1971–2060. Journal of Cleaner Production, 305, 127098.

Živković, J. (2020). Urban Form and Function. Climate Action, 862-871. doi:https://doi.org/10.1007/978-3-319-95885-9_78

Zomer, C. D., Costa, M. R., Nobre, A., & Rüther, R. (2013). Performance compromises of building-integrated and building-applied photovoltaics (BIPV and BAPV) in Brazilian airports. Energy buildings, 66, 607-615.

Report

Aprue2. (2016). programme de développement de l'efficacité énergétique à l'horizon 2030. Retrieved from

CDER. (2015). Nouveau programme national sur l'efficacité énergétique (2016-2030). Retrieved from https://rise.esmap.org/data/files/library/algeria/EE/EE%201.1%20Nouveau%20programme%20sur%20l_EE%20(2016-2030)%20-%20Copy.pdf

Cheng, V., Steemers, K., Montavon, M., & Compagnon, R. (2006). Urban form, density and solar potential. Retrieved from

DTR-C3.2. (1997). Règlement Thermique des Bâtiments d'Habitation - Règles de Calcul des Déperditions Calorifiques, Fascicule 1, Document Technique Règlementaire. Retrieved from Ministre de l'habitat et de l'urbanisme, CNERIB, Alger, :

DTR-C3.4. (2016). Règlement Thermique des Bâtiments d'Habitation - Règles de Calcul des Apports Calorifiques des Bâtiments, Fascicule 2, Document Technique Règlementaire. Retrieved from

European Training Foundation. (2018). ALGERIA EDUCATION, TRAINING AND EMPLOYMENT DEVELOPMENTS 2017. Retrieved from https://www.etf.europa.eu/sites/default/files/m/036F2BBBD29D051EC125824A003ED8B5_Algeria%202017.pdf

Hanin, Y., Le Fort, B., Meuris, C., & Vanderstraeten, P. (2012). Densité et densification, proposition d'un lexique pour les tissus urbanisés en Wallonie. Retrieved from

Kamel DALI. (2017). Eco-construction et Efficacité énergétique en Algérie. Retrieved from https://www.german-energy-solutions.de/GES/Redaktion/DE/Publikationen/Praesentationen/2017/170808-iv-algerien-kamel-dali-fra.pdf?__blob=publicationFile&v=4

Kämpf, J. H. (2009). On the modelling and optimisation of urban energy fluxes. Retrieved from

l'Office National des Statistiques. (2008). RGPH, Recensement de la Population et de l'Habitat en Algérie. Retrieved from Algeria:

Ministere de la transition energetique et des energies renouvelables. (2021). Synthèse du bilan des activités du Ministère de la Transition Energétique et des Energies Renouvelables. Retrieved from https://mteer.gov.dz/Documents/Synthèse%20du%20bilan%20des%20activités%20du%20Ministère%20de%20la%20Transition%20Energétique%20et%20des%20Energies%20Renouvelables%202020.pdf

Ministry of energy. (2010). Bilan Energétique National 2010. Retrieved from https://www.energy.gov.dz/Media/galerie/bilan_energetique_national_2019_5f7b107553bcd.pdf

Ministry of energy. (2020). Bilan Energétique National 2019. Retrieved from https://www.energy.gov.dz/Media/galerie/bilan_energetique_national_2019_5f7b107553bcd.pdf

Montavon, M. (2010). Optimisation of urban form by the evaluation of the solar potential. Retrieved from

Munari Probst, M. C., Roecker, C., Frontini, F., Scognamiglio, A., Farkas, K., Maturi, L., & Zanetti, I. (2013). Solar Energy Systems in Architecture-integration criteria and guidelines. Retrieved from

Nakicenovic, N., Alcamo, J., Davis, G., Vries, B. d., Fenhann, J., Gaffin, S., . . . Kram, T. (2000). Special report on emissions scenarios. Retrieved from

Nebojsa Jakica, M. K., Rebecca J. Yang, W.M.Pabasara, U. Wijeratne, Eric Too, Ron Wakefield, Johannes Eisenlohr , Simon Boddaert, Pierluigi Bonomo, Erika Saretta, Francesco Frontini, Alessandra Zanelli, Sara Freitas , Philippe ALAMY, Jonathan Leloux. (2019). BIPV Design and Performance Modelling: Tools and Methods. Retrieved from

Peronato, G. (2014). Built density, solar potential and daylighting: application of parametric studies and performance simulation tools in urban design. Retrieved from

Rawlings, R. (2010) Capturing solar energy. In: CIBSE KNOWLEDGE SERIES.

RGPH. (2008). 5eme Recensement de la Population et de l'Habitat en Algérie de l'Office National des Statistiques. Retrieved from

Shukla, P., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H., Roberts, D., . . . Van Diemen, R. (2019). IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Retrieved from

Torcellini, P., Pless, S., Deru, M., & Crawley, D. (2006). Zero energy buildings: a critical look at the definition. Retrieved from

UNFCCC. (2011). Climate change science Retrieved from https://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf

United Nation. (2018). The World's Cities in 2018. Retrieved from https://www.un.org/en/events/citiesday/assets/pdf/the_worlds_cities_in_2018_data_booklet.pdf

World Health Organization. (1990). Indoor environment: health aspects of air quality, thermal environment, light and noise. Retrieved from

Thesis

Alkama, D. (1995). Analyses typologiques de l'habitat: cas de Biskra.

Benharkat, S. (2006). Impact de l'éclairage naturel zenithal sur le confort visuel dans les salles de classe. Cas d'étude. Université Mentouri Constantine, Retrieved from https://bu.umc.edu.dz/theses/architecture/BEN4473.pdf

Benlatreche, T. (2006). Effets thermo-radiatifs et caractérisation microclimatique des cours intérieures dans les édifices publics.

Berghauser Pont, M. Y., & Haupt, P. A. (2009). Space, density and urban form. Delft University of Technology,

Bouamama, W. (2013). Au sujet de la politique d'efficacité énergétique en Algérie: Approche systémique pour un développement durable; cas de programme Eco-Bat. niversité d'Abou Bakr Belkaid Telemcen,

BOUKHABLA, M. (2015). L'influence des facteurs climatiques sur la modification de l'îlot de chaleur urbain dans une rue «canyon, dièdre et dégagée», Cas des lotissements Biskra. Université Mohamed Khider-Biskra,

DJAKPO, L. (2016). STRATEGIE ARCHITECTURALE DE CONCEPTION BIOCLIMATIQUE DES BATIMENTS EN REGION TROPICALE HUMIDE AU BENIN.

DJEDDOU, B. (2016). L'impact de la configuration urbaine sur l'exploitation du gisement solaire. Cas de la ville de Biskra. Université Mohamed Khider-Biskra,

Fahed, J. (2018). Etude numérique du potentiel de rafraichissement des techniques de réduction des ilots de chaleur urbain (ICU) sous climat méditerranéen. Toulouse, INSA,

FOUZIA, B. (2017). Les maisons à patio dans la tradition culturelle musulmane (Le patio en tant que système de communication) Le cas d'étude : maisons à patio – Constantine. UNIVERSITE HADJ LAKHDAR DE BATNA, UNIVERSITE HADJ LAKHDAR DE BATNA. Retrieved from file:///C:/Users/pc/Downloads/gha%20BELKHIRI%20FOUZIA%20(1).pdf

Funk, D. (2010). L'énergie solaire: circonstances et conditions d'exploitation au Québec. Université de Sherbrooke.,

Ghali, E. O. (2011). The Effects of Climate Change on Forest Industry and Environment: Finland and Morocco.

Hanifa, R. (2017). Impact du renouvellement urbain par les projets structurants de modernisation. Cas de Constantine.

Harzallah, A. (2007). Émergence et évolution des préconisations solaires dans les théories architecturales et urbaines en France, de la seconde moitié du XIXe siècle à la deuxième guerre mondiale. Nantes,

Heraou, A. (2018). Evolution des politiques de l'habitat en Algérie LE LSP comme solution a la crise chronique du logement cas d'étude la ville de chelghoum laid.

Johari, F. (2021). Urban building energy modeling: A systematic evaluation of modeling and simulation approaches. Uppsala University,

Laid, H. (2018). Etude de l'evolution des typologies de l'habitat individuel a constantine: de la medina a la ville nouvelle ali mendjeli.

Lee, K.-l. G. (2009). Sustainable urban renewal model for a high density city: Hong Kong.

Lwin, K. K. (2010). Online micro-spatial analysis based on GIS estimated building population: a case of Tsukuba City. Dissertation (143 p.). Graduate School of Life and Environmental Sciences at …,

Mahaya, C. (2014). Optimisation de la forme urbaine par l'évaluation du potentiel solaire. Université Mohamed Khider Biskra,

Marolla, C. (2020). Climate Change Impacts on Health: The Urban Poor in the World's Megacities.

Merdji, S. (2010). Métamorphose architecturale du paysage urbain Constantine : De la ville coloniale a la nouvelle ville UNIVERSITE MAHMOUD MENTOURI CONSTANTINE, Retrieved from http://193.194.84.143/bitstream/handle/123456789/12295/MER5947.pdf?sequence=1&isAllowed=y

Peronato, G. (2019). Urban planning support based on the photovoltaic potential of buildings: a multi-scenario ranking system. EPFL,

Selougha, A., & Wilkinson, N. (1984). Typology of housing in Constantine. (Master's), University of Newcastle, University of Newcastle.

Siret, D. (1997). Propositions pour une approche déclarative des ambiances dans le projet architectural: application à l'ensoleillement. Université de Nantes,

Web page

APRUE. (2019). PROGRAMME ECO-BAT. Retrieved from http://www.aprue.org.dz/index.php/programmes/batiment/18-batiment/34-programme-eco-bat

Arnold, C. (2016). Building Envelope Design Guide - Introduction Retrieved from https://www.wbdg.org/guides-specifications/building-envelope-design-guide/building-envelope-design-guide-introduction

Centre National d'Etudes et de Recherches Intégrées du Bâtiment, C. (2011). DOCUMENT TECHNIQUE REGLEMENTAIRE- REGLEMENTATION THERMIQUE DU BATIMENT. Retrieved from https://dokumen.tips/documents/reglement-algerien-sur-les-thermiques-des-batiments-version-de-05-09-2011.html

Constantine d'hier et d'aujourd'hui. (2016). Histoire de Constantine et de ses communautés. Retrieved from http://www.constantine-hier-aujourdhui.fr/LaVille/histoire.htm#top

ENCYCLOPEDIE de L'AFN. (2006). Historique Constantine - Ville — 1830-1962. Retrieved from https://encyclopedie-afn.org/Historique_Constantine_-_Ville

Geography and Global Climate Change Clearinghouse. (2010). Leading organizations involved in climate change research, policy making and education. Retrieved from http://www.aag.org/cs/programs/interdisciplinary/climatechange/clearinghouse/organizations

GLOBAL WIND ATLAS. (n,d). Globale wind-ALgeria-Constantine. Retrieved from https://globalwindatlas.info/area/Algeria/Constantine

Green building store. (2018). Understanding windows: U values, Psi values & g values. Retrieved from https://www.greenbuildingstore.co.uk/understanding-windows-u-values-psi-values-g-values/

Hagen, K. (2021). Building heights. Retrieved from https://help.spacemaker.ai/en/articles/4532050-building-heights

IEA. (2018). Total CO2 emissions, Algeria 1990-2018. Retrieved from https://www.iea.org/data-and-statistics/data-browser?country=ALGERIA&fuel=CO2%20emissions&indicator=TotCO2

IEA. (n, d). Total energy supply (TES) by source, Algeria 1990-2018. Retrieved from https://www.iea.org/data-and-statistics/data-browser?country=ALGERIA&fuel=Energy%20supply&indicator=TPESbySource

IRENA. (n,d). Renewable energy data- Algeria,. Retrieved from https://www.irena.org/Statistics/View-Data-by-Topic/Climate-Change/Avoided-Emissions-Calculator

kent, U. o. (2019). Urban Albedo. The capacity of urban surfaces to reflect solar radiation. Retrieved from https://research.kent.ac.uk/urbanalbedo/

Météo Algérie. (n,d,). Le Climat en Algérie. Retrieved from https://www.meteo.dz/climat.html#:~:text=Le%20Climat%20en%20Algérie,-Eu%20égard%20à&text=Il%20est%20de%20type%20méditerranéen,chaine%20de%20l%27Atlas%20Saharien.

Ministry of energy. (n, d-a). Bilan de Réalisation de la Première Tranche du Programme national d'Efficacité Energétique. Retrieved from https://www.energy.gov.dz/?article=bilan-de-realisation-de-la-premiere-tranche-du-programme-national-drefficacite-energetique

Ministry of energy. (n, d-b). Energies Nouvelles, Renouvelables et Maitrise de l'Energie. Retrieved from https://www.energy.gov.dz/?rubrique=energies-nouvelles-renouvelables-et-maitrise-de-lrenergie#:~:text=A%20travers%20ce%20programme%20d,de%202021%2C%20le%20solaire%20thermique.

Oxford-Lexico. (n,d). Oxford English and Spanish Dictionary, Synonyms, and Spanish to English Translator. Retrieved from https://www.lexico.com/definition/form

statist. (2020). Oil production in Algeria 1998-2020. Retrieved from https://www.statista.com

UNEP. (2020). Cities and climate change | UNEP. Retrieved from https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities

United Nation. (n, d). Percentage of population in urban and ural areas. Retrieved from https://population.un.org/wup/Country-Profiles/

Urban-redevelopment-authority, A. S. G. A. W. (2019). Bungalows (or Detached Houses), Site Coverage. Retrieved from https://www.ura.gov.sg/Corporate/Guidelines/Development-Control/Residential/Bungalows/Site-Coverage

Annexes

ANNEXES

Annex 1

Name of site = Constantine (Ain El)
Latitude [°] = 36,283, Longitude [°] = 6,617, Altitude [m] = 694
Climatic zone = IV, 1

Radiation model = Default (hour); Temperature model = Default (hour)

Month	Ta	RH	FF	DD	RR	G_Gh	G_Dh	G_Ghr	Sd	N	Tsky
Jan	6,6	80	2,4	257	67.0	110	41	23	142	4	-6,1
Feb	7,6	74	2,6	270	62.0	139	55	28	153	3	-5,7
Mar	10,9	69	2,5	270	56.0	196	70	39	191	3	-2,8
Apr	13,5	67	2,7	270	50.0	234	93	47	218	3	0,1
May	18,1	63	2,4	208	40.0	282	100	56	272	2	3,8
Jun	23,4	49	2,4	78	12.0	320	94	64	305	1	5,9
Jul	26,9	44	2,4	78	17.0	332	78	66	346	0	8,2
Aug	25,9	49	2,4	78	21.0	290	82	58	315	1	9,1
Sep	21,3	62	2,1	150	38.0	227	76	45	257	2	7,1
Oct	17,9	65	2,1	270	35.0	171	59	34	207	2	4,4
Nov	11,3	74	2,4	270	47.0	125	45	25	167	3	-1,9
Dec	7,8	80	2,5	270	65.0	99	37	20	148	3	-4,4
Year	15,9	65	2,4	254	509.0	210	69	42	2721	2	1,5

Diffuse radiation model = Default (hour) (Perez)
Tilt radiation model = Default (hour) (Perez)
Radiation: 1991-2010
Temperature: 2000-2009
Legend:

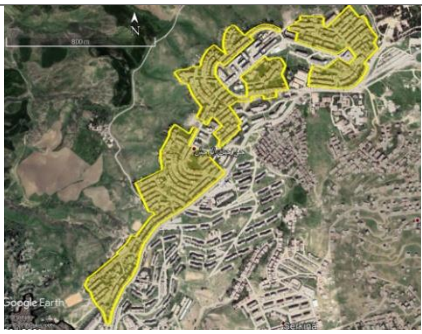
Ta:	Air temperature
RH:	Relative humidity
FF:	Wind speed
DD:	Wind direction
RR:	Precipitation
G_Gh:	Mean irradiance of global radiation horizontal
G_Dh:	Mean irradiance of diffuse radiation horizontal
G_GHr:	Global radiation reflected from ground
Sd:	Sunshine duration
N:	Cloud cover fraction
Tsky:	Sky temperature

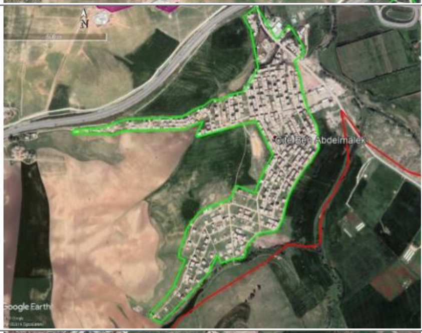
Radiation in [W/m2]
Temperature in [°C]
Pressure in [hPa]
Wind speed in [m/s]
Luminance in [lux]
Sunshine duration in [h]
Snow depth in [mm]
UVA/B in [Wh/m2]
SD: Only 1 station(s) for interpolation
Measured parameters (WMO nr: 604190) = Ta, FF, RR, Td, Rd
Gh: Use of precalculated radiation map based on satellite and ground information due to low density of network.
Uncertainty of yearly values: Gh = 4%, Bn = 8 %, Ta = 0.3 °C
Trend of Gh / decade = -1.9%
Variability of Gh / year = 3.5%
P90 and P10 of yearly Gh, referenced to average = 96.5%, 104.5

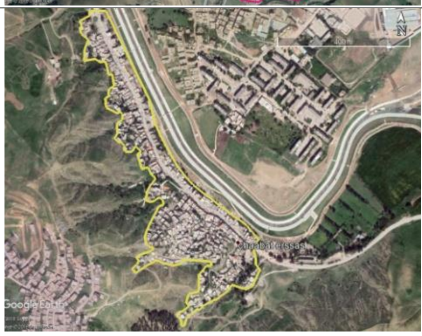
Annex 2

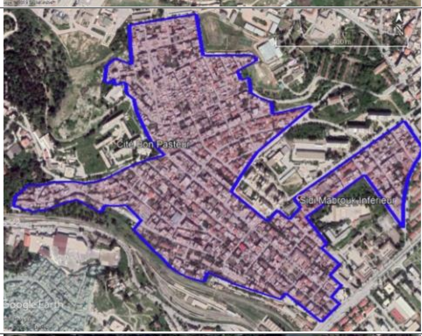
Table 1. urban form description of individual houses in the city of Constantine.

District	Urban form	Area m²	Description of urban fabrics
City El Bir		322 617	The city has an irregular shape, and the urban fabric is very dense. This high density is explained by the concept of terraced houses on regular and irregular plots, where traffic is organised around curved passages to alleys, and regular and curvilinear streets and low connectivity. The housing estate contains two types of housing, informal and planned. The height of the buildings varies between one and three storeys. Also, one can see the presence of vegetation and an empty lot for future construction. The construction is post and beam with hollow body floors and a compression slab, as well as brick or blockwork and flat roofs.
City des Palmiers		60 418	Irregular form of the subdivision houses with medium density. The linear layout of the planned houses isolated on regular blocks divided into often similar plots and surrounded by dihedral streets. The height of the constructions is two storeys. One can see the presence of vegetation on the small gardens of the houses. The construction is of the post and beam type with hollow body floors and compression slab, the masonry is in hollow brick or breeze block and the roofs are often red tile.
City Emir Abdelkader		361 313	This irregular urban form of the city has a very dense and compact fabric in the north part (informal settlement), and a medium density in the south part (planned settlement). In the north part the compact urban fabric is caused by the tight arrangement of informal constructions on large irregular or triangular surfaces, the latter are separated by streets and contain narrow dead ends. Thus, in the south the urban fabric consists of semi-detached buildings on often uniform plots. The streets surround the blocks. The height of the buildings varies between one and three storeys. The construction is of the post and beam type with hollow body floors and the compression slab, as well as the masonry

			is in brick or breeze block and the roofs are often red tile in the southern part, while the northern part of the housing estate has flat roofs.
Housing subdivision Ain El Bey I 1ère Tranche		89 695	Trapezoidal form of the housing estate with a high density. Rectangular blocks in strips separated by canyon streets, this type of street is created by the juxtaposition and facing of the planned constructions. The height of the constructions varies between one and four storeys. The construction is of the post and beam type with hollow body floors and the compression slab, as well as the masonry is in brick or breeze block and the roofs are often flat and accessible.
Djbel El Ouihch		449 789	The dense urban fabric contains scattered and irregular parcels. The presence of regular and curved blocks, represented by juxtaposed planned and informal constructions and often surrounded by canyon streets. A weak presence of vegetation throughout the city. The construction is of the post and beam type with hollow body floors and compression slab, the masonry is brick or breeze block and the roofs are flat terraces.
Housing subdivision (POS II A, II B) « Sidi Naamoune, les Cerisiers, Abane Ramdane, Elislah, Les Amandiers, Oued Yaagoub, EPLF »		663 546	A group of housing estates in the process of being developed, programmed in the POS (II A, II B), the urban fabric is checkerboard with a medium density, as well as the distribution of the houses is planned, whose juxtaposition on the plots and the opposite allows the creation of regular blocks and dihedral and open streets. Some blocks are transformed into a large plot containing a Haut-standing villa. One can see the presence of vegetation. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry. There are two types of roofs, roofs with tile frames and flat roofs.

Housing subdivision of Villat Boudiaf		480	Regular form of the housing estate, dense urban fabric marked by formal rectangular blocks, while the houses take the same form on regular and similar plots. The layout of the buildings creates dihedral or canyon streets. The height of the buildings is two stories. Vegetation is present on the small gardens of the houses. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.
Sissaoui 2		3113 958	An irregular urban form with a dense fabric of planned dwellings, building heights vary from one to three storeys. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.
City BEN ABDELMALEK		396 269	A spread out and irregular urban form consisting of a dense fabric with aligned and planned dwellings, the height of the dwellings reaches three storeys. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.
City El Gamass		1 105 395	A very dense fabric containing informal dwellings and chalets, with heights ranging from one to three storeys. The informal dwellings have a post and beam structure with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs. The chalets are built with a metal frame with prefabricated filling of sandwich panels covered with a skin against humidity. The foundations are made of a concrete platform.
City Riad et Mona		1 279 807	A dense urban fabric with planned self-built dwellings with an average height of two floors. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.

Les Combattants		159 252	An irregular urban form composed of aligned planned dwellings forming a more or less dense fabric, their height is two stories. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry and red tile roofs.
El Manchar		166 102	Informal housing forming a compact, very dense and anarchic urban fabric, the height varies from one to two floors. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and concrete or tile roofs.
Boussouf		636 599	Three separate entities form a dense fabric containing informal and planned dwellings, the height is ranged between one to three storeys. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roof terraces.
Chaabat Erssas		135 947	A dense fabric of informal housing that develops linearly along the road, the height of the buildings varies from one to two storeys. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.
City Boumerzoug		128 892	Informal houses attached to each other constitute a compact and very dense fabric that shapes an irregular urban form, the average height of the buildings is two stories. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.

City Onama		285 417	The informal housing complex is an irregular and linear urban layout with the road, the fabric is very dense with heights varying from one to three storeys. The construction is of the post and beam type with hollow body floors and the compression slab, as well as the masonry is of brick or breeze block and the roofs are flat terraces.
City Yasmine		200 051	An irregular urban form consisting of a dense fabric of planned and semi-detached dwellings, the height of the buildings varies from two to three storeys. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry. There are two types of roofs, roofs with tile frames and flat roofs.
City Khaznadar		254 947	A set of planned, semi-detached dwellings, located along the curvature of the streets, forming a dense fabric, the height of the constructions varies from one to three floors. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry. There are two types of roofs, roofs with tile frames and flat roofs.
City Sidi Mabrouk inférieur		395 235	A combination of informal and planned settlements, the buildings are semi-detached, and the organisation of the lower part is more aligned than the upper part, the height of the buildings varies from one to three floors. The building system is made up of a reinforced concrete structure with cement concrete filling, there are two types of roofs, roofs with tile frames and flat roofs.
Sidi M'Cid		415 528	The urban fabric is more or less dense, with informal grouped and scattered housing units, the height of the buildings varies between one and two floors. The construction is of the post and beam type with hollow body floors and the compression slab, as well as the masonry is made of bricks or breeze blocks and the roofs are flat terraces.

City Abbas		261 483	A compact urban form with a dense and organised fabric, the planned buildings are semi-detached and aligned with the streets, the height of the constructions varies from one to three storeys. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry and flat terrace roofs.
City Bentellis		153 571	A group of informal housing units attached to each other forming a dense and compact fabric and giving an irregular urban form. The height of the buildings varies from one to three storeys. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.
Housing subdivision Géric		259 903	A compact urban form consisting of uniformly planned dwellings aligned to form a dense fabric, authors vary from one to three storeys. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry, There are two types of roofs, roofs with tile frames and flat roofs.
Housing subdivision Ain El Bey I 5ème Tranche		100 680	An irregular urban form characterised by a medium dense fabric, the planned dwellings have an average height of two floors. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry. There are two types of roofs, roofs with tile frames and flat roofs.
City 17 logements (Chalets)		13 057	A deformed linear urban form consisting of cottages with a low density, the height of these constructions is 6m. The chalets are constructed by a metal frame with prefabricated infill of sandwich panels covered with a moisture-proof skin. The foundations are a concrete platform.

City 47 logements (Chalets)		26 581	A deformed linear urban form consisting of chalets with a low density, the construction of these chalets is 6m. The chalets are built by a metal frame with prefabricated filling of sandwich panels covered with a skin against humidity. The foundations are made of a concrete platform.
Housing subdivision (Bab Djdid) Ben Chikou		47 476	A deformed linear urban form composed of planned housing buildings and characterised by dense and compact urban fabric, the average height of the houses is two storeys. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry, there are two types of roofs, roofs with tile frames and flat roofs.
City 16 logements (Chalets) ONM		5 167	A regular linear urban form of low density cottages with a height of 6m. The chalets are constructed with a metal frame with prefabricated infill of sandwich panels covered with a moisture-proof skin. The foundations are a concrete platform.
Housing subdivision Ain El Bey I 2ème Tranche		78 701	An irregular urban form characterised by a dense and compact fabric, their planned dwellings are semi-detached and aligned, the average height of all buildings is three stories. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry, there are two types of roofs, roofs with tile frames and flat roofs.
City 53 logements (Chalets)		49 367	A deformed square urban form composed of a group of chalets and planned dwellings with a medium density, the height varies from one to three storeys. The cottages are constructed by a metal frame with prefabricated infill of sandwich panels covered with a moisture-proof skin. The foundations are a concrete platform.

City 58 logements (Chalets)		33 501	A deformed square urban form composed of a set of chalets with a medium density, their height is 6m. These buildings are constructed by a metal frame with prefabricated filling of sandwich panels covered with a skin against humidity. The foundations are a concrete platform.
Housing subdivision Ain El Bey El Fedj 1ère Tranche		117 675	An irregular urban form characterised by a dense and compact fabric, the planned dwellings are semi-detached and aligned according to the streets, the average height of the whole buildings is three floors. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry, there are two types of roofs, roofs with tile frames and flat roofs.
Housing subdivision Ain El Bey El Fedj 2ème Tranche		108 145	An irregular urban form characterised by a dense and compact fabric, the planned dwellings are semi-detached and aligned according to the streets, the average height of the whole buildings is three floors. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry, there are two types of roofs, roofs with tile frames and flat roofs.
City Ben Chergui		1 109 094	Two large irregular urban compositions with a compact and very dense urban fabric, the buildings are semi-detached, sometimes aligned and often arranged in an anarchic way, the height of the constructions varies from one to three storeys. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.
City Sissaoui 1		1 057 828	The urban fabric is more or less dense, due to the incomplete implementation of the informal houses, the built entities are grouped and scattered, the height of the constructions varies between one and three floors. The construction is of the post and beam type with hollow body floors and the compression slab, as well as the masonry is made of bricks or breeze blocks and the roofs are flat terraces.

City Zaouch		565 380	Irregular urban form composed of two types of houses; chalets and planned houses, the urban fabric is dense, the construction are semi-attached and aligned with the roads, the height of the chalets is 6m, as well as the average height of the informal dwellings is two stories. The cottages are constructed by a metal frame with prefabricated infill of sandwich panels covered with a moisture-proof skin. The foundations are a concrete platform. For the informal settlements, the construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.
City du Muriers		46 935	An irregular urban form characterised by a dense and compact fabric, the planned dwellings are semi-detached and aligned, the average height of all buildings is two stories. The construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry, there are two types of roofs, roofs with tile frames and flat roofs.
City Ain Berda		1 174 617	The urban fabric is more or less dense, due to the incomplete implementation of the informal houses, the built entities are grouped and scattered, the height of the constructions varies between one and three floors. The construction is of the post and beam type with hollow body floors and the compression slab, as well as the masonry is made of bricks or breeze blocks and the roofs are flat terraces.
City Nouvelle Préfabriquée		48 609	An irregular urban form consisting of chalets and informal houses, the overall density is medium, the height of the chalets is 6m, and the average height of the informal houses is two storeys. The chalets are constructed by a metal frame with prefabricated infill of sandwich panels covered with a moisture-proof skin. The foundations are a concrete platform. For the informal houses, the construction is post and beam with hollow body floors and compression slab, as well as brick or breeze block masonry and flat roofs.

Chalets El Bir		70 823	An irregular urban form consisting of low density chalets with a height of 6m. These chalets are built by a metal frame with prefabricated filling of sandwich panels covered with a skin against humidity. The foundations are a concrete platform.
Hacene Boudjenana		54 792	An irregular urban form consisting of low density chalets with a height of 6m. These chalets are built by a metal frame with prefabricated filling of sandwich panels covered with a skin against humidity. The foundations are a concrete platform.
Housing subdivision Rouabah		81 997	Irregular urban form characterised by a dense and compact fabric, the planned dwellings are semi-detached and their average height is two storeys. The construction is post and beam with hollow body floors and compression slab, as well as hollow brick or breeze block masonry and flat roofs.
Housing subdivision Frères Guedjguedj		341 028	A compact and dense urban fabric formed by planned, semi-detached and aligned dwellings, the average height of the buildings is two floors. The building system is made up of a reinforced concrete structure with hollow body filling. There are two types of roofs, roofs with tile frames and flat roofs.
Housing subdivision le Plateau		200 011	An irregular urban form with a low density of planned dwellings, the height of which varies from one to three storeys. The construction is post and beam with hollow body floors and compression slab, and the masonry is brick or breeze block and the roofs are flat terraces.

Housing subdivision Ain El Bey El Fedj 2ème Tranche		229 715	A set of planned, semi-detached dwellings aligned with the streets forming a dense and compact fabric, the average height of the constructions is two floors. The structure is of the post and beam type with hollow body floors and compression slab, as well as the masonry is of brick or breeze block, There are two types of roofs, roofs with tile frames and flat roofs.
Housing subdivision El Kalitousse		215 361	An urban fabric with a medium density, the planned buildings are semi-detached and located along the curve of the streets. Their height varies between one and three floors. The construction is of the post and beam type with hollow body floors and the compression slab, as well as the masonry is of brick or breeze block. There are two types of roofs, roofs with tile frames and flat roofs.
Housing subdivision Bel Hadj et Lamouri		140 211	A group of planned, semi-detached and aligned dwellings which form a compact and dense fabric, the average height of the buildings is two storeys. The construction is of the post and beam type with hollow body floors and compression slab, as well as brick or breeze block masonry. There are two types of roofs, roofs with tile frames and flat roofs.

Annex 3


```
<CompositeCategory id="1" name="Wall" icon="">
        <Composite id="32" name="Wall 0" color="-16776961" category="Wall">
                <CompositeLayer materialID="131" thickness="0.02"/>
                <CompositeLayer materialID="2222" thickness="0.03" insulation="true"/>
                <CompositeLayer materialID="444" thickness="0.15"/>
                <CompositeLayer materialID="1" thickness="0.05"/>
                <CompositeLayer materialID="444" thickness="0.1"/>
                <CompositeLayer materialID="119" thickness="0.02"/>
        </Composite>
        <Composite id="30" name="Wall 1" color="-16776961" category="Wall">
                <CompositeLayer materialID="131" thickness="0.02"/>
                <CompositeLayer materialID="444" thickness="0.15"/>
                <CompositeLayer materialID="1" thickness="0.05"/>
                <CompositeLayer materialID="444" thickness="0.1"/>
                <CompositeLayer materialID="119" thickness="0.02"/>
        </Composite>
        <Composite id="31" name="Wall 2" color="-16776961" category="Wall">
          <CompositeLayer materialID="169" thickness="0.02"/>
                <CompositeLayer materialID="447" thickness="0.5"/>
                <CompositeLayer materialID="119" thickness="0.02"/>
        </Composite>

------------------------------------------------------------------------------------------------------------
  <CompositeCategory id="2" name="Roof" icon="">
        <Composite id="43" name="Roof zero" color="-17111" category="Roof">
                <CompositeLayer materialID="276" thickness="0.02"/>
                <CompositeLayer materialID="126" thickness="0.04"/>
                <CompositeLayer materialID="445" thickness="0.16"/>
                <CompositeLayer materialID="3333" thickness="0.04" insulation="true"/>
                <CompositeLayer materialID="119" thickness="0.02"/>
        </Composite>
        <Composite id="33" name="Roof one" color="-17111" category="Roof">
                <CompositeLayer materialID="276" thickness="0.02"/>
                <CompositeLayer materialID="126" thickness="0.04"/>
                <CompositeLayer materialID="445" thickness="0.16"/>
                <CompositeLayer materialID="119" thickness="0.02"/>
        </Composite>
        <Composite id="34" name="Roof two" color="-17111" category="Roof">
                <CompositeLayer materialID="448" thickness="0.02"/>
                <CompositeLayer materialID="449" thickness="0.03" insulation="true"/>
                <CompositeLayer materialID="502" thickness="0.03"/>
                <CompositeLayer materialID="500" thickness="0.02"/>
        </Composite>
        <Composite id="35" name="Roof three" color="-17111" category="Roof">
                <CompositeLayer materialID="448" thickness="0.02"/>
                <CompositeLayer materialID="126" thickness="0.15"/>
                <CompositeLayer materialID="119" thickness="0.02"/>
        </Composite>
------------------------------------------------------------------------------------------------------------
<CompositeCategory id="3" name="Floor" icon="">
        <Composite id="36" name="Floor one" color="-6711681" category="Floor">
                <CompositeLayer materialID="445" thickness="0.10"/>
                <CompositeLayer materialID="126" thickness="0.1"/>
                <CompositeLayer materialID="276" thickness="0.02"/>
                <CompositeLayer materialID="446" thickness="0.01"/>
```

</Composite>
<Composite id="37" name="Floor two" color="-6711681" category="Floor">
<CompositeLayer materialID="447" thickness="0.30"/>
<CompositeLayer materialID="501" thickness="0.01"/>
<CompositeLayer materialID="276" thickness="0.02"/>
<CompositeLayer materialID="446" thickness="0.01"/>
</Composite>

<CompositeCategory id="4" name="Ground" icon="">
<Composite id="1000" name="Green" category="ground">
<CompositeLayer materialID="503" thickness="0.1"/>
</Composite>
<Composite id="21" name="CitySim Asphalt road" category="ground">
<CompositeLayer materialID="280" thickness="3.855"/>
<CompositeLayer materialID="376" thickness="0.1"/>
<CompositeLayer materialID="281" thickness="0.02"/>
<CompositeLayer materialID="201" thickness="0.025"/>
</Composite>
<Composite id="1010" name="Sidewalk" category="ground">
<CompositeLayer materialID="29" thickness="0.15"/>
</Composite>

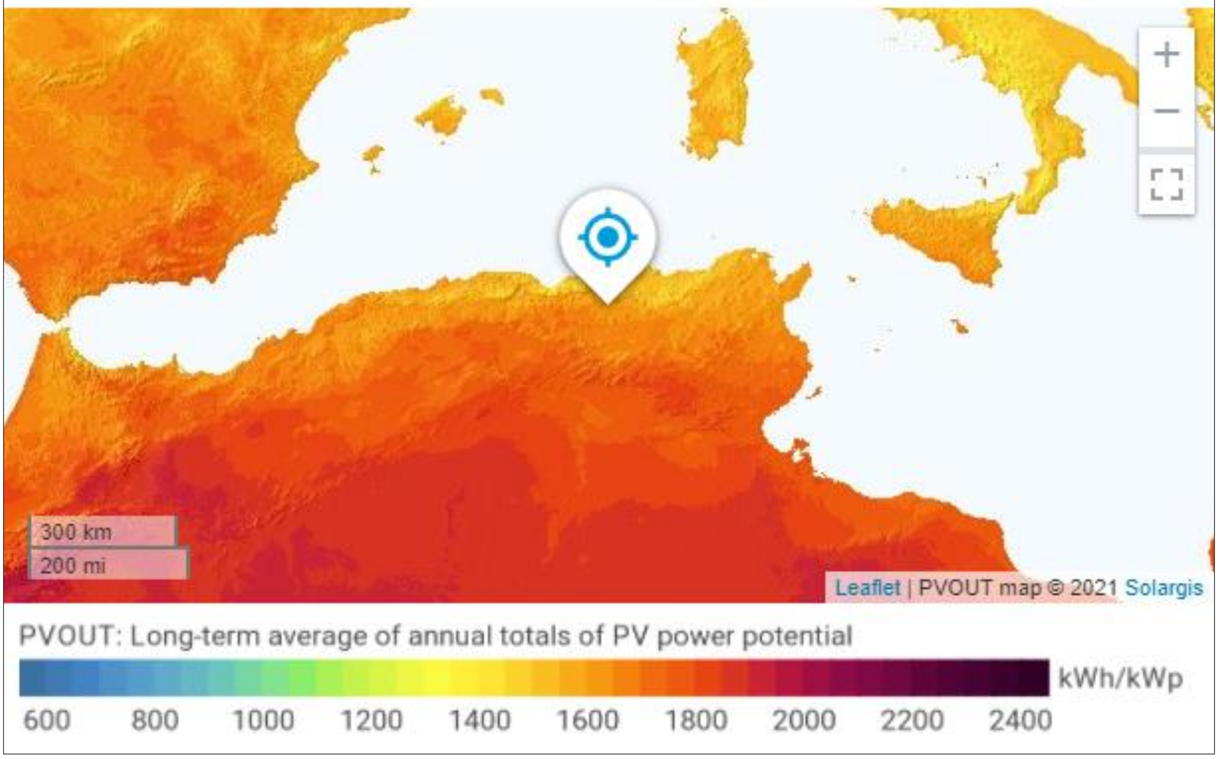
<PhotoVoltaic model="JKM335PP-72-J4V" brand="Jinko Solar" name="Jinko Solar JKM335PP-72-J4V" id="16" type="Poly-c-Si" Ac="1.94" Tref="25" Tcnoct="45" muVoc="-0.14918" Vmp="38" Pmp="335"/>

Annex 4

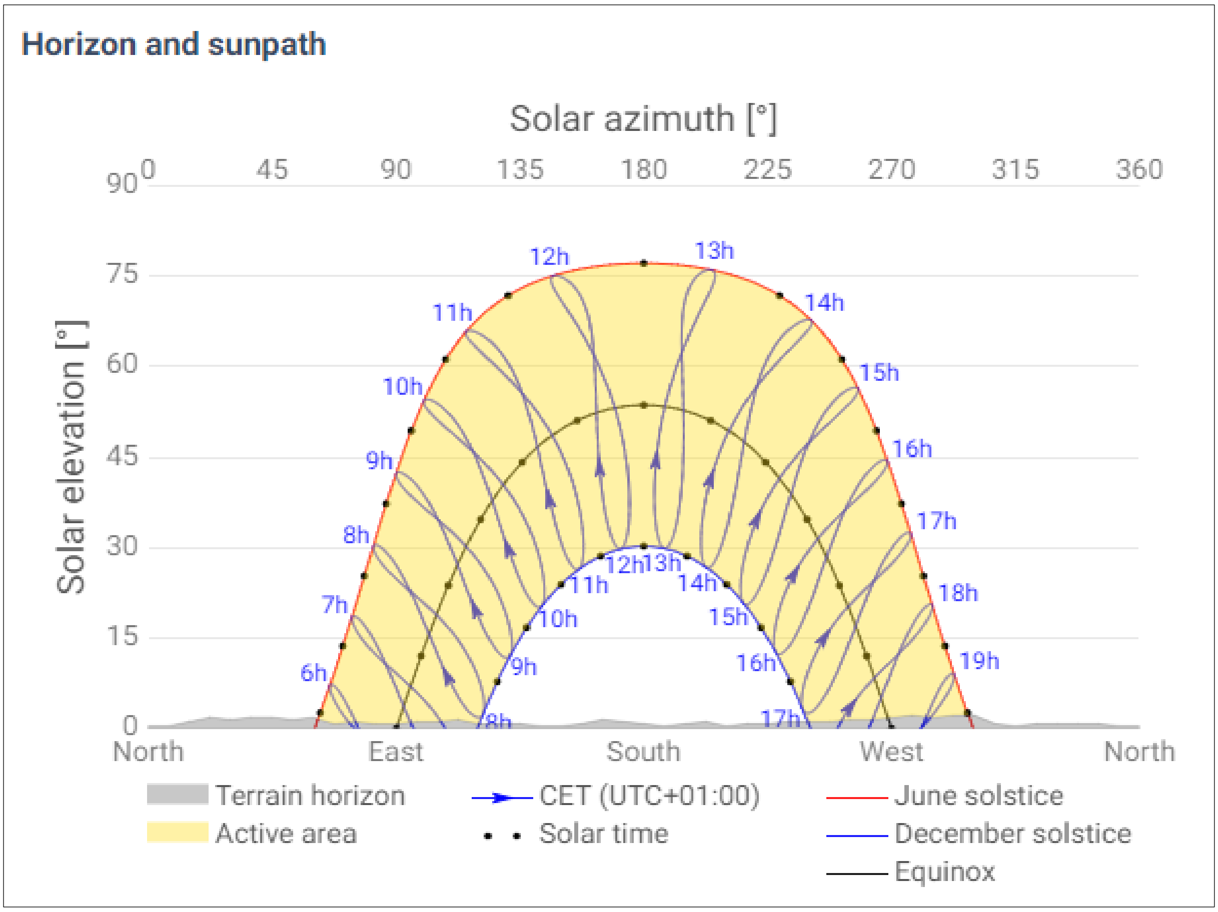
Map data — Per year

Direct normal irradiation	DNI	**1781.6**	kWh/m²
Global horizontal irradiation	GHI	**1771.1**	kWh/m²
Diffuse horizontal irradiation	DIF	**679.5**	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	**2018.6**	kWh/m²
Optimum tilt of PV modules	OPTA	**32 / 180**	°
Air temperature	TEMP	**16.4**	°C
Terrain elevation	ELE	**734**	m

PVOUT map



PVOUT: Long-term average of annual totals of PV power potential


Horizon and sunpath
Solar azimuth [°]
0
45
90
135
180
225
270
315
360
Solar elevation [°]
90
75
60
45
30
15
0
North
East
South
West
North
6h
7h
8h
9h
10h
11h
12h
13h
14h
15h
16h
17h
18h
19h
Terrain horizon
Active area
CET (UTC+01:00)
Solar time
June solstice
December solstice
Equinox

PV system configuration

Pv system: **Small residential**

Azimuth of PV panels: **Default** (180°)

Tilt of PV panels: **Default** (32°)

Installed capacity: **1 kWp**

Change PV system

Annual averages

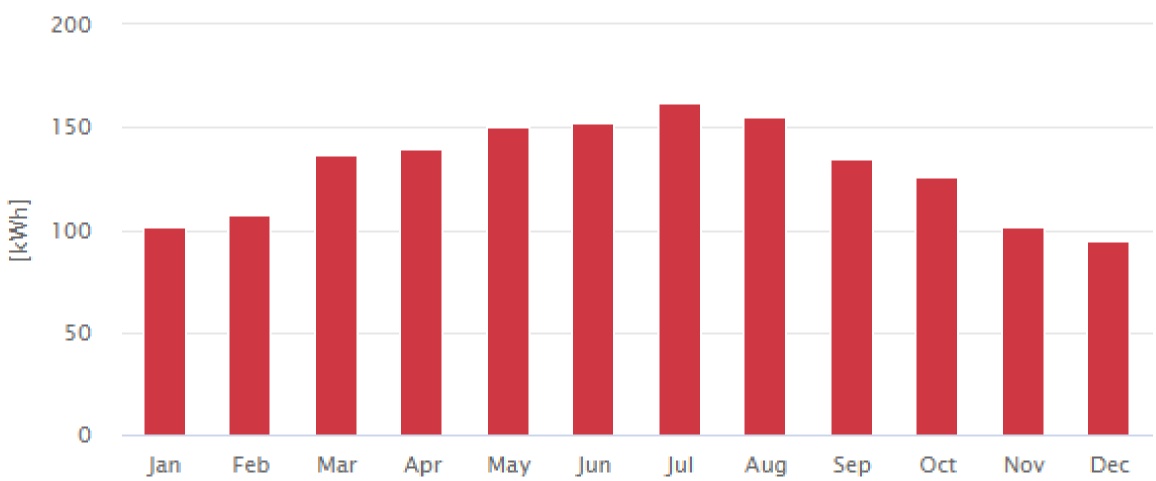
Total photovoltaic power output and Global tilted irradiation

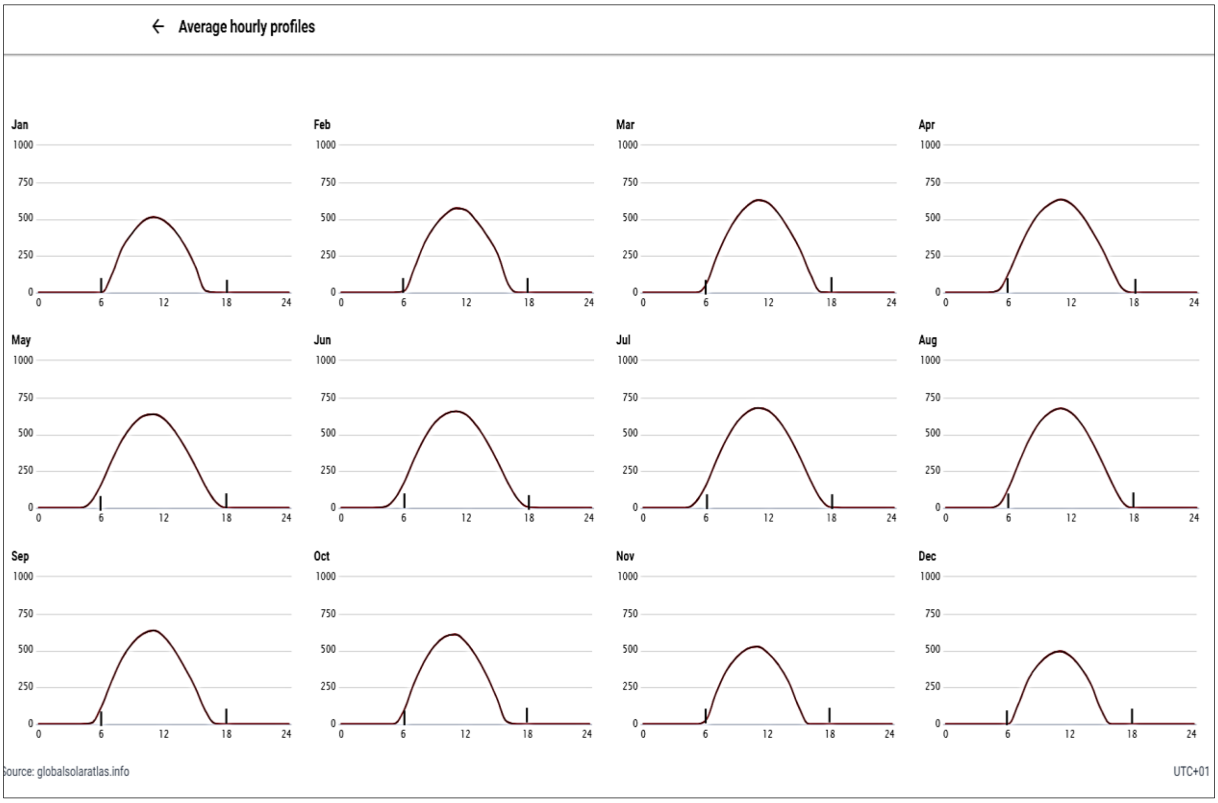
1.560
MWh per year

2015.8
kWh/m^2 per year

Monthly averages

Total photovoltaic power output





Average hourly profiles

Total photovoltaic power output [Wh]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5					1	4	1					
5 - 6				14	41	51	39	18	6			
6 - 7		9	55	132	161	169	154	136	116	84	23	
7 - 8	120	164	240	295	321	334	323	308	292	271	207	133
8 - 9	302	340	398	441	462	477	473	468	446	422	361	307
9 - 10	406	456	516	545	564	582	587	584	551	531	454	408
10 - 11	485	532	593	604	623	639	654	651	614	593	510	472
11 - 12	514	574	628	633	637	657	679	676	636	610	527	495
12 - 13	490	558	607	603	606	632	659	646	594	559	484	464
13 - 14	425	483	530	527	526	555	589	568	504	465	405	388
14 - 15	322	385	421	416	416	446	480	447	384	338	289	275
15 - 16	181	261	292	290	286	313	341	304	250	182	115	99
16 - 17	13	59	123	141	146	168	187	153	88	16		
17 - 18			4	20	39	53	57	31	2			
18 - 19					1	5	4					
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	3,258	3,822	4,408	4,661	4,831	5,084	5,227	4,992	4,484	4,072	3,377	3,042

Annex 5

Table. S1. Modelled indoor temperature range, modelling heating and cooling error for the four case studies.

Case study	T_{MIN} (°C)	T_{MAX} (°C)	HEATING MODELLING (%)	NEEDS ERROR	COOLING MODELLING (%)	NEEDS ERROR
A	18.0	25.0		42		70
	17.0	26.0		33		62
	16.0	27.0		22		52
	15.0	28.0		8		39
	14.0	29.0		-10		21
	14.5	**29.8**		**0**		**0**
	14.5	30.0		0		-6
B	18	25		184		110
	17	26		148		72
	16	27		114		38
	15	28		82		9
	14	28,3		52		1
	13	28,3		25		1
	12	**28,3**		**1**		**1**
C	18	25		27		-34
	17	24		10		-21
	16	23		5		-7
	16,3	22		0		8
	16,3	**22,5**		**0**		**0**
D	18	25		15		128
	17	26		0		83
	17	27		0		44
	17	28		0		10
	17	**28,3**		**0**		**1**

CV

Sofiane BENSEHLA

Born on 13. 01. 1994 in Tiaret, Algeria
Permanent email address: bensehlasofiane@gmail.com

EDUCATION

2017.11 – 2021. 12	**PhD degree in Architecture.** University 8 Mai 1945 Guelma, Algeria. Laboratory of civil engineering and hydraulic. Thesis title: *The impact of the urban form on energy consumption and solar access, case of individual housing subdivisions in Constantine.* Grade: very honorable. **Visiting researcher** (6 months), fcul, Instituto Dom luiz, University of Lisbon, Portugal, under the supervision of Pr. Miguel Centeno Brito.
2015.09 – 2017. 06	**Master degree in Sustainable Architecture and Green Energy.** University Salah Boubnider Constantine 3, Algeria. Grade: honorable.
2012.09 – 2015. 06	**Bachelor degree in Architecture.** University Salah Boubnider Constantine 3, Algeria. Grade: honorable.

INTERSHIP

2014. 03 - 2014. 03 2016. 03 - 2016. 03 2017. 03 - 2017. 03	**A practical internship of one month on the architectural technical level.** Technical study office 'Belaid Khaled' in Tiaret in Algeria.

TEACHING

2018.09 - 2019. 06	**Temporary teacher.** Department of Architecture, University 8 Mai 1945 Guelma, Algeria. Bachelor-level intensive class. 2D and 3D modelling, Computer assisted design (AutoCAD, Sketch up, Rhino).

PERSONAL SKILLS

2D modelling	AutoCAD.
3D modelling	Sketch up, Rhino-Grasshopper.
Building energy modelling	Citysim, Trnsys, Laydybug (Energyplus), Envimet, Meteonorm.
PV performance modelling	PVsyst.
OS	Windows.
Graphics	Photoshop, Lumion, Twinmotion.
OfficeSuite	Microsoft Office.

Languages

Arabic (native), French (fluent), English (B2).

SCIENTIFIC PUBLICATIONS

Bensehla, Sofiane, Youcef Lazri, and Miguel Centeno Brito. "Solar potential of urban forms of a cold semi-arid city in Algeria in the present and future climate." *Energy for Sustainable Development 62 (2021): 151-162.*

Sofiane Bensehla, Youcef Lazri, Rodrigo Amaro e Silva, Miguel Centeno Brito. The Impact of Building Shape and Density on Active Solar Energy Potential. *EU PVSEC Proceeding, 2020, pp; 1968-1971.*

Bensehla Sofiane, Dr. Lazri Youcef, Réussir la ville intelligente, l'étude des deux oasis intelligentes ; la ville de Masdar à Abu Dhabi et la ville de Hassi Messaoud en Algérie, *Smart Cities in the Current Context (Reality and Prospects) Proceeding, 2019, pp ; 214-226.*

SCIENTIFIC CONFERENCES

Bensehla Sofiane, Dr. Lazri Youcef, Réussir la ville intelligente, l'étude des deux oasis intelligentes ; la ville de Masdar à Abu Dhabi et la ville de Hassi Messaoud en Algérie, Smart Cities in the Current Context (Reality and Prospects), Berlin, Germany,28-29 March 2019.
Bensehla Sofiane, Dr. Lazri Youcef, The impact of using thermal insulation and solar energy on the reduction of energy consumption, case of housing in Constantine, Algeria. International Symposium on Technology & Sustainable Industry Development, ISTSID'2019, EL OUED, ALGERIA, 24 - 26 February 2019.
Bensehla Sofiane, Dr. Lazri Youcef, Consommation d'énergie et énergies renouvelables en Algérie, Séminaire national sur les énergies renouvelables et le développement durable, Batna en Algérie, 25 juin 2018.

Bensehla Sofiane, Dr. Lazri Youcef, Faire du projet urbain un projet énergétique - Cas de la ville de Lyon - France, Deuxième session plénière des doctorants internationaux et des maîtres en architecture, Batna en Algérie, du 8 au 9 octobre 2018.

Bensehla Sofiane, Dr. Lazri Youcef, Développement énergétique local en Algérie, levier de la durabilité, Première réunion nationale sur la gestion des villes et le développement durable, M'sila en Algérie, 13 décembre 2018.

Bensehla Sofiane, M. Lazri Youcef, Conception énergétique intégrée dans l'urbanisme, cas de l'Algérie, Deuxième séminaire national : Architecture et environnement, Batna en Algérie, 11-12 décembre 2018.

Bensehla Sofiane, Dr. Lazri Youcef, La relation entre l'approche du projet urbain et la ville durable, séminaire national : Villes durables et projets urbains partagés, Guelma en Algérie, du 4 au 5 novembre 2018.

Sofiane Bensehla, Youcef Lazri, Rodrigo Amaro e Silva, Miguel Centeno Brito. The Impact of Building Shape and Density on Active Solar Energy Potential, 2020, 37th European Photovoltaic Solar Energy Conference and Exhibition.

CERTIFICATIONS

2018. 10	**PhD students' support days (**Thesis redaction) University Larbi Ben M'Hidi, Oum El Bouaghi.
2020. 10	**Solar Energy System Overview**, Online course (Coursera website). University at Buffalo, The State University of New York.
2020. 11	**Grammar and Punctuation**, Online course (Coursera website). University of California.
2021. 03	**Programming for Everybody** (Getting Started with Python), Online course (Coursera website). University of Michigan.