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Development of a decision-support model based on fuzzy logic for optimizing of High Energy Performance (HPE) housing design in Algeria

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To the soul of my father;
to my mother, brothers, and sisters;
to my wife;
to my daughter.

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Abstract

In Algeria, the final energy consumption remains dominated by the housing sector, which represents 36% of the total final consumption. In 2019, the energy use increased more than 80 % from 2009. Thus, the prospects for developing the housing stock will lead to an exponential increase in this energy consumption. However, Buildings in the residential sector nevertheless have a significant potential for energy savings. In this context, the construction of energy-efficient housing is essential for controlling energy consumption in the residential sector.

The performance optimization of low-energy buildings should always take place in the early design stages when most of the critical decisions affecting building energy performance are made by integrating the optimal values of different building parameters depending on the climatic conditions. To design and construct low-energy buildings, it is essential to assure informed decision-making during the early design phases. Therefore, there is a need for the development of decision support tools that can predict the building performance and support the design decision making of low-energy buildings.

This research aims to contribute to the implementation of energy-efficient housing buildings across the Algerian territory and under all Algerian climate zones through informed design decision making in the early design stages of low-energy building. Therefore, this thesis developed a decision support model that could estimate building energy performance (cooling and heating energy loads) in early design stages without using building performance simulation tools. The model provides rapid, energy-relevant feedback, and visualize possible consequences of the design decisions.

Initially, the bioclimatic potential of all Algerian climate zones has been investigated using a dual approach that combines psychrometric chart-based analysis with building performance simulation analysis (EnergyPlus) to provide accurate bioclimatic design recommendations. Afterwards, the thermal and energetic behaviour of the typical multi-family apartment buildings, across the Algerian territory, has been evaluated using BPS techniques (EnergyPlus) combined with GIS to generate a new spatial distribution map for energy demand and thermal comfort estimation in Algeria. These maps will inform building designers without accessing, analyzing, or interpreting dense textual information.

Then, the typical multi-family apartment building design has been optimized for each climate zone using a mixed approach that combine between building performance simulation (BPS) tool (EnergyPlus) and building performance optimization (BPO) algorithm (NSGA-II). Finally, this research ends by developing a design decision-making model based on prediction using an Adaptive Neuro-Fuzzy Inference System (ANFIS) to estimate the cooling and the heating energy loads of the typical multifamily social residential building through the building design parameters variation. As a result, this thesis provided design recommendations for each climate zone and a decision-making model that presented a high accuracy level.

Keywords: low-energy building, energy efficiency, thermal comfort, climatic zoning; design optimization, NSGA-II, ANFIS, decision-making model.

Résumé

En Algérie, la consommation finale reste dominée par le secteur résidentiel qui représente 36% de la consommation finale totale .En 2019 cette consommation a augmenté de plus de 80% par rapport à 2009. Ainsi, Les perspectives de développement du parc de logements conduiront à une augmentation exponentielle de cette consommation énergétique. Cependant, le secteur des bâtiments résidentiel présentent néanmoins un potentiel d'économies d'énergie important. Dans ce contexte, la réalisation de logements performants s'impose comme une nécessité à la maîtrise des consommations énergétiques du secteur résidentiel.

L'optimisation des performances des bâtiments à basse consommation doit toujours avoir lieu dans les étapes primaires de la conception, lorsque la plupart des décisions clés affectant la performance énergétique des bâtiments sont prises par l'intégration des valeurs optimales des différents paramètres du bâtiment en fonction des conditions climatiques. Afin de concevoir et construire tels bâtiments, il est essentiel de garantir une prise de décision informée au cours des phases primaires de conception. Par conséquent, il est nécessaire de développer des outils d'aide à la décision capables de prédire la performance du bâtiment et de soutenir la prise de décision de conception de bâtiments basse consommation.

Cette recherche vise à contribuer à la mise en œuvre de bâtiments résidentiels basse consommation énergétique sur tout le territoire Algérien et sous toutes les zones climatiques Algériennes par une prise de décision informée dès les premières phases de conception. Par conséquent, cette thèse a développé un modèle d'aide à la décision capable d'estimer la performance énergétique du bâtiment (charges énergétiques de climatisation et de chauffage) aux premières phases de la conception sans utiliser les outils de simulation de la performance du bâtiment. Ainsi, il peut fournir une rétroaction rapide et pertinente sur le plan énergétique et visualiser les conséquences possibles des décisions de conception.

Dans un premier temps, le potentiel bioclimatique de toutes les zones climatiques algériennes a été étudié en combinant deux approches d'analyse : la première approche d'analyse est basée sur le diagramme psychrométrique et la deuxième est basée sur la simulation de la performance des bâtiments (EnergyPlus), afin de fournir des recommandations précises de conception bioclimatique pour l'Algérie. Par la suite, le comportement thermique et énergétique d'un immeuble d'habitation typique a été évalué sur le territoire algérien à l'aide de techniques BPS (EnergyPlus) combinées à un SIG pour générer de nouvelles cartes de distribution spatiale de la consommation énergétique et de l'estimation du confort thermique en Algérie. Ces cartes informeront les concepteurs de bâtiments sans accéder, analyser ou interpréter des informations textuelles denses.

Ensuite, la conception d’immeubles d'habitation typique a été optimisé pour chaque zone climatique à l'aide d'une approche mixte combinant l'outil de simulation de la performance du bâtiment (BPS) (EnergyPlus) et l'algorithme d'optimisation de la performance du bâtiment (BPO) (NSGA-II). Enfin, cette recherche se termine par le développement d'un modèle d’aide à la décision pour la conception du bâtiment. Ce modèle est basé sur la prédiction à l'aide d'un système d'inférence neuro-floue adaptatif (ANFIS) pour estimer les charges énergétiques de chauffage et de climatisation du bâtiment résidentiel typique grâce à la variation de leurs paramètres de conception. En conséquence, cette thèse a fourni des recommandations de conception pour chaque zone climatique et un modèle de prise de décision présentant un niveau de précision élevé.

Mot clés : bâtiment basse consommation, efficacité énergétique, confort thermique, zonage climatique ; optimisation de la conception, NSGA-II, ANFIS, modèle d’aide à la décision.

ملخص

لا يزال قطاع السكن في الجزائر يهيمن على الاستهلاك النهائي للطاقة ، والذي يمثل 36٪ من إجمالي الاستهلاك. في عام 2019 ، زاد استخدام الطاقة بأكثر من 80٪ عن عام 2009. وبالتالي ، فإن احتمالات زيادة حظيرة السكن ستؤدي إلى زيادة هائلة في استهلاك الطاقة. لهذا يعتبر قطاع المباني خاصة السكني منه ذو إمكانات كبيرة لتوفير الطاقة. في هذا السياق ، يعد بناء المساكن الموفرة للطاقة أمرًا ضروريًا للتحكم في استهلاك الطاقة.

يجب ان يتم تحسين أداء المباني منخفضة الاستهلاك في المراحل الأولية من التصميم ، اي في الوقت الذي يتم فيه اتخاذ معظم القرارات الرئيسية التي تؤثر على أدائه الطاقوي من خلال ادراج القيم المثلى لعناصره المختلفة وفقًا للمعطيات المناخية. فمن أجل تصميم وإنشاء مثل هذا النوع من المباني من الضروري ضمان اتخاذ قرارات اكيدة خلال مراحل التصميم الأولية. لذلك، هناك حاجة ماسة لتطوير أدوات دعم القرار القادرة على التنبؤ بأداء المبنى واتخاذ قرارات مثلى للتصميم.

يهدف هذا البحث إلى المساهمة في تنفيذ المباني السكنية ذات الاستهلاك المنخفض للطاقة في جميع أنحاء التراب الجزائري وعبر جميع المناطق المناخية في الجزائر من خلال اتخاذ قرارات اكيدة في المراحل الأولى للتصميم. لذلك فقد طورت هذه الأطروحة نموذجًا لدعم القرار قادرًا على التنبؤ بالأداء الطاقوي للمبنى (احمال تبريد الهواء و التدفئة) في المراحل الأولى من التصميم دون استخدام أدوات محاكاة لأداء المبنى. وبالتالي ، يمكن أن يوفر هذا النموذج ملاحظات سريعة وتقدير النتائج المحتملة لقرارات التصميم.

في البداية ، تمت دراسة الإمكانات البيومناخية لجميع المناطق المناخية في الجزائر باستخدام نهج مزدوج يجمع بين التحليل القائم على الرسم البياني النفسي (psychrometric chart) وتحليل محاكاة أداء المبنى (EnergyPlus) لتقديم توصيات دقيقة للتصميم البيومناخي. بعد ذلك ، تم تقييم السلوك الحراري والطاقوي للمباني السكنية الاكثر انتشارا (نموذجي) عبر الأراضي الجزائرية ، باستخدام تقنيات محاكاة اداء المبنى (EnergyPlus)(BPS) جنبًا إلى جنب مع نظام المعلومات الجغرافية (GIS) لإنشاء خرائط توزيع جغرافي جديدة لاستهلاك الطاقة وتقدير الراحة الحرارية في هذا النوع من المباني في الجزائر. هذه الخرائط ستساعد مصممي المباني في مهمتهم دون الاعتماد إلى المعلومات النصية الكثيفة أو تحليلها أو تفسيرها.

بعد ذلك ، تمت عملية تحسينات لتصميم المبنى السكني في كل منطقة مناخية باستخدام نهج مختلط يجمع بين أداة محاكاة أداء المبانى (EnergyPlus) وخوارزمية تحسين أداء المباني (NSAG-II) (BPO). أخيرًا ، يختتم هذا البحث من خلال تطوير نموذج مساعد لاتخاذ قرارات التصميم بناءً على التنبؤ باستخدام نظام الاستدلال العصبي الضبابي التكيفي (ANFIS) لتقدير أحمال طاقة التبريد و التدفئة للمبنى السكني النموذجي اعتمادا على تباين تصميم عناصر المبنى. نتيجة لذلك ، قدمت هذه الأطروحة توصيات التصميم لكل منطقة مناخية ونموذج مساعد لصنع القرار عالي الدقة.

الكلمات المفتاحية: مبنى منخفض الاستهلاك ، كفاءة الطاقة ، الراحة الحرارية ، تقسيم المناطق المناخية ؛ تحسين التصميم ، (NSGA-II) خوارزمية جينية غير مسيطرة مع إستراتيجية النخبة ،(ANFIS) نظام الاستدلال العصبي الضبابي التكيفي ، نموذج دعم القرار.

Acronyms

ANFIS: Adaptive Neuro-Fuzzy Inference System

ANN: Artificial Neural Network

ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BESO: Building Energy Simulation and Optimization

BPO: Building Performance Optimization

BPS: Building Performance Simulation

CNERIB : Centre National d’Etudes et de Recherches Intégrées du Bâtiment

CV (RMSE): Coefficient of Variation or Root-Mean-Square Error

DBT: Dry-Bulb Temperature

DEC: Direct Evaporative Cooling

DHW : Domestic Hot Water

DTR : Document Technique Réglementaire

EEP: Energy and Environmental Performance

GA: Genetic Algorithm

GIS: geographic information systems

HVAC: Heating, Ventilation, and Air Conditioning

IEA : International Energy Agency

Ktep : kilotonne d'équivalent pétrole

LCC: life-cycle cost

MBE: Mean Bias Error

MCDM: Multi-criteria Decision Making

ME: Ministry of Energy

MED-ENEC: Energy Efficiency in the Construction Sector in the Mediterranean

MENA: Middle East and North Africa

MHUV : Ministère de l'Habitat et de l'Urbanisme et de la Ville

NV: Natural Ventilation

NSGA-II: Non-dominated Sorting Genetic Algorithm

ONS: Office National des Statistiques

PMV: Predicted Mean Vote

PPD: Predicted Percentage of Dissatisfied

PSH: Passive Solar Heating

RECREEE: Regional Center for Renewable Energy and Energy Efficiency

TMY: Typical Meteorological Year

UNDP: United Nations Development Programme

U-value: heat-transfer coefficient [W/m^2 K]

WBT: Wet-Bulb Temperature

WWR: Window-to-Wall Ratio

Table of contents

List of Figures

List of Tables

I. Chapter 1: General introduction

I.1. Background

Worldwide, the buildings and buildings construction sectors combined are responsible for over one-third of global final energy consumption, and nearly 40% of total direct and indirect CO2 emissions (IEA, 2020). Energy demand from buildings and buildings construction continues to rise (see Fig.I-1), driven by improved access to energy in developing countries, greater ownership and use of energy-consuming devices, and rapid growth in the global building's floor area (IEA, 2020).

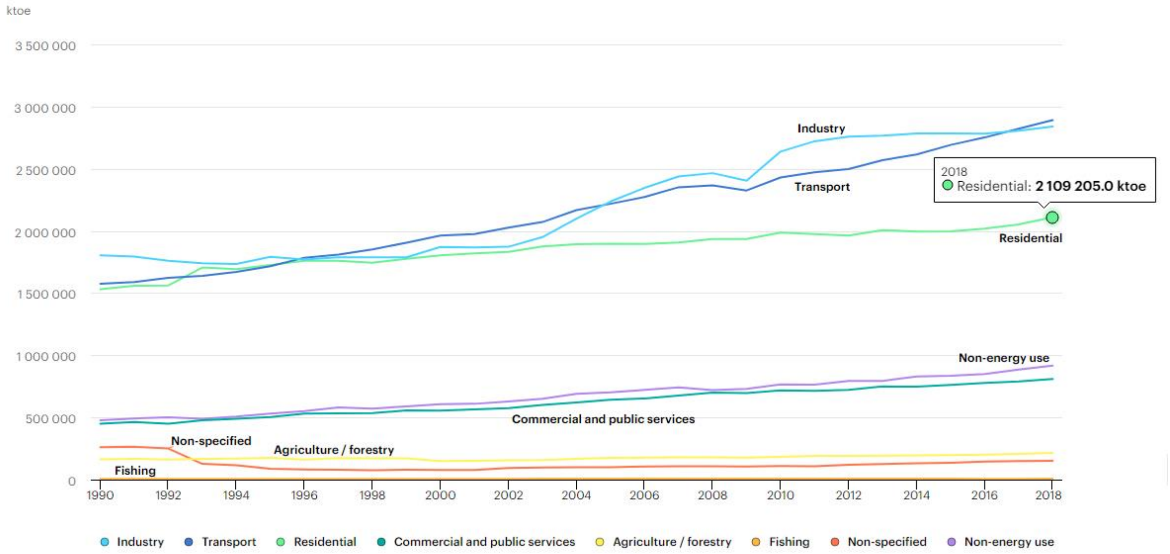


Figure I-1: *Total final consumption (TFC) by sector, World 1990-2018 (IEA, 2020)*

In Algeria, the final consumption remains dominated by the household sector which represents 36% of the total final consumption, followed by transport sector which represents 30.6% and finally the construction and public works sector with 22.7% (ME, 2020). Global final energy consumption in the household sector in 2019 increased more than 80 % from 2009. This energy consumption growth is correlated with changes in household lifestyles which is represented by the evolution of the level of household appliances and thermal comfort (cooling and heating) (Bouznit et al., 2018; Athmane Ouahab, 2015). Thus, the prospects for developing the housing stock will lead to an exponential increase in this energy consumption. However, Buildings in the residential sector nevertheless have a significant potential for energy savings (Athmane Ouahab, 2015). In this context, the construction of energy-efficient housing is essential for controlling energy consumption in the residential sector.

To address these issues, many developed and developing countries are focusing their attention on energy performances. They are migrating from these conventional buildings towards an energy-efficient buildings particularly low energy building. Therefore, Algeria launched several actions falling within the national energy management program (PNME 2007-2011 and PNME 2010-2014), notably the Eco-Bat program. This program is in partnership with the Ministry of Housing (MHUV) and the National Agency for the Promotion and Rationalization of the Use of Energy (APRUE). This project is funded by the national fund for energy control (FNME). It aims at building 3000 energy-efficient housing units that ensuring optimization of indoor thermal comfort by reducing energy consumption related mainly to heating and cooling objectives (APRUE, 2020).

The pilot project, including 600 energy-efficient housing, is launched in 2011. This project is divided across 11 provinces (wilayas) which are selected to cover the different climatic zones of the national territory. Also, this project aims to achieve different variants of bioclimatic housing, depending on the variation of local climates; promote the use of local materials for the construction of housing and demonstrate the feasibility of saving energy whatever the climatic conditions. However, beyond the knowledge and expertise that is in improvement, the dissemination of good practices in the field remains low in the absence of effective regulation and residential building energy efficiency design and assessment codes (Moussaoui et al., 2018).

Generally, low-energy building concept is based on improving the building envelope to reduce heating and cooling demand, and using high efficiency equipments as well as renewable energy sources (Chlela et al., 2009). Moreover, Passive design measures such as the building layout, building form, building envelope thermophysics, infiltration & air-tightness can make great contributions to low-energy building designs depending on climatic conditions (Chen et al., 2018) (Gou et al., 2018).

I.2. Research problems

Studies show that low-energy building performance-optimization pathways are almost always determined in the early design stages. More than 40% of energy-saving capacities come from the earlier designing stage (Han et al., 2018). However, during these stages, building designers have relatively limited information about the effects of building parameters on energy performance. Besides, the number of parameters that can affect the building energy consumption is huge, and different parameters are often in contrasting influences. This huge number of building parameters involves the largest number of design possibilities which should be considered by designers during the early stages of building design. This number of possibilities produces very high uncertainty regarding performance decisions of low-energy building design. Hence, informing the uncertainty of designers during early design stages for decision making is very important.

During these stages, building performance simulations (BPS) could help designers to choose the optimal solution regarding the considered criteria. However, performing such parametric study is rather complicated, time consuming because it is based on a post-decision trial and error approach (Ascione et al., 2016b; Attia et al., 2012; Gou et al., 2018; Huang and Niu, 2016; Østerg\aard et al., 2016), where the simulation results are compared to the desired value (requires a large number of simulations runs), and forces architects to rely on simulation experts during the early design stages because building energy simulation models require a high degree of technical specification to characterize a building. These reasons limit the building performance simulation tools application during the early stages of design.

On the one hand, current design and decision support tools are inadequate to support and inform the design of NZEBs, specifically during early design phases (Attia et al., 2012), where less than 8 percent of more than 400 building simulations tools listed by the U.S. Department of Energy have potential for early design deployment potential (Østerg\aard et al., 2016). On the other hand, a little effort has been made to develop the required methods and tools that can predict the building performance and support the design decision making of buildings (Attia et al., 2012, 2009; Hygh et al., 2012). As a result, key design decisions that can drive building energy performance are often made in the absence of model-based estimates.

It is in this context that this work was carried out. It will therefore be necessary to develop a decision support model that allows designers to produce low-energy building in Algeria. The proposed model could estimate building energy performance (cooling and heating energy loads) in early design stages without using building performance simulation tools, provide rapid, energy-relevant feedback, and visualize possible consequences of the design decisions—this model based on simulated data of the different combinations of design variables variations. A more detailed explanation of the aim and the objectives of this thesis is given in the following section of the introduction.

I.3. Research aims and objectives

This research aims to contribute to the implementation of energy-efficient housing buildings across the Algerian territory and under all Algerian climate zones through informed design decision making in the early design stages of low-energy building. The specific objectives of this research incorporate the following:

1) Analyze the bioclimatic potential of the Algerian climate zones using a mixed approach combing bioclimatic charts and building performance simulations to assess the climate and provide accurate bioclimatic design recommendations for Algeria.
2) Develop new zoning maps based on the thermal energy demand and indoor-discomfort hours of the current social residential building archetype in Algerian territory using BPS and GIS tools with a recent weather files dataset to adequately inform building designers without accessing, analyzing, or interpreting dense textual information.
3) Investigate the influence of the multi-family apartment building characteristics on the definition of optimal passive and energy efficiency solutions considering heating and cooling energy performance across the Algerian territory through a mixed approach that combine between building performance simulation (BPS) tool and building performance optimization (BPO) algorithm.
4) Develop a design decision-making model based on prediction using an Adaptive Neuro-Fuzzy Inference System (ANFIS) to estimate the cooling and the heating energy loads of the typical multifamily social residential building through the building design parameters variation.

I.4. Thesis outline

This thesis consists of 4 core chapters in addition to an introduction and conclusion chapters. A discussion section is added after each core chapter. Thus, there is no discussion chapter in this thesis.

In Part-I (Chapter 2 and chapter 3) the bioclimatic potential of all Algerian climate zones is investigated, and the thermal and energetic behaviour of the typical multi-family apartment building is evaluated across the Algerian territory. In Part-II (Chapter 4 and Chapter 5) the typical multi-family apartment building design is optimized for each climate zone, and a design decision-making model is proposed. The thesis is made up of a series of articles that have been published or under review in peer-reviewed journals. For this reason, some overlap may occur between the various chapters.

The introduction, scope and outline of this thesis is presented in **Chapter 1**. Afterwards, **Chapter 2** focus to analyze the bioclimatic potential of the Algerian climate zones based on a comparative approach that quantifies the bioclimatic potential of different locations in Algeria using recent weather datasets. Firstly, the annual bioclimatic potential is quantified using simple psychrometric charts without considering the building effect. Secondly, a simulation model for a representative case study in Algeria is used to assess the bioclimatic potential, including the building effect. **Chapter 3** develops new spatial distribution maps for energy demand and thermal comfort estimation in Algeria. This chapter combines the powers of BPS and GIS tools with recent weather files dataset and analyses the climate of Algeria, taking into account the impact of typical and representative housing archetype. **Chapter 4** proposes an optimization approach to select the optimal solution that leads to minimize the cooling and the heating energy loads of the typical multi-family reference case in each climate zone, and the improvement of the energy performance is compared with the base case results. **Chapter 5** is aimed to develop a design decision-making model for predicting the cooling and heating energy loads of residential buildings in Algeria according to the most influential building envelope design variables. Finally, the results of this thesis are summarized, and future researchers are recommended in **Chapter 6**.

I.5. List of publications

I.5.1. Peer-reviewed journal articles

- Chapter 2 is based on:

  Semahi, S., Zemmouri, N., Singh, M. K., & Attia, S. (2019). Comparative bioclimatic approach for comfort and passive heating and cooling strategies in Algeria. *Building and Environment*, *161*, 106271.

  Semahi, S., Benbouras, M. A., Mahar, W. A., Zemmouri, N., & Attia, S. (2020). Development of Spatial Distribution Maps for Energy Demand and Thermal Comfort Estimation in Algeria. *Sustainability*, *12*(15), 6066.

- Chapter 3 is based on:

  Semahi, S., Zemmouri, N., Hamdy, M. & Attia, S. (2021). Optimization of passive envelope design measures for multi-family apartment building using NSGA-II. Energy and Buildings, Under writing.

- Chapter 4 is based on:

  Semahi, S., Benbouras, M. A., Zemmouri, M. & Attia, S. (2021). Development of Adaptive Neuro Fuzzy Inference System (ANFIS) model for estimating building heating and cooling loads. Journal of Building Engineering, Under writing.

I.5.2. Un-refereed publications

Semahi, S., Zemmouri, N., & Attia, S.: Evaluation of thermal comfort potential of passive heating and cooling strategies in Algeria. Presented at the 2019 Doctoral Seminar on Sustainability Research in the Built Environment (DS²BE-2019). Leuven, Belgium.

II. Chapter 2: Thermal comfort and passive design potential analysis of Algerian climate zones

The energy consumption and thermal comfort in buildings are heavily affected by weather conditions. Therefore, the aim of this chapter is to analyze the bioclimatic potential of Algerian climate zones. This analysis was made based on eight representative locations using recent weather datasets (2003–2017). The thermal comfort and passive design potential analysis were based on a psychometric chart applying the adaptive comfort model ASHRAE 55-2017.In addition, an evaluation of the bioclimatic potential was conducted using simulations of a monitored and calibrated residential building model in Algeria using EnergyPlus. The building model has been tested in eight previously selected locations. The heating and cooling energy load results were calculated for each climatic zone and compared. The results allow architects and urban planners to better understand the climate and provide practical design guidance.

II.1. Introduction:

The present and future of sustainably built environments is influenced by the ability of architects, engineers, and urban designers to create buildings that reduce building-associated carbon dioxide emissions and at the same time achieve high levels of thermal comfort (Attia, 2018a). However, this ability is influenced by the understanding of the local climate and the application of corresponding bioclimatic design principles and strategies (Manzano-Agugliaro et al., 2015). In the past, many innovative heating, ventilation, and air conditioning (HVAC) technologies have been proposed to improve the indoor conditions, regardless of energy savings. Today, the integration of passive and active design solutions in newly constructed buildings is becoming a must worldwide. The recent progress with respect to adaptive thermal comfort models and their proliferation influence our understanding of the bioclimatic building performance (Carlucci et al., 2018; de Dear et al., 2013; Pérez-Fargallo et al., 2018). Therefore, bioclimatic studies that investigate the effects of climate on the thermal comfort conditions and the building heating and cooling energy demand are increasingly receiving attention from the research and development community (Attia et al., 2019; Chen et al., 2017; Roshan et al., 2017a).

Integrating bioclimatic analysis tools into daily urban or architectural design practices is a challenge but an essential step towards realizing effective climate-responsive design (Attia et al., 2019). Several analytical tools are available for the quantification of the potential effectiveness of design strategies, e.g., the ECOTECT Weather Tool (Autodesk, 2019) and Climate Consultant (Milne, 2016; Milne et al., 2007). However, most of those analytical tools depend on static comfort models of fully space-conditioned buildings and are not suitable for buildings in hot climates (Attia et al., 2019). More importantly, some of them lack sensitivity to hot climates and provide misleading design recommendations (Attia et al., 2019; Krishan, 2001; Pajek and Košir, 2018; Roshan et al., 2017a). Providing accurate bioclimatic design recommendations is essential for making informed design decisions in early design stages (Attia et al., 2012; Visitsak and Haberl, 2016).

In this chapter, we adopt a dual approach that combines psychrometric chart-based analysis with building performance simulation analysis for the development of accurate bioclimatic design recommendations for Algeria. This research approach is inspired by and builds on the work of Kumar et al. and Kishore et al. (Kishore and Rekha, 2018; Kumar et al., 2016) and adds up on to it. Our research approach integrates the ASHRAE-55 adaptive comfort model as a novel assessment component. The main aim of this paper is to analyze the bioclimatic potential of passive design strategies in Algeria. The chapter has two objectives:

1. Evaluate the thermal comfort and bioclimatic design potential of eight selected cities, which represent the six official climate zones of Algeria, based on a psychometric chart and the adaptive comfort model ASHRAE 55-2017.
2. Validate the bioclimatic potential analysis by simulating the heating and cooling energy loads of a calibrated residential building for the eight selected cities.

The value of this chapter is based on providing a systematic and methodological approach to assess the bioclimatic design potential in Algerian cities based on updated weather datasets. Validated bioclimatic design recommendations for comfort and passive heating and cooling in Algeria are obtained by using a recent dataset (2003–2017) of eight Algerian cities and a calibrated reference building for building performance simulation.

The chapter is organized as follows. A literature is provided in Section II.2. The research methodology and analysis results are described in detail in Sections II.3 and Section II.4. Section II.5 reflects on the results of the reference case simulation and provides a critical discussion. The chapter is concluded in Section II.6 by highlighting the key findings and contributions of the study.

II.2. Literature Review:

The importance of bioclimatic studies is growing and gaining momentum every year. The aim of bioclimatic studies is to understand the climate to maximize the benefits of bioclimatic building design strategies and ensure thermal comfort and increase the energy efficiency. Although being one of the most important aspects of building energy efficiency, several advances have been made in this field in recent years. Our literature review included more than 140 publications, found on Scopus and the Web of Science, relevant to the field of bioclimatic analysis. However, we selected the most relevant publications and classified them into groups using three main categories, which are described in the following paragraphs.

The first group of studies regarding bioclimatic analysis contains the oldest publications that relied on using bioclimatic charts to assess the climate and provide design recommendations for designers. The building bioclimatic chart indicates if the temperature and humidity conditions are within the comfort range of a building designed to effectively benefit from bioclimatic design strategies (Watson and Labs, 1983). The most important publications of this group based on charts 1) are Mollier’s psychrometric chart (1923), 2) Olgyay’s chart (1963), and 3) Dekay and Browns chart (2004) (DeKay and Brown, 2013; Gatley, 2004; Olgyay, 2015).

The chart of Mollier is the one that is most famous and widely used by engineers, architects, and urban planners (Kumar et al., 2016). The chart evolved and benefited from the significant contributions of Givoni and Milne in 1979 that combined different bioclimatic design strategies in a chart (Milne and Givoni, 1979). In the same year, Milne developed an interactive computer-aided tool for passive solar design that later became the Climate Consultant program (Milne and Yoshikawa, 1979). In the 1980s and 1990s, several researchers contributed to the psychrometric chart and applied unique comfort models (Szokolay, 1986). More recently, several researchers applied the psychrometric chart to local contexts (Guan et al., 2015; La Roche and Liggett, 2001; Mahmoud, 2011; Osman and Sevinc, 2019). The chart of Olgyay has been used less because it is less comprehensive. However, several researchers applied it and validated its outcomes in the last years. The work of Katafygiotou et al. (Katafygiotou and Serghides, 2015) on Cyprus and Pajek et al. (Pajek and Košir, 2017) on Slovenia have recently become two of the most cited publications. The third type of chart that was published in 2004 by Dekay and Brown has been used in recent research in Australia, Iran, and Madagascar (Ahmed et al., 2014; Attia et al., 2019; Milne, 2016; Roshan et al., 2017b). Unfortunately, bioclimatic charts lack sensitivity to hot climates and provide misleading design recommendations (Attia et al., 2012; Kumar et al., 2016).

The second group of studies regarding bioclimatic analysis mainly relies on building performance simulations to assess the climate and provide recommendations for designers. The building performance simulation (BPS) is the replication of aspects of the building performance using a computer-based, mathematical model created on the basis of fundamental physical principles and sound engineering practice (De Wilde,P., 2018). This group is characterized by an abundance of publications worldwide. Therefore, we focused on the publications most relevant to Algeria, which aimed to calculate the bioclimatic potential or heating/cooling degree days or run simulations to predict the impact of climate change. This includes the work of Khoukhi et al. (Khoukhi and Fezzioui, 2012) who assessed the effectiveness of bioclimatic design strategies in hot dry regions of Algeria and that of Imessad et al. (Imessad et al., 2014) who focused on assessing the effectiveness of passive cooling in Algiers. Among those studies, the study of Ghedamsi et al. (Ghedamsi et al., 2016) is the most relevant and comprehensive study in which the annual heating and cooling requirements of buildings in different regions of Algeria were calculated using the degree days method. Unfortunately, none of those studies followed a comprehensive approach that covers all climatic regions of Algeria while providing validated bioclimatic design recommendations that designers can apply in early design stages. More importantly, most studies that follow the simulation-based approach are post-design evaluations and mainly consider only hypothetical non-bioclimatic comfort models and thus do not validate early-design bioclimatic recommendations.

The third group of studies regarding bioclimatic analysis mainly relies on a mixed approach combing bioclimatic charts and building performance simulations to assess the climate and provide recommendations for designers. This group of studies emerged in 2017 with the work of Pajek et al. (Pajek and Košir, 2018) who investigated the climatic potential of five cities in Slovenia and the work of Ali-Toudert et al. (Ali-Toudert and Weidhaus, 2017a) who focused on two climatic zones in Algeria. The work of Kumar et al. and Kishore et al. (Kishore and Rekha, 2018; Kumar et al., 2016) also belong to this group because they systematically combined bioclimatic chart analysis with building performance analysis for India. The advantage of the mixed approach is that it allows comparing the simulation results with the bioclimatic potential analysis to validate the design recommendation. More importantly, validated design recommendations are grouped and classified in a comprehensive way based on this approach, which contributes to the consolidation of the knowledge of bioclimatic design on national scales.

This overview and classification of literature demonstrate that the mixed bioclimatic analysis approach should be adopted to obtain information about the design of bioclimatic buildings. The literature review indicates that this mixed bioclimatic analysis approach has been the most studied approach in recent years, particularly in Algeria. Thus, the lack of validated design recommendations for bioclimatic design may inhibit the integration of bioclimatic design solutions and technologies in future buildings.

In this chapter, we present the results of the application of a mixed approach that combines bioclimatic analysis and building performance simulations to address several of the points mentioned above. More specifically, the validity of bioclimatic design strategies in Algeria was tested based on a recent weather dataset (2003–2017), adaptive comfort model, and calibrated reference study.

II.3. Materials and Methods:

The research methodology is based on a comparative approach that quantifies the bioclimatic potential of different locations in Algeria using recent weather datasets. Firstly, the annual bioclimatic potential is quantified using simple psychrometric charts without considering the building effect. Secondly, a simulation model for a representative case study in Algeria is used to assess the bioclimatic potential including the building effect. Our methodology is inspired by the work of Khambadkone and Jain (Khambadkone and Jain, 2017) who applied this approach in India. We applied their methodology to a new context.

Figure II-1 presents the detailed conceptual framework of the study describing the steps of the research methodology. The conceptual framework of this study can be divided into four major steps. Each step is described in detail in the following sections.

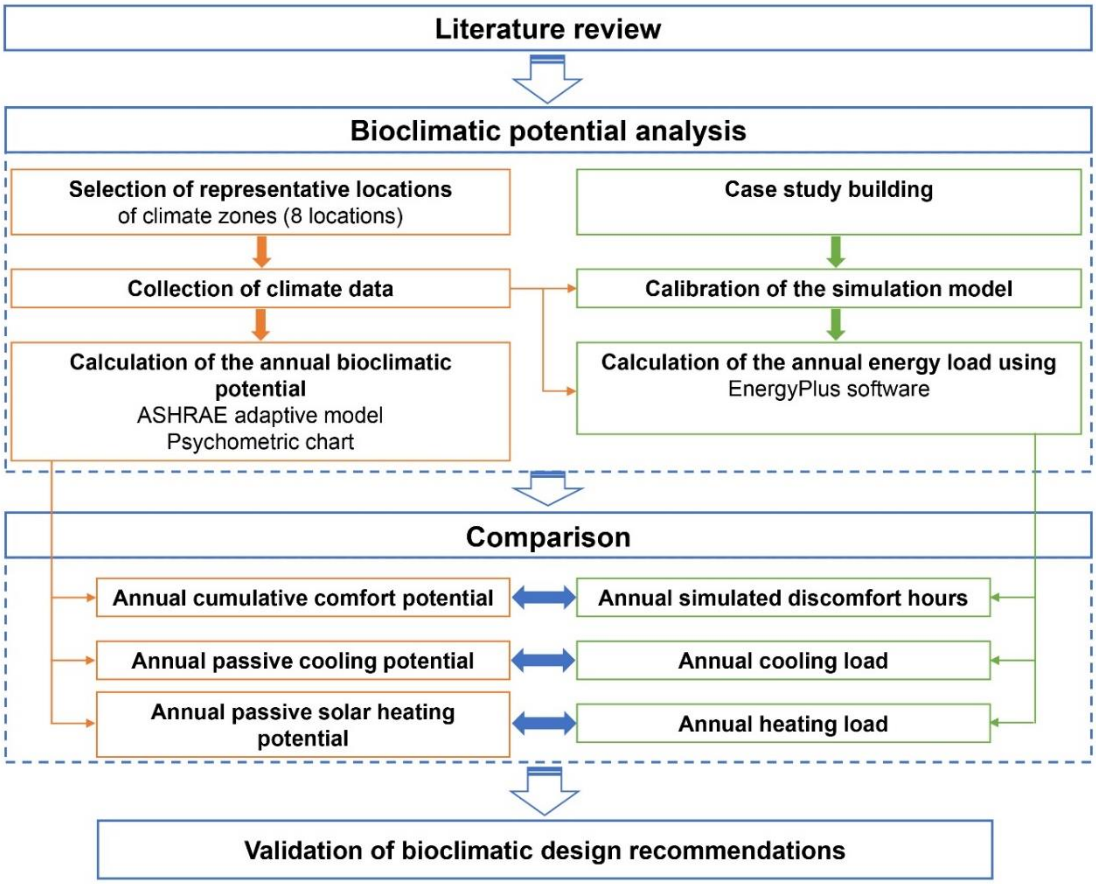


Figure II-1 : *Conceptual framework of this study*

II.3.1. Selection of representative locations

According to the Algerian National Center of Studies and Researches Integrees of the Building (CNERIB: Centre National d'Etudes et de Recherches Integrees du Batiment) and the thermal regulation (DTR C3-2) (CNERIB, 1997a) for residential buildings, Algeria has six distinguished climatic zones: Zone (A): in the north of Algeria, including the coastal zone; Zone (B): in the south of zone (A), including the plain behind the seashore; Zone (C): in the south of zone (B), including the highlands; Zone (D): in the south of Algeria, including the desert; and the climate zones (B') and (D'), representing subzones within the main zones (B) and (D), respectively. Some of the characteristics of the subzones differ from those of the main zones. For example, they have the same characteristics in winter as the main zones, but they are very hot in summer compared with the main zones (B) and (D). For our investigation, we selected eight locations because climate zone (D) covers a large area in the south of Algeria and we thus added two weather stations to this zone (see Table

II-1). Among those weather stations, we distinguished Guezzam city, located in the south of Tamanrasset Region, because it has specific climatic characteristics. Guezzam has an annual global radiation that exceeds 7600 Wh/m² (Yaiche et al., 2014). This could have an impact on other climate data for this location. We also used a map with the official climatic zones of Algeria. Figure II-2 indicates the locations of the eight selected weather stations.

Table II-1: *Geographical information about the eight selected representative locations in Algeria*

Nº.	**Name of location**	**Station code**	**Coordinates**		**Altitude (m)**	**Climate zone (CNERIB classification)**
1	Algiers	AL	36.6 °N	3.2 °E	25	A
2	Guelma	GL	36.4 °N	7.4 °E	228	B
3	Chlef	CH	36.2 °N	1.3 °E	141	B'
4	Setif	SF	36.1 °N	5.3 °E	1050	C
5	Biskra	BS	34.7 °N	5.7 °E	88	D
6	Bechar	BC	31.6 °N	2.2 °W	811	D
7	Adrar	AR	27.8 °N	0.1 °W	280	D'
8	Tamanrasset (Guezzam)	TM	19.6 °N	5.8 °E	400	D

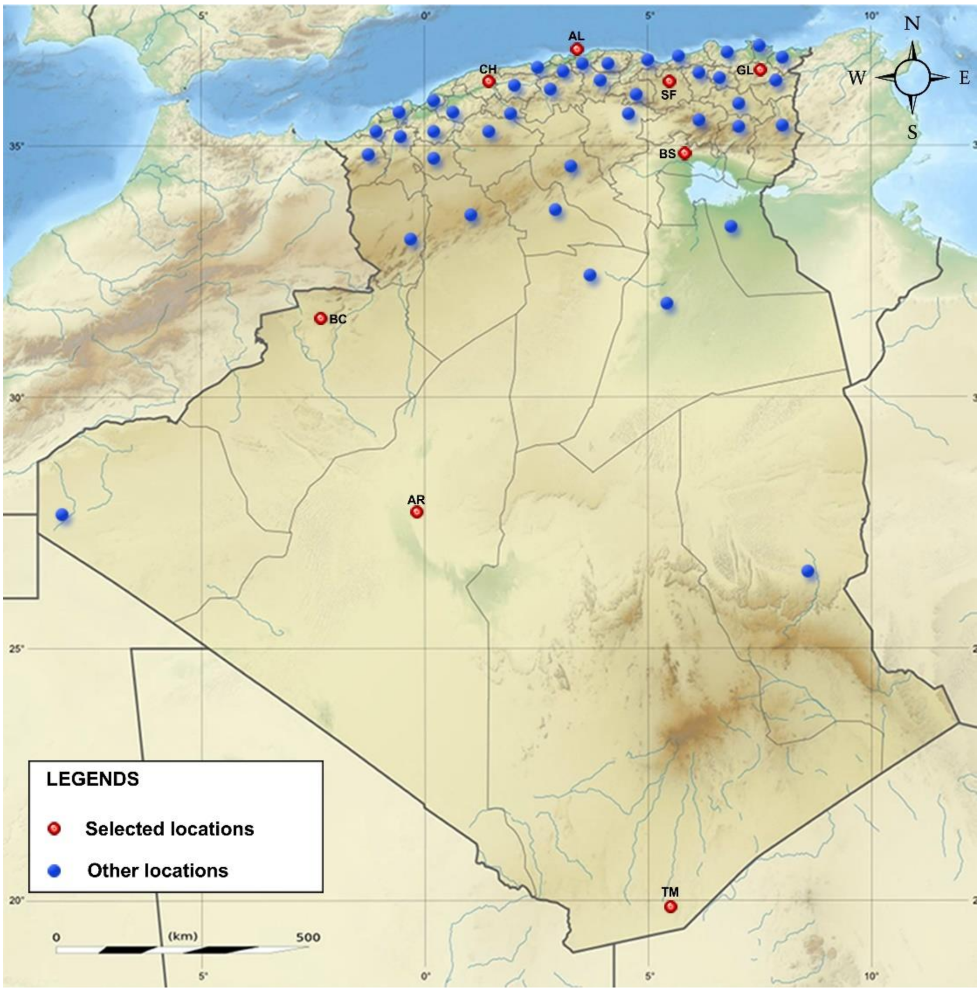


Figure II-2: *Algerian map showing the eight selected location (source: Carte du monde, 2018 - adapted by the author)*

II.3.2. Climate data

In this study, recent weather datasets (2003–2017) for eight locations were used. The last version of the Typical Meteorological Year (TMY) hourly weather data files for the eight selected locations was used (see Table II-1). These weather data were created by the Algerian National Meteorology Office and made available by the United States Department of Energy (Linda K. Lawrie and Crawley, 2019).

II.3.3. Calculation of annual bioclimatic potential

A psychrometric chart and the adaptive comfort model ASHRAE 55-2017 were used to calculate the bioclimatic potential of the eight selected locations. The selection of the ASHRAE 55-2017 adaptive comfort model was based on the recommendations of Attia et al. (Attia et al., 2019) who consider it as the best available socioeconomic model that sets no humidity limit, which is essential in the coastal cities of Algeria.

The hourly weather data of each location were plotted on the psychrometric chart. The data plots were created using three major bioclimatic design strategies or combinations of the three strategies:

- Passive Solar Heating (PSH)
- Natural Ventilation (NV)
- Direct Evaporative Cooling (DEC)

The literature review indicated that the three strategies listed above are the most effective design strategies, which are suitable for the climate of Algeria and should be prioritized by designers (Fezzioui et al., 2009a; Khoukhi and Fezzioui, 2012). The boundaries of the thermal comfort zone were limited by the comfort temperature calculated by the adaptive comfort model ASHRAE 55-2017. The zone of direct evaporative cooling was limited by the thermal comfort zone. The wet-bulb temperature (WBT) maximum in summer is ~24°C and the Dry Bulb Temperature (DBT) maximum is about 44°C (in hot–dry developing countries) according to Givoni (Givoni, 1992). The potential of thermal comfort, passive cooling, and passive heating were calculated based on the number of hourly data points within each boundary on the chart. The passive solar heating zone is a function of the building design. The lower limit of this zone is defined by the lowest outdoor air temperature at which the available solar radiation will produce minimum comfort temperatures. The bioclimatic chart for the eight selected locations was created based on these assumptions. Equations (II-1) and (II-2) provide the basis of the bioclimatic potential calefactions:

- Optimal comfort temperature (°C) (Milne, 2016; Pérez-Fargallo et al., 2018):

$T_c = 0.31f(T_{out}) + 17.8 \qquad 10°C \le f(T_{out}) \le 33.5°C \qquad$ (II-1)

Upper 90% acceptability limit (°C):

$T_c = 0.31f(T_{out}) + 20.3 \qquad 10°C \le f(T_{out}) \le 33.5°C$

Lower 90% acceptability limit (°C):

$T_c = 0.31f(T_{out}) + 15.3 \qquad 10°C \le f(T_{out}) \le 33.5°C,$

where $f(T_{out})$ is the prevailing mean outdoor air temperature $(t_{pma(out)})$ in ASHRAE 55 for 2013 and 2017 and the mean monthly outdoor air temperature in ANSI/ASHRAE 55 for 2004 and 2010.

- Prevailing mean outdoor air temperature (°C) (Pérez-Fargallo et al., 2018):

$$\bar{t}_{pma(out)} = (1 - \alpha)\,[t_{e\,(d-1)} + \alpha \cdot t_{e\,(d-2)} + \alpha^2 \cdot t_{e\,(d-3)} + \alpha^4 \cdot t_{e\,(d-4)} + \ldots], \qquad \text{(II-2)}$$

where α is a constant ranging between 0 and 1 and $t_{e\,(d-1)}$ is the daily mean external air temperature at time d of a series of equal intervals (day).

In the last two versions, ANSI/ASHRAE 55 suggests an α value of 0.9 for climates in which the day-to-day temperature variation is relatively minor, such as the humid tropics, and a lower α value of 0.6 for mid-latitude climates in which the day-to-day temperature variation is more pronounced.

II.3.4. Reference building

Our reference building should be the most common housing archetype in Algeria. For this reason, we aimed to characterize the Algerian housing sector which can help us to well select a representative reference building.

II.3.4.1 Characterization of the Algerian Housing Sector

The Algerian Census Database of the residential sector was analyzed between 1999 and 2018, to understand the relationship between the energy use of the building sector and the residential building stock in Algeria. In addition, the national energy use data of the residential building sector, between 2009 and 2018, were collected. The data on the energy use of each building archetype was found websites of the Algerian Ministry of Energy web site (ME, 2020), the Ministry of Housing (MHUV, 2018), and the National Office of Statistics (ONS, 2018). The data were analyzed, organized and visualized to represent the energy use in Algeria by sector and the evolution of energy use of the residential sector. The compiled data can be found in Appendices A and B.

The building sector in Algeria is the largest consumer of fossil energy, consuming 46% of the total national energy bill, out of which residential buildings consume the most significant part of 37%. The breakdown of energy use by sector is shown in Figure II-3(a).

As shown in Figure II-3(b), the energy use of the residential sector increased considerably in the last ten years (2009–2019) from around 9000 KTep to more than 18,140 KTep. The main reason associated with this increase in energy demand is the substantial increase in population and housing units (ME, 2020).

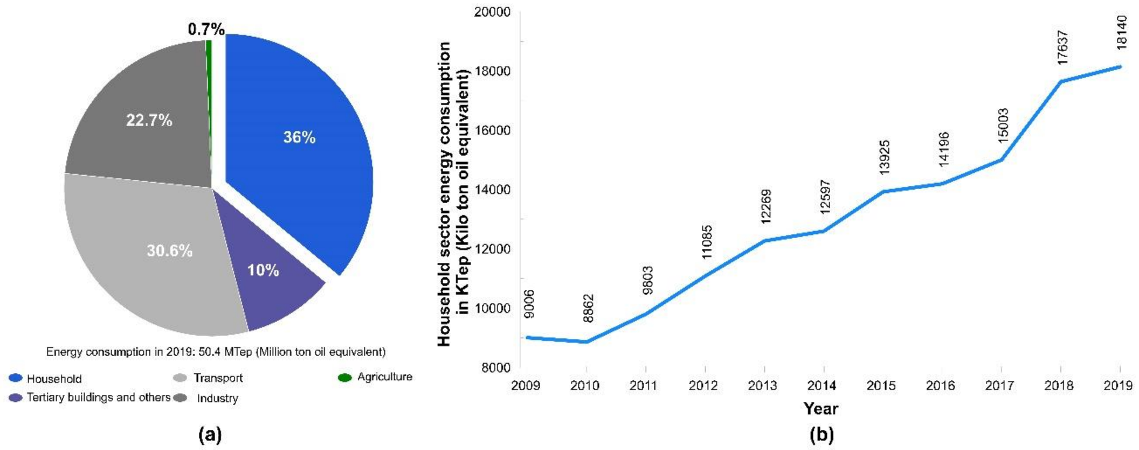


Figure II-3: *Energy use in Algeria. (a) Breakdown of energy use by sector; (b) evolution of energy use of the residential sector between 2009 and 2019*

In the last decade, the Algerian authorities built more than three million dwellings. For example, between 1999 and 2018, more than 3.6 million dwellings were built. The residential building sector in Algeria is generally composed of two main typologies: (i) multifamily apartment buildings, which represent 51% of the residential sector and (ii) single-family houses, which represent 49% of the residential sector. The latter is divided into rural housing and self-constructed housing (see Figure II-4(a)) (Appendix A).

There are several categories of the multifamily apartment building archetype depending on the contract type that reflects the residents' income (Public rental housing, participatory public housing, rental–ownership housing and free promotional housing) (see Figure II-4(b)). The social residential buildings category (Public rental housing) represents the central part (31%) in the multifamily building's archetype. This category is intended for the low-income population in Algeria. The percentage of residential housing typologies by contract type is shown in Figure II-4(b). The dwellings of the social housing building category have been increased every year, as shown in Figure II-4(c), which presents the evolution of constructed social residential units. The Algerian Ministry of housing, urbanism and the city launched a program of 800 thousand dwellings between 2009–2014 and 800 thousand dwellings between 2015 and 2019 (Appendix A). Therefore, we can say that the multifamily social housing typology as the most common housing archetype in Algeria.

II.3.4.2 Case study:

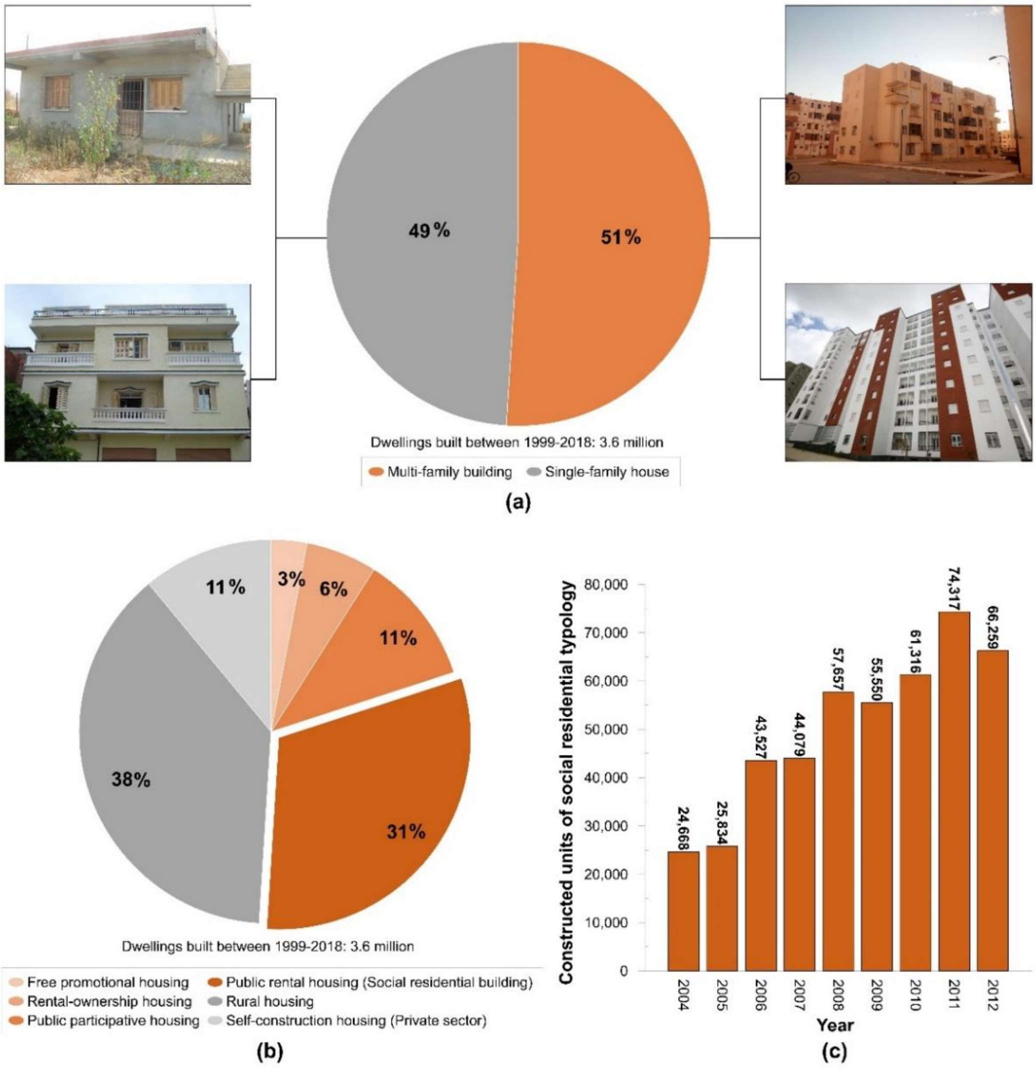


Figure II-4: *Characterization of residential housing typologies in Algeria. (a) Dwelling's archetypes; (b) dwellings contract types; (c) evolution of social housing units (Appendix A).*

Based on the characterization of the Algerian housing stock, the selected building model for this study represents a typical multifamily social residential building (see Figure II-5(a)). The number of floors of this archetype is ranging between two and six stories. Each level is subdivided into two flats. The floor height is 2.8 m, and the floor area of each household is approximately 70 m2.

The case study includes a multifamily social housing typology in Biskra in the southwest of Algeria (coordinates: 34°51′N 5°44′E; altitude: 87 m; Biskra, Latin Vescera). Biskra's climate is classified as hot desert climate and falls in zone BWh in the Köppen climate classification (Beck et al., 2018). This typology was chosen because it represents the most common typology in Algeria. The selected apartment was in the first floor to be more representative because the ground floor and highest floor are more affected by the outdoor environment. In addition, we were able to take real measurements in this apartment. The building geometry (see Figure II-5(b,c,d)) of the real building components was used as the simulation model input. Table II-2 presents the thermophysical properties of the building elements according to the Algerian Thermal Regulation of Residential Buildings (CNERIB, 1997a).

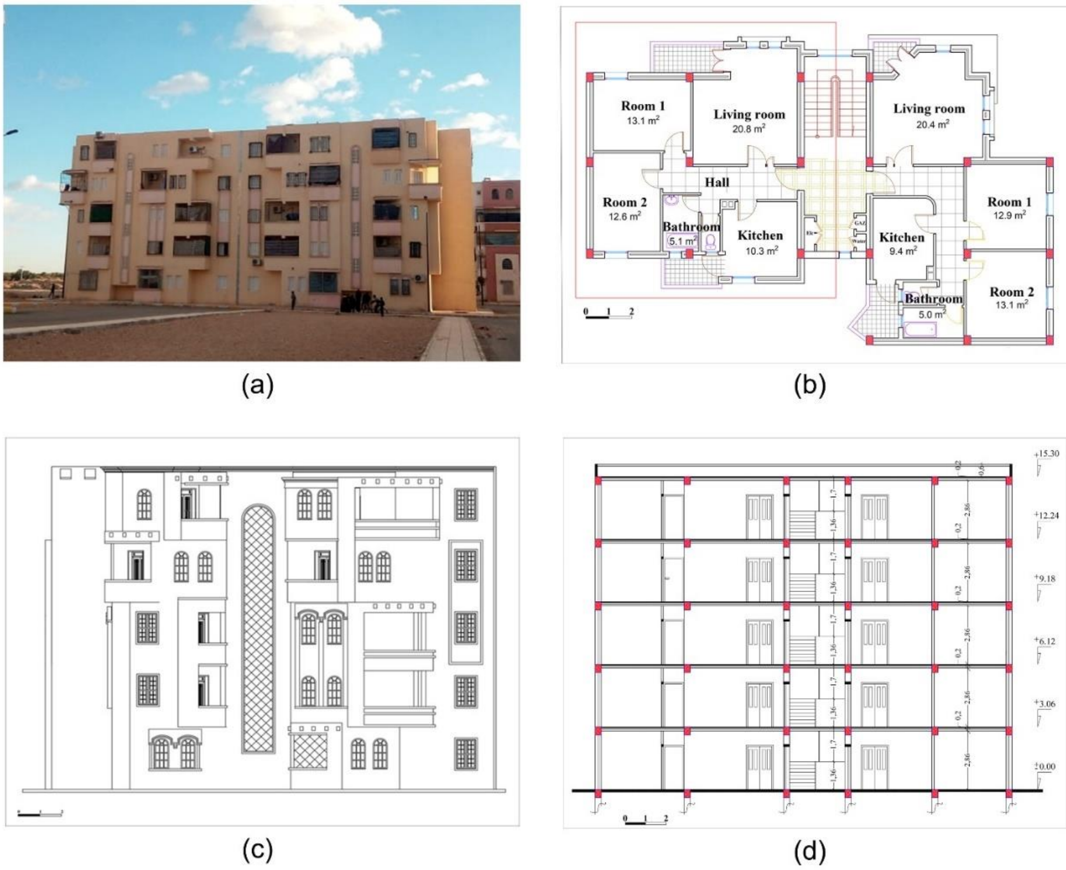


Figure II-5: *Details of the selected multi-family social housing building typology; (a) real view of the building, (b) floor plan, (c) section, (d) front façade*

II.3.5. Simulation model and validation

The reference building was modeled using EnergyPlus v.8.3 software, which is a validated program for the simulation of the building thermal performance (DOE, 2014). Figure II-6 shows the 3D model of the reference building.

The building geometry (see Fig. II-5(a,b,c)) and thermal properties of the real building components (Table II-2) were used as the simulation model input. The systems of heating, cooling, and Domestic Hot Water (DHW) were represented based on a building audit, similar to the schedules of occupancy, lighting, heating, cooling, and DHW (see Fig.II-7). The TMY hourly weather data file for Biskra was used to represent the outdoor weather conditions. The following two sections describe the performance monitoring that was conducted for the reference building and the use of the monitoring data to validate the model.

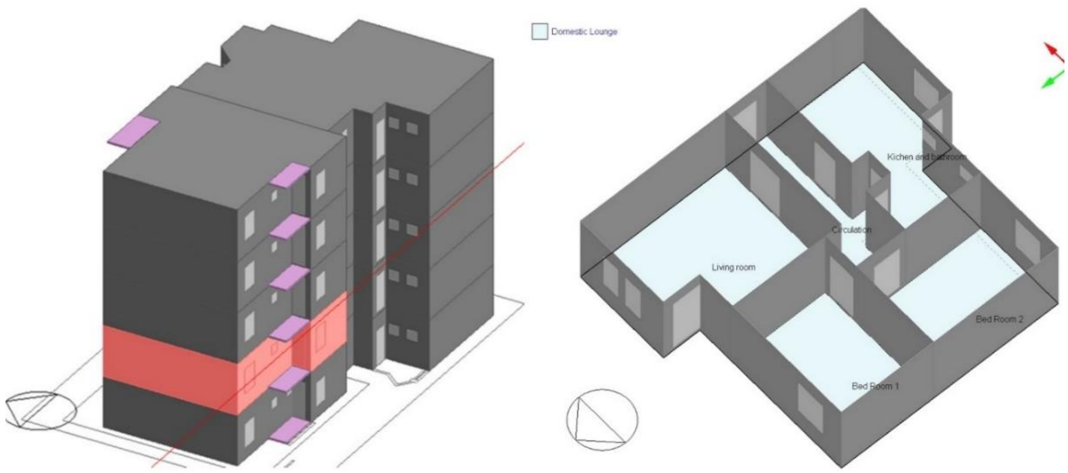


Figure II-6: *Simulated building model developed using DesignBuilder (EnergyPlus)*

Table II-2: *Thermal properties of the building elements of the selected multi-family social housing typology (CNERIB, 1997; Derradji et al., 2017)*

N°	Building element	Outside to inside	Composition	Thickness (m)	Thermal conductivity (W/m-K)	Density (kg/m3)	Specific heat capacity (kJ/kg K)	U-value (W/m2-K)
1	Exterior wall	Layer 1	Mortar	0.02	1.15	1900	1.08	1.118
		Layer 2	Hollow brick	0.15	0.48	900	0.93	
		Layer 3	Air cavity	0.05	0.024	1.22	1.00	
		Layer 4	Hollow brick	0.1	0.48	900	0.93	
		Layer 5	Plaster	0.02	0.35	800	0.93	
2	Partition wall	Layer 1	Plaster	0.02	0.35	800	0.93	1.857
		Layer 2	Hollow brick	0.1	0.48	900	0.93	
		Layer 3	Plaster	0.015	0.35	800	0.93	
3	Internal floor	Layer 1	Tiling	0.02	1.7	2200	0.93	1.985
		Layer 2	Mortar	0.03	1.15	1900	1.08	
		Layer 3	Concrete slab (hollow block)	0.2	1.45	1450	1.08	
		Layer 4	Plaster	0.02	0.35	800	0.93	
4	Roof	Layer 1	Tightness	0.015	0.7	2100	1.04	0.584
		Layer 2	Mortar	0.04	1.15	1900	1.08	
		Layer 3	Polystyrene	0.05	0.04	20	1.4	
		Layer 4	Concrete slab (hollow block)	0.2	1.45	1450	1.08	
		Layer 5	Plaster	0.02	0.35	800	0.93	
5	Ground floor	Layer 1	Concrete	0.1	1.75	2500	1.08	3.259
		Layer 2	Mortar	0.03	1.15	1900	1.08	
		Layer 3	Tiling	0.02	1.7	2200	0.93	

II.3.5.1 Building audit and monitoring

The indoor air temperature and energy consumption of the selected apartment were monitored during 2016. A walkthrough visit was performed to identify the major energy use equipment (e.g., heating systems, air conditioners, ceiling fans, lighting, water heaters, stoves) and questions were asked about the living habits of the occupants to create occupancy and other related schedules. The indoor air temperatures were continuously recorded from January 21–27, 2016, (168 h) in the winter period and from July 12–18, 2016, (168 hours) in the summer period. The indoor air temperatures were determined every hour with a Testo-480 measurement kit. We used the sensor temperature and humidity. The measurement range is -20°C to +70°C at an accuracy of ±0.5°C. The instrument was installed in the living room. The measurements taken in the main living space of the apartment are considered representative, similar to the work of Colton et al. (Colton et al., 2014) and Lai et al. (Lai et al., 2009). To avoid data distortion due to radiation from floor and walls, the instrument was placed in the center of the space at a height of 1.4 m, which is the medium clear height of the living room. The monthly electric and gas consumptions (kWh) were registered during 2016; the data were collected from electricity and gas meters.

II.3.5.2 Calibration method

The calibration focused on how closely the simulated results match the monitored data. The calibration was an essential step to allow the creation of a reliable simulation model. The simulation model was calibrated using the present building physics conditions and patterns of energy use. To calibrate the building simulation model, ASHRAE Guideline 14 was followed. Three indices of the ASHRAE Guideline 14 were used for our manual calibration: 1) mean bias error (MBE), and 2) coefficient of variation or root-mean-square error [CV (RMSE)] and 3) the coefficient of determination R^2. The MBE is a nondimensional measure of the overall bias error between the measured and simulated data with a known time resolution. The CV (RMSE) indicates how well the simulation model describes the variability in the measured data. The coefficient of determination, denoted R^2 is the proportion of the variance in the dependent variable that is predictable from the independent variable(s). The MBE, CV (RMSE) and R^2 values were calculated using the following equations:

$$MBE = \frac{\sum_{i=1}^{Np}(Mi - Si)}{\sum_{i=1}^{Np} Mi} \ (\%) \tag{II-3}$$

$$CV\ (RMSE) = \frac{1}{M}\sqrt{\frac{\sum_{i=1}^{Np}(Mi - Si)^2}{Np}} \ (\%) \tag{II-4}$$

$$R^2 = 1 - \frac{SSres}{SStot}\,, \qquad \text{(II-5)}$$

where *Mi* and *Si* are the measured and simulated data at time interval *I, Np* is the total number of data values used for the calculation, *SSres* is the sum of squares of residuals and *SStot* is the total sum of squares.

According to ASHRAE Guideline 14 (ASHRAE, 2002), the simulation model is considered calibrated if:

- hourly MBE values are within ±10% and hourly CV (RMSE) values are below 30%
- monthly MBE values are within ±5% and monthly CV (RMSE) values are below 15%

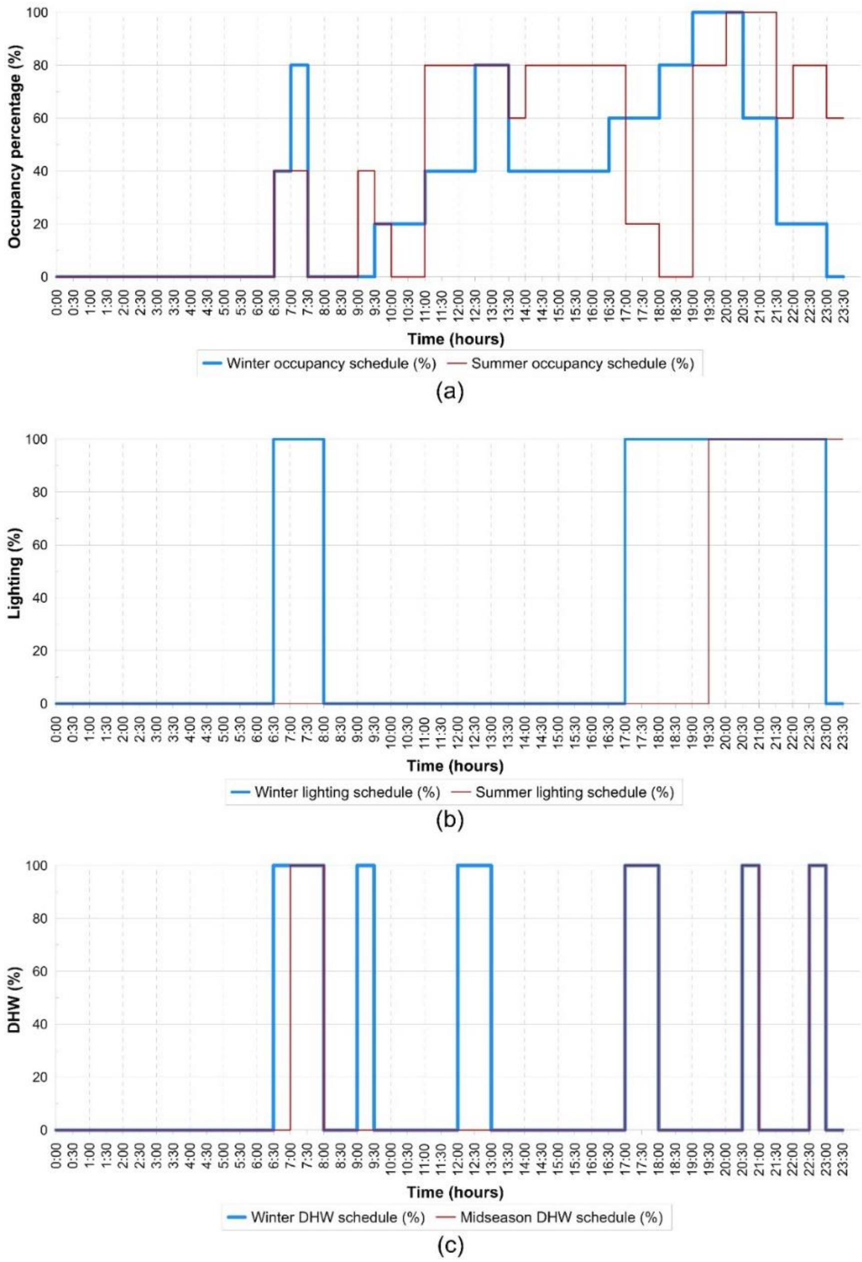


Figure II-7: *Winter and summer schedules of the simulated building model. (a) living room occupancy, (b) living room lighting, and (c) DWH*

The simulation was calibrated using two data categories: 1) hourly indoor temperature, and 2) monthly energy consumption. Each data category has two subcategories: winter and summer indoor temperature and electricity and gas consumption. A manual calibration was used and the initial model (reference case) went through several trial-and-error modifications. The airtightness values, schedules (occupancy, lighting, heating, cooling, and DHW), and setpoint temperature values were modified during the calibration. The MBE and CV (RMSE) values were calculated after each simulation run and compared with the accuracy thresholds of ASHRAE Guideline 14. We calculated R^2 for hourly indoor temperature (during summer and winter time) and monthly energy use (gas and electricity use). Table II-3 and Figure II-7 summarize the final model input. The results of the validation of the simulation model calibration are described in Section II.4.2.

Table II-3: *Simulation model parameter input*

	Model input measures	**Value**
Envelope	External wall (W/m^{2}K)	1.118 (CNERIB, 1997a)
	External wall surface absorptance, CCF	0.6
	Internal floor (W/m^{2}K)	1.985
	Air tightness (Vol/h)	3
	WWR (%)	11.47°N, 12.78°S
	Opening (W/m^{2}K)	5.778
	Solar Heat Gain Coefficient (SHGC)	0.81
Occupancy	Density (people/m^2)	0.0844
	Schedules	see Fig. II-7(a)
Lighting	Installation power density (W/m^2)	15 (to achieve 300 Lux)
	Schedules	see Fig. II-7(b)
Ventilation and air conditioning	Outside air (l/s per person)	10
	Temperature setpoint (°C)	Heating 22°C, Cooling 28°C (CNERIB, 1997a, 1997b)
	COP/EER	1.8/1.8
DHW	Winter period (December–March) (l/m^2/day)	3.15
	Midseason period (April and May, October and November) (l/m2/day)	1.89
	Schedules	see Fig. II-7(c)
Plug loads	Average installation power density (W/m^2)	10

II.3.6. Calculation and comparison of energy loads

After validating the building performance simulation model, the thermal comfort and annual energy consumption of the reference case were calculated. The annual energy consumption and discomfort hours of the eight selected locations were simulated. A statistical method was used to compare the results of the simulation and bioclimatic potential. The results of the simulation and the comparison with the bioclimatic potential analysis are described in Section II.4.3.

II.4. Results:

II.4.1. Bioclimatic potential of the eight selected locations

The monthly minimum and maximum adaptive comfort temperature ranges for the selected eight locations were calculated using the ASHRAE adaptive model and Eqs (1) and (2). The weather data used in this calculation are the averages of 15 years (2003–2017) for each location. Table II-4 shows that each city has a monthly upper and lower limit. Based on the identification of the monthly adaptive comfort limit thresholds indicated in Table II-4, we selected the highest and lowest comfort temperatures of all months for each location to obtain the annual adaptive comfort temperature range.

Table II-4: *Indoor adaptive comfort temperatures (°C) for the eight selected locations*

Nº	Name of City	90% Acceptability Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Algiers	Max (°C)	23.6	23.4	24.3	15.2	26.2	27.3	28.3	28.4	27.6	26.7	24.8	24	**28.4**
		Min (°C)	18.6	18.4	19.3	20.2	21.2	22.3	23.3	23.4	22.6	21.7	19.8	19	**18.4**
2	Guelma	Max (°C)	22.9	22.9	23.9	24.6	26.1	27.1	28.7	28.1	27	26.4	24.6	23.4	**28.7**
		Min (°C)	18.4	18.4	18.9	19.6	21.1	22.1	23.7	23.1	22	21.4	19.6	18.4	**18.4**
3	Chlef	Max (°C)	23.6	23.5	24.8	25.6	26.8	28.9	29.5	29.4	28.2	27.3	25.1	24.1	**29.5**
		Min (°C)	18.6	18.5	19.8	20.6	21.8	23.9	24.5	24.4	23.2	22.3	20.1	19.1	**18.5**
4	Setif	Max (°C)	21.7	21.7	23.1	24.2	25.3	27.3	28.4	28.2	26.6	25.4	23.5	22	**28.4**
		Min (°C)	18.4	18.4	18.4	19.2	20.3	22.3	23.4	23.2	21.6	20.4	18.5	17	**18.4**
5	Biskra	Max (°C)	24	24.3	25.7	27	28.6	30.1	30.6	30.6	29.1	27.7	25.4	24.2	**30.6**
		Min (°C)	19	19.3	20.7	22	23.6	25.1	26.1	25.9	24.1	22.7	20.4	19.2	**19**
6	Bechar	Max (°C)	23.5	24.2	25.6	27.3	28.2	29.8	30.6	30.9	29.2	27.5	24.7	23.3	**30.6**
		Min (°C)	18.5	19.2	20.6	22.3	23.2	24.8	26.2	25.9	24.2	22.5	19.7	18.4	**18.4**
7	Adrar	Max (°C)	24.3	25.7	26.9	28.2	30.1	30.6	30.6	30.6	30.5	28.8	26.1	24.5	**30.6**
		Min (°C)	19.3	20.7	21.9	23.2	25.1	26.3	27.2	26.9	25.5	23.8	21.1	19.5	**19.3**
8	Tamanrasset (in Guezzam)	Max (°C)	26	27.1	29	30.1	30.6	30.6	30.6	30.6	30.6	29.6	28.4	27.2	**30.6**
		Min (°C)	21	22.1	24	25.1	26.6	26.8	26.5	26.2	26.1	24.6	23.4	22.2	**21**

The annual bioclimatic potential of the three major design strategies was calculated (see Table II-5). The percentage of each bioclimatic strategy's potential is listed in Table II-5. The psychrometric charts were plotted using the hourly weather data for each location, as shown in Figure II-8.

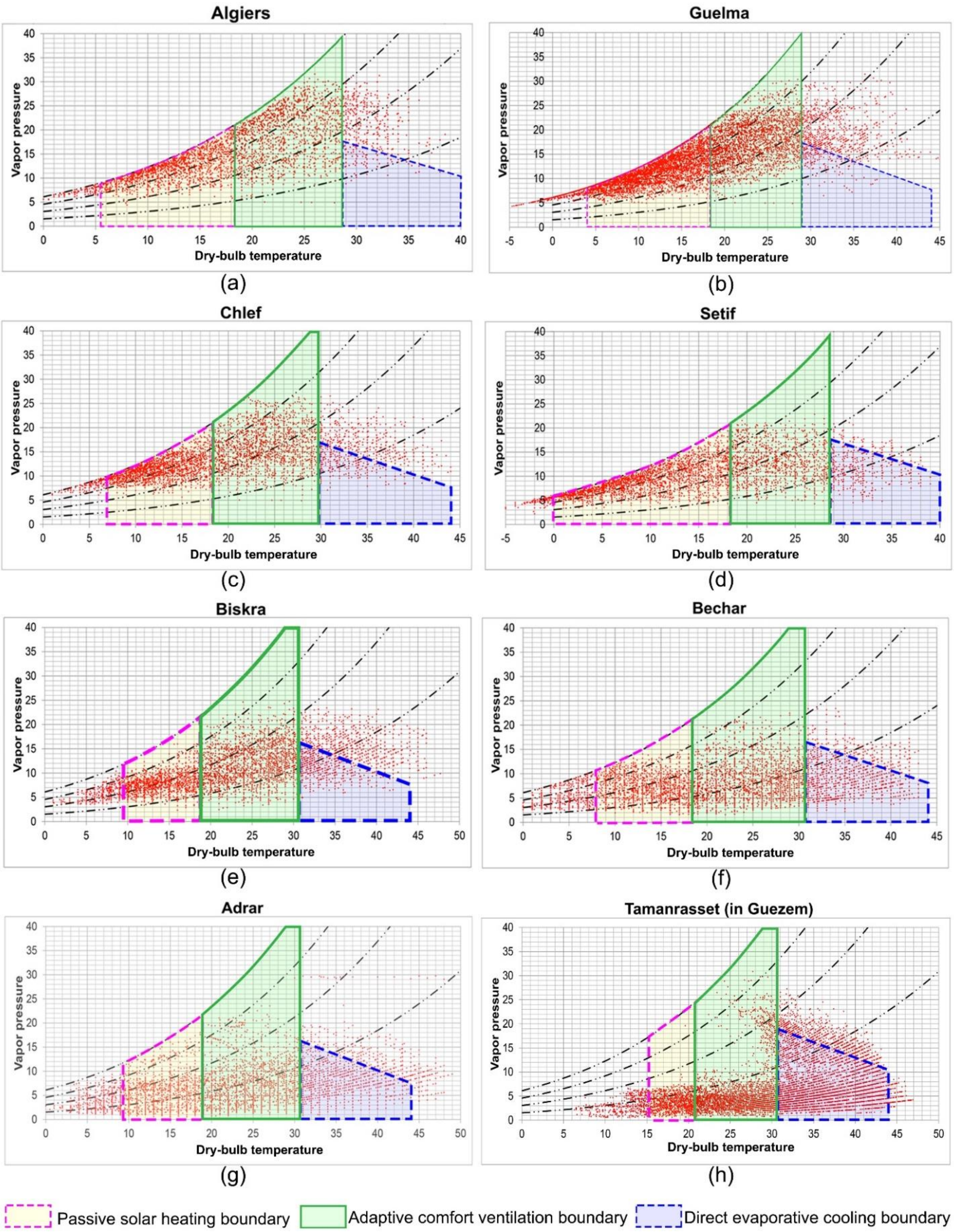


Figure II-8: *Bioclimatic chart with hourly weather data for (a) Algiers, (b) Guelma, (c) Chlef, (d) Setif, (e) Biskra, (f) Bechar, (g) Adrar, and (h) Tamanrasset*

Table II-5: *Annual potential (%) of thermal comfort and passive heating/cooling strategies for the eight selected locations*

Nº.	Name of City	Comfort (%)	Natural Ventilation (%)	Direct Evaporative Cooling (%)	Passive Solar Heating (%)	Natural Ventilation + Direct Evaporative Cooling (%)
1	Algiers	22.1	18.9	2.9	13.1	21.9
2	Guelma	18.6	13.7	4	11.9	17.8
3	Chlef	27.9	18.9	10.5	10.3	29.4
4	Setif	18.4	11.5	9.9	13.9	21.5
5	Biskra	26.4	17.4	21.5	9.3	39
6	Bechar	23.8	16.3	30.3	10.8	46.7
7	Adrar	23.8	15.1	38.7	4.6	53.9
8	Tamanrasset (in Guezzam)	18.5	12.5	47.5	0.8	60

II.4.1.1 Annual thermal comfort potential

The annual thermal comfort potential (%) was calculated for the different locations, as shown in Figure II-9. It represents the percentage of comfortable time (h) during the year without the use of any bioclimatic strategies. Figure II-9 shows that the weather in Chlef is characterized by the highest number of hours within the comfort limits (28%). This location has a higher comfort period compared with the other locations in Algeria. In contrast, the annual comfort potential of Setif and Tamanrasset (within the Tamanrasset Province) is ~18.5%. These locations have the lowest number of comfort hours throughout the year.

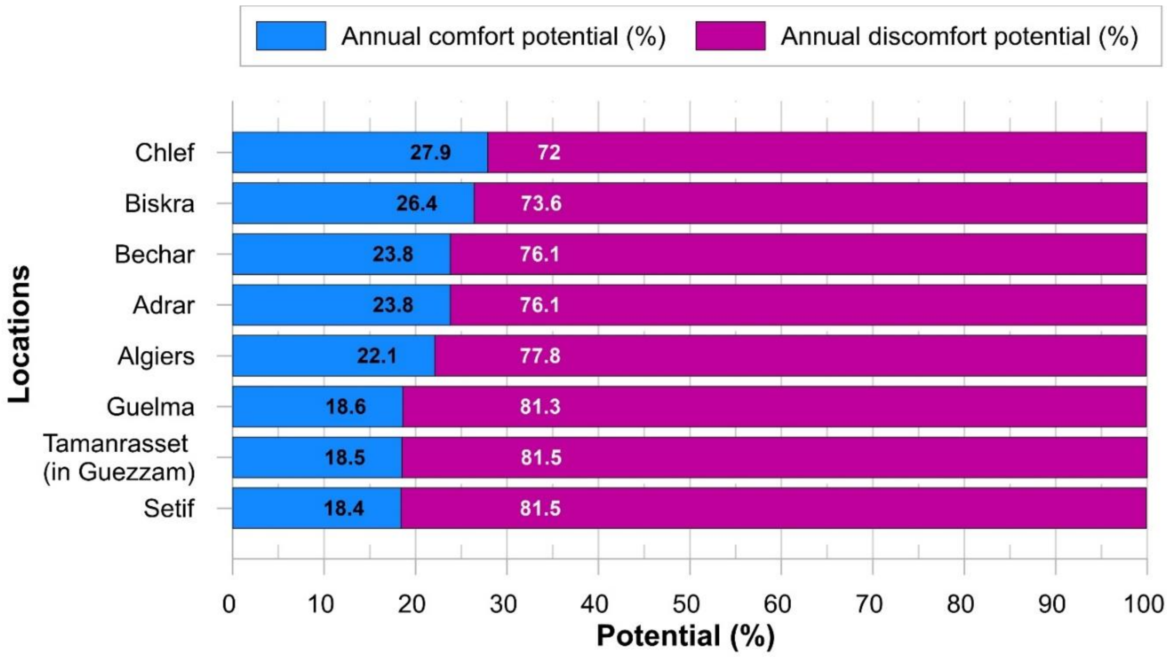


Figure II-9: *Annual thermal comfort potential (%) for the eight selected locations*

II.4.1.2 Annual natural ventilation potential

The annual natural ventilation potential (%) was calculated for the different locations shown in Figure II-10(a). The natural ventilation strategy allows to extend the upper comfort threshold to a maximum of 3°C according to ASHRAE 55 (ASHRAE, 2017). As shown in Figure II-10(a), the highest potential to increase the comfort hours by natural ventilation was observed in Chlef and Algiers (~19%). In contrast, Setif has the lowest value (11.6%); natural ventilation can be considered as an effective passive strategy.

II.4.1.3 Annual direct evaporative cooling potential

The annual evaporative cooling potential (%) for the different locations was calculated, as shown in Figure II-10(b). It represents the percentage of time during the year during which the comfort limit is extended above the upper limits of comfort by using direct evaporative cooling. Evaporative cooling can extend the comfort period by ~47.5% in Tamanrasset (in Guezzam). This value shows that evaporative cooling is very effective in the Tamanrasset Province. In contrast, evaporative cooling is the least effective strategy in Algiers (3%).

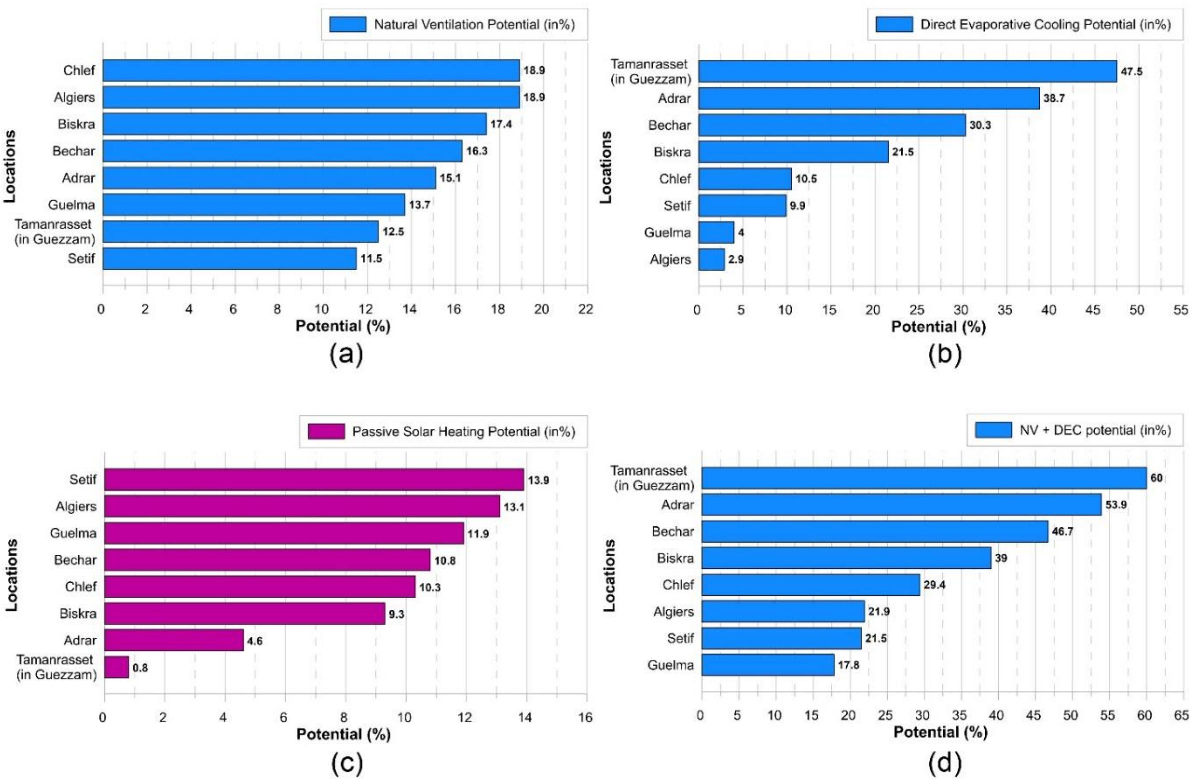


Figure II-10: *Annual passive design potential (%) for the eight selected locations. (a) natural ventilation, (b) direct evaporative cooling, (c) passive solar heating, and (d) natural ventilation and direct evaporative cooling*

II.4.1.4 Annual passive solar heating potential

The annual passive solar heating potential (%) for the different locations is shown in Figure II-10(c). It represents the percentage of time during the year during which the comfort is extended below the lower comfort threshold through direct solar radiation. Passive solar heating extends the comfort period by ~14% in Chlef, which has the highest potential compared with the other locations. The lowest passive solar heating potential is obtained in Tamanrasset (1%).

II.4.2. Validation of the simulation model calibration

The MBE, CV(RMSE) and R^2 were used for different comparisons between measured and simulated data. Table II-6 outlines the MBE, CV(RMSE) and R^2 calibration results. The model was validated using Table II-6.

Figure II-11 shows the comparison between the measured and simulated indoor temperatures for the monitored periods. In the winter period, the MBE is -2% and the CV(RMSE) is 5.1%, while the admitted limit is ±10% and ±30%, respectively. In the summer period, the MBE is -1.5% and the CV(RMSE) is 4.9%, while the admitted limit is ±10% and ±30%, respectively.

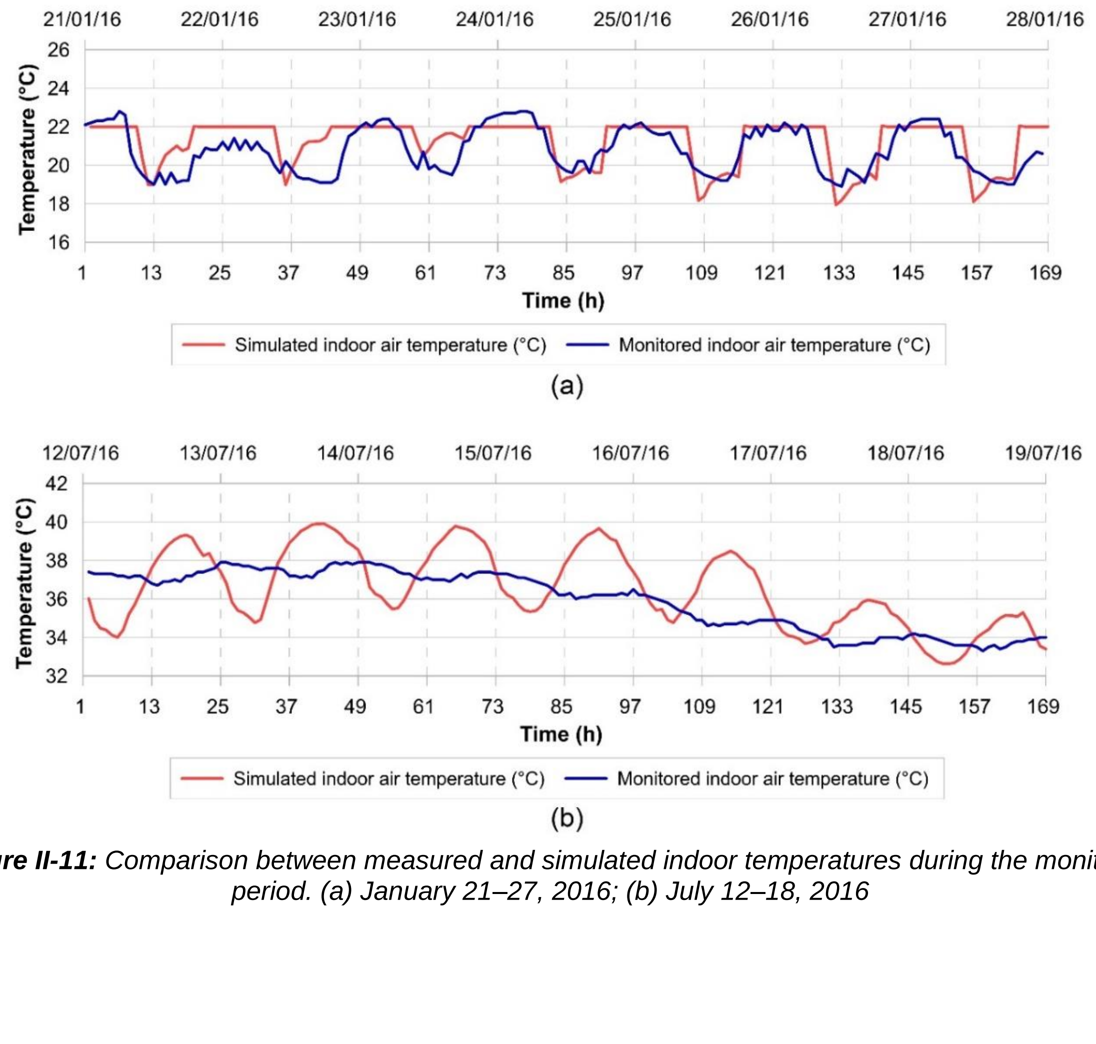


Figure II-11: *Comparison between measured and simulated indoor temperatures during the monitored period. (a) January 21–27, 2016; (b) July 12–18, 2016*

The model MBE and CV(RMSE) values for the hourly data are within ASHRAE-recommended hourly values. The simulation model was calibrated using hourly data.

Figure II-12 shows the comparison between the measured and simulated energy consumptions during the monitored periods. For the electricity consumption, the MBE is -0.6% and the CV(RMSE) is 7.8%, while the admitted limit is ±5% and ±15%, respectively. For the gas consumption, the MBE is 0.4% and the CV(RMSE) is 6.6%, while the admitted limit is ±5% and ±15%, respectively. The model MBE and CV(RMSE) values for the monthly data are within ASHRAE-recommended hourly values. The simulation model was calibrated using monthly data, which validate it.

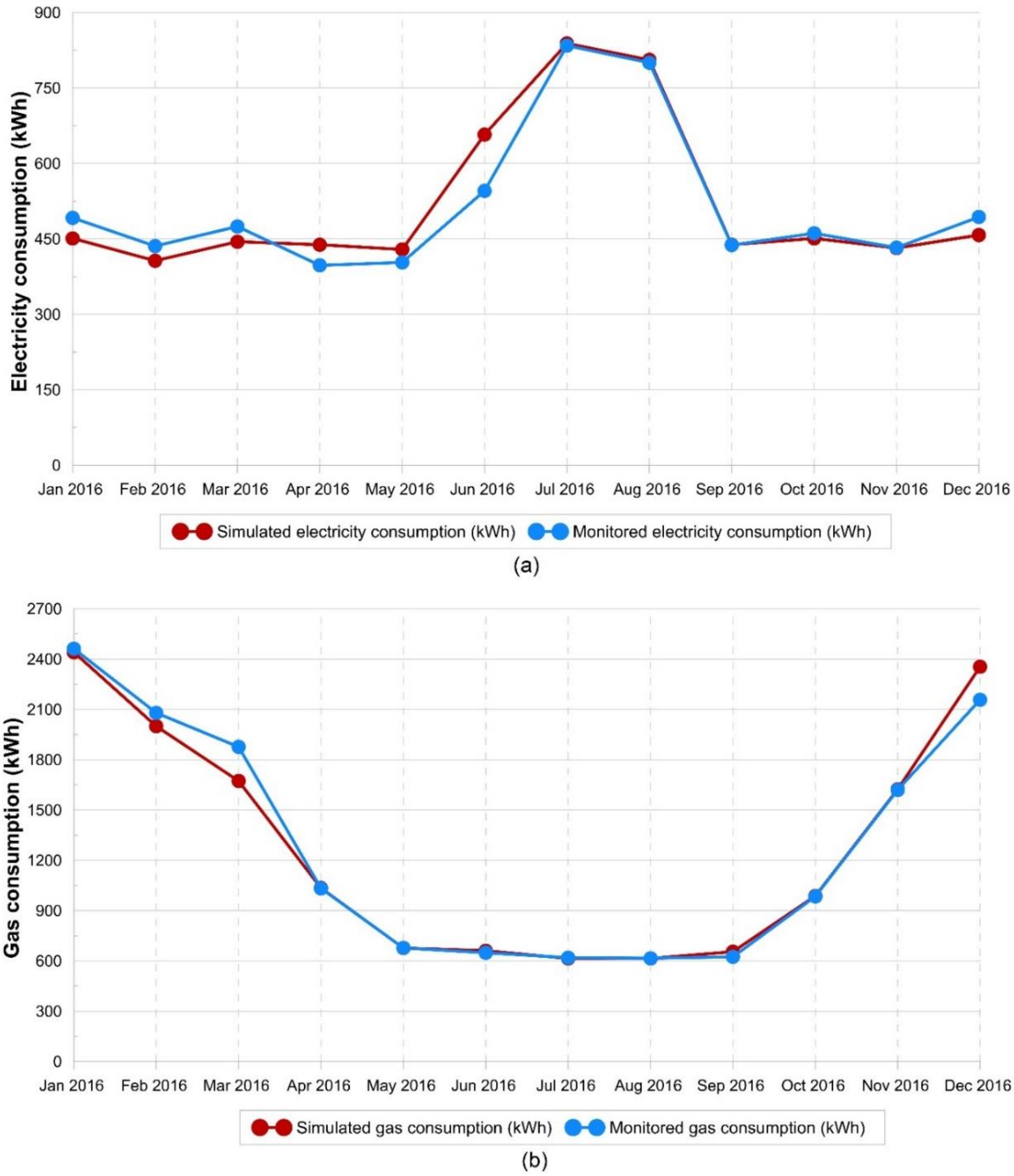


Figure II-12: *Monthly comparisons of the monitored and simulated energy and consumptions for 2016. (a) electric consumption, (b) gas consumption*

Table II-6: *Summary of the validation of the calibration criteria of the simulation model*

Validation Criteria	Winter Indoor Air Temp.	Summer Indoor Air Temp.	Monthly Electricity Use	Monthly Gas Use
MBE (%)	−2	−1.52	−0.68	0.4
CV-RMSE (%)	5.12	4.97	7.83	6.67
R^2	0.75	0.63	0.92	0.98

MBE: mean bias error, CV (RMSE) root-mean-square error and R^2 the coefficient of determination

Figure II-13 shows the regression analysis between the measured and simulated monthly and hourly data during the monitored periods. For the electricity consumption (see Figure II-13(a)) and gas use (see Figure II-13(b)) R^2 values are 0.92 and 0.98 respectively. For the indoor temperatures R^2 is 0.75 for the winter period (see Figure II-13(c)) and it is 0.63 for the summer period (see Figure II-13(d)). So, the correlation between the monitored and simulated data are strong for monthly electricity and gas use, while there is a mean correlation for summer and winter indoor air temperature. The simulation model was calibrated using monthly and hourly data.

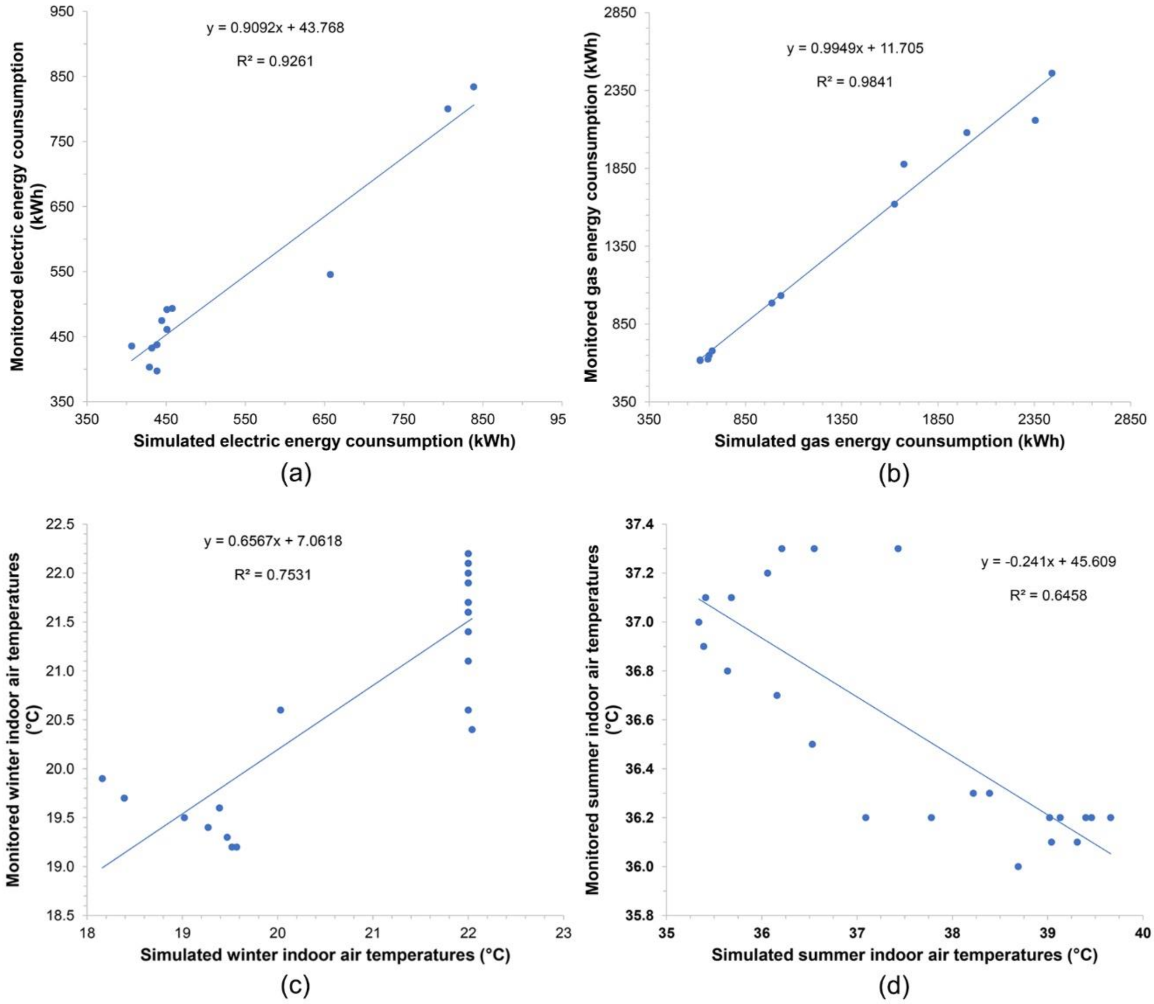


Figure II-13: *linear regression between monitored and simulated data*

II.4.3. Energy loads for the eight selected locations

II.4.3.1 Annual cumulative comfort potential and simulated discomfort hours

The annual cumulative comfort potential represents the percentage of time during the year during which comfort is achieved by using passive strategies (Natural Ventilation (NV), Direct Evaporative Cooling (DEC), and Passive Solar Heating (PSH)). The annual simulated discomfort hours indicate the percentage of time during the year during which passive or active strategies are necessary to achieve comfort. Figure II-14 shows the comparison between the annual cumulative comfort potential (estimated potential) and annual simulated discomfort hours for the eight selected locations.

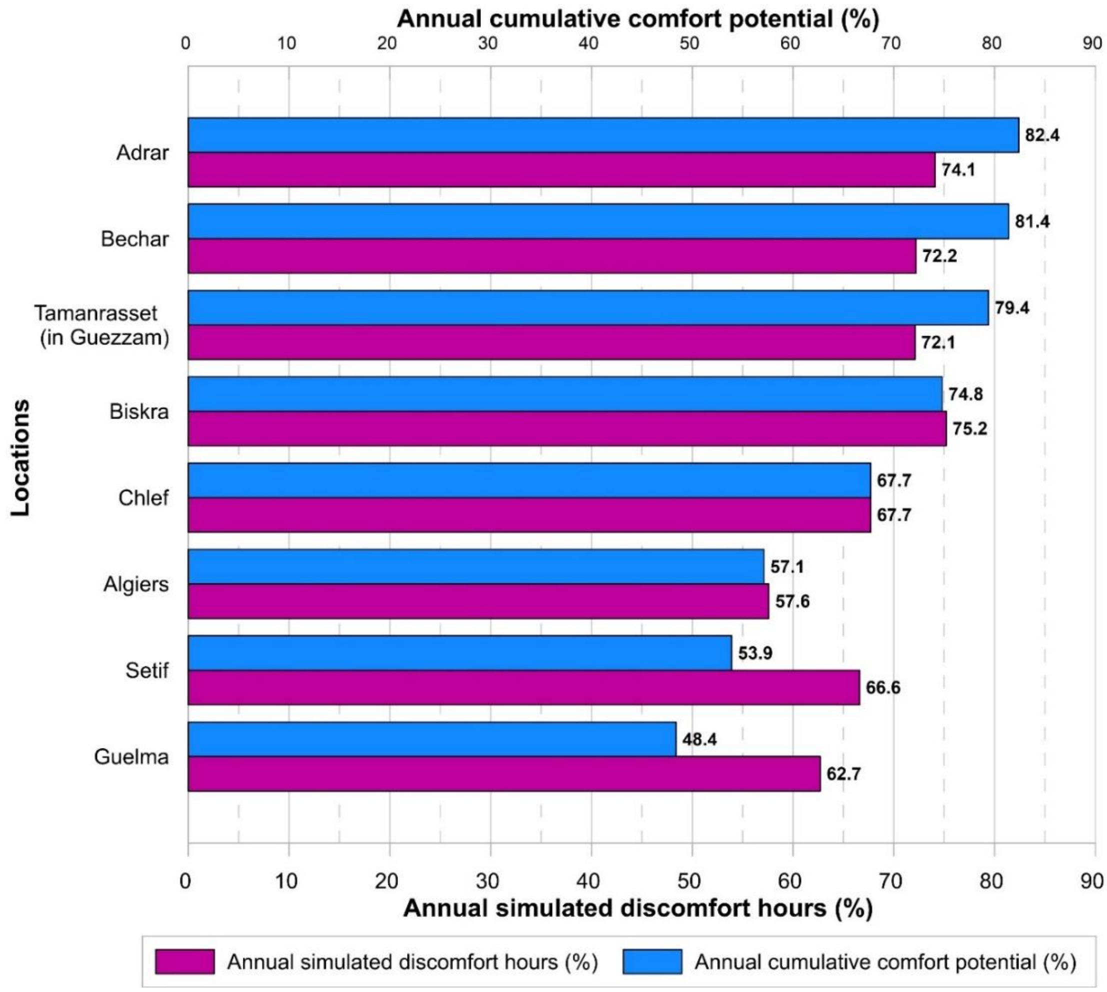


Figure II-14: *Comparison between the annual cumulative comfort potential (%) and annual simulated discomfort hours (%)*

The combination of the bioclimatic strategies in Adrar has a comfort potential of 82%. This is the highest value compared with the other locations. However, the simulation result lowers the potential comfort estimation coverage to ~75%. In fact, the simulation results indicate that Adrar, Bechar, Tamanrasset, and Biskra have a potential of 75% to passively achieve thermal comfort. On the other hand, nearly 48.5% of the total annual hours are potentially comfortable if all passive strategies would be combined in Guelma. This is the lowest value compared with the other locations. However, the simulation result increases the potential comfort estimation coverage to ~63%. The comfort potential calculation and simulation analysis for Chlef and Algiers yield almost identical results.

Figure II-15 shows the percentage of the annual simulated discomfort hours in winter and summer. Based on our simulation, Guelma, Setif, and Algiers have common summer discomfort hours ranging between 7% and 10%, while the winter discomfort hours range between 51% and 60%. Chlef, Bechar, Biskra, and Adrar have summer discomfort hours ranging between 25% and 49%, while the winter discomfort hours range between 26% and 43%. Surprisingly, Chlef, which is located in the north of Algeria (Zone B'), has the same discomfort hours percentage as Zone D in the south of Algeria (desert). The percentage of summer discomfort hours in Tamanrasset is above 67%, while that of the winter discomfort hours is below 5%. This result can be explained by the solar radiation parameter, which is very high in this zone. It can exceed 7000 Wh/m², which was confirmed by Yaiche et al. (Yaiche et al., 2014).

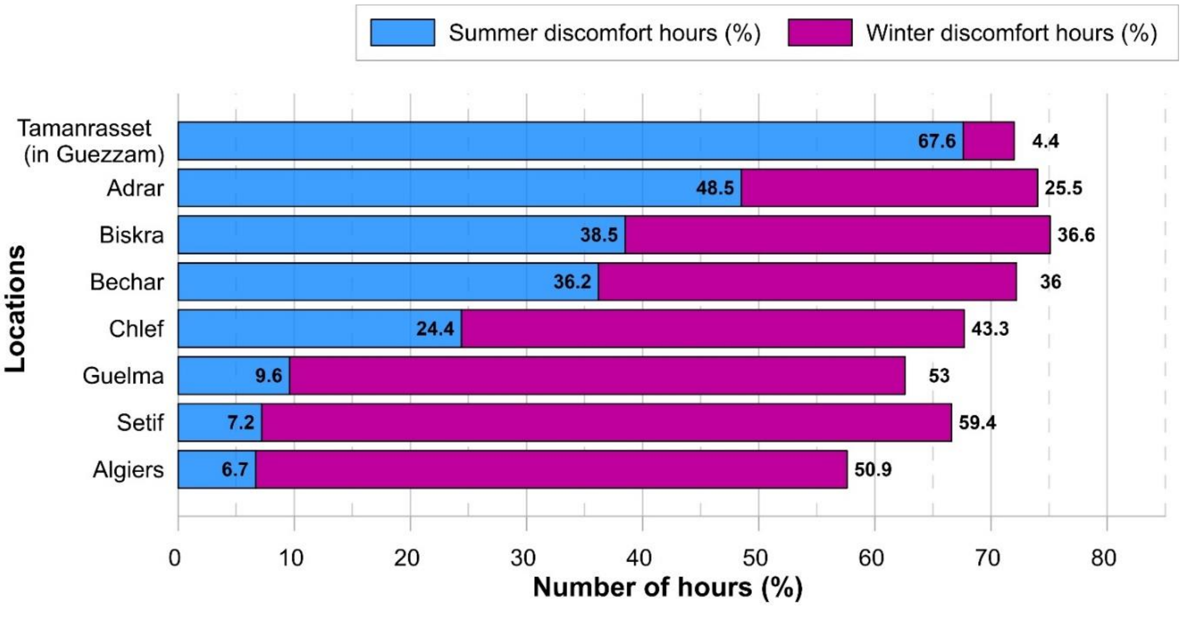


Figure II-15: *Percentage of the annual simulated discomfort hours in winter and summer based on the ASHRAE-55 adaptive comfort model (90% limit)*

To determine the correlation between the psychrometric-based and simulation-based analysis results, Figure II-16 shows the results of the linear regression analysis between the annual cumulative comfort potential and annual simulated discomfort hours. The regression analysis between the annual cumulative comfort potential and annual simulated discomfort hours indicates a strong correlation, with a Pearson correlation coefficient (R) of 0.8 and regression coefficient (R^2) of 0.6 (Table II-7).

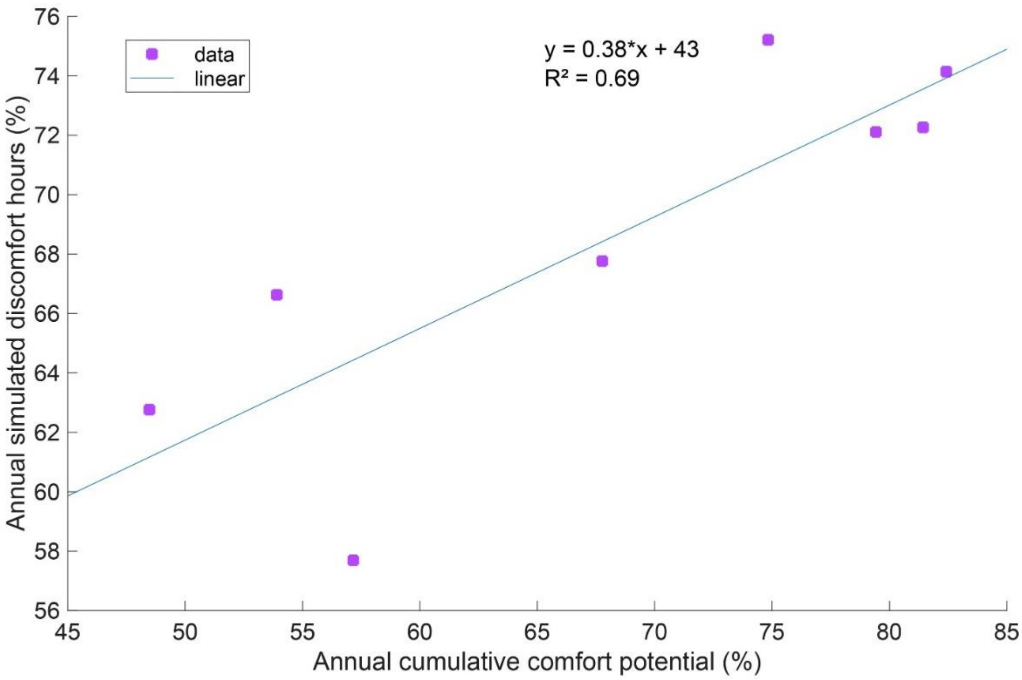


Figure II-16: *Linear regression of the annual cumulative comfort potential (%) and annual simulated discomfort hours (%)*

II.4.3.2 Annual passive cooling potential and annual cooling load

The annual passive cooling potential represents the addition of the annual natural ventilation and annual evaporative cooling potential. This value indicates the period of time during which cooling is required and thus the cooling energy consumption. Figure II-17 shows the comparison between the annual passive cooling potential (estimated cooling potential based on the psychrometric chart) and annual cooling load (simulated cooling load) for the eight selected locations. Tamanrasset has the highest annual passive cooling potential (60%) as well as the highest annual cooling energy consumption (163.9 kWh/m^2) compared with the other locations. Guelma, Setif, and Algiers have the lowest passive cooling potentials (between 17.8% and 21.9%) as well as the lowest cooling loads (6.1 kWh/m^2 for Setif, 9.9 kWh/m^2 for Algiers, and 13.3 kWh/m^2 for Guelma).

Figure II-18 shows the results of the linear regression analysis between the annual passive cooling potential and annual cooling load for the eight selected locations. The regression analysis between the annual cooling potential and annual cooling load indicates a strong correlation, with a Pearson correlation coefficient (R) of 0.96 and regression coefficient (R^2) of 0.9 (Table II-7).

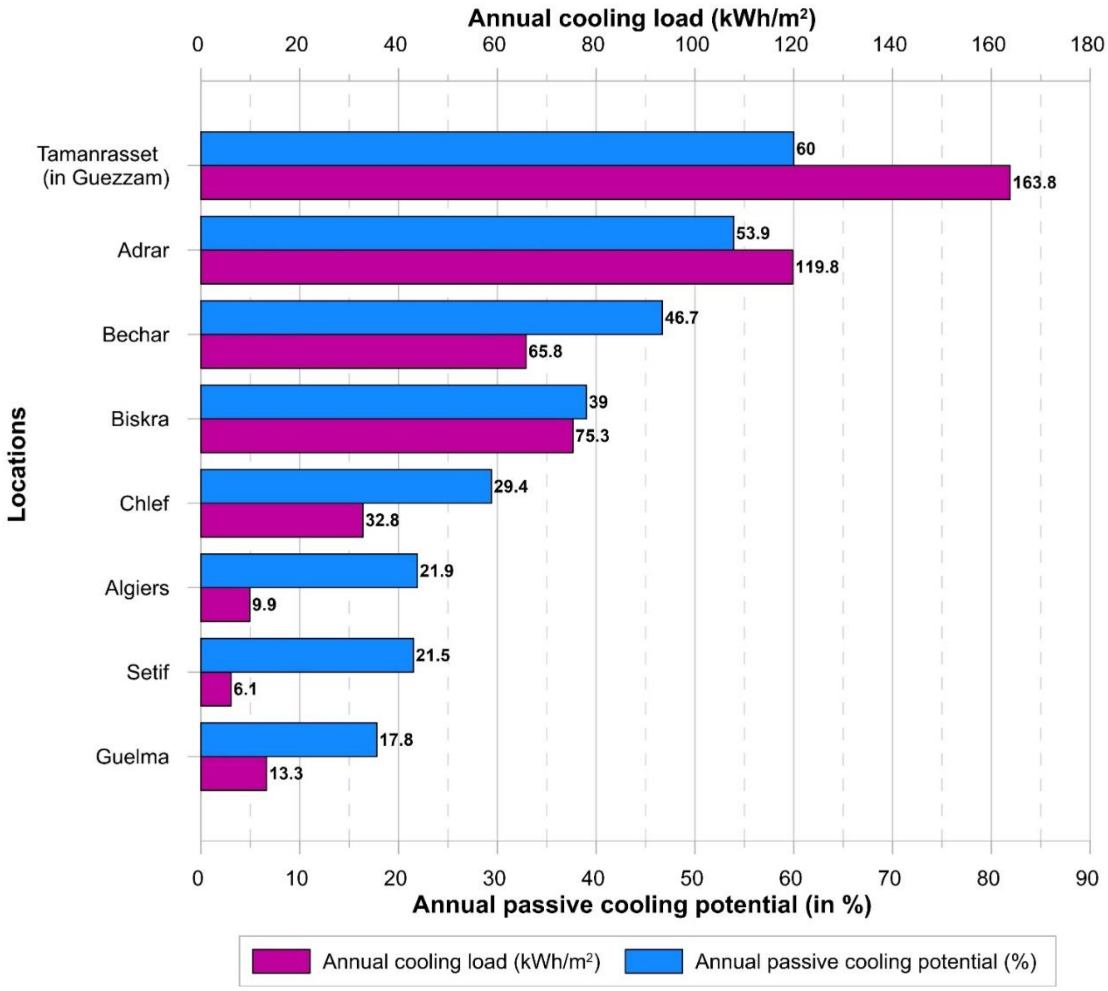


Figure II-17: *Comparison between the annual passive cooling potential (%) and annual cooling load (kWh/m2)*

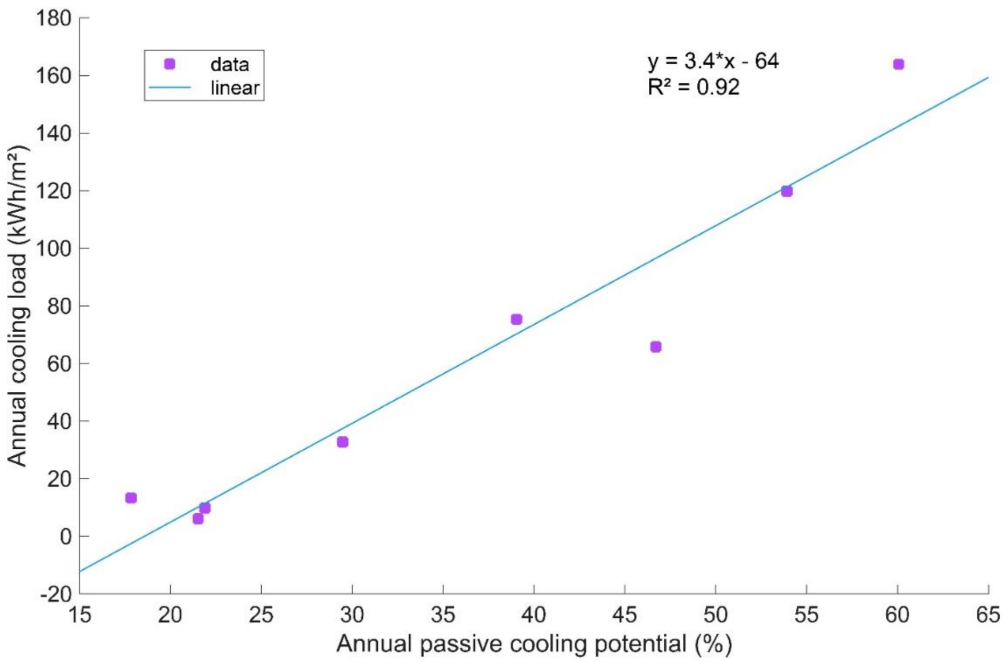


Figure II-18: *Linear regression of the annual passive cooling potential (%) and annual cooling load (kWh/m2)*

II.4.3.3 Annual passive solar heating potential and annual heating load

The passive solar heating potential indicates the period of time during which heating is required and thus the heating energy consumption. Figure II-19 shows the comparison between the annual passive heating potential (estimated heating potential) and annual heating load (simulated heating load) for the eight selected locations. The passive solar heating potential of all locations is low and does not exceed 14%. Setif has the highest annual passive heating potential (13.9%) as well as the highest annual heating energy consumption (180.8 kWh/m^2) compared with the other locations. Tamanrasset has the lowest passive heating potential (0.8%) as well as the lowest heating load (5.1 kWh/m^2). Figure II-20 shows the results of the linear regression analysis between the annual passive heating potential and annual heating load for the eight selected locations. The regression analysis between the annual heating potential and annual heating load indicates a strong correlation, with a Pearson correlation coefficient (R) of 0.88 and regression coefficient (R^2) of 0.7 (Table II-7).

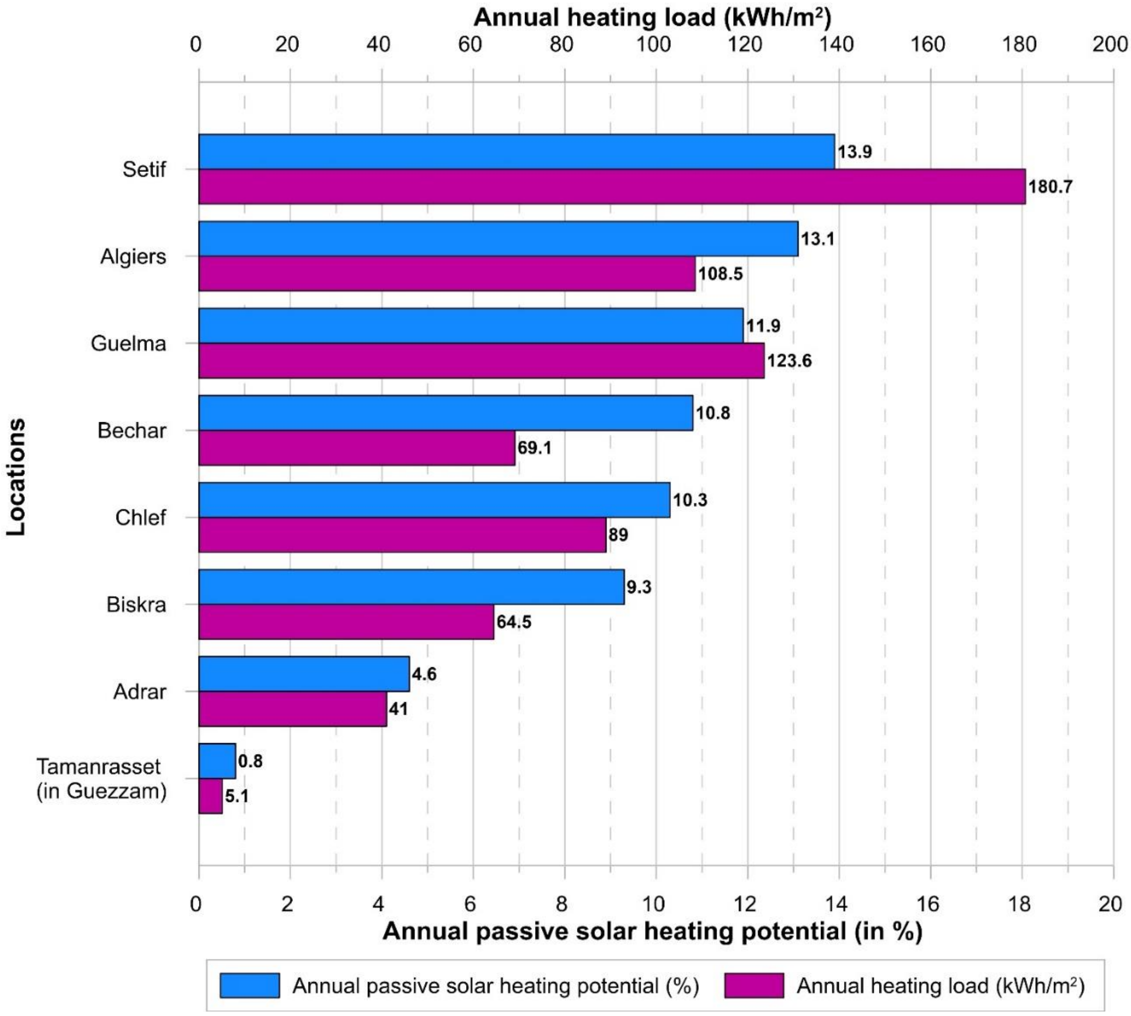


Figure II-19: *Comparison between the annual passive heating potential (%) and annual heating load (kWh/m2)*

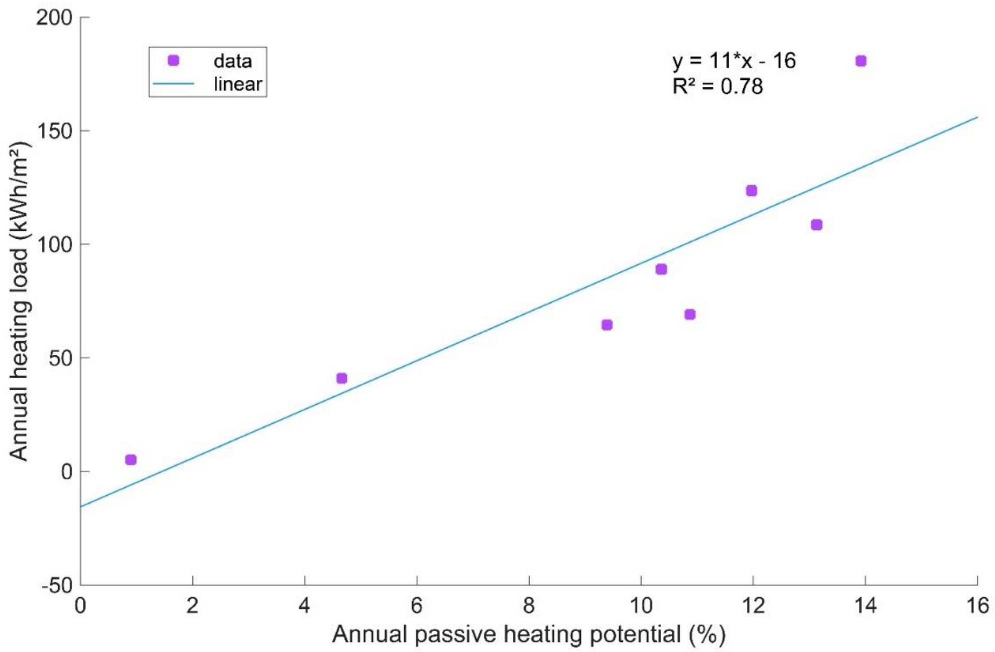


Figure II-20: *Linear regression of the annual passive heating potential (%) and annual heating load (kWh/m2)*

Table II-7:*Summary of the validation of the linear regression between the annual bioclimatic potential and annual energy loads*

Validation criteria	R **(Pearson correlation coefficient)**	R^2 **(Regression coefficient)**
Passive cooling potential / cooling load	0.9	0.9
Passive heating potential / heating load	0.8	0.7
Cumulative comfort potential / simulated discomfort hours	0.8	0.6

II.5. Discussion:

II.5.1. Summary of the main findings

In this study, we performed a climatic analysis of eight Algerian cities to assess the effectiveness of bioclimatic design strategies. We applied a mixed approach that combines psychometric chart analysis and building performance simulation analysis. By using recent and high-quality weather datasets, we quantified the effectiveness of bioclimatic design strategies based on an accurate and modern approach using a recent adaptive comfort model (ASHARE 55-2017). Our study findings indicate that psychrometric chart-based bioclimatic potential analysis for investigated locations does not generally correspond with the simulation-based energy and comfort analysis (see Table II-8). For example, the estimation of the discomfort hours in Algiers is almost identical, (57% and 58%), when calculated using both approaches. This result agrees with the results of Ali-Toudert et al. (Ali-Toudert and Weidhaus, 2017a) who evaluated the A and D climate zones. The cumulative comfort potential analysis results (using psychrometric charts and building performance simulations) for almost all cities are almost identical, except for Setif and Guelma for which the psychrometric charts indicate a significant underestimation of the discomfort hours compared with the simulation results (see Figure II-14).

To summarize the major simulation-based findings, we list the most important and tangible outcomes of our bioclimatic analysis of the thermal comfort (see Table II-8):

- Based on our simulation, Guelma, Setif, and Algiers have common summer discomfort hours ranging between 7% and 10%, while the winter discomfort hours range between 51% and 60%.
- Chlef, Bechar, Biskra, and Adrar have summer discomfort hours ranging between 25% and 49%, while the winter discomfort hours range between 26% and 43%. Surprisingly, Chlef, which is located in the north of Algeria (Zone B'), has the same discomfort hours percentage as Zone D in the south of Algeria (desert).
- The percentage of summer discomfort hours in Tamanrasset is above 67%, while that of the winter discomfort hours is below 5%. This result can be explained by the solar radiation parameter, which is very high in this zone. It can exceed 7000 Wh/m², which was confirmed by Yaiche et al. (Yaiche et al., 2014).

Our bioclimatic analysis results regarding the passive cooling potential are listed below:

- The bioclimatic potential analysis overestimates the cooling needs of most locations, except for Adrar and Tamanrasset.
- Regarding the passive cooling, our annual cooling load calculation indicates that Adrar and Tamanrasset are the locations with the highest amounts, with cooling requirements as reported by Ghedamsi et al. (2016) (Ghedamsi et al., 2016). Tamanrasset is followed by Bechar, Biskra, and Chlef.
- The locations with the least cooling requirements are grouped and include Algiers, Setif, and Guelma because they more easily receive humid winds from the sea (see Figure II-17 and Table II-8) (Sahabi Abed and Matzarakis, 2017).

The direct evaporative cooling represents the most effective strategy in the south of Algeria (Zones D and D') because the climate in the south is hot and dry (warm climate with very high temperatures during summer). The evaporative cooling potential exceeds 50%. In addition, the direct evaporative cooling potential of the climate increases as the location geographically changes from the north towards the south of Algeria. The evaporative cooling potential is very low (<4%) in the north (Zones A and B) because these zones are exposed to the sea. However, these zones have the highest natural ventilation potential.

With respect to the passive heating potential, there is a significant difference between the potential estimation and calculation of the heating needs for Setif and Guelma. Our results indicate that the difference of the bioclimatic potential between stations in the same zone is significant although some locations are in the same climate zone (see Table II-8). Our bioclimatic analysis results regarding the passive heating potential are listed below:

- The annual heating load calculation indicates that Setif has the highest heating load requirements due to its geographical location and altitude.
- Setif is followed by Algiers, Guelma, and Chlef, which form a group with similar heating load requirements.
- Bechar, Biskra, and Adrar benefit slightly less from passive heating.
- Tamanrasset is an extreme, where passive heating is the least effective because Tamanrasset is influenced by solar irradiation (see Figure II-19 and Table II-8).
- The heating loads in the south represent 30% of the cooling loads. In contrast, the cooling loads in the north represent 11% of the heating loads, which agrees with the results obtained by Ghedamsi et al. (Ghedamsi et al., 2016), Kharchi et al. (Kharchi et al., 2012), and Belkacem et al. (Belkacem et al., 2017).

Table II-8: *Summary of the findings*

Climate Zone		A	B	B’	C	D	D	D	D’
Representative location		**Algiers**	**Guelma**	**Chlef**	**Setif**	**Biskra**	**Bechar**	**Tamanrasset (in Guezzam)**	**Adrar**
Estimation	Annual passive cooling potential (%)	21.9	17.8	29.4	21.5	39	46.7	60	53.9
	Annual passive solar heating potential (%)	13.1	11.9	10.3	13.9	9.3	10.8	0.8	4.6
	Annual cumulative comfort potential (%)	57.1	48.4	67.7	53.9	74.8	81.4	79.4	82.4
Simulation	Annual cooling load (kWh/m²)	9.9	13.3	32.8	6.1	75.3	65.8	163.8	119.8
	Annual heating load (kWh/m²)	108.5	123.6	89	180.7	64.5	69.1	5.1	41
	Annual simulated discomfort hours (%)	57.6	62.7	67.7	66.6	75.2	72.2	72.1	74.1

II.5.2. Strength and limitations of the study

The strength of the study relates to the use of a recent approach that combines simple chart-based bioclimatic analysis with simulation based advanced building performance analysis. The study uses high-quality data based on a recently compiled climatic dataset for Algerian weather stations. We believe that this recent approach, which was already used by Kumar et al. and Kishore et al. (Kishore and Rekha, 2018; Kumar et al., 2016) and resembles similar approaches of Attia et al. (Attia et al., 2019), Pajek et al. (Pajek and Košir, 2018), and Ali-Toudert et al. (Ali-Toudert and Weidhaus, 2017a), benefits from the abundance of weather station data, advancements of simulation approaches and computational power, and advancement of the definition of adaptive comfort standards for hot climates. Our study is the first study that provides an accurate estimation of the bioclimatic potential for the whole country of Algeria in contrast to previous research (Ali-Toudert et al. 2017) that focused on specific climate zones of Algeria.

The quantification of the effectiveness of the bioclimatic strategies based on recent weather provided insights into the bioclimatic design potential for the six climatic zones of Algeria. Based on the use of the calibrated simulation model, reliable results could be obtained regarding the thermal building performance and associated consequences of active heating and cooling system requirements.

On the other hand, this study has several limitations. Our reference case does not represent different housing typologies and is not adapted to the climate of each climatic zone. In addition, the calibration period of the simulation model is only one week for indoor temperatures and one year for electricity readings using a manual trial-and-error-based calibration approach. The study could have benefited from a longer monitoring period (three to five years) and an automated calibration using annual hourly data. However, we conducted our study using the best available data.

II.5.3. Implications for the practice

The study results help to identify which bioclimatic design strategy is the most effective in each climate zone. We believe that architects and building engineers can apply our findings to their design concepts in early design stages to improve the indoor thermal comfort using passive design solutions. The presented tables and figures allow designers to apply adequate bioclimatic design strategies and evaluate the need for active systems in each climate zone using an adaptive comfort model that is suitable for the hot climate of Algeria. The National Building Efficiency Standard of Algeria must be updated. Therefore, we believe that the engagement with code officials to adopt and implement our findings and recommendations will anchor the impact of our study in the professional practice of building energy efficiency.

II.6. Conclusion:

The low energy building design is influenced by the understanding of the local climate and the application of corresponding bioclimatic design principles and strategies. This chapter focused to analyze the bioclimatic potential of the Algerian climate zones to provide accurate bioclimatic design recommendations. The bioclimatic potential of the six climate zones, including eight cities of Algeria, was calculated and compared using psychrometric charts and building performance simulations. A monitoring-based simulation model was created and calibrated for a reference case including eight Algerian cities. Despite the strong correlation between both bioclimatic potential analysis approaches (psychrometric chart-based and simulation-based), the results indicate a contradiction of bioclimatic potential estimations in several heating-dominated cities such as Setif, Guelma, and cooling dominated cities such as Tamanrasset. Therefore, our study findings indicate the misleading nature of psychrometric-based bioclimatic potential analysis in all cooling-dominated cities and all heating dominated cities. Overall, Algerian cities can be classified into two major categories including cooling- or heating-dominated cities. The percentage of average discomfort hours in Algerian households across all climatic zones is 60%. Evaporative cooling is the most effective bioclimatic design strategy in Algeria, accounting for 60% of the hours annually in cooling-dominated cities due to their arid nature. Passive solar heating is the most effective bioclimatic design strategy in Algeria, accounting for 40% of the hours annually in heating-dominated cities due to their high altitudes. The following design recommendations characterize the bioclimatic conditions of each investigated city and provide guidance regarding the most effective passive design strategies based on Tables II-1 and Tables II-5:

1. Algiers has a subtropical Mediterranean climate with dry summers. Natural ventilation and direct evaporative cooling are the most effective during summer and passive solar heating is the most effective during winter.
2. Guelma has a Mediterranean climate and is moderately rainy with colder and longer winters than those on the coast with hot and less humid summers. Natural ventilation and passive solar heating are effective in summer and winter, respectively.
3. Chlef has a subhumid and Mediterranean climate with cold winters and hot summers. The cooling period is long, accounting for 56% of the annual hours. Natural ventilation is the most effective during summer, followed by direct evaporative cooling. In winter, passive solar heating is the most effective strategy.

4. Setif has a continental climate with hot dry summers and very cold dry winters. In winter, passive solar heating is the most effective. In summer, natural ventilation and direct evaporative cooling are the most effective.

5. Biskra has an arid climate with the high temperature disparity between day and night as well as between summer and winter. Direct evaporative cooling is the most effective strategy in the summer, followed by natural ventilation. However, passive solar heating is the most effective in the winter. The duration of the heating period is equal to that of the cooling period.

6. Bechar has an arid climate with a high temperature disparity between day and night as well as between summer and winter. Direct evaporative cooling is the most effective strategy in summer, followed by natural ventilation. However, passive solar heating is needed in winter. The duration of the heating period is the same as that of the cooling period.

7. Adrar has an arid climate with dry and very hot summers and very cold winters. Direct evaporative cooling is the most effective strategy in summer, followed by natural ventilation. However, passive solar heating is needed in winter. The heating period accounts for 52% of the annual hours.

8. Tamanrasset has very dry or hyper arid and sunny climate all year round. Direct evaporative cooling is the most effective strategy in summer and passive solar heating is unnecessary in winter.

Our study confirms, the need for a new bioclimatic comfort map for Algeria with more representative weather stations. Our study confirms also that the current climatic classification of Algeria is obsolete. This issue represents the aim of the next chapter (Chapter 3).

III. Chapter 3: Spatial distribution maps for energy demand and thermal comfort estimation in Algeria

Climatic spatial maps are essential for understanding the thermal conditions of cities and estimate their cooling and heating energy needs. Climate maps allow building designers and city planners to get adequately informed without accessing, analyzing or interpreting dense textual information. In this study, a representative residential benchmark model was simulated in seventy-four cities of Algeria. The simulation results were interpolated using geographic information systems to generate six high-resolution maps that spatially estimate and visualize the discomfort hours and cooling/heating energy needs. The unique methodology relies on a reliable weather dataset (2004–2018) and combines the power of building performance simulation and geographic information systems. The results of these analyses provide easy to understand and web-based atlas that can be used to explore regional and local climate and quantify the discomfort hours, the heating/cooling energy needs and energy use intensity. The spatial maps are not a static product, but rather data-rich content, which can be expanded to include the most important cities of Algeria. The capabilities of the tool allow architects and urban planners to understand the climate better and propose practical design guidance.

III.1. Introduction:

Climatic zoning and climatic spatial maps are indispensable for sustainable city planning and design. They can help identify climate patterns, climatic classifications, thermal comfort boundaries and climatic threshold temperatures for cooling and heating degree day (Attia et al., 2019; Roshan et al., 2017b, 2017a; Semahi et al., 2019a). In the last forty years, climactic zoning became essential in building energy efficiency programs (Walsh et al., 2017). Historically, climatic zoning and climatic analysis were used in the field of urban planning and building design by simply analyzing weather and climatic data in association with bioclimatic charts and spatial maps (Attia, 2018b; Roshan et al., 2019b). The work of several early researchers, in the built environment domain, aimed to visualize climatic data worldwide using simple statistical methods (Barenbrug, 1965; DeKay and Brown, 2013; Givoni, 1992, 1969; Olgyay, 2015). Consequently, more than 80 study in 60 countries in the world are investigated the climatic classification and zoning for bioclimatic and energy efficient buildings design.

The classical research methodology used in climatic zoning studies is based on processing weather and climate variables to visualize and compare data in relation to specific thermal comfort thresholds. Clustering methods or other statistical analysis techniques are used to support the identification of climatic zones and suggesting passive urban and building design recommendations to achieve maximum thermal comfort (DeKay and Brown, 2013; Givoni, 1992; Roshan et al., 2019a). The quantification and classification of climate are based on large data sets of measured data without the use of building simulation tools and supporting thermal regulations and design guides with statistics-based design guidance.

III.1.1. State of the Art of Climatic Zoning

In the recent ten years, researchers profited from the advancement in the building performance simulation (BPS) and the geographic information systems (GIS) domains to make climatic zoning research more accurate. The progress of computational programs allowed researchers to define new climatic zoning analysis and maps incorporating typical reference buildings resulting in refined climatic maps and zoning classification. This includes the works of Attia et al. (Attia et al., 2019) and Praene et al. (Praene et al., 2019) in Madagascar, Verichev et al. (Verichev and Carpio, 2018) in Chile, Groppi et al. (Groppi et al., 2018) and Moghadam et al. (Moghadam et al., 2018) in Italy, Borah et al. (Borah et al., 2015) and Singh et al. (Singh et al., 2015) in India, Roshan et al. (Roshan et al., 2019b) in Iran, Pajek et al. (Pajek and Košir, 2018) in Slovenia, Walsh et al. (Walsh et al., 2018) in

Nicaragua and Pajek et al. (Pajek et al., 2019) in Europe. Thus, the proliferation of climatic analysis based on GIS and/or BPS techniques reflects a structural tendency. There is an imminent transition in the scientific community where GIS and BPS techniques are combined to become fundamental methods for future climatic analyses (Walsh et al., 2017).

The relation between climatic zoning and sustainable city design is significant and is translated into planning tools and maps among several countries. In some states, typical values of weather data for city planning and building energy load calculations are established for each climatic zone. In contrast, the energy use intensity should respect specific limit for each zone (Singh et al., 2015). In other countries, there are particular performance targets for each climatic zone (Poggi et al., 2017). The importance of climatic zoning is high in countries with a weak regulation landscape and energy efficiency implementation infrastructure. In most of the cases, there is no information available on the relationship between zoning and urban design guidelines or building energy performance (Walsh et al., 2017).

III.1.2. Studies on Climatic Zoning in Algeria

Like many other countries, Algeria is looking forward to updating its existing climatic zoning maps and revises its energy efficiency programs for cities. Algeria is increasingly urbanized, and its future will be shaped in dense energy-dependent cities. Already, some existing studies investigated the climatic zoning in Algeria, including the work of CNERIB (CNERIB, 1997a, 1997b), Mesri et al. (Mesri et al., 2013), Ghedamsi et al. (Ghedamsi et al., 2016), Beck et al. (Beck et al., 2018) and Mokhtara et al. (Mokhtara et al., 2019). However, none of those studies combined the weather data analysis with GIS and BPS, as shown in Table 1. Nothing found in literature on climatic zoning in Algeria is up-to-date except in the light of GIS, BPS and this current work.

Therefore, our study aims to develop new spatial distribution maps for energy demand and thermal comfort estimation in Algeria. This work combines the powers of BPS and GIS tools with a recent weather files dataset and analyses the climate of Algeria, taking into account the impact of typical and representative housing archetype. Based on a current dataset (2003–2017) of seventy-four weather stations and a calibrated residential benchmark model, the study presents new zoning maps based on the thermal energy demand and indoor-discomfort hours of the current social residential building archetype in Algerian territory.

The results provide a higher resolution climatic classification of the Algeria with nine climate zones. Each climate zone is associated with quantified calculation of the discomfort hours and cooling and heating energy needs. The study findings are useful for architects, building engineers, city planners and decision-makers in a critical moment, where the Algerian government is looking forward to revising the existing Algerian code. There is a need for climatic spatial maps of cities that embed careful analysis, acceptable forecasting and planning abilities (Attia et al., 2019). This study brings researchers one-step closer to realize a new and more accurate climatic zoning to help navigate the sizeable Algerian terrain of climate uncertainty across a landscape of potential. Climate maps allow building designers and city planners to get adequately informed without accessing, analyzing or interpreting dense textual information (Cicelsky and Meir, 2014; Mokhtara et al., 2019). The outcomes are essential to facilitate the management of energy efficiency and building design across Algerian cities. They can help to minimize the uncertainty in the estimation of discomfort hours and energy demand in residential buildings. Moreover, an extensive weather dataset (2003–2017) is used, which is not common to see a work dealing with climatic zoning and comfort optimization (Gaspari et al., 2018; Missoum et al., 2014; Poggi et al., 2017; Stavrakakis et al., 2012a). This study contributes to research efforts that analyses and visualize climatic data for sustainable city development (Walsh et al., 2018, 2017).

Table III-1: *Comparative analysis of Algeria’s climate classifications found in the literature*

	Köppen (Beck et al., 2018)	**CNERIB** (CNERIB, 1997a, 1997b)	**Mesri et al.** (Mesri et al., 2013)	**Ghedamsi et al.** (Ghedamsi et al., 2016)
No. of zones	5 climate zones	6 climate zones	3 climate zones	7 climate zones
Classification parameters	- Vegetation - Air temperature - Rainfall	- Daily mean outdoor air temperature	- Sunshine duration - Temperature - Water vapor pressure - Evaporation - Relative humidity - Rainfall	- Daily mean outdoor air temperature
No. of Weather stations	Several stations worldwide	31 stations	52 stations	48 stations
Classification Approach	Cluster analysis	Heating and cooling degree-days	Clustering method	Heating and cooling degree-days

III.2. Methodology:

The research methodology resulted in a calculation and visualization approach for thermal energy demand and indoor-discomfort hours of multifamily social residential buildings in Algeria. The used calculation method is based on a dynamic building performance simulation approach applied to the calibrated model of multifamily social residential buildings. Figure III-1 presents the detailed conceptual framework of the study describing the steps of the research methodology. The research methodology of this study is divided into four significant steps. Each step is described in detail in the following sections.

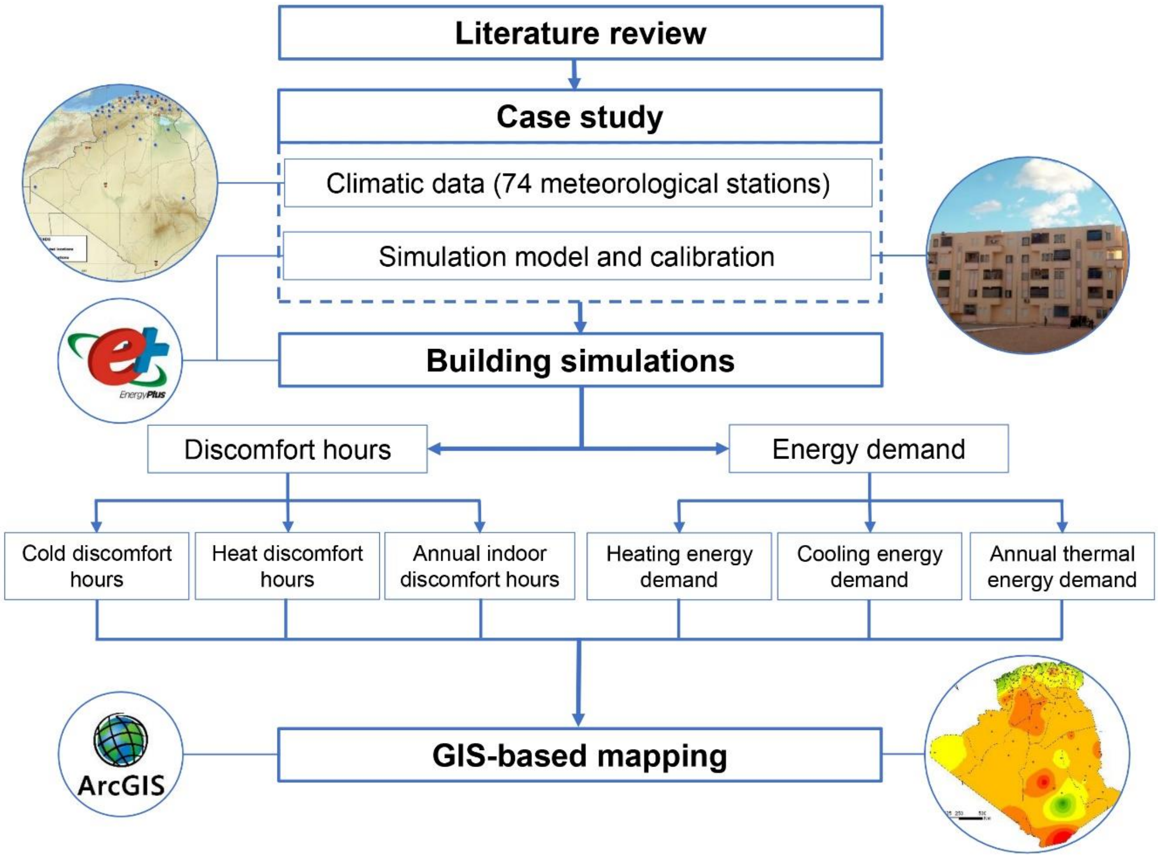


Figure III-1: *Study conceptual framework*

III.2.1. Climate Data and Reference Model Creation

The second step of the methodology was to select a representative dwelling archetype. This step involved a selection of the representative dwelling archetype based on a simple characterization of the Algerian housing sector, identification and acquisition of available weather stations and weather files, monitoring of a representative dwelling, and finally, the creation of a virtual and calibrated building performance simulation model.

III.2.1.1 Representative dwelling archetype

Based on the characterization of the Algerian housing stock (see section II.3.4.1), the selected building model for this study represents a typical multifamily social residential building which represents the most common typology in Algeria. The thermophysical properties of the building elements, the constructional details, and the geometrical design of the representative dwelling is shown in section II.3.4.2.

III.2.1.2 Climatic Data

The different climatic zones described by the Algerian Thermal Regulation (DTR C3-2) indicate six distinct climatic zones (see section II.3.1). However, this classification is outdated because it relies on old weather datasets (1960–1990) and is too generic, with only six climate zones for a country of 2.382 million km2. Therefore, this study opted for a higher resolution classification resulting in seventy-four (74) selected locations within the forty-eight Algerian provinces (see Figure III-2).

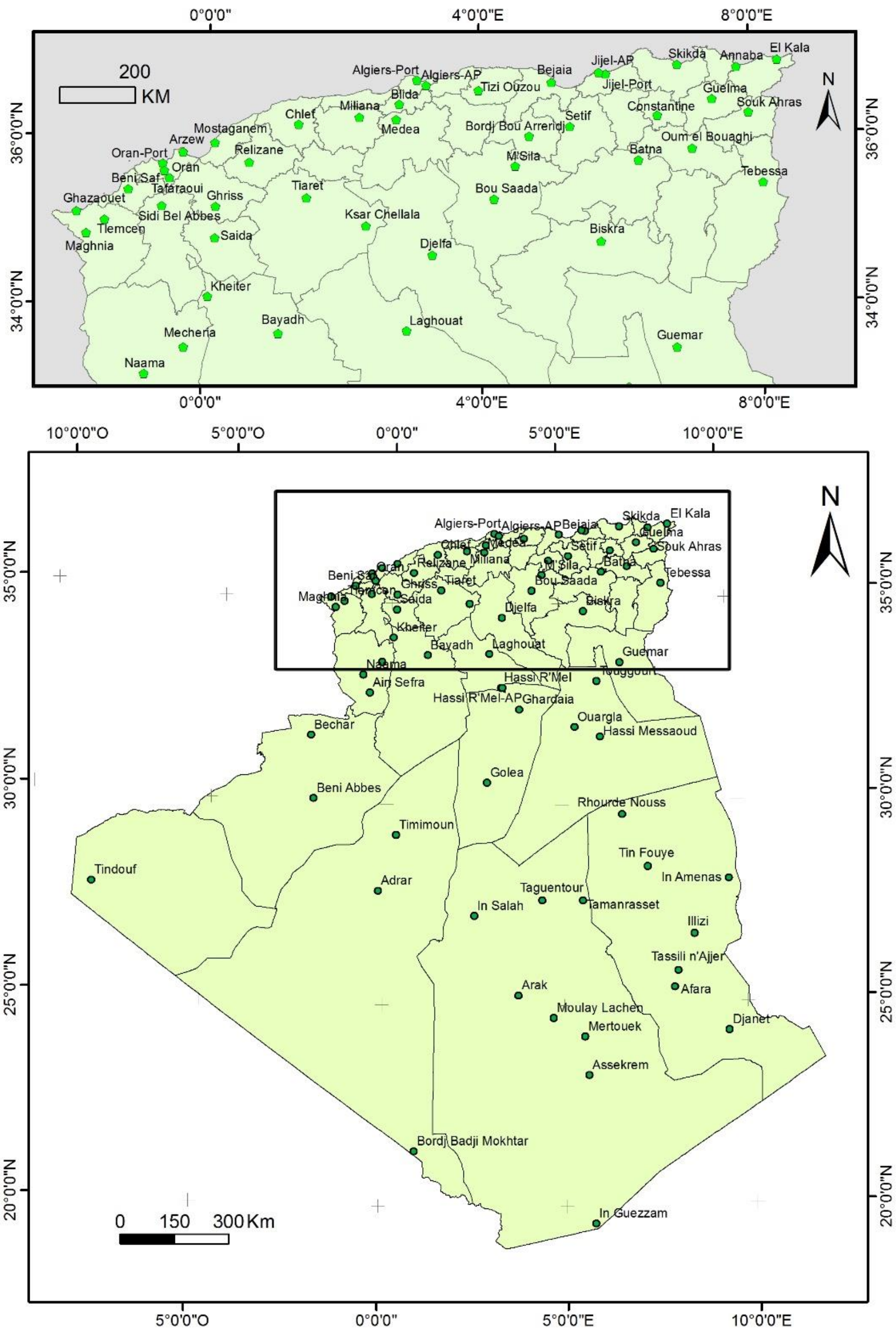


Figure III-2: *Distribution of the 74 studied locations across Algerian territory*

The weather data used in this study are the averages of fifteen years (2004–2018), which represents the recent weather datasets for the seventy-four (74) selected locations. The chosen locations represent new meteorological stations in Algeria with an extensive territorial coverage. This choice was confirmed by the lack of availability of TMY3 (1991–2005) for the seventy-four (74) selected locations. Each weather file consists of hourly records of dry-bulb temperature, dew point temperature, pressure and total horizontal solar radiation. The weather data were made available by the United States Department of Energy (Linda K. Lawrie and Crawley, 2019).

III.2.1.3 Reference Model Creation and Calibration

The reference building was modeled using EnergyPlus v.8.3 software. The building model is calibrated under hourly and monthly data through winter and summer indoor temperature and electricity and gas use. The monitoring, the calibration and validation process of model accuracy is described in detail in section II.3.5.1 and section II.3.5.2. The thermophysical properties of the building elements, according to the Algerian Thermal Regulation of Residential Buildings (CNERIB, 1997a).

III.2.2. Building Performance Simulation

In this part, EnergyPlus V8.9.0 software was used. EnergyPlus is developed by the US Department of Energy (DOE) and is one of the most widely used detailed and dynamic energy simulation programs (DOE, 2014). The annual indoor-discomfort hours and the annual energy demand were simulated in the seventy-four selected locations (meteorological stations).

III.2.2.1 Discomfort Hours

The number of indoor-discomfort hours was calculated based on the adaptive comfort model ASHRAE 55-2017 (ASHRAE, 2017). The selection of the ASHRAE 55-2017 adaptive comfort model was based on the recommendations of Attia et al. (Attia et al., 2019; Attia and Carlucci, 2015) who consider it as the best available socioeconomic model that sets no humidity limit, which is essential in the coastal cities of Algeria (Semahi and Attia, 2019a). Three categories of discomfort hours were calculated:

- The cold-discomfort hours. They represent the number of hours, which the operative temperature is lower than the temperature of the comfort range (see Figure III-3).

- The heat-discomfort hours. They represent the number of hours in which the operative temperature is upper than the temperature of the comfort range (see Figure III-4).
- The annual indoor-discomfort hours. They represent the addition of the cold-discomfort hours and the heat-discomfort hours (see Figure III-5).

III.2.2.2 Energy Demand

The energy demand of the residential building model was simulated in seventy-four selected locations. The heating and cooling system activation is based on the setpoints of heating and cooling temperatures. Three categories of energy demand were calculated: (1) heating energy demand (see Figure III-6), (2) cooling energy demand (see Figure III-7) and (3) annual thermal energy demand (see Figure III-8), which represents the addition of heating energy demand and the cooling energy demand.

III.2.3. Plotting on GIS-Based Maps

The visualization of the discomfort hours and energy demand results used a geographic information system (GIS) technique. Geographic information systems (GIS) are commonly used to represent spatial data and visualization issues associated with multiscale geographic data. An essential feature of a GIS is the ability to generate new information by integrating the existing diverse datasets sharing a compatible spatial referencing system. GIS methods allow direct viewing of the spatial difference and a direct comparison of values associated with the region use pattern on the map. To present the spatial distribution of residential building energy demand and indoor-discomfort hours in Algeria, we adopted the following steps:

The first step is the creation of an administrative map of the study area, extracted from the Weather Algeria website (“Carte-Algerie: Plan et Cartes des Villes Algérienne,” 2019). Then, critical thematic layers were identified for curing out the target application after the normative calibration of the under-studied map. The climate data were rostered and georeferenced to allow conducting a more detailed spatial analysis of the features of thematic layers. We have identified first, three layers, (1) the provinces layer, (2) the Mediterranean Sea layer and (3) the neighboring countries layer. The geographic coordinate system projection facilitated the creation of layers and the shapefiles characterizing the study areas. The findings are presented by areal entities in polygons formats representing the major Algerian provinces (or Willayat).

The second step consists of integrating an Excel table with the GIS software ArcGIS. ArcGIS software version 10.0, developed by the Environmental Systems Research Institute, was used (ESRI 2019). The objective of this step is to make it possible to read the digital data of used meteorological stations, which were generally characterized by their geographic coordinate system projection and their climatic parameters. The seventy-four stations were identified in ArcGIS as 74 seventy-four (see Figure III-2). The meteorological station's layer has been added for the sake of beginning the deterministic spatial method explained in the follow step.

The third step involved data treatment using the inverse distance weighted (IDW) interpolation method. The (IDW) method is used to interpolate spatial data, which is based on a concept of distance weighting (Childs, 2004). The IDW method involves the process of assigning values to unknown points by using values from a scattered set of known points (Childs, 2004). Hence, the main objective of this technique is to provide (interpolate) new data in locations where there were no meteorological stations. The simulation results of the building performance simulation were georeferenced (74 locations) to produce residential building performance maps. The final step was the visualization of annual spatial distribution maps for residential building energy demand and indoor-discomfort hours for Algeria and assigning a legend.

III.3. Results:

The resulting estimates of the indoor-discomfort hours and building energy demand in the seventy-four selected locations were visualized in ArcGIS to show the distribution of annual spatial distribution in Algeria (Semahi and Attia, 2019b). This section covers two categories of the calculation results. (1) The first category is the number of indoor-discomfort hours, including the cold-discomfort hours, hot-discomfort hours and annual-discomfort hours; (2) The second category is the thermal energy demand, including the heating energy demand, cooling energy demand and annual energy demand.

III.3.1. Indoor-Discomfort Hours

III.3.1.1 Cold-Discomfort Hours

Figure III-3 shows the spatial distribution of annual cold-discomfort hours in all regions of Algeria. Based on the cold-discomfort hours map, Algeria can be grouped into three main zones and nine subzones. The first zone represents the northern coastal zone. The second one includes the subcostal zone and highlands zone, which is situated between the coastal zone and the desert zone. The third zone covers the South of Algeria (desert).

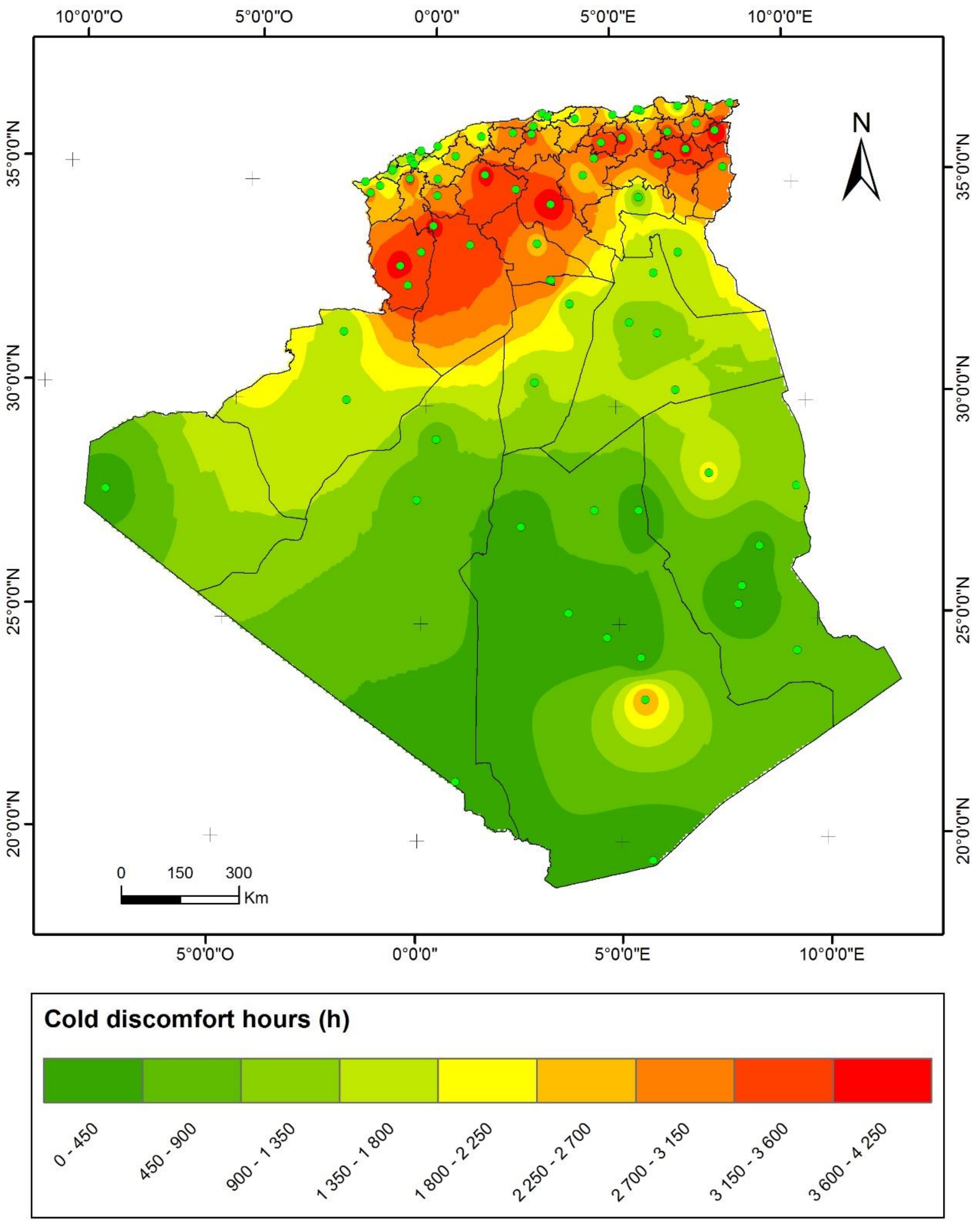


Figure III-3: *Cold-discomfort hours map*

Based on our simulation, we found that the maximum number of cold-discomfort hours is registered in Souk Ahras on the Northeast of Algeria, with 4213 h of cold discomfort, which represents 48% of hours in the year. Djelfa follows with 4190 in the Center of Algeria and Naama with 3988 h in the West of Algeria (see Figure III-3). On the opposite, In Guezam (Tamanrasset) and Bordj Badji Mokhtar (Adrar) in the extreme South of Algeria, both have the minimum number of cold-discomfort hours with 0 and 16 h, respectively (see Figure III-

3). Assekrem, in the extreme South of Algeria, has a high number of cold-discomfort hours around 2657 h due to its high-altitude of 2726 m above sea level.

Results indicate a significant difference between the maximum and minimum the number of cold-discomfort hours in Algeria, which exceeds 4200 h. Table III-2 shows the percentage of the Algerian territory occupied by each range of the cold-discomfort hours. The cold-discomfort hours, in 77.2% of Algerian territory, is ranging between 0 and 1800 h. It represents around 20% of the total hours of the year. The cold-discomfort hours in 17.6% of Algerian territory is ranging between 2250 and 4250 h, which represents, respectively 25.5% and 48.5% of the total hours of the year. The cold-discomfort hours in the rest of Algeria, (around 5.2% of Algerian territory) is ranging between 1800 and 2250 h, which represents, respectively 20.5% and 25.5% of the total hours of the year.

Table III-2: *Territory surfaces in percentage of cold-discomfort hours zones*

Cold-discomfort hours range (hours)	0–450	450–900	900–1350	1350–1800	1800–2250	2250–2700	2700–3150	3150–3600	3600–4250
Territory surface in percentage (%)	18.3	25.8	16.9	16.2	5.2	4.7	6.5	5.6	0.7

III.3.1.2 Heat-Discomfort Hours

Figure III-4 shows the spatial distribution of annual heat-discomfort hours in all regions of Algeria. Based on the heat-discomfort hours, Algeria can be grouped into three main zones, which are divided into nine (09) subzones. The first zone in the North of Algeria is situated between the Mediterranean Sea and the Southern Highlands zone. The second zone covers the North of the desert zone. The third zone represents the South of the desert zone.

Based on building performance simulation results, the maximum number of heat-discomfort hours is registered in In Guezam (Tamanrasset) on the extreme South of Algeria with 7879 h, which represents 90% of hours in the year. It is followed by Arak (Tamnrasset) with 7294 and Bordj Badji Mokhtar (Adrar) with 6475 h (see Figure III-4). On the opposite, Assekrem (Tamanrasset) in the extreme South of Algeria has the minimum number of heat-discomfort hours with 1489 h. Assekrem (Tamanrasset) is followed by Sidi Bel Abbes in the West of Algeria with 1983 and Djelfa in the center of Algeria with 2048 h. Results indicate a significant difference between the maximum and minimum number of cold-discomfort hours in Algeria, which is around 6400 h.

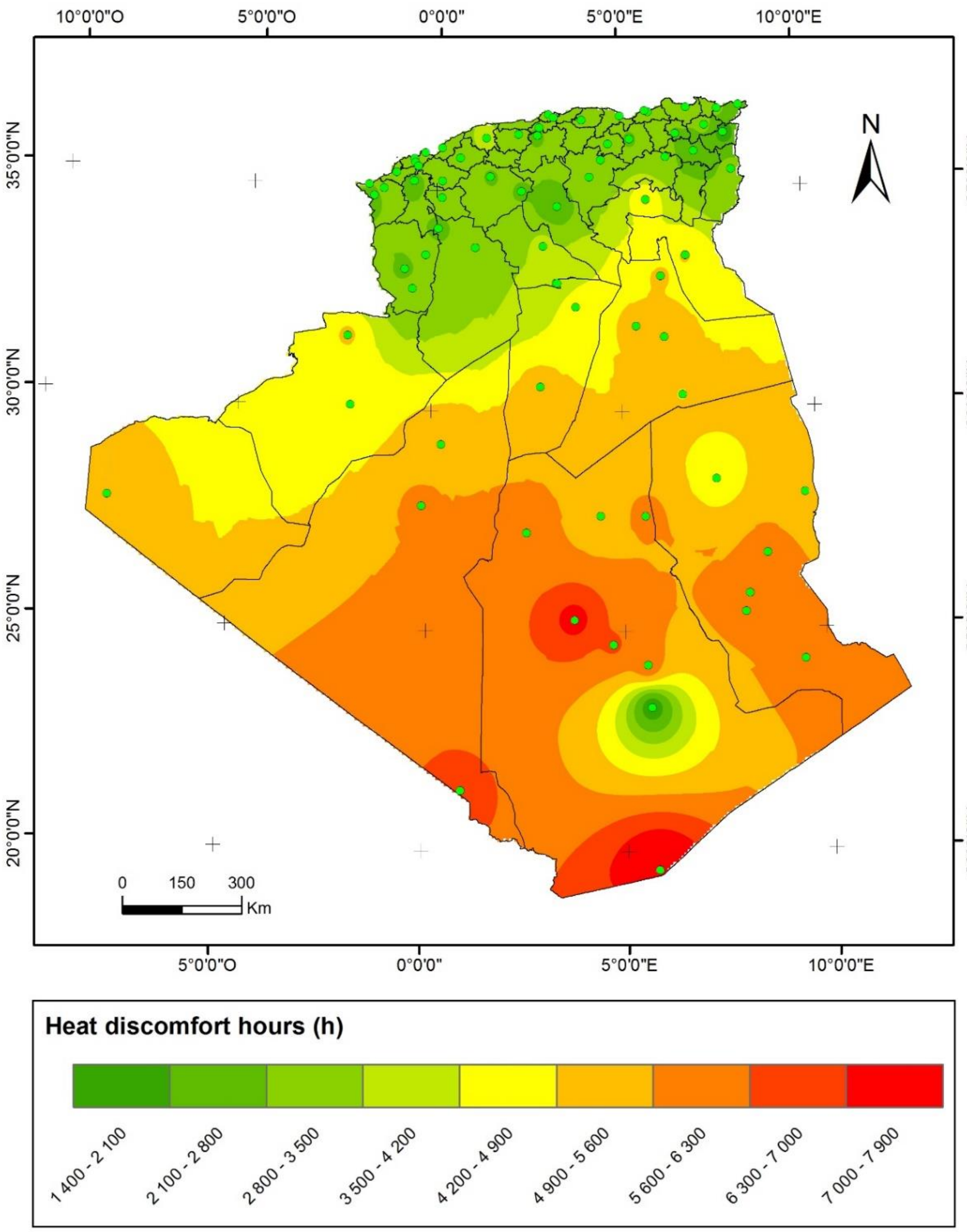


Figure III-4: *Heat-discomfort hours map*

Table III-3 shows the percentage of the Algerian territory occupied by each range of the heat-discomfort hours. The heat-discomfort hours in 61.5% of Algerian territory is ranging between 4900 and 7900 h, which represents 56% and 90% of the total hours of the year, respectively. The heat-discomfort hours in 23.3% of Algerian territory is ranging between 3500 and 4900 h, which represents 39.9% and 55.9% of the total hours of the year, respectively. The cold-discomfort hours in the rest of Algeria (15.2% of Algerian territory) are ranging between 1400 and 3500 h, which represents 15.9% and 55.9% of the total hours of the year, respectively (see Table III-3).

Table III-3: *Territory surfaces in percentage of heat-discomfort hour zones*

Heat-discomfort hours range (hours)	1400–2100	2100–2800	2800–3500	3500–4200	4200–4900	4900–5600	5600–6300	6300–7000	7000–7900
Territory surface in percentage (%)	0.2	2.3	12.7	5.3	18	31.8	25.8	3	0.8

III.3.1.3 Annual-Discomfort Hours

Figure III-5 shows the spatial distribution of yearly-discomfort hours in all regions of Algeria. Based on the yearly-discomfort hours, Algeria is divided into three major zones, which are divided into nine subzones (see Figure III-5). The first zone occupies the coastal zone on the North except Tipaza and the South of Chlef. It holds the subcostal in the east and west. This zone includes Assekrem (Tamanrasset) in the extreme South of Algeria.

The second zone is bordered by the coastal zone and the desert zone in the east and the South of the highlands in the west of Algeria (except Bordj Bou Arreridj and the southeast of Setif). This zone includes some locations in the desert zone in the South of Algeria like Tendouf and Taguentour, Aguemar and Mertouek in Tamanrasset. The third zone occupies the desert zone and the south part of the highlands in the west of Algeria like Tiatret and Naama. This zone includes two subzones that have several annual-discomfort hours higher than the central zone. The first subzone includes Al-bayadh, the South of Laghouat, the west of Ghardaïa and Bordj Badji Mokhtar (Adrar). The next subzone includes In Guezam and Arak in Tamanrasset.

Based on simulation results, the maximum number of annual-discomfort hours is registered in In Guezam and Arak. Both locations are in Tamanrasset with 7879 and 7344 h, respectively. On the opposite, the minimum number of annual-discomfort hours is registered in Oran with 3895 h, followed by Beni Saf (Ain Temouchent) on the west of Algeria with 4107 h and Assekrem (Tamanrasset) with 4146 h. Table III-4 shows the percentage of the Algerian territory occupied by each range of the annual-discomfort hours.

In addition, results indicate the annual-discomfort hours in 77% of Algerian territory is ranging between 6100 and 7900 h, which represents 70% and 90%, respectively, of the total number of hours of the year. In 16.5% of Algerian territory, the number of annual-discomfort hours is ranging between 5800 and 6100 h, which represents 66% and 70%, respectively, of the total number of hours of the year (see Table III-4). Only in 6.5% of Algeria territory, the number of annual-discomfort hours is ranging between 4000 and 5800 h, which represents about 45% and 66%, respectively, of the total number of hours in the year.

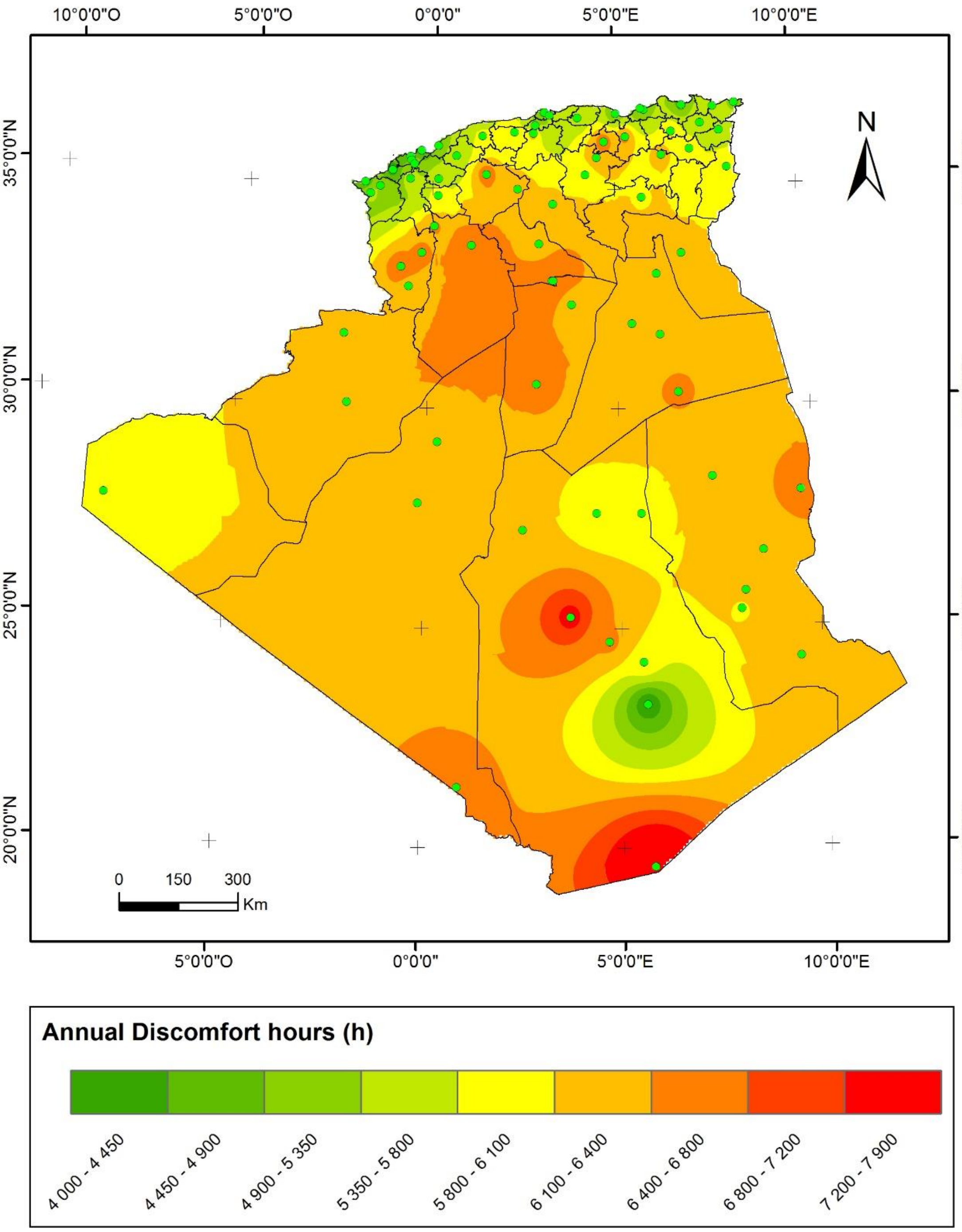


Figure III-5: *Annual indoor-discomfort hours map:*

Table III-4: *Territory surfaces in percentage of annual indoor-discomfort hours zones.*

Annual indoor-discomfort hours range (hours)	4000–4450	4450–4900	4900–5350	5350–5800	5800–6100	6100–6400	6400–6800	6800–7200	7200–7900
Territory surface in percentage (%)	0.2	0.5	1.5	4.3	16.5	62	12.9	1.2	0.8

III.3.2. Thermal Energy Demand

Following the indoor-discomfort hours of the social residential building archetype, the thermal energy demand of this archetype, was analyzed across all the Algerian territory. This section illustrates the spatial maps for the heating and cooling demand and annual energy demand.

III.3.2.1 Heating Energy Demand

Figure III-6 shows the spatial distribution of annual heating energy demand in all regions of Algeria. Based on the heating energy demand, Algeria is divided into three main zones, which can be divided into nine subzones. The first zone represents the coastal zone, the subcostal zone and the North of the desert. The second one includes the highlands, situated between the subcostal zone and the North of the desert zone. The third zone covers the South of Algeria (desert).

Based on simulation results the maximum heating energy demand is registered in Djelfa in the Center of Algeria with 150.5 kWh/m^2 followed by Souk Ahras on the Northeast of Algeria with 143.4 kWh/m^2 and Naama with 132.7 kWh/m^2 in the West of Algeria (see Figure III-6). On the opposite, In Guezam, Arak (Tamanrasset) and Bordj Badji Mokhtar (Adrar) in the extreme South of Algeria have the minimum of heating energy demand with 2, 5.6 and 8.9 kWh/m^2, respectively (see Figure III-6). Assekrem (Tamanrasset) in the extreme South has a high heating energy demand of around 84.2 kWh/m^2.

In addition, results indicate a significant difference between the maximum and minimum of heating energy demand in Algeria, which is about 148 kWh/m^2. Table III-5 shows the percentage of the Algerian territory occupied by each range of the heating energy demand. The heating energy demand in 78.3% of Algerian territory is ranging between 0 and 60 kWh/m^2. The heating energy demand in 16.4% of Algerian territory is fluctuating between 75 and 150 kWh/m^2. The heating energy demand in the rest of Algeria (around 5.3% of Algerian territory) is ranging between 60 and 75 kWh/m^2 (see Table III-5).

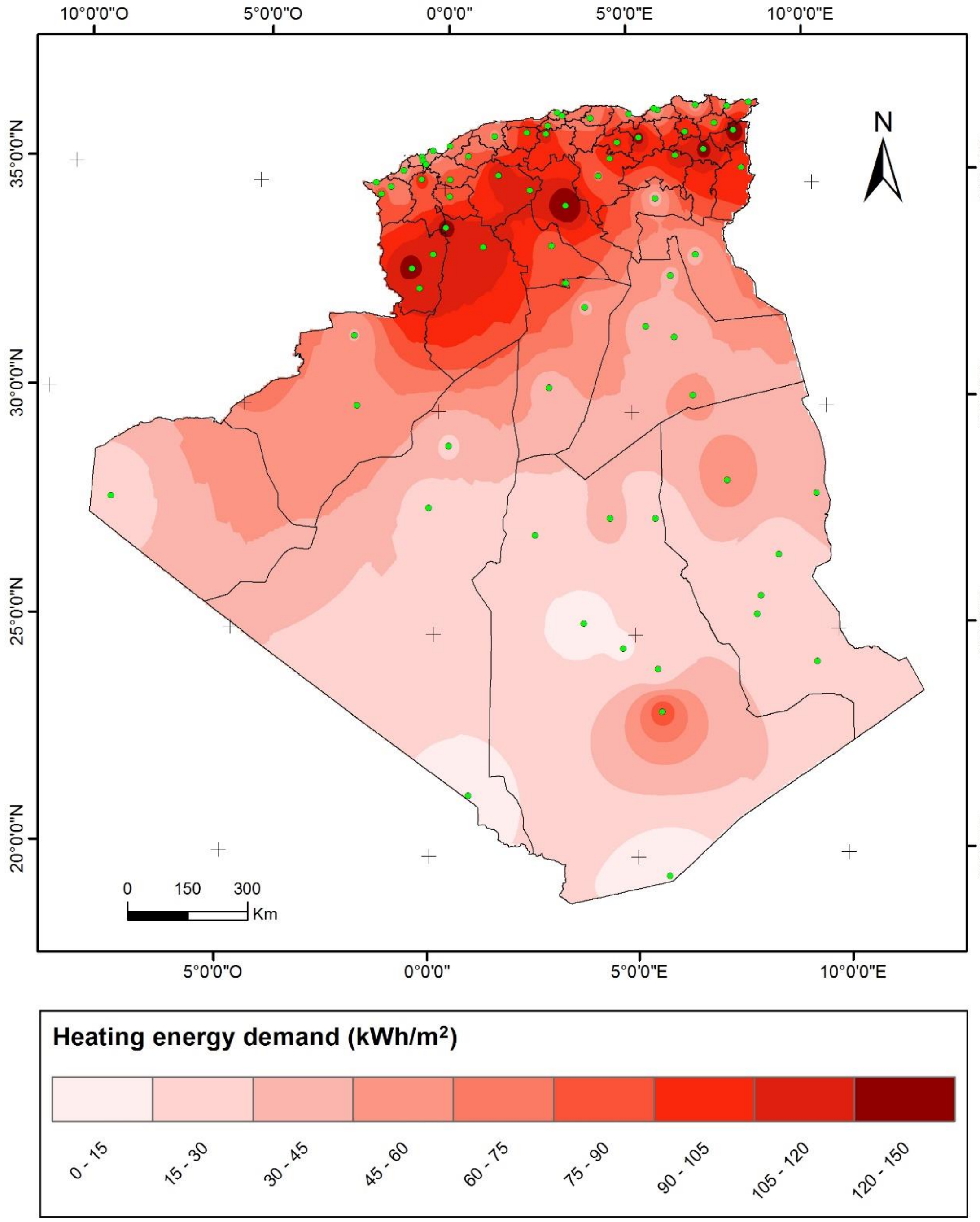


Figure III-6: *Heating energy demand map.*

Table III-5: Territory surfaces in percentage of heating energy demand zones.

Heating energy demand range (kWh/m²)	0–15	15–30	30–45	45–60	60–75	75–90	90–105	105–120	120–150
Territory surface in percentage (%)	3.8	33.8	24.2	16.4	5.3	6	5.6	4.2	0.5

III.3.2.2 Cooling Energy Demand

Figure III-7 shows the spatial distribution of annual cooling energy demand in all regions of Algeria. Based on the cooling energy demand, Algeria is divided into three main zones with nine subzones. The first zone includes the North of Algeria, which is situated between the Mediterranean Sea and the North of the desert zone. The second zone represents the extreme South and the southwest of Algeria (Adrar and the west of Tamanrasset). Moreover, the third zone is situated between the previous two zones.

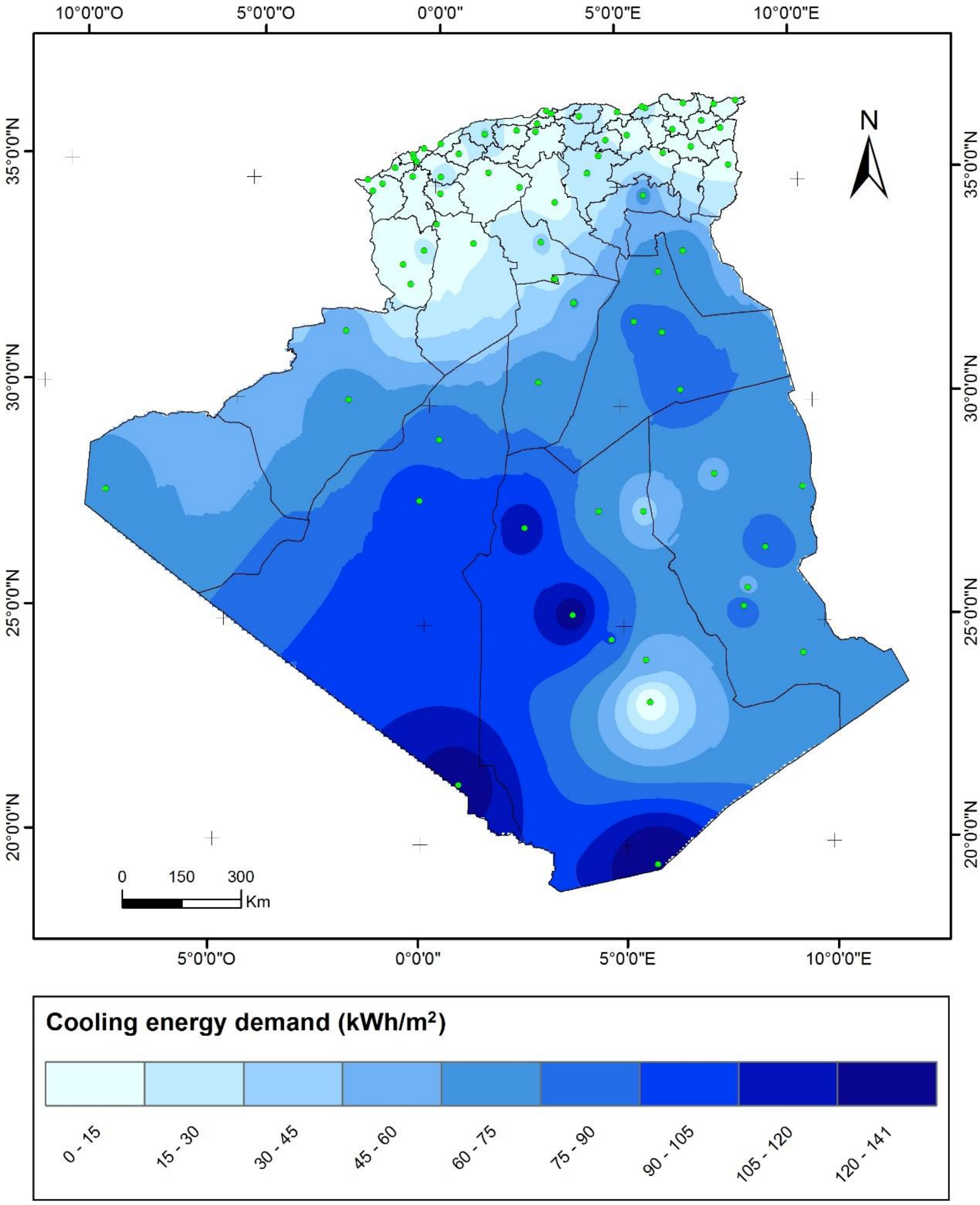


Figure III-7:*Cooling energy demand map.*

Based on our simulation we found that the maximum cooling energy demand is registered in In Guezam (Tamanrasset) on the extreme South of Algeria with 140.9 kWh/m^2 followed by Arak (Tamnrasset) with 131.1 kWh/m^2 and Bordj Badji Mokhtar (Adrar) with 113.3 kWh/m^2 (see Figure III-7). On the opposite, Assekrem (Tamanrasset) in the extreme South of Algeria has the minimum cooling energy demand with 0 kWh/m^2 due to its high altitude. Souk Ahras follow it on the east of Algeria with 1.3 kWh/m^2 and Djelfa in the center of Algeria with 2.8 kWh/m^2 and Sidi Bel Abbes on the west of Algeria with 3.6 kWh/m^2.

Results indicate a significant difference between the maximum and minimum of cooling energy demand in Algeria, which is more than140 kWh/m^2. Table III-6 shows the percentage of the Algerian territory occupied by each range of the cooling energy demand. The cooling energy demand in 57.7% of Algerian territory is ranging between 45 and 90 kWh/m^2. The cooling energy demand in 21.9% of Algerian territory is fluctuating between 90 and 140 kWh/m^2. The cooling energy demand in the rest of Algeria (around 20.4% of Algerian territory) is ranging between 0 and 45 kWh/m^2 (See Table III-6).

Table III-6: *Territory surfaces in percentage of cooling energy demand zones.*

Cooling energy demand range (kWh/m^2)	0–15	15–30	30–45	45–60	60–75	75–90	90–105	105–120	120–141
Territory surface in percentage (%)	9.3	6.9	4.2	12.7	30.8	14.2	16.8	3.6	1.5

III.3.2.3 Annual Energy Demand

Figure III-8 shows the spatial distribution of annual thermal energy demand in all regions of Algeria. Based on the yearly thermal energy demand, Algeria is divided into three major zones, which are divided into eight subzones (see Figure III-8).

The first zone occupied the coastal zone on the North except Tipaza and Chlef. This zone includes some locations in the desert zone in the South of Algeria like Aguemar, Mertouek, Assekrem in Tamanrasset and Tindouf. The second zone consists of the subcostal zone and the North of the highlands zone in the west of Algeria. This zone also comprises M’Sila, the North of Biskra and the southeast region of Algeria like Illizi and the east of Tamanrasset. The third zone occupies the desert zone, the highlands in the east and the south part of the highlands in the west of Algeria like Tiaret and Naama. This zone includes two subzones that have an annual energy demand higher than the central zone. The first subzone includes Djelfa, Naama, Rhourde-Nouss (Ouargla), Bordj Badji Mokhtar (Adrar) and In Guezam and Arak in Tamanrasset. The next subzone includes Tiaret, Al-

Bayadh, Mecheria and Ain Sefra in Naama, Beni Abbes (Bechar), Belkebir (Adrar) and In Salah (Tamanrasset).

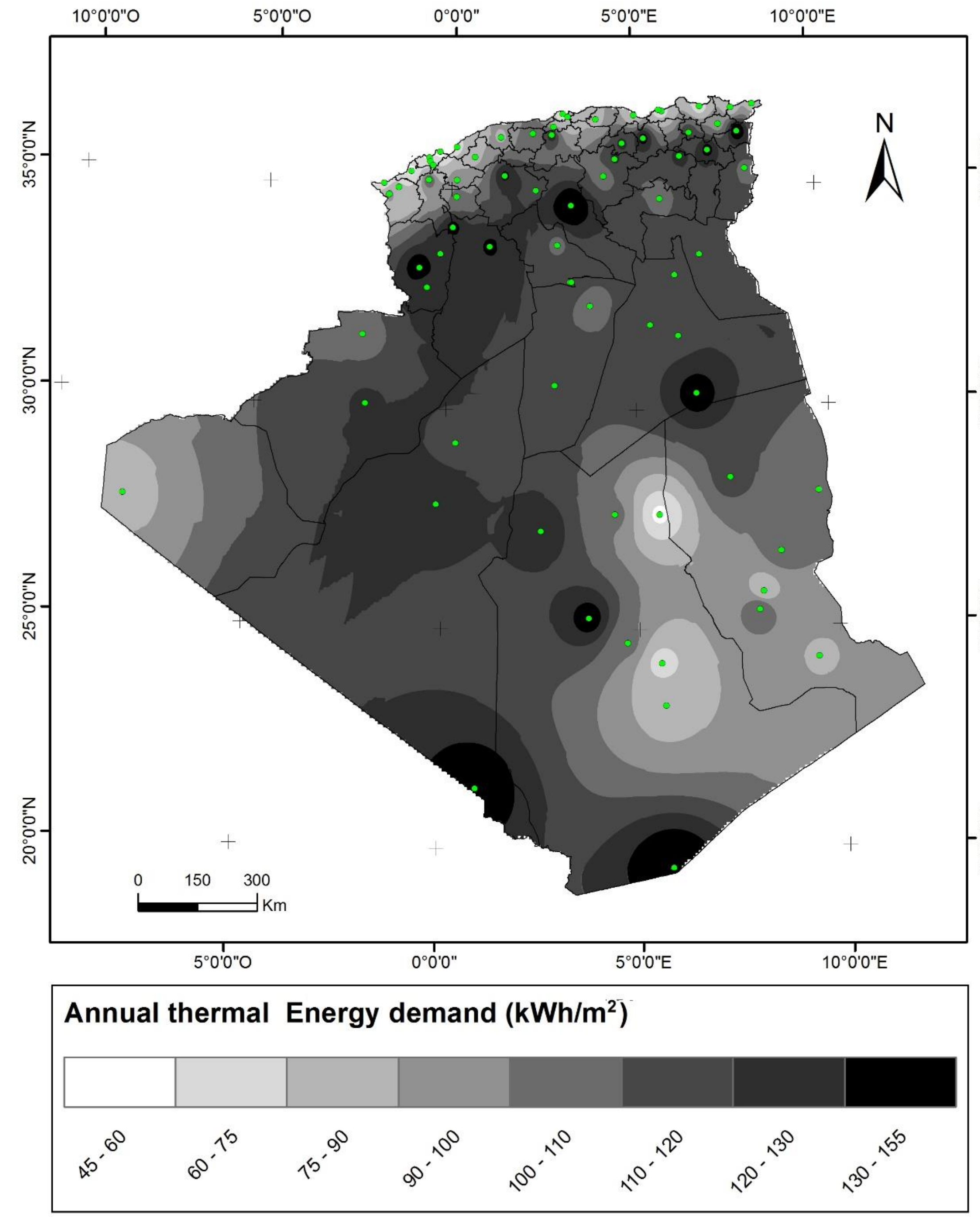


Figure III-8: *Annual thermal energy demand map.*

Based on simulation results, the maximum annual thermal energy demand is registered in Djelfa with 153.3 kWh/m^2, followed by Souk Ahras with 144.7 kWh/m^2 and In Guezam with 142.9 kWh/m^2. On the opposite, the minimum annual thermal energy demand is found in Oran with 44.2 kWh/m^2, followed by Algiers with 45.8 kWh/m^2 and Beni Saf (Ain

Temouchent) on the west of Algeria with 55 kWh/m^2. Table III-7 shows the percentage of the Algerian territory occupied by each range of the annual energy demand.

Results indicate the yearly energy demand in 64.7% of Algerian territory; the annual energy demand is ranging between 110 and 155 kWh/m^2. In 28.6% of Algerian territory, the yearly energy demand is fluctuating between 90 and 110 kWh/m^2. In 6.7% of Algeria territory is ranging between 45 and 90 kWh/m^2 (see Table III-7).

Table III-7: *Territory surfaces in percentage of annual thermal energy demand zones.*

Annual thermal energy demand range (kWh/m^2)	45–60	60–75	75–90	90–100	100–110	110–120	120–130	130–155
Territory surface in percentage (%)	0.1	0.9	5.6	13.7	14.9	42.8	19.2	2.7

Furthermore, Figure III-9 illustrates the climatic map of Algeria, including the average annual temperature distribution. Mean annual temperatures range from 16 °C in the North to 24 °C in the South of Algeria.

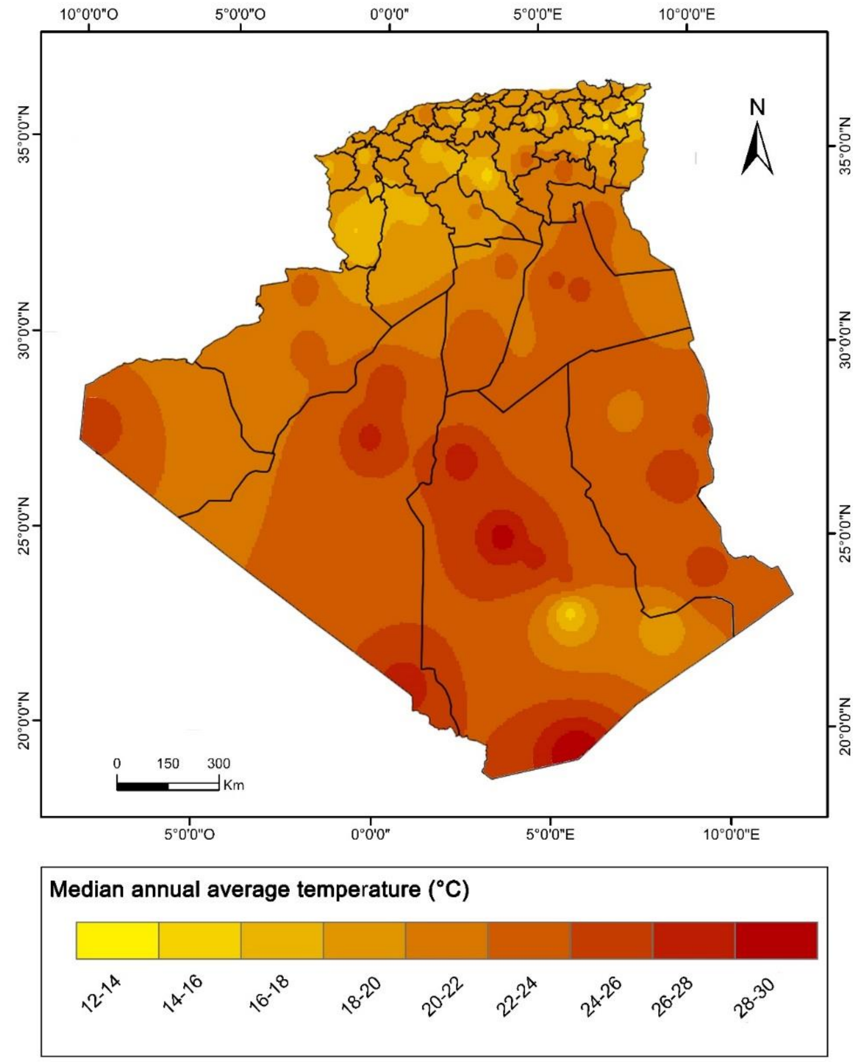


Figure III-9: *Median annual average temperature distribution across Algeria.*

In Algeria, generally, there are relatively large variations between summer and winter temperatures. Although Figure III-9 represents the climate variations similar to Figure III-8, it is difficult to estimate the energy demand and comfort conditions. Figure III-6– III-8 remain more informative regarding the energy needs and cooling and heating loads estimation for the seventy-four investigated cities.

III.4. Discussion:

In this chapter, thermal energy demand and the indoor-discomfort hours of a social residential building archetype was investigated in seventy-four locations across to the 48 provinces of Algeria. With the support of a Geographic Information Systems (GIS) tool, new zoning maps of the spatial distribution of thermal energy demand and indoor-discomfort hours for a social residential building archetype across Algerian territory were created. The following discussion highlights the main study findings and elaborates on the study strength and limitations, explains the implications for the practice and proposes future research.

III.4.1. Summary of the Main Findings

The study findings indicate that the thermal and energetic behavior of the current social residential building archetype is different in each location across the Algerian territory. The disparity between the maximum and minimum the number of annual-discomfort hours in Algeria is significant and reaches 3900 h. The discrepancy between the maximum and minimum of cold-discomfort hours is 4200 h; however, it is 6400 h for heat discomfort. Regarding the thermal energy demand, our results indicate a significant difference between the maximum and the minimum, which is around 109 kWh/m^2.

The difference between the maximum and the minimum of cooling energy demand is 141 kWh/m^2. However, it is 148 kWh/m^2 for heating energy demand. This difference is due to the contrast between the conditions of climate zones. For example, the highlands zone has a continental climate with hot, dry summers and freezing dry winters. Nevertheless, the desert zone has an arid climate with dry, very hot summers and cold winters and sunny weather almost year-round (Semahi et al., 2019a).

Concerning the primary outcomes of the spatial distribution of the-discomfort hours and thermal energy demand, we obtained three major climatic zones with nine subzones for five selected indicators: annual indoor-discomfort hours, cold-discomfort hours, heat-discomfort hours, heating energy demand and cooling energy demand. There are similarities between the zoning of cold-discomfort hours and heating energy demand. Moreover, the heat-discomfort hours zoning is so like the cooling energy demand zoning.

From 56% until 90% of the year (between 4900 and 7900 h), the current social residential building archetype across more than 61.5% of Algerian territory has a heat-discomfort state. This zone covers the desert zone, which has a hot and dry climate. The cooling energy demand required in this zone is ranging between 60 and 141 kWh/m2. For this zone, passive cooling strategies must be given more importance by the architect. Only in 17.7% of Algeria territory, the current social residential building archetype has a cold discomfort from 25.5% to 48.5% of the total hours of the year (between 2250 and 4250 h). This zone covers the subcostal zone and highlands zone, which has a very cold climate in winter. The heating energy demand required in this zone is ranging between 90 and 150 kWh/m^2. For this zone, passive heating strategies must be given more importance by architects.

III.4.2. Strength and Limitations of the Study

This study presents six new maps that show the spatial distribution of thermal comfort and energy use demand in Algeria. The maps are in high-resolution and consistent based on recent weather data sets, representing seventy-four meteorological stations. This study provides a more substantial spatial coverage for the Algerian territory involving data compared to previous studies that used data from forty-eight locations (Ghedamsi et al., 2016) and forty locations (Mokhtara et al., 2019), respectively. The study presents nine sub-zones instead of only the three or only seven zones obtained by the previous studies. This new classification is more accurate and informative than the current official Algerian climatic zoning, which has only six climatic zones (CNERIB, 1997a). In addition, the used interpolation method to generate the spatial maps is a suitable way to determine mapping zones in areas without available data across Algerian territory (Carpio et al., 2015). Therefore, our maps will be more accurate (high resolution) than previous research. Thus, the results are reliable and provide an opportunity for future designers to estimate the thermal and energetic performance expected in social residential housing, for all locations of Algeria.

Regarding the methodology, none of the previous studies, found in literature, calculated the energy demand and the indoor-discomfort hours based on a calibrated reference building that complies with the Algerian construction standards and passive design principles and best practices (Semahi et al., 2019a). Worldwide, few studies combine GIS and BPS techniques with recent weather data set to generate up-to-date climatic zoning maps (Walsh et al., 2017). Our methodology is based on building performance simulation that requires hourly data of multiple variables for the 8760 hours of the year. Building performance simulation provides more accurate results compared to the degree-days method (Ghedamsi et al., 2016), cluster analysis, Givoni’s bioclimatic chart and Mahoney tables (Carpio et al., 2015; Walsh et al., 2018, 2017). Therefore, the methodology can be transferred to any other climatic regions in the Global South. The methodology provides a data-driven approach based on GIS and BPS techniques to generate high-resolution maps that can help designers to find patterns or identify climates that difficult to grasp from weather files. We strongly believe that our methodology is valid and straightforward to apply in countries that are in an early stage of implementing energy efficiency measures for their building sector. This includes countries in Africa and, more specifically, the Middle East and North Africa (MENA) region. After the oil crisis in the 1970s, climate zone maps were used as an instrument in Northern Countries to inform designers. Today, many countries in the Global South, are obliged to deliver energy efficiency targets. Those countries do not have up-to-date climatic characterization maps that are building-related. Therefore, the importance of climatic zoning is high in countries with a weak energy policy landscape. Therefore, this methodology can be transferred to fill in this gap.

On the other hand, this study has some limitations. The most important limitation is the use of only one housing archetype. Even though the used multifamily residential archetype represents the dominant household typologies of Algeria, single-family households represent a large part of the residential building stock. The selected housing archetype design does not embed many climate-responsive features. However, we need to remind the reader that it is the first study to present spatial maps based on an original monitored building in Algeria. The selected archetype is used in an identical way throughout all the 74 study locations in 48 provinces, which makes it strongly representative. Therefore, it is recommended to explore other building typologies (offices, schools, hospitals, etc.) and climate-responsive archetypes, in the future. Moreover, the proposed thermal comfort is mainly based on the adaptive model of ASHRAE (ASHRAE, 2017). The results would have been influences if we chose another thermal comfort model (Attia and Carlucci, 2015). The same applies to the choice of EnergyPlus for building performance simulation. The result would have been influenced if another tool such as TRNSYS, Modelica, etc. was used. Therefore, designers should rely on the relative comparisons between the different cities based on the particular and limited reference conditions of this study.

III.4.3. Implications for the Practice

Algeria has a very large surface area around 2.4 million km^2 and a disparity of topographic variations, which leads to various climatic zones across its territory. We can find littorals zones (Mediterranean Sea), plains zones, highlands zones, mountain zones, desert zones. The Algerian territory knows many levels of altitude, which is ranging between −40 m to 2900 m. Algeria has a various geographic distribution of annual global solar irradiation, which is ranging between 4500 Wh/m^2 to more than 7000 Wh/m^2 from the North to the South (M.R. Yaiche et al. 2014). These causes can explain the difference in thermal comfort and energy demand across the Algerian territory.

The new spatial maps allow building designers and decision-makers to make quick and easy assessments of the thermal energy demand and indoor-discomfort hours in each location in Algeria. The maps quantify the expected performance results with high precision to inform professionals, including architects and building engineers and policymakers.

More important, the study proves that the current residential building archetype of social housing is not adapted to the climatic conditions and disparity between many locations of Algeria. Despite falling in North Africa and having most of its cities between the latitude from 23° to 37° (North), Algeria has a significant topographic variation (highest point: 2900 m and lowest point: −40) consisting of massive areas extensively dissected into mountains and oasis. Reflecting on the study findings, the importance of developing more climate-responsive buildings that correspond to the nine different climatic zones of Algeria emerges as an essential recommendation.

Therefore, the spatial maps allow future designers to better react to the climate disparity of Algerian cities and think about the best fit for climate bioclimatic principles, strategies and solutions to design and implement comfortable and efficient residential buildings. The maps can provide quantifiable guidance regarding the heat and cold indoor-discomfort hours and the expected heating and cooling energy use. We hope that our study findings can form the basis for a new climatic zoning map or tool for Algeria and get integrated into the future development of the Algerian building thermal standard.

III.5. Conclusions:

The estimation of thermal comfort and energy demand for newly built construction is fundamental. Therefore, designing low energy buildings and estimating their energy needs for heating and cooling represent a major preoccupation of building designers and decision makers. This chapter aimed to evaluate and present the current thermal comfort and energy consumption behaviour of the multifamily residential building archetype across the Algerian territory. This study created six novel and accurate spatial maps with the help of geographic information systems, building performance simulation and a rich dataset of weather data. The research methodology combined the results of running simulations of a multifamily residential benchmark model in seventy-four cities of Algeria with their geographic locations. The research methodology reflects a novel approach to the development of climatic analysis based on GIS and/or BPS techniques. The spatial maps were used to estimate future energy needs for cooling and heating as Algerian cities and regions continue to grow and target their thermal comfort expectations. Conventional climatic zoning and spatial mapping studies are based on only weather data regardless of the influence of the building physical properties. Therefore, the methodology can be used in other climatic regions worldwide. However, we know from building performance simulation that the thermal comfort and energy needs of buildings vary widely based on location. Finally, this study offers data-rich maps that are visual and can help designers to find patterns or identify climates that difficult to grasp from weather files.

Because it was found that the current residential building archetype of social housing is not adapted to deferent climatic conditions and there is a disparity between many locations of Algeria, future work will focus on identifying optimal solutions related to building design for each zone in Algeria. The optimization of passive envelope design measures for multi-family apartment building under all Algerian climate zones represents the objective of the next chapter (chapter 4). These solutions include building orientation, opaque building envelope, transparent building envelope, shadings and the control of mechanical systems.

VI. Chapter 6: General conclusion:

Low-energy building performance-optimization pathways should always take place in the early design stages when most of the critical decisions affecting building energy performance are made by integrating the optimal values of different building parameters depending on the climatic conditions. To design and construct low-energy buildings, it is essential to assure informed decision-making during the early design phases. Therefore, there is a need for the development of decision support tools that can predict the building performance and support the design decision making of low-energy buildings.

This research aimed to contribute to the implementation of energy-efficient housing buildings across the Algerian territory and under all Algerian climate zones through informed design decision making in the early design stages of low-energy building. This thesis developed a decision support model that could estimate building energy performance (cooling and heating energy loads) in early design stages without using building performance simulation tools. This model provides rapid, energy-relevant feedback, and visualize possible consequences of the design decisions.

Initially, we investigated the bioclimatic potential of all Algerian climate zones using a dual approach that combines psychrometric chart-based analysis with building performance simulation analysis (EnergyPlus). Then, we evaluated the thermal and energetic behaviour of the typical multi-family apartment building across the Algerian territory to provide accurate bioclimatic design recommendations for Algeria and inform building designers without accessing, analyzing, or interpreting dense textual information through spatial distribution maps for energy demand and thermal comfort estimation. This part presented the base case, which is optimized in the next part.

Afterwards, we optimized the typical multi-family apartment building design for each climate zone using a mixed approach that combine between building performance simulation (BPS) tool (EnergyPlus) and building performance optimization (BPO) algorithm (NSAG-II). Finally, we developed a design decision-making model based on prediction using an Adaptive Neuro-Fuzzy Inference System (ANFIS) to estimate the cooling and the heating energy loads of the typical multifamily social residential building through the building design parameters variation.

VI.1.Summary of the main findings

To understand the local climate and provide corresponding bioclimatic design principles and strategies, all Algerian climate zones have been investigated, and the bioclimatic potential has been calculated. Through the application of a mixed approach that combines bioclimatic analysis and building performance simulations, the following findings have been concluded:

- Psychrometric chart-based bioclimatic potential analysis for investigated locations does not generally correspond with the simulation-based energy and comfort analysis. Therefore, this method can be used to provide global and general recommendations.
- The bioclimatic potential analysis underestimates the cooling needs in the very hot zone and underestimates the heating needs in the very cold zone.
- Algerian cities can be classified into two major categories, including cooling- or heating-dominated cities.
- The percentage of average discomfort hours in Algerian households across all climatic zones is around 60%.
- Evaporative cooling is the most effective bioclimatic design strategy in Algeria, accounting for 60% of the hours annually in cooling-dominated cities due to their arid nature.
- Passive solar heating is the most effective bioclimatic design strategy in Algeria, accounting for 40% of the hours annually in heating-dominated cities due to their high altitudes.

To understand the thermal and energy behaviour of the current typical multi-family apartment building across the Algerian territory, a novel approach to the development of climatic analysis based on GIS and BPS techniques has been used. The following outcomes have been obtained:

- The current residential building archetype of social housing is not adapted to the climatic conditions and disparity between many locations of Algeria.
- Nine sub-zones divided the Algerian territory according to discomfort hours or energy demands.
- The disparity between the maximum and the minimum number of annual-discomfort hours in Algeria is significant and reaches 3900 h.
- The discrepancy between the maximum and the minimum of cold-discomfort hours is 4200 h; however, it is 6400 h for heat discomfort.

- Regarding the thermal energy demand, our results indicate a significant difference between the maximum and the minimum, which is around 109 kWh/m^2.
- The difference between the maximum and the minimum of cooling energy demand is 141 kWh/m^2. However, it is 148 kWh/m^2 for heating energy demand.

To optimize the typical multi-family apartment building design across the Algerian territory, a mixed approach that combine between building performance simulation (BPS) tool (EnergyPlus) and building performance optimization (BPO) algorithm (NSAG-II) have been used. The following outcomes have been concluded:

- The current base case that represents the most commonly constructed architectural type in Algeria is far away from the optimal design recommendations.
- The optimization results of passive and energy measures applied for the base case, of a typical multi-family social residential building, in Algeria, show significant improvements in the energy performance.
- Our optimization approach achieved energy saving ranging from around 21% to 51%. The energy saving rate is between 33% and 51% for heating dominated cities and between 21% and 25% for cooling dominated cities.

To develop a decision support model that allows designers to design low-energy building in Algeria, an Adaptive Neuro-Fuzzy Inference System (ANFIS) was used. The proposed approach could estimate building energy performance (cooling and heating energy loads) in early design stages without using building performance simulation tools. With this model, we avoided barriers presented when using building performance simulation tools. The following results have been provided:

- Proposed ANFIS prediction models were presented a high accuracy level. This is confirmed by the high coefficient of determination values R^2=0.9 for cooling ANFIS model and R^2=0.89 for heating ANFIS model.
- The developed ANFIS model allows building designers and decision-makers to make quick and easy assessments of the cooling and heating energy loads for residential building design in Algeria.

For design decision-making based on the ANFIS outputs, we can use the cooling and heating energy loads provided by the base case for each climate zone as the upper limit of building energy consumption threshold, and the cooling and heating energy loads offered by the optimal solution for each climate zone as the lower limit of building energy consumption threshold.

VI.2.Research innovations

A list of the contributions generated by this thesis is given in the following:

- The strength of the study relates to the use of a recent approach that combines simple chart-based bioclimatic analysis with simulation-based advanced building performance analysis. The study uses high-quality data based on a recently compiled climatic dataset for Algerian weather stations.
- Our study is the first study that provides an accurate estimation of the bioclimatic potential for the whole country of Algeria in contrast to previous research that focused on specific climate zones of Algeria. Also, with the use of the calibrated simulation model, reliable results could be obtained regarding the thermal building performance and associated consequences of active heating and cooling system requirements.
- Worldwide, few studies combine GIS and BPS techniques with recent weather data set to generate up-to-date climatic zoning maps. Building performance simulation provides more accurate results compared to the degree-days method, cluster analysis, Givoni’s bioclimatic chart, and Mahoney tables.
- This study presents six new maps in high-resolution that show the spatial distribution of thermal comfort and energy demand in Algeria. Thus, the study presents nine sub-zones instead of only the three or only seven zones obtained by the previous studies. This new classification is more accurate and informative than the current official Algerian climatic zoning, which has only six climatic zones. Also, the used interpolation method to generate the spatial maps is a suitable way to determine mapping zones in areas without available data across Algerian territory.
- An advanced simulation approach involving automated optimization (NSGA-II) was used and applied for the first time, in the Algerian context. This study was mainly based on adopting the variables identified by the Algerian thermal regulation (DTR C3-2) that primarily address the envelope’s thermal performance and surfaces orientation.
- Development of design decision-making models using the adaptive neuro-fuzzy inference system (ANFIS) to estimate the building energy consumption based on the building passive design variables for a mainstream building typology. This approach applied for the first time in the architectural building design in the Algerian context and showed very good learning and prediction capabilities and could easily handle complex non-linear problems.

VI.3.Research limitations and future work

Several limitations have been encountered which are evident in several aspects as following:

- Our reference case does not represent the different Algerian housing typologies and is not adapted to the climate conditions of each zone. Besides, the calibration period of the simulation model is only two weeks for indoor temperatures and one year for energy consumption (electricity and gas) readings using a manual trial-and-error-based calibration approach. The study could have benefited from a more extended monitoring period (three to five years) and an automated calibration using annual hourly data. However, we conducted our study using the best available data.
- The proposed thermal comfort is mainly based on the adaptive model of ASHRAE. The results could have influences if we chose another thermal comfort model. The complexity and findings abundance of the optimization process forced the authors to focus on one objective as an essential milestone. Thus, further investigation should address multiple objectives.
- The present study of optimization did not address retrofit opportunities or optimal comfort adaptations. Further investigations will be carried out to evaluate the influence of occupants' adaptation on comfort, cost, and optimal carbon solutions.
- The use of simulated data for training and testing of the ANFIS model represents maybe a limitation and affects the reliability of the generated results. However, the use of data obtained from Measurement and acquisition will make the model prediction more reliable.
- Characteristics of the proposed ANFIS, such as the number and shape of membership functions, were obtained from the literature. These two factors are the most influential characteristics of the designed ANFIS-based model accuracy. It is recommended to investigate the variation of these factors and compare the obtained ANFIS model's accuracy to select the most performant one.
- It will be interesting to compare our ANFIS model with other soft computing methodologies such as Artificial Neural Network (ANN), genetic programming (GP), Support vector machine (SVM) to demonstrate the merits of the proposed ANFIS approach.

References

Ahmad, A.S., Hassan, M.Y., Abdullah, M.P., Rahman, H.A., Hussin, F., Abdullah, H., Saidur, R., 2014. A review on applications of ANN and SVM for building electrical energy consumption forecasting. Renew. Sustain. Energy Rev. 33, 102–109.

Ahmed, A.-S.F., Khan, K.-M.M.K., Oo, A.-A.M.T., Rasul, R.-M.G., 2014. Selection of suitable passive cooling strategy for a subtropical climate. Int. J. Mech. Mater. Eng. 9, 1–11.

Al-Ghandoor, A., Samhouri, M., Al-Hinti, I., Jaber, J., Al-Rawashdeh, M., 2012. Projection of future transport energy demand of Jordan using adaptive neuro-fuzzy technique. Energy 38, 128–135.

Ali-Toudert, F., Weidhaus, J., 2017a. Numerical assessment and optimization of a low-energy residential building for Mediterranean and Saharan climates using a pilot project in Algeria. Renew. Energy 101, 327–346.

Ali-Toudert, F., Weidhaus, J., 2017b. Numerical assessment and optimization of a low-energy residential building for Mediterranean and Saharan climates using a pilot project in Algeria. Renew. Energy 101, 327–346.

Al-Saadi, S.N., Al-Jabri, K.S., 2020. Optimization of envelope design for housing in hot climates using a genetic algorithm (GA) computational approach. J. Build. Eng. 101712.

Amasyali, K., El-Gohary, N.M., 2018. A review of data-driven building energy consumption prediction studies. Renew. Sustain. Energy Rev. 81, 1192–1205.

APRUE, 2020. Efficacité énergétique dans le bâtiment [WWW Document]. http://www.aprue.org.dz. URL http://www.aprue.org.dz/prg-eco-bat.html (accessed 10.23.20).

Aramesh, A., Montazerin, N., Ahmadi, A., 2014. A general neural and fuzzy-neural algorithm for natural gas flow prediction in city gate stations. Energy Build. 72, 73–79.

Asadi, S., Amiri, S.S., Mottahedi, M., 2014. On the development of multi-linear regression analysis to assess energy consumption in the early stages of building design. Energy Build. 85, 246–255.

Ascione, F., Bianco, N., De Stasio, C., Mauro, G.M., Vanoli, G.P., 2017. Artificial neural networks to predict energy performance and retrofit scenarios for any member of a building category: A novel approach. Energy 118, 999–1017.

Ascione, F., Bianco, N., De Stasio, C., Mauro, G.M., Vanoli, G.P., 2016a. Multi-stage and multi-objective optimization for energy retrofitting a developed hospital reference building: A new approach to assess cost-optimality. Appl. Energy 174, 37–68. https://doi.org/10.1016/j.apenergy.2016.04.078

Ascione, F., Bianco, N., De Stasio, C., Mauro, G.M., Vanoli, G.P., 2015. A new methodology for cost-optimal analysis by means of the multi-objective optimization of building energy performance. Energy Build. 88, 78–90. https://doi.org/10.1016/j.enbuild.2014.11.058

Ascione, F., Bianco, N., Mauro, G.M., Napolitano, D.F., 2019a. Building envelope design: Multi-objective optimization to minimize energy consumption, global cost and thermal discomfort. Application to different Italian climatic zones. Energy 174, 359–374.

Ascione, F., Bianco, N., Mauro, G.M., Napolitano, D.F., 2019b. Building envelope design: Multi-objective optimization to minimize energy consumption, global cost and thermal discomfort. Application to different Italian climatic zones. Energy 174, 359–374.

Ascione, F., Bianco, N., Mauro, G.M., Vanoli, G.P., 2019c. A new comprehensive framework for the multi-objective optimization of building energy design: Harlequin. Appl. Energy 241, 331–361.

Ascione, F., Bianco, N., Mauro, G.M., Vanoli, G.P., 2019d. A new comprehensive framework for the multi-objective optimization of building energy design: Harlequin. Appl. Energy 241, 331–361. https://doi.org/10.1016/j.apenergy.2019.03.028

Ascione, F., De Masi, R.F., de Rossi, F., Ruggiero, S., Vanoli, G.P., 2016b. Optimization of building envelope design for nZEBs in Mediterranean climate : Performance analysis of residential case study. Appl. Energy 183, 938–957. https://doi.org/10.1016/j.apenergy.2016.09.027

Ascione, F., De Masi, R.F., de Rossi, F., Ruggiero, S., Vanoli, G.P., 2016c. Optimization of building envelope design for nZEBs in Mediterranean climate: Performance analysis of residential case study. Appl. Energy 183, 938–957.

ASHRAE, 2017. ANSI/ ASHRAE Standard 55-Thermal Environmental Conditions for Human Occupancy. American Society of Heating. Refrigerating and AirConditioning Engineers (ASHRAE), Atlanta. GA. USA.

ASHRAE, 2002. ASHRAE Guideline 14-2002: measurement of energy and demand savings. ASHRAE Atlanta Ga. 1–165.

Attia, S., 2018a. Net Zero Energy Buildings (NZEB): Concepts, frameworks and roadmap for project analysis and implementation. Butterworth-Heinemann.

Attia, S., 2018b. Regenerative and positive impact architecture: Learning from case studies. Springer.

Attia, S., 2018c. Net Zero Energy Buildings (NZEB): Concepts, frameworks and roadmap for project analysis and implementation. Butterworth-Heinemann.

Attia, S., Beltrán, L., De Herde, A., Hensen, J., 2009. “Architect friendly”: A comparison of ten different building performance simulation tools, in: Proceedings of 11th International Building Performance Simulation Association Conference and Exhibition. International Building Performance Simulation Association (IBPSA).

Attia, S., Carlucci, S., 2015. Impact of different thermal comfort models on zero energy residential buildings in hot climate. Energy Build. 102, 117–128.

Attia, S., Gratia, E., De Herde, A., Hensen, J.L., 2012. Simulation-based decision support tool for early stages of zero-energy building design. Energy Build. 49, 2–15.

Attia, S., Hamdy, M., Ezzeldin, S., 2017. Twenty-year tracking of lighting savings and power density in the residential sector. Energy Build. 154, 113–126.

Attia, S., Hamdy, M., O’Brien, W., Carlucci, S., 2013. Assessing gaps and needs for integrating building performance optimization tools in net zero energy buildings design. Energy Build. 60, 110–124.

Attia, S., Lacombe, T., Rakotondramiarana, H.T., Garde, F., Roshan, G., 2019. Analysis tool for bioclimatic design strategies in hot humid climates. Sustain. Cities Soc. 45, 8–24.

Autodesk, 2019. Ecotect Weather Tool. Version 8.

Azari, R., Garshasbi, S., Amini, P., Rashed-Ali, H., Mohammadi, Y., 2016. Multi-objective optimization of building envelope design for life cycle environmental performance. Energy Build. 126, 524–534.

Badeche, M., Bouchahm, Y., 2020. Design optimization criteria for windows providing low energy demand in office buildings in Algeria. Environ. Sustain. Indic. 6, 100024.

Baglivo, C., Congedo, P.M., Di Cataldo, M., Coluccia, L.D., D’Agostino, D., 2017. Envelope design optimization by thermal modelling of a building in a warm climate. Energies 10, 1808.

Barenbrug, A.W.T., 1965. Psychrometry and psychrometric charts. Transvaal and Orange Free State Chamber of Mines of South Africa.

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci. Data 5, 180214.

Belkacem, N., Loukarfi, L., Missoum, M., Naji, H., Khelil, A., Braikia, M., 2017. Assessment of energy and environmental performances of a bioclimatic dwelling in Algeria’s North. Build. Serv. Eng. Res. Technol. 38, 64–88.

Berghout, B., Forgues, D., 2019. Passive ambient comfort and correlation of strategies and vernacular devices for habitat design in arid zones: the case of Biskra, Algeria. Buildings 9, 87.
Borah, P., Singh, M.K., Mahapatra, S., 2015. Estimation of degree-days for different climatic zones of North-East India. Sustain. Cities Soc. 14, 70–81.
Bouabaz, M., Mordjaoui, M., Bouleknafet, N., Belghoul, B., 2015. Forecasting the energy consumption using neural network approach, in: Progress in Clean Energy, Volume 1. Springer, pp. 311–320.
Bouziane, S.E., Khadir, M.T., 2020. Predictive Agents for the Forecast of CO 2 Emissions Issued from Electrical Energy Production and Gas Consumption, in: Embedded Systems and Artificial Intelligence. Springer, pp. 183–191.
Bouznit, M., Pablo-Romero, M.P., Sánchez-Braza, A., 2018. Residential electricity consumption and economic growth in Algeria. Energies 11, 1656.
Bre, F., Fachinotti, V.D., 2017. A computational multi-objective optimization method to improve energy efficiency and thermal comfort in dwellings. Energy Build. 154, 283–294. https://doi.org/10.1016/j.enbuild.2017.08.002
Breesch, H., Janssens, A., 2010. Performance evaluation of passive cooling in office buildings based on uncertainty and sensitivity analysis. Sol. Energy 84, 1453–1467.
Carpio, M., Jódar, J., Rodíguez, M.L., Zamorano, M., 2015. A proposed method based on approximation and interpolation for determining climatic zones and its effect on energy demand and CO2 emissions from buildings. Energy Build. 87, 253–264.
Carte-Algerie: Plan et Cartes des Villes Algérienne [WWW Document], 2019. . Carte Algér. URL http://www.carte-algerie.com (accessed 6.12.20).
Çaydaş, U., Hasçalık, A., Ekici, S., 2009. An adaptive neuro-fuzzy inference system (ANFIS) model for wire-EDM. Expert Syst. Appl. 36, 6135–6139.
Cellura, M., Longo, S., Montana, F., Sanseverino, E.R., 2019. Multi-Objective Building Envelope Optimization through a Life Cycle Assessment Approach, in: 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe). IEEE, pp. 1–6.
Chen, H.-Y., Lee, C.-H., 2019. Electricity consumption prediction for buildings using multiple adaptive network-based fuzzy inference system models and gray relational analysis. Energy Rep. 5, 1509–1524.
Chen, X., Yang, H., Zhang, W., 2018. Simulation-based approach to optimize passively designed buildings: a case study on a typical architectural form in hot and humid climates. Renew. Sustain. Energy Rev. 82, 1712–1725.
Chen, Y., Tong, Z., Malkawi, A., 2017. Investigating natural ventilation potentials across the globe: Regional and climatic variations. Build. Environ. 122, 386–396.
Childs, C., 2004. Interpolating surfaces in ArcGIS spatial analyst. ArcUser July-Sept. 3235, 32–35.
Chlela, F., Husaunndee, A., Inard, C., Riederer, P., 2009. A new methodology for the design of low energy buildings. Energy Build. 41, 982–990.
Cicelsky, A., Meir, I.A., 2014. Parametric analysis of environmentally responsive strategies for building envelopes specific for hot hyperarid regions. Sustain. Cities Soc. 13, 279–302.
CNERIB, 2007. DTRC3-2, Thermal regulation of residential buildings calculation methods for determining building heat losses, Algiers. Centre National d'Etudes et de Recherches Intégrées du Bâtiment, Algiers.
CNERIB, 1997a. DTRC3-2, Thermal regulation of residential buildings e calculating methods for determining building heat losses.
CNERIB, 1997b. DTRC3-4, Air Conditioning-Calculating Methods for Determining Building Heat Gains.
Colton, M.D., MacNaughton, P., Vallarino, J., Kane, J., Bennett-Fripp, M., Spengler, J.D., Adamkiewicz, G., 2014. Indoor air quality in green vs conventional multifamily low-income housing. Environ. Sci. Technol. 48, 7833–7841.

Costa, H.R. do N., La Neve, A., 2015. Study on application of a neuro-fuzzy models in air conditioning systems. Soft Comput. 19, 929–937.

Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J., 2001. EnergyPlus: creating a new-generation building energy simulation program. Energy Build. 33, 319–331.

De Wilde, P., 2018. Building performance analysis. John Wiley & Sons.

Deb, C., Eang, L.S., Yang, J., Santamouris, M., 2015. Forecasting energy consumption of institutional buildings in Singapore. Procedia Eng. 121, 1734–1740.

DeKay, M., Brown, G.Z., 2013. Sun, wind, and light: architectural design strategies. John Wiley & Sons.

Delgarm, N., Sajadi, B., Azarbad, K., Delgarm, S., 2018. Sensitivity analysis of building energy performance: a simulation-based approach using OFAT and variance-based sensitivity analysis methods. J. Build. Eng. 15, 181–193.

Djebbar, K.E.-B., Salem, S., Mokhtari, A., 2018. A MULTI-OBJECTIVEOPTIMIZATION APPROACH OF HOUSING IN ALGERIA. A STEP TOWARDS SUSTAINABILITY. Urban. Arhit. Constr. 9, 131.

DOE, U., 2014. EnergyPlus energy simulation software, energy efficiency and renewable energy. US Dep. Energy Wash. DC Www Energyplus Netweather Accessed 14.

Ehrgott, M., Tenfelde-Podehl, D., 2003. Computation of ideal and nadir values and implications for their use in MCDM methods. Eur. J. Oper. Res. 151, 119–139.

Ekici, B.B., Aksoy, U.T., 2011. Prediction of building energy needs in early stage of design by using ANFIS. Expert Syst. Appl. 38, 5352–5358.

Ferdyn-Grygierek, J., Grygierek, K., 2017. Multi-variable optimization of building thermal design using genetic algorithms. Energies 10, 1570.

Ferrara, M., Fabrizio, E., Virgone, J., Filippi, M., 2014. A simulation-based optimization method for cost-optimal analysis of nearly Zero Energy Buildings. Energy Build. 84, 442–457.

Fesanghary, M., Asadi, S., Geem, Z.W., 2012. Design of low-emission and energy-efficient residential buildings using a multi-objective optimization algorithm. Build. Environ. 49, 245–250.

Fezzioui, N., Khoukhi, M., Dahou, Z., Aït-Mokhtar, K., Larbi, S., 2009a. Bioclimatic architectural design of ksar de kenadza: south-west area of Algeria hot and dry climate. Archit. Sci. Rev. 52, 221–228.

Fezzioui, N., Khoukhi, M., Dahou, Z., Aït-Mokhtar, K., Larbi, S., 2009b. Bioclimatic architectural design of ksar de kenadza: South-west area of algeria hot and dry climate. Archit. Sci. Rev. 52, 221–228.

Foucquier, A., Robert, S., Suard, F., Stéphan, L., Jay, A., 2013. State of the art in building modelling and energy performances prediction: A review. Renew. Sustain. Energy Rev. 23, 272–288.

Gaspari, J., Fabbri, K., Lucchi, M., 2018. The use of outdoor microclimate analysis to support decision making process: Case study of Bufalini square in Cesena. Sustain. Cities Soc. 42, 206–215.

Gatley, D.P., 2004. Psychrometric chart celebrates 100th anniversary. Ashrae J. 46, 16.

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 Build. 121, 309–317.

Givoni, B., 1992. Comfort, climate analysis and building design guidelines. Energy Build. 18, 11–23.

Givoni, B., 1969. Man, climate and architecture. Elsevier;().

Gossard, D., Lartigue, B., Thellier, F., 2013. Multi-objective optimization of a building envelope for thermal performance using genetic algorithms and artificial neural network. Energy Build. 67, 253–260.

Gou, S., Nik, V.M., Scartezzini, J.-L., Zhao, Q., Li, Z., 2018. Passive design optimization of newly-built residential buildings in Shanghai for improving indoor thermal comfort while reducing building energy demand. Energy Build. 169, 484–506.

Groppi, D., de Santoli, L., Cumo, F., Garcia, D.A., 2018. A GIS-based model to assess buildings energy consumption and usable solar energy potential in urban areas. Sustain. Cities Soc. 40, 546–558.

Grygierek, K., Ferdyn-Grygierek, J., 2018. Multi-objective optimization of the envelope of building with natural ventilation. Energies 11, 1383.

Guan, L., Bennett, M., Bell, J., 2015. Evaluating the potential use of direct evaporative cooling in Australia. Energy Build. 108, 185–194.

Hamdani, M., Bekkouche, S.M.E.A., Benouaz, T., Belarbi, R., Cherier, M.K., 2014. Minimization of indoor temperatures and total solar insolation by optimizing the building orientation in hot climate. Eng. Struct. Technol. 6, 131–149.

Hamdy, M., Hasan, A., Siren, K., 2011. Impact of adaptive thermal comfort criteria on building energy use and cooling equipment size using a multi-objective optimization scheme. Energy Build. 43, 2055–2067.

Hamdy, M., Mauro, G., 2017. Multi-Objective Optimization of Building Energy Design to Reconcile Collective and Private Perspectives: CO2-eq vs. Discounted Payback Time. Energies 10, 1016. https://doi.org/10.3390/en10071016

Hamdy, M., Nguyen, A.-T., Hensen, J.L., 2016. A performance comparison of multi-objective optimization algorithms for solving nearly-zero-energy-building design problems. Energy Build. 121, 57–71.

Han, T., Huang, Q., Zhang, A., Zhang, Q., 2018. Simulation-based decision support tools in the early design stages of a green building—A review. Sustainability 10, 3696.

Harkouss, F., Fardoun, F., Biwole, P.H., 2018. Passive design optimization of low energy buildings in different climates. Energy 165, 591–613.

Heiselberg, P., Brohus, H., Hesselholt, A., Rasmussen, H., Seinre, E., Thomas, S., 2009. Application of sensitivity analysis in design of sustainable buildings. Renew. Energy 34, 2030–2036.

Helton, J.C., Davis, F.J., 2003. Latin hypercube sampling and the propagation of uncertainty in analyses of complex systems. Reliab. Eng. Syst. Saf. 81, 23–69.

Helton, J.C., Davis, F.J., Johnson, J.D., 2005. A comparison of uncertainty and sensitivity analysis results obtained with random and Latin hypercube sampling. Reliab. Eng. Syst. Saf. 89, 305–330.

Hoare, A., Regan, D.G., Wilson, D.P., 2008. Sampling and sensitivity analyses tools (SaSAT) for computational modelling. Theor. Biol. Med. Model. 5, 4. https://doi.org/10.1186/1742-4682-5-4

Huang, Y., Niu, J., 2016. Optimal building envelope design based on simulated performance: History, current status and new potentials. Energy Build. 117, 387–398.

Hygh, J.S., DeCarolis, J.F., Hill, D.B., Ranjithan, S.R., 2012. Multivariate regression as an energy assessment tool in early building design. Build. Environ. 57, 165–175.

IEA, 2020. Buildings – Topics [WWW Document]. IEA. URL https://www.iea.org/topics/buildings (accessed 10.22.20).

Imessad, K., Derradji, L., Messaoudene, N.A., Mokhtari, F., Chenak, A., Kharchi, R., 2014. Impact of passive cooling techniques on energy demand for residential buildings in a Mediterranean climate. Renew. Energy 71, 589–597.

Jallal, M.A., González-Vidal, A., Skarmeta, A.F., Chabaa, S., Zeroual, A., 2020. A hybrid neuro-fuzzy inference system-based algorithm for time series forecasting applied to energy consumption prediction. Appl. Energy 268, 114977.

Jang, J.-S., 1993. ANFIS: adaptive-network-based fuzzy inference system. IEEE Trans. Syst. Man Cybern. 23, 665–685.

Janssen, H., 2013. Monte-Carlo based uncertainty analysis: Sampling efficiency and sampling convergence. Reliab. Eng. Syst. Saf. 109, 123–132.

Katafygiotou, M.C., Serghides, D.K., 2015. Bioclimatic chart analysis in three climate zones in Cyprus. Indoor Built Environ. 24, 746–760.

Khambadkone, N.K., Jain, R., 2017. A bioclimatic analysis tool for investigation of the potential of passive cooling and heating strategies in a composite Indian climate. Build. Environ. 123, 469–493.

Kharchi, R., Benyoucef, B., Mokhtari, F., Imessad, K., 2012. Dynamic Simulation of both Thermal and Energetic Behavior for Dwellings Located in Algiers. J Earth Sci Clim. Change 3, 2.

Khoukhi, M., Fezzioui, N., 2012. Thermal comfort design of traditional houses in hot dry region of Algeria. Int. J. Energy Environ. Eng. 3, 5.

Kishore, K.N., Rekha, J., 2018. A bioclimatic approach to develop spatial zoning maps for comfort, passive heating and cooling strategies within a composite zone of India. Build. Environ. 128, 190–215.

Krishan, A., 2001. Climate responsive architecture: a design handbook for energy efficient buildings. Tata McGraw-Hill Education.

Kumar, S., Mathur, J., Mathur, S., Singh, M.K., Loftness, V., 2016. An adaptive approach to define thermal comfort zones on psychrometric chart for naturally ventilated buildings in composite climate of India. Build. Environ. 109, 135–153.

La Roche, P., Liggett, R., 2001. Very simple design tools: a web based assistant for the design of climate responsive buildings. Archit. Sci. Rev. 44, 437–448.

Lai, A.C.K., Mui, K.W., Wong, L.T., Law, L.Y., 2009. An evaluation model for indoor environmental quality (IEQ) acceptance in residential buildings. Energy Build. 41, 930–936.

Lapisa, R., Bozonnet, E., Salagnac, P., Abadie, M.O., 2018. Optimized design of low-rise commercial buildings under various climates–Energy performance and passive cooling strategies. Build. Environ. 132, 83–95.

Lawrie, Linda K., Crawley, D.B., 2019. Development of Global Typical Meteorological Years (TMYx) [WWW Document]. URL http://climate.onebuilding.org/ (accessed 1.17.19).

Lawrie, Linda K, Crawley, D.B., 2019. Development of Global Typical Meteorological Years (TMYx).

Li, H., Wang, S., Cheung, H., 2018. Sensitivity analysis of design parameters and optimal design for zero/low energy buildings in subtropical regions. Appl. Energy 228, 1280–1291.

Li, K., Su, H., Chu, J., 2011. Forecasting building energy consumption using neural networks and hybrid neuro-fuzzy system: A comparative study. Energy Build. 43, 2893–2899.

Li, Z., Genovese, P.V., Zhao, Y., 2020. Study on Multi-Objective Optimization-Based Climate Responsive Design of Residential Building. Algorithms 13, 238.

Loeppky, J.L., Sacks, J., Welch, W.J., 2009. Choosing the sample size of a computer experiment: A practical guide. Technometrics 51, 366–376.

Machairas, V., Tsangrassoulis, A., Axarli, K., 2014a. Algorithms for optimization of building design: A review. Renew. Sustain. Energy Rev. 31, 101–112.

Machairas, V., Tsangrassoulis, A., Axarli, K., 2014b. Algorithms for optimization of building design: A review. Renew. Sustain. Energy Rev. 31, 101–112.

Magnier, L., Haghighat, F., 2010. Multiobjective optimization of building design using TRNSYS simulations, genetic algorithm, and Artificial Neural Network. Build. Environ. 45, 739–746.

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, 1091.

Mahmoud, A.H.A., 2011. An analysis of bioclimatic zones and implications for design of outdoor built environments in Egypt. Build. Environ. 46, 605–620.

Manzano-Agugliaro, F., Montoya, F.G., Sabio-Ortega, A., García-Cruz, A., 2015. Review of bioclimatic architecture strategies for achieving thermal comfort. Renew. Sustain. Energy Rev. 49, 736–755.

Mao, J., Yang, J.H., Afshari, A., Norford, L.K., 2017. Global sensitivity analysis of an urban microclimate system under uncertainty: Design and case study. Build. Environ. 124, 153–170.

Mardani, A., Van Fan, Y., Nilashi, M., Hooker, R.E., Ozkul, S., Streimikiene, D., Loganathan, N., 2019. A two-stage methodology based on ensemble Adaptive Neuro-Fuzzy Inference System to predict carbon dioxide emissions. J. Clean. Prod. 231, 446–461.

ME, 2020. Ministry of Energy, National Energy Review 2019 [WWW Document]. URL www.energy.gov.dz (accessed 10.22.20).

Menberg, K., Heo, Y., Choudhary, R., 2016. Sensitivity analysis methods for building energy models: Comparing computational costs and extractable information. Energy Build. 133, 433–445.

Mesri, M., Ghilane, A., Bachari, N.E.I., 2013. An approach to spatio-temporal analysis for climatic data. Renew. Sustain. Energy Rev. 16, 413–424.

MHUV, 2018. Ministry of Housing Planning and the City, Les livraisons de Logements [WWW Document]. URL http://www.mhuv.gov.dz (accessed 6.22.20).

Milne, M., 2016. Climate Consultant.

Milne, M., Givoni, B., 1979. Architectural design based on climate. Energy Conserv. Build. Des. 96–113.

Milne, M., Liggett, R., Al-Shaali, R., 2007. Climate consultant 3.0: A tool for visualizing building energy implications of climates, in: Proceedings of the Solar Conference. AMERICAN SOLAR ENERGY SOCIETY; AMERICAN INSTITUTE OF ARCHITECTS, p. 466.

Milne, M., Yoshikawa, S., 1979. SOLAR-5: an interactive computer-aided passive solar design system, in: Proceedings of the 3rd Annual Passive Solar Conference, AS/ISES, San Jose, CA, January.

Missoum, M., Hamidat, A., Loukarfi, L., Abdeladim, K., 2014. Impact of rural housing energy performance improvement on the energy balance in the North-West of Algeria. Energy Build. 85, 374–388.

Mlakić, D., Nikolovski, S., Vucinic, D., 2016. Standalone application using JAVA and ANFIS for predicting electric energy consumption based on forecasted temperature. Ann. DAAAM Proc. 27, 671–677.

Moghadam, S.T., Toniolo, J., Mutani, G., Lombardi, P., 2018. A GIS-statistical approach for assessing built environment energy use at urban scale. Sustain. Cities Soc. 37, 70–84.

Mokhtara, C., Negrou, B., Settou, N., Gouareh, A., Settou, B., 2019. Pathways to plus-energy buildings in Algeria: design optimization method based on GIS and multi-criteria decision-making. Energy Procedia 162, 171–180.

Mokhtari, F., Loukarfi, L., Chikhi, M., Imessad, K., Ait Messaoudene, N., 2017. A passive wall design to minimize building temperature swings for Algerian Saharan climate. Sci. Technol. Built Environ. 23, 1142–1150.

Mordjaoui, M., Haddad, S., Medoued, A., Laouafi, A., 2017. Electric load forecasting by using dynamic neural network. Int. J. Hydrog. Energy 42, 17655–17663.

Moussaoui, F., Cherrared, M., Kacimi, M.A., Belarbi, R., 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. Sustain. Cities Soc. 42, 622–636.

Naji, S., Shamshirband, S., Basser, H., Keivani, A., Alengaram, U.J., Jumaat, M.Z., Petković, D., 2016. Application of adaptive neuro-fuzzy methodology for estimating building energy consumption. Renew. Sustain. Energy Rev. 53, 1520–1528.

Nguyen, A.-T., Reiter, S., Rigo, P., 2014. A review on simulation-based optimization methods applied to building performance analysis. Appl. Energy 113, 1043–1058.

Nilashi, M., Dalvi-Esfahani, M., Ibrahim, O., Bagherifard, K., Mardani, A., Zakuan, N., 2017. A soft computing method for the prediction of energy performance of residential buildings. Measurement 109, 268–280.

Olgyay, V., 2015. Design with climate: bioclimatic approach to architectural regionalism-new and expanded edition. Princeton university press.

ONS, 2018. Algerian National Office of Statistics, Statistiques sociales (Habitat) [WWW Document]. URL www.ons.dz (accessed 6.22.20).

Osman, M.M., Sevinc, H., 2019. Adaptation of climate-responsive building design strategies and resilience to climate change in the hot/arid region of Khartoum, Sudan. Sustain. Cities Soc. 47, 101429.

Østerg\aard, T., Jensen, R.L., Maagaard, S.E., 2016. Building simulations supporting decision making in early design–A review. Renew. Sustain. Energy Rev. 61, 187–201.

Ouahab, Athmane, 2015. Modélisation des consommations d'énergie et des émissions de CO2 à long terme appliquée au secteur résidentiel algérien (PhD Thesis). Tours.

Ouahab, A., 2015. Les gisements d'économie d'énergie et des émissions de CO2 à l'horizon 2050 dans le secteur résidentiel algérien. Rev. Énerg. Renouvelables 18, 667–682.

Pajek, L., Košir, M., 2018. Implications of present and upcoming changes in bioclimatic potential for energy performance of residential buildings. Build. Environ. 127, 157–172.

Pajek, L., Košir, M., 2017. Can building energy performance be predicted by a bioclimatic potential analysis? Case study of the Alpine-Adriatic region. Energy Build. 139, 160–173.

Pajek, L., Tekavec, J., Drešček, U., Lisec, A., Košir, M., 2019. Bioclimatic potential of European locations: GIS supported study of proposed passive building design strategies, in: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p. 012008.

Pérez-Fargallo, A., Pulido-Arcas, J.A., Rubio-Bellido, C., Trebilcock, M., Piderit, B., Attia, S., 2018. Development of a new adaptive comfort model for low income housing in the central-south of Chile. Energy Build. 178, 94–106.

Poggi, F., Firmino, A., Amado, M., 2017. Assessing energy performances: A step toward energy efficiency at the municipal level. Sustain. Cities Soc. 33, 57–69.

Praene, J.P., Malet-Damour, B., Radanielina, M.H., Fontaine, L., Riviere, G., 2019. GIS-based approach to identify climatic zoning: A hierarchical clustering on principal component analysis. Build. Environ. 164, 106330.

Pudleiner, D., Colton, J., 2015. Using sensitivity analysis to improve the efficiency of a Net-Zero Energy vaccine warehouse design. Build. Environ. 87, 302–314.

Rahmouni, S., Smail, R., 2019. A design approach towards sustainable buildings in Algeria. Smart Sustain. Built Environ.

Rodríguez, G.C., Andrés, A.C., Muñoz, F.D., López, J.M.C., Zhang, Y., 2013. Uncertainties and sensitivity analysis in building energy simulation using macroparameters. Energy Build. 67, 79–87.

Roshan, G., Almomenin, H.S., da Silveira Hirashima, S.Q., Attia, S., 2019a. Estimate of outdoor thermal comfort zones for different climatic regions of Iran. Urban Clim. 27, 8–23.

Roshan, G., Oji, R., Attia, S., 2019b. Projecting the impact of climate change on design recommendations for residential buildings in Iran. Build. Environ. 155, 283–297.

Roshan, G.R., Farrokhzad, M., Attia, S., 2017a. Defining thermal comfort boundaries for heating and cooling demand estimation in Iran's urban settlements. Build. Environ. 121, 168–189.

Roshan, G.R., Ghanghermeh, A.A., Attia, S., 2017b. Determining new threshold temperatures for cooling and heating degree day index of different climatic zones of Iran. Renew. Energy 101, 156–167.

Sahabi Abed, S., Matzarakis, A., 2017. Seasonal regional differentiation of human thermal comfort conditions in Algeria. Adv. Meteorol. 2017.

Semahi, S., Attia, S., 2019b. Atlas of spatial distribution for energy demand and thermal comfort estimation in Algeria.

Semahi, S., Benbouras, M.A., Mahar, W.A., Zemmouri, N., Attia, S., 2020. Development of Spatial Distribution Maps for Energy Demand and Thermal Comfort Estimation in Algeria. Sustainability 12, 6066.

Semahi, S., Zemmouri, N., Singh, M.K., Attia, S., 2019b. Comparative bioclimatic approach for comfort and passive heating and cooling strategies in Algeria. Build. Environ. 161, 106271.

Seyedzadeh, S., Rahimian, F.P., Glesk, I., Roper, M., 2018. Machine learning for estimation of building energy consumption and performance: a review. Vis. Eng. 6, 5.

Shamshirband, S., Petković, D., Enayatifar, R., Abdullah, A.H., Marković, D., Lee, M., Ahmad, R., 2015. Heat load prediction in district heating systems with adaptive neuro-fuzzy method. Renew. Sustain. Energy Rev. 48, 760–767.

Shi, X., Tian, Z., Chen, W., Si, B., Jin, X., 2016. A review on building energy efficient design optimization rom the perspective of architects. Renew. Sustain. Energy Rev. 65, 872–884. https://doi.org/10.1016/j.rser.2016.07.050

Singh, M.K., Mahapatra, S., Teller, J., 2015. Development of thermal comfort models for various climatic zones of North-East India. Sustain. Cities Soc. 14, 133–145.

Singh, R., Lazarus, I.J., Kishore, V.V.N., 2016. Uncertainty and sensitivity analyses of energy and visual performances of office building with external venetian blind shading in hot-dry climate. Appl. Energy 184, 155–170.

Song Yanga, W.T., Cubic, E., Menga, Q., Liua, Y., Weia, L., 2016. Comparison of sensitivity analysis methods in building energy assessment. Procedia Eng. 146, 174–181.

Soufiane, F., Atef, A., Mohamed, M., Salaheddine, D., 2019. Quantifying the effectiveness of mass proportions and the orientation for buildings on thermal performance in Tebessa, Algeria, in: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p. 012008.

Stavrakakis, G.M., Tzanaki, E., Genetzaki, V.I., Anagnostakis, G., Galetakis, G., Grigorakis, E., 2012a. A computational methodology for effective bioclimatic-design applications in the urban environment. Sustain. Cities Soc. 4, 41–57.

Stavrakakis, G.M., Zervas, P.L., Sarimveis, H., Markatos, N.C., 2012b. Optimization of window-openings design for thermal comfort in naturally ventilated buildings. Appl. Math. Model. 36, 193–211.

Stevanović, S., 2013. Optimization of passive solar design strategies: A review. Renew. Sustain. Energy Rev. 25, 177–196.

Szokolay, S.V., 1986. Climate analysis based on the psychrometric chart. Int. J. Ambient Energy 7, 171–182.

Tabrizchi, H., Javidi, M.M., Amirzadeh, V., 2019. Estimates of residential building energy consumption using a multi-verse optimizer-based support vector machine with k-fold cross-validation. Evol. Syst. 1–13.

Talpur, N., Salleh, M.N.M., Hussain, K., 2017. An investigation of membership functions on performance of ANFIS for solving classification problems, in: IOP Conference Series: Materials Science and Engineering. IOP Publishing Melaka, Malaysia, p. 012103.

Tian, W., 2013. A review of sensitivity analysis methods in building energy analysis. Renew. Sustain. Energy Rev. 20, 411–419.

Tian, W., Choudhary, R., 2012. A probabilistic energy model for non-domestic building sectors applied to analysis of school buildings in greater London. Energy Build. 54, 1–11.

Tian, Z., Zhang, X., Jin, X., Zhou, X., Si, B., Shi, X., 2018. Towards adoption of building energy simulation and optimization for passive building design: A survey and a review. Energy Build. 158, 1306–1316.

Tuhus-Dubrow, D., Krarti, M., 2010. Genetic-algorithm based approach to optimize building envelope design for residential buildings. Build. Environ. 45, 1574–1581.

Verichev, K., Carpio, M., 2018. Climatic zoning for building construction in a temperate climate of Chile. Sustain. Cities Soc. 40, 352–364.

Visitsak, S., Haberl, J.S., 2016. An analysis of design strategies for climate-controlled residences in selected climates. Proc. SimBuild 1.

Walsh, A., Cóstola, D., Labaki, L.C., 2018. Performance-based validation of climatic zoning for building energy efficiency applications. Appl. Energy 212, 416–427.

Walsh, A., Cóstola, D., Labaki, L.C., 2017. Review of methods for climatic zoning for building energy efficiency programs. Build. Environ. 112, 337–350.

Wang, Z., Srinivasan, R.S., 2017. A review of artificial intelligence based building energy use prediction: Contrasting the capabilities of single and ensemble prediction models. Renew. Sustain. Energy Rev. 75, 796–808.

Watson, D., Labs, K., 1983. Climatic Design: Energy-efficient Building Principles and Practices. McGraw-Hill.

Wei, Y., Zhang, X., Shi, Y., Xia, L., Pan, S., Wu, J., Han, M., Zhao, X., 2018. A review of data-driven approaches for prediction and classification of building energy consumption. Renew. Sustain. Energy Rev. 82, 1027–1047.

Yaiche, M.R., Bouhanik, A., Bekkouche, S.M.A., Malek, A., Benouaz, T., 2014. Revised solar maps of Algeria based on sunshine duration. Energy Convers. Manag. 82, 114–123.

Yıldız, Y., Arsan, Z.D., 2011. Identification of the building parameters that influence heating and cooling energy loads for apartment buildings in hot-humid climates. Energy 36, 4287–4296.

Yong, S.-G., Kim, J.-H., Gim, Y., Kim, J., Cho, J., Hong, H., Baik, Y.-J., Koo, J., 2017. Impacts of building envelope design factors upon energy loads and their optimization in US standard climate zones using experimental design. Energy Build. 141, 1–15.

Yu, W., Li, B., Jia, H., Zhang, M., Wang, D., 2015. Application of multi-objective genetic algorithm to optimize energy efficiency and thermal comfort in building design. Energy Build. 88, 135–143.

Zhang, Y., 2012. Use jEPlus as an efficient building design optimisation tool, in: CIBSE ASHRAE Technical Symposium, London, Apr. pp. 18–19.

Zhang, Y., 2009. Parallel EnergyPlus and the development of a parametric analysis tool. IBPSA BS2009 27–30.

Zhao, H., Magoulès, F., 2012. A review on the prediction of building energy consumption. Renew. Sustain. Energy Rev. 16, 3586–3592.

Appendix A: evolution of residential housing typologies in Algeria

➢ *Constructed dwellings between 2004 and 2012 in Algeria (ONS, 2018):*

Année	LPL	LSP	Loc vente	Promptionnel	Aoto-construction	Total urbain	Rural	Total
2004	24668	17285	5885	9292	35293	92423	24045	**116468**
2005	25834	15787	12350	8027	27574	89572	42907	**132479**
2006	43527	23769	7128	8435	18630	101489	76287	**177776**
2007	44079	19325	8491	5028	14671	91594	88336	**179930**
2008	57657	37123	1827	4070	15176	115853	104968	**220821**
2009	55550	37924	9043	5644	18142	126303	91492	**217795**
2010	61316	28889	7777	4891	11761	114634	76239	**190873**
2011	74317	28114	6816	6061	30836	146144	66521	**212665**
2012	66259	24732	2422	5454	14750	113617	85562	**199179**
Total	**428539**	**215663**	**55854**	**47610**	**151540**	**899206**	**632312**	**1531518**

- *Breakdown of constructed rural dwellings by Province (wilaya) between 1999 and 2005* (MHUV, 2018)*:*

WILAYA	1999		2000		2001		2002		2003		2004		2005	
	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés
ADRAR	7.410	5.412	8.610	7.584	9.210	8.610	9.010	8.610	9.060	8.209	23 811	11 313	24 897	21 616
CHLEF	10.100	7.711	11.800	8.901	12.800	9.763	13.300	11.812	13.200	11.562	13 400	11 575	25 400	13 607
LAGHOUAT	4.310	2.778	4.802	3.761	4.802	4.588	5.202	4.782	5.652	4.802	5 252	4 520	7 852	5 095
OUM EL BOUAGHI	4.565	2.890	5.065	3.468	5.065	4.131	5.465	4.920	5.865	4.964	4 695	3 804	10 195	4 047
BATNA	8.640	6.470	9.740	7.953	10.240	9.174	10.340	9.543	10.840	9.555	9 240	8 474	19 240	8 947
BEJAIA	7.575	4.924	9.675	5.807	10.768	6.579	11.168	8.584	12.518	9.336	11 918	8 133	21 918	8 976
BISKRA	5.197	4.501	5.997	5.256	5.997	5.997	6.497	5.997	6.310	5.121	5 810	4 591	11 310	5 310
BECHAR	3.390	2.465	3.590	2.814	3.590	3.043	3.990	3.210	4.190	3.327	5 940	2 774	8 440	3 666
BLIDA	3.740	2.021	4.540	2.754	4.540	3.045	4.940	3.646	5.010	3.627	3 809	2 950	6 809	3 267
BOUIRA	6.450	4.099	7.750	5.385	7.750	6.125	8.250	6.242	10.200	6.242	9 100	4 922	15 600	6 485
TAMANRASSET	4.980	4.711	5.780	5.316	5.780	5.697	6.080	5.710	6.280	5.727	4 240	3 880	7 240	4 208
TEBESSA	5.165	3.950	5.765	4.795	6.965	5.481	7.465	6.655	8.165	6.972	7 765	7 030	15 765	7 761
TLEMCEN	6.590	3.973	7.890	5.252	7.890	6.375	7.990	7.058	9.390	7.518	8 970	6 659	17 970	7 877
TIARET	6.925	6.605	7.725	7.475	8.720	7.725	9.220	7.854	10.320	8.289	9 920	7 315	18 420	8 417
TIZI OUZOU	7.295	3.946	8.995	4.848	8.995	5.815	9.495	6.869	11.795	7.268	10 885	6 119	30 885	6 869
ALGER	200	200	200	200	200	200	200	200	350	200	150	0	150	0
DJELFA	6.305	4.806	7.305	5.477	8.305	6.078	8.705	6.936	8.655	7.067	9 655	6 903	19 155	8 213
JIJEL	6.186	4.362	6.986	5.059	6.986	5.288	7.386	5.536	7.736	5.589	6 810	4 691	11 810	5 422
SETIF	9.540	7.217	13.840	9.050	15.840	11.693	16.840	12.340	17.390	13.113	19 390	12 274	25 390	13 256
SAIDA	4.445	2.858	4.745	3.790	6.078	4.064	6.478	4.070	7.078	3.919	5 150	3 358	10 150	3 638
SKIKDA	7.400	5.254	8.400	6.328	8.400	6.663	8.700	6.855	10.000	6.247	8 740	4 854	15 740	4 916
SIDI BEL ABBES	5.590	3.925	6.090	4.700	7.090	5.449	7.590	5.760	8.040	5.824	10 447	5 242	14 447	6 110
ANNABA	2.375	1.867	2.875	2.063	2.875	2.150	3.075	2.150	4.325	2.221	5 196	1 699	10 196	1 919
GUELMA	4.570	3.773	5.170	4.275	5.670	4.757	6.070	5.077	6.470	5.502	6 070	5 113	12 070	5 550
CONSTANTINE	3.050	1.751	3.350	2.023	3.350	2.430	3.550	2.685	3.750	2.796	2 880	2 358	6 380	2 592
MEDEA	9.040	8.543	10.640	8.825	11.640	9.440	12.140	10.262	12.740	10.709	13 560	10 098	21 560	11 276
MOSTAGANEM	6.160	5.559	7.360	5.835	7.736	6.797	8.136	7.582	9.036	7.716	9 016	7 473	15 016	8 320
M'SILA	7.655	5.519	8.955	6.519	10.455	6.932	10.955	7.831	11.155	8.895	9 755	8 503	18 255	9 090
MASCARA	4.910	2.394	5.810	2.793	6.810	3.982	7.310	5.105	8.410	6.624	10 322	6 382	19 322	7 951
OUARGLA	4.455	3.740	4.855	4.296	4.855	4.379	5.155	4.611	4.655	3.961	5 355	3 404	10 355	4 380
ORAN	3.756	2.859	4.456	2.988	4.456	3.258	3.856	3.395	5.006	3.666	4 168	3 353	4 668	3 579
EL BAYADH	3.975	3.482	4.475	3.815	4.475	4.110	4.875	4.244	7.225	4.095	6 625	3 798	17 125	4 552
ILLIZI	3.650	3.101	3.750	3.376	3.750	3.553	4.150	3.649	4.150	3.712	3 140	1 753	3 640	1 916
BORDJ BOU ARRERIDJ	5.960	4.268	6.960	4.987	7.010	5.727	7.410	6.191	7.440	6.264	7 306	5 242	11 806	5 907
BOUMERDES	5.450	2.872	6.250	3.133	6.250	4.318	6.650	4.548	7.000	4.564	5 300	3 391	10 300	3 680
EL TARF	5.775	5.005	6.375	5.775	6.375	6.206	6.775	6.310	7.125	6.310	5 960	5 310	14 460	5 757
TINDOUF	3.405	2.853	3.605	3.080	3.605	3.232	3.805	3.232	3.255	2.805	2 464	1 995	3 424	2 285
TISSEMSILT	4.940	2.458	6.740	2.988	6.580	3.463	7.080	3.992	7.780	4.211	6 245	3 725	12 245	4 766
EL OUED	5.710	4.114	6.410	5.186	6.410	5.856	6.810	6.349	6.810	6.091	7 310	5 121	10 310	5 672
KHENCHELA	4.465	3.393	4.865	3.937	4.865	4.143	5.265	4.513	5.615	4.596	5 680	3 762	12 680	5 045
SOUK AHRAS	6.763	5.394	7.263	6.211	7.263	6.713	7.663	6.963	7.825	6.881	6 745	5 956	13 245	6 237
TIPAZA	7.650	5.022	7.650	5.846	7.650	6.406	8.050	6.591	7.350	5.183	7 371	4 387	10 871	4 693
MILA	5.920	3.193	7.020	4.090	7.020	4.968	7.420	5.621	7.820	5.912	6 450	5 146	11 450	5 518
AIN DEFLA	8.535	4.743	9.735	5.228	9.835	6.721	10.335	8.043	10.935	8.639	11 175	7 885	17 675	8 944
NAAMA	3.110	2.794	3.310	3.088	3.310	3.278	3.710	3.297	4.910	3.223	4 526	3 441	10 526	4 324
AIN TEMOUCHENT	3.310	2.346	4.310	2.933	4.310	3.582	4.710	3.695	5.860	4.267	5 260	4 249	8 260	4 850
GHARDAIA	4.505	2.619	4.705	3.022	4.705	3.402	5.105	3.922	4.755	3.530	4 355	3 615	7 355	4 157
RELIZANE	6.705	5.055	7.605	6.003	7.605	6.835	8.105	7.453	9.005	7.527	7 755	6 926	13 755	7 710

➢ *Breakdown of constructed rural dwellings by Province (wilaya) between 2007 and 2009* (MHUV, 2018)*:*

WILAYA	2007		2008*		2009	
	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés
ADRAR	33 977	23 600	22 664	14 295	27 664	18 970
CHLEF	28 774	23 792	19 199	13 946	20 699	16 070
LAGHOUAT	11 852	6 709	7 332	2 819	7 332	3 444
OUM EL BOUAGHI	13 662	8 264	11 398	8 057	12 698	9 543
BATNA	24 136	14 203	17 662	12 999	18 162	15 793
BEJAIA	21 743	10 857	15 110	5 794	15 110	10 429
BISKRA	16 502	8 885	12 911	6 678	12 911	8 844
BECHAR	15 508	8 410	13 234	7 789	14 984	10 486
BLIDA	8 880	4 369	5 930	1 878	4 665	2 701
BOUIRA	20 750	10 482	21 611	8 219	23 011	10 543
TAMANRASSET	10 474	6 313	6 594	4 500	6 594	6 249
TEBESSA	21 499	15 951	15 969	13 138	16 469	15 012
TLEMCEN	23 296	10 190	16 637	6 120	18 637	8 541
TIARET	23 746	16 258	18 931	14 185	19 953	17 158
TIZI OUZOU	28 820	10 342	24 201	11 143	28 201	16 181
ALGER	896	0	896	0	896	0
DJELFA	26 305	10 847	19 402	6 971	19 402	10 484
JIJEL	12 114	8 048	9 423	4 389	9 423	5 785
SETIF	30 880	23 418	21 606	14 090	21 606	17 069
SAIDA	13 374	4 976	10 016	2 220	10 016	3 574
SKIKDA	11 987	5 735	9 133	4 183	9 633	6 067
SIDI BEL ABBES	18 447	9 302	9 205	5 757	9 205	7 169
ANNABA	9 758	3 678	8 059	4 860	8 059	6 492
GUELMA	12 881	9 385	9 768	6 046	10 268	7 433
CONSTANTINE	9 036	5 604	6 178	3 622	5 178	3 747
MEDEA	25 260	15 846	15 902	9 023	16 402	11 117
MOSTAGANEM	18 182	14 469	12 209	7 638	13 709	9 555
M'SILA	21 475	17 136	15 972	10 659	16 972	12 130
MASCARA	20 126	15 575	15 744	12 205	18 344	13 715
OUARGLA	16 050	7 613	13 146	5 911	14 646	8 398
ORAN	5 042	4 075	1 789	849	1 689	1 047
EL BAYADH	20 265	8 521	16 467	8 620	18 467	12536
ILLIZI	5 756	2 755	4 003	1 541	4 003	1 927
BORDJ BOU ARRERIDJ	14 110	10 195	11 368	6 514	12 368	7 716
BOUMERDES	8 626	3 829	3 909	742	4 909	1 114
EL TARF	13 860	8 599	10 050	4 881	11 050	6 775
TINDOUF	5 040	2 805	3 045	1 168	3 045	1 469
TISSEMSILT	14 812	8 247	12 587	6 129	12 587	9 149
EL OUED	14 590	7 633	9 469	4 254	9 469	6 136
KHENCHELA	20 910	9 325	17 648	9 078	18 648	11 280
SOUK AHRAS	18 845	9 778	12 889	6 322	13 389	8 282
TIPAZA	11 127	5 537	7 640	2 691	9 640	4 176
MILA	12 300	8 021	8 654	3 981	11 654	5 253
AIN DEFLA	17 946	12 659	13 061	6 761	14 061	8 372
NAAMA	14 782	6 194	11 341	5 128	12 319	7 723
AIN TEMOUCHENT	8 260	5 956	4 511	2 992	6 011	3 714
GHARDAIA	11 868	6 045	8 253	3 650	12 753	4 673
RELIZANE	15 505	12 618	10 579	8 116	13 579	9 949

- *Breakdown of constructed urban dwellings by Province (wilaya) between 1999 and 2005* (MHUV, 2018)*:*

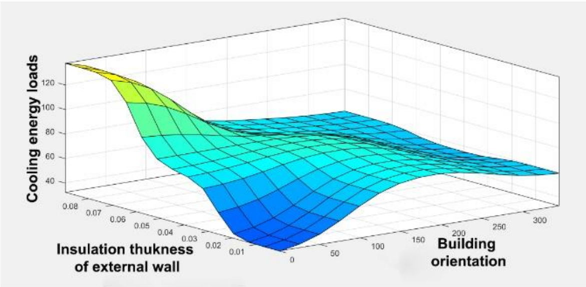
WILAYA	1999		2000		2001		2002		2003		2004		2005	
	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés
ADRAR	6.485	4.012	7.167	5.806	5.968	4.829	7.429	6.479	6.945	5.317	8 611	6 783	11 120	7 899
CHLEF	18.190	12.520	19523	14.383	20.433	15.180	20.579	16.463	19.841	16.793	17 643	15 239	30 897	16 912
LAGHOUAT	13.081	9.982	13.185	10.972	8.962	7.252	7.625	6.469	8.248	6.688	7 621	7 181	10 216	7 637
OUM EL BOUAGHI	19.015	13.082	18.573	13.264	22.669	16.767	19.043	14.220	18.685	15.485	18 278	16 317	22 319	11 035
BATNA	32.141	24.023	32.640	26.482	24.770	18.838	21.973	17.762	22.685	18.315	20 870	16 954	27 328	13 162
BEJAIA	22.124	16.328	24.776	18.210	22.402	15.770	23.706	17.711	22.299	15.169	18 336	12 847	27 739	14 787
BISKRA	15.704	11.801	15.541	13.727	14.088	11.722	13.442	11.190	12.902	10.579	14 050	12 958	23 668	13 636
BECHAR	9.043	7.533	9.653	7.431	11.387	9.080	9.200	7.434	9.022	7.782	10 022	8 702	15 297	8 963
BLIDA	22.624	14.667	24.806	15.886	30.442	18.920	27.956	17.658	27.064	18.294	19 205	12 779	29 880	14 548
BOUIRA	23.907	17.428	25.585	17.645	17.189	9.722	16.349	12.857	15.724	12.956	10 916	9 123	21 116	9 217
TAMANRASSET	6.178	5.302	6.076	4.467	5.525	4.144	5.725	5.207	5.448	4.982	5 948	4 878	8 034	5 030
TEBESSA	17.922	14.687	18.644	15.321	16.755	12.397	15.420	12.885	12.571	10.416	10 673	9 532	18 763	9 964
TLEMCEN	28.839	23.162	34.343	25.892	31.905	23.086	27.700	20.983	23.038	17.345	19 873	17 230	34 474	17 892
TIARET	21.994	18.302	18.218	14.244	25.323	20.844	26.539	21.531	27.286	22.426	19 318	15 209	23 817	15 771
TIZI OUZOU	27.075	16.786	28.192	17.849	31.146	19.437	29.765	20.736	29.111	19.707	19 597	12 327	25 772	13 585
ALGER	84.888	40.115	91.205	49.718	119.984	58.037	125.111	64.244	136.996	63.865	128 974	58 628	157 666	56 647
DJELFA	23.470	18.348	24.280	20.492	18.318	14.651	14.870	13.134	15.702	14.132	15 849	14 914	25 180	15 491
JIJEL	16.772	11.394	16.386	11.630	15.464	10.829	15.552	11.669	11.714	8.445	11 093	8 949	15 762	9 289
SETIF	34.722	28.627	36.612	30.801	38.241	33.393	39.565	35.523	40.409	34.447	20 000	15 159	35 830	16 326
SAIDA	10.093	8.291	11.617	8.608	13.436	10.322	13.344	10.585	12.554	9.849	10 033	8 930	13 126	8 665
SKIKDA	26.091	20.019	26.385	19.672	24.688	16.576	22.531	15.300	22.010	15.671	19 178	12 873	22 981	12 370
SIDI BEL ABBES	20.820	16.197	26.927	17.715	28.523	19.385	28.051	21.846	27.991	19.882	24 730	20 622	37 521	23 417
ANNABA	39.782	33.256	38.200	31.248	43.557	31.325	34.072	25.170	34.988	25.855	24 308	15 973	39 005	17 959
GUELMA	19.048	16.379	19.524	16.389	14.225	9.812	12.798	9.845	11.082	8.482	10 070	8 309	18 680	9 141
CONSTANTINE	55.730	42.244	61.007	44.868	68.413	47.243	50.825	33.979	43.590	26.765	35 951	24 255	54 515	26 377
MEDEA	29.627	25.323	31.952	25.804	31.026	24.749	17.804	12.879	17.647	13.491	16 362	12 366	21 948	13 167
MOSTAGANEM	20.362	15.638	21.665	15.750	18.982	13.514	18.342	14.314	18.631	13.518	15 210	12 850	24 027	14 317
M'SILA	24.749	19.435	22.011	16.987	25.436	19.215	22.494	17.894	20.294	15.950	18 739	15 239	25 929	17 151
MASCARA	16.456	12.886	17.306	13.826	16.620	12.440	17.047	13.985	17.740	13.726	17 699	15 153	25 715	16 156
OUARGLA	14.480	10.716	15.553	12.139	12.653	8.739	11.975	9.176	10.450	7.138	11 317	8 470	18 677	9 845
ORAN	35.312	24.965	35.910	26.101	49.411	30.834	53.328	33.813	51.553	33.215	43 626	28 887	74 080	33 526
EL BAYADH	6.676	4.975	6.760	5.096	6.795	5.172	6.738	5.244	6.344	4.745	6 372	5 822	8 272	6 124
ILLIZI	3.207	2.505	3.905	2.840	4.156	2.832	4.307	3.229	4.434	3.445	4 400	3 876	6 519	4 150
BORDJ BOU ARRERIDJ	16.862	11.833	17.862	13.048	20.455	15.687	19.609	15.302	20.701	14.819	18 196	13 791	24 774	15 476
BOUMERDES	24.375	16.977	26.211	18.659	29.763	20.998	28.136	20.311	37.033	20.879	25 764	10 737	32 308	13 008
EL TARF	13.913	11.207	13.487	11.307	15.620	13.196	15.669	13.414	15.793	13.989	10 750	9 918	14 735	10 477
TINDOUF	2.772	1.871	3.272	2.016	3.380	2.280	3.080	2.344	3.372	2.456	3 822	2 868	4 882	3 102
TISSEMSILT	10.669	6.677	10.877	7.093	11.364	7.808	10.876	7.774	11.045	8.311	10 644	8 329	13 294	8 573
EL OUED	11.173	9.206	12.073	8.981	11.031	7.540	11.311	9.433	10.834	9.374	9 365	8 283	14 169	8 693
KHENCHELA	16.871	13.771	16.838	13.907	17.468	13.398	17.473	14.181	10.628	7.399	10 261	8 334	18 605	8 635
SOUK AHRAS	15.860	13.262	16.255	13.448	17.729	14.764	17.039	15.198	16.206	15.234	12 756	12 229	20 869	10 838
TIPAZA	24.447	18.113	26.225	19.329	25.252	16.625	23.984	16.939	24.993	17.030	18 395	12 517	26 220	13 490
MILA	14.137	9.905	15.087	11.472	10.682	7.372	10.550	8.180	11.100	9.128	9 844	7 990	15 232	8 414
AIN DEFLA	15.080	8.684	16.070	8.990	16.571	10.185	16.130	11.309	16.494	11.229	15 520	12 171	21 080	13 713
NAAMA	7.757	6.303	8.125	6.588	9.096	7.934	9.268	7.941	10.164	7.923	9 314	7 788	9 036	6 249
AIN TEMOUCHENT	14.495	11.393	20.592	12.749	17.452	11.002	17.437	12.992	17.775	13.331	13 901	12 795	23 301	13 990
GHARDAIA	9.088	5.801	10.188	6.611	9.001	5.053	9.606	6.368	10.063	6.892	10 076	8 274	17 726	8 565
RELIZANE	20.705	16.196	22.970	18.140	17.740	12.716	17.594	13.288	18.135	15.977	13 830	12 516	21 976	13 651

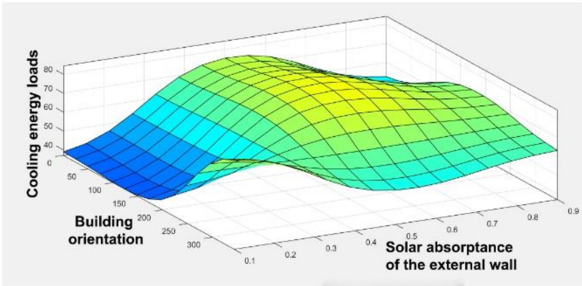
➢ *Breakdown of constructed urban dwellings by Province (wilaya) between 2007 and 2009* (MHUV, 2018)*:*

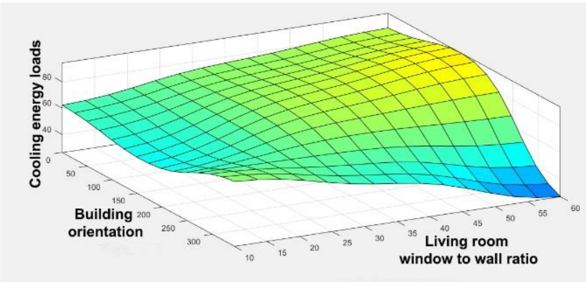
WILAYA	2007		2008*		2009	
	Inscrits	Achevés	Inscrits	Achevés	Inscrits	Achevés
ADRAR	12 895	9 366	6 527	2 831	7 551	3 247
CHLEF	28 759	14 484	18 494	6 138	18 479	9 270
LAGHOUAT	15 733	9 485	10 009	3 686	9 173	4 793
OUM EL BOUAGHI	26 949	13 852	16 295	6 358	18 564	9 270
BATNA	31 794	16 688	22 908	8 120	26 914	13 019
BEJAIA	25 304	14 308	16 742	7 353	18 343	11 258
BISKRA	25 373	16 090	15 090	6 002	17 659	7 766
BECHAR	11 463	7 809	6 411	3 574	6 865	4 430
BLIDA	32 948	19 083	20 697	8 809	24 677	11 966
BOUIRA	21 038	9 750	11 482	1 893	14 198	3 284
TAMANRASSET	10 354	6 254	5 670	2 573	5 589	3 213
TEBESSA	18 529	12 168	10 093	4 439	12 240	6 606
TLEMCEN	38 377	20 141	22 374	6 246	22 757	8 627
TIARET	27 017	20 522	16 438	8 809	17 647	10 369
TIZI OUZOU	28 824	16 006	18 303	5 594	21 193	7 598
ALGER	130 541	60 346	135 949	39 492	136 441	50 673
DJELFA	23 904	19 364	12 668	5 184	14 888	6 403
JIJEL	20 159	11 769	12 237	4 376	13 734	6 712
SETIF	42 166	26 782	34 253	16 656	37 167	21 216
SAIDA	13 448	7 684	8 620	2 502	9 453	3 101
SKIKDA	23 640	9 695	20 703	6 136	23 267	8 810
SIDI BEL ABBES	36 218	24 057	20 939	8 549	22 591	11 796
ANNABA	38 595	22 630	28 828	12 030	31 575	15 130
GUELMA	19 685	12 154	13 527	5 630	15 088	7 602
CONSTANTINE	60 623	32 387	42 177	13 478	51 452	18 030
MEDEA	25 308	16 013	17 242	5 669	22 071	7 542
MOSTAGANEM	26 966	16 196	17 615	7 914	20 345	10 443
M'SILA	28 714	19 759	17 598	7 057	21 705	9 014
MASCARA	21 189	14 859	13 383	5 785	14 963	7 710
OUARGLA	20 519	12 629	13 727	6 880	15 403	8 774
ORAN	72 729	33 568	55 801	21 588	60 815	27 783
EL BAYADH	10 252	6 252	5 050	1 726	5 865	2 303
ILLIZI	7 101	3 154	4 260	1 039	4 192	1 410
BORDJ BOU ARRERIDJ	25 589	17 387	19 876	9 279	22 112	11 470
BOUMERDES	31 776	17 214	26 386	12 138	30 375	14 483
EL TARF	13 837	7 198	9 737	1 969	11 729	3 338
TINDOUF	6 889	3 346	3 482	1 239	3 658	1 844
TISSEMSILT	13 503	6 917	9 755	2 214	11 204	3 532
EL OUED	18 678	9 743	11 129	2 425	8 760	3 586
KHENCHELA	17 438	10 605	10 646	4 134	12 078	5 218
SOUK AHRAS	16 391	10 901	9 370	2 275	10 138	3 045
TIPAZA	26 071	13 067	21 513	6 101	25 984	9 996
MILA	20 553	11 775	14 628	6 253	17 205	7 999
AIN DEFLA	23 264	15 795	12 824	5 238	15 324	6 499
NAAMA	8 680	6 216	3 677	1 942	4 003	2 454
AIN TEMOUCHENT	24 505	15 907	13 541	4 848	14 715	6 258
GHARDAIA	17 893	8 294	12 843	2 496	14 782	4 168
RELIZANE	20 542	12 783	13 908	5 828	17 381	7 560
TOTAL ALGERIE	**1 262 723**	**722 452**	**885 425**	**322 495**	**982 312**	**430 618**
Non affectés location - vente	55 764	/	40 770	/	…	/

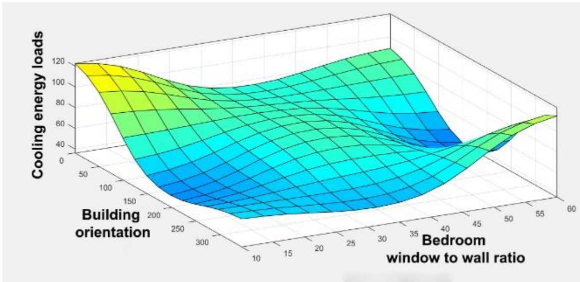
Appendix B: Predicted ANFIS non-linear relationship between inputs and outputs

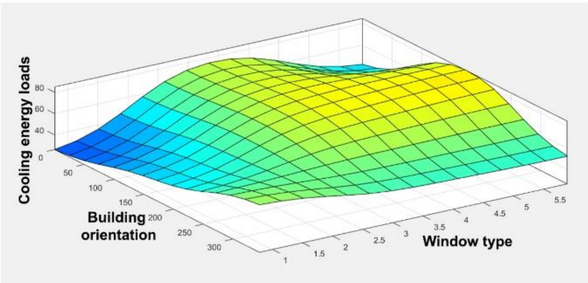
These figures presented the variation of cooling and heating energy loads based on two design variables variations. That means how the variation of two design variables affect the energy loads.

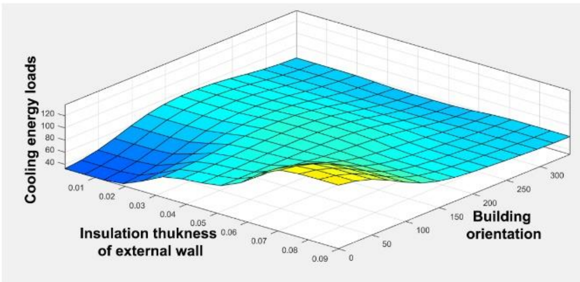


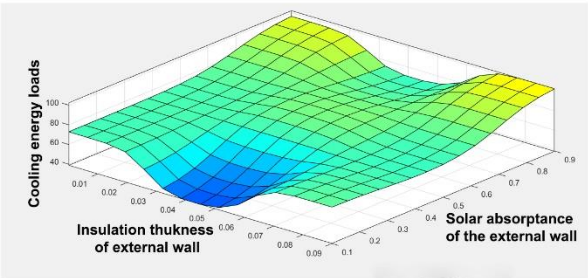


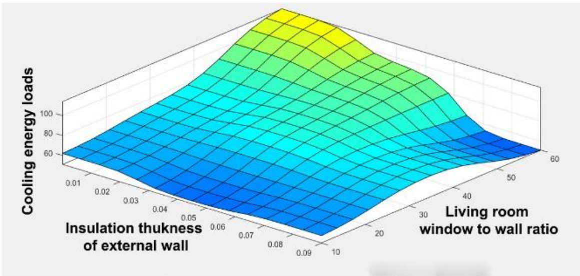


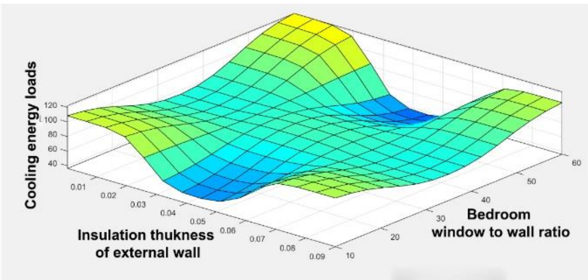


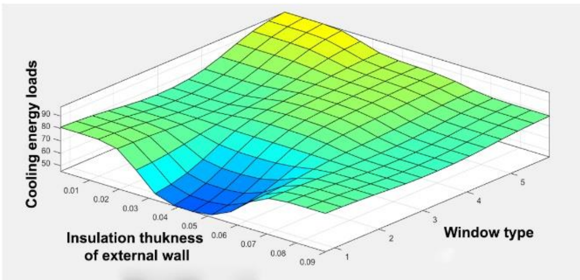


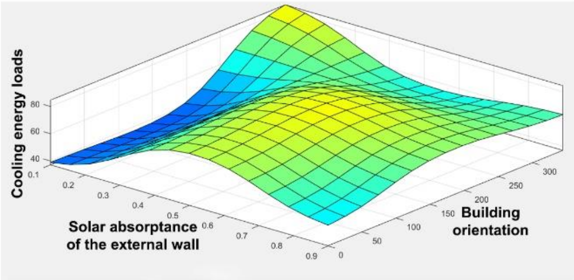


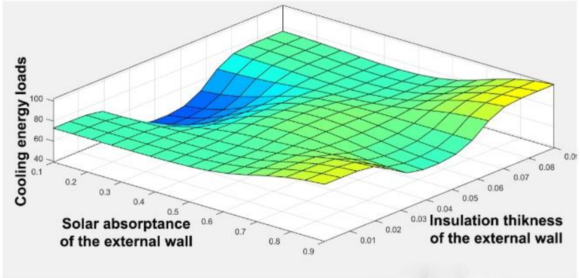


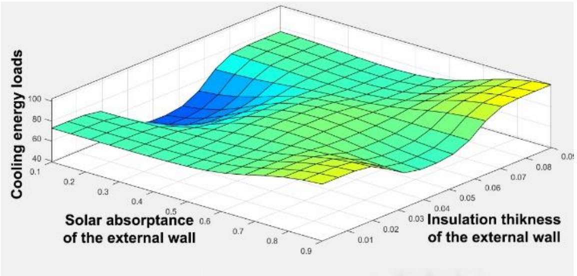


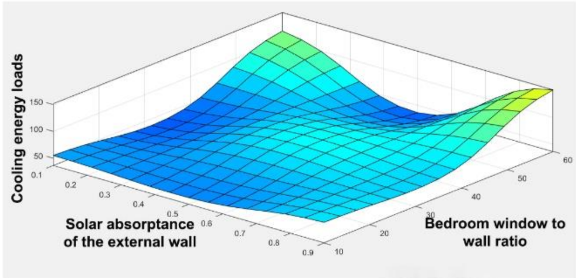


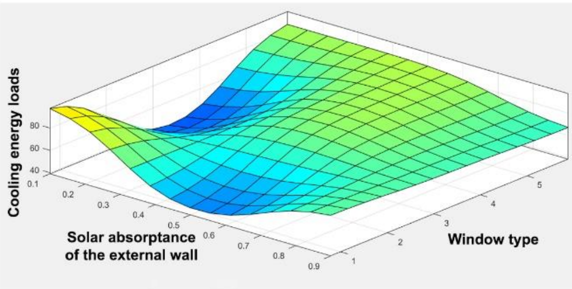


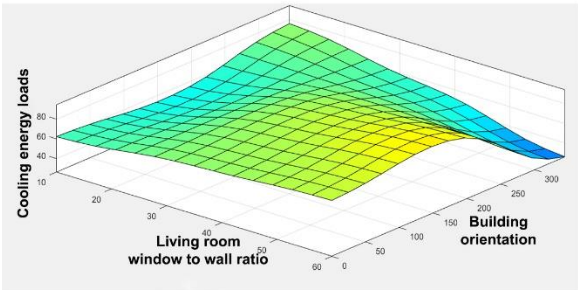

Cooling energy loads
Solar absorptance
of the external wall
Building
orientation

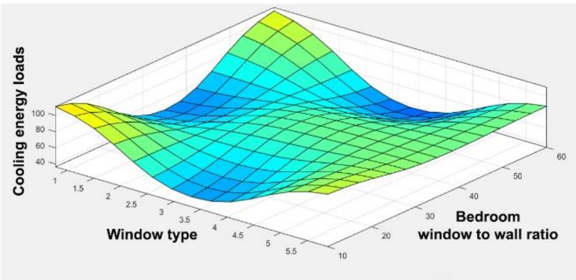

Cooling energy loads
Solar absorptance
of the external wall
Insulation thikness
of the external wall

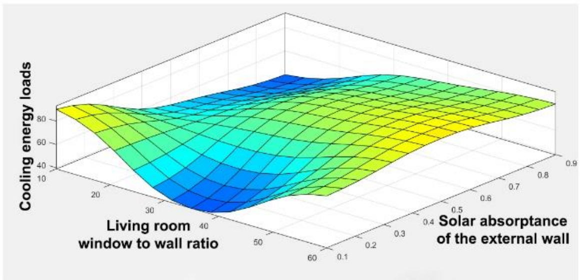

Cooling energy loads
Solar absorptance
of the external wall
Insulation thikness
of the external wall

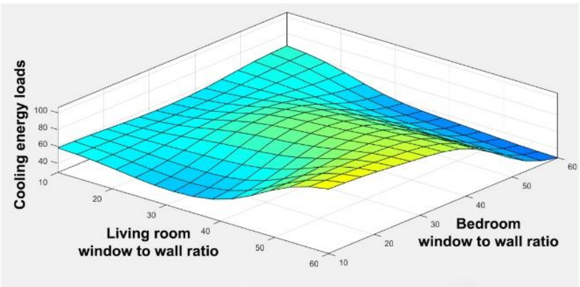

Cooling energy loads
Solar absorptance
of the external wall
Bedroom window to
wall ratio

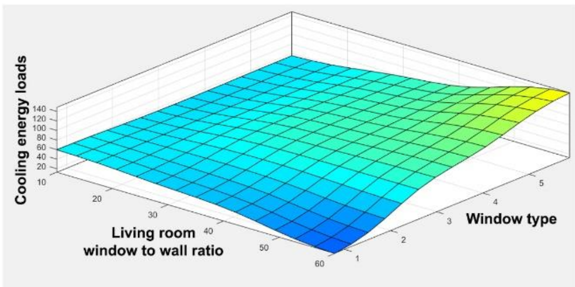

Cooling energy loads
Solar absorptance
of the external wall
Window type

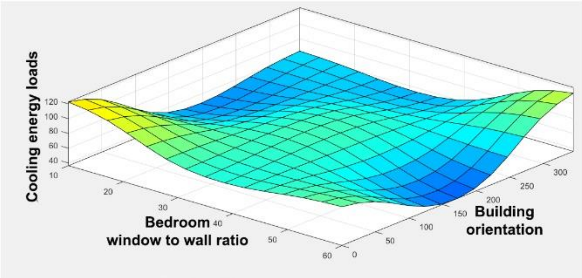

Cooling energy loads
Living room
window to wall ratio
Building
orientation

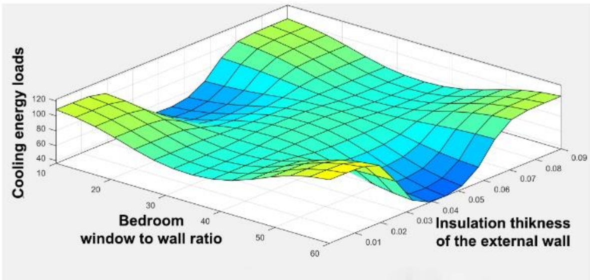

Cooling energy loads
Window type
Bedroom
window to wall ratio

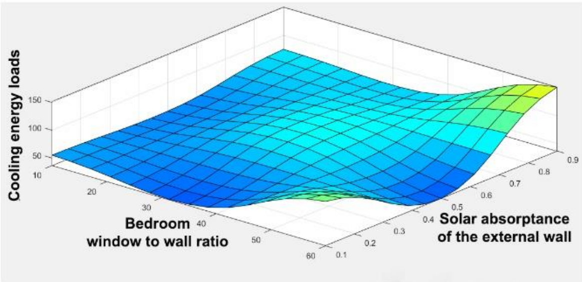

Cooling energy loads
Living room
window to wall ratio
Solar absorptance
of the external wall

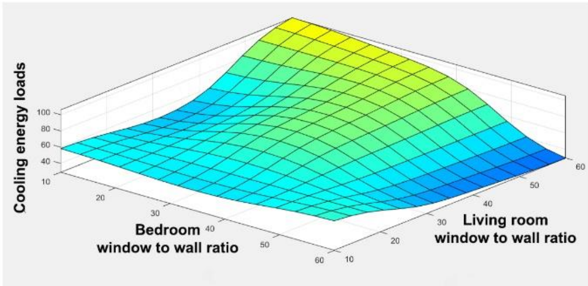

Cooling energy loads
Living room
window to wall ratio
Bedroom
window to wall ratio

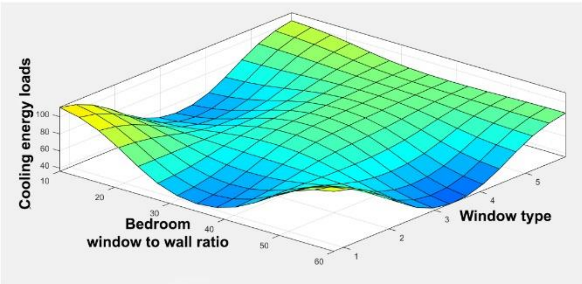

Cooling energy loads
Living room
window to wall ratio
Window type

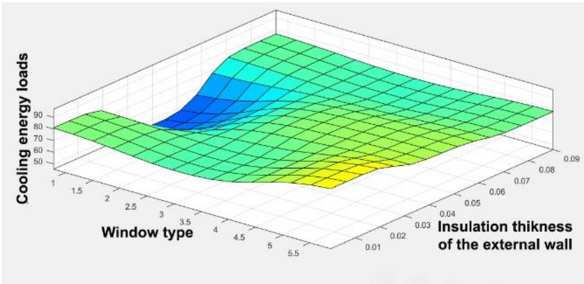

Cooling energy loads
Bedroom
window to wall ratio
Building
orientation

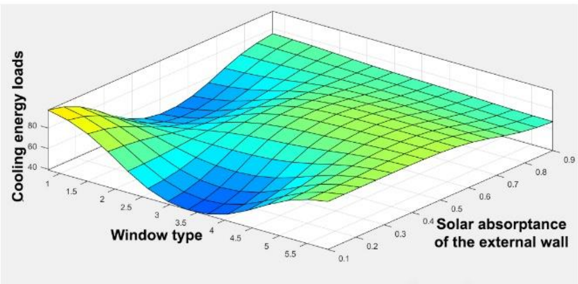

Cooling energy loads
Bedroom
window to wall ratio
Insulation thikness
of the external wall

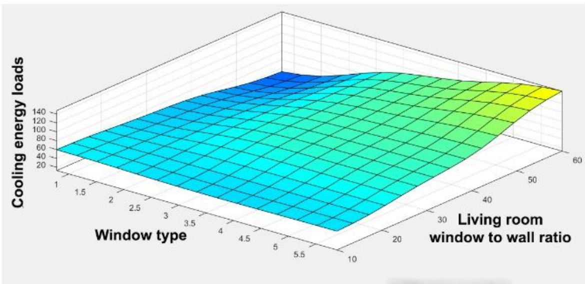

Cooling energy loads
Bedroom
window to wall ratio
Solar absorptance
of the external wall

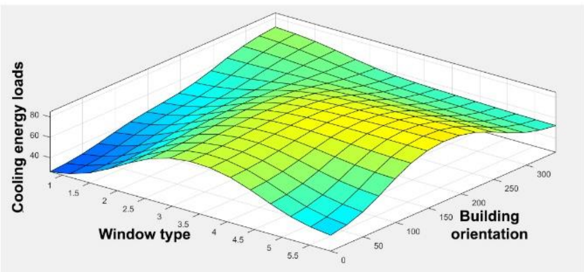

Cooling energy loads
Bedroom
window to wall ratio
Living room
window to wall ratio

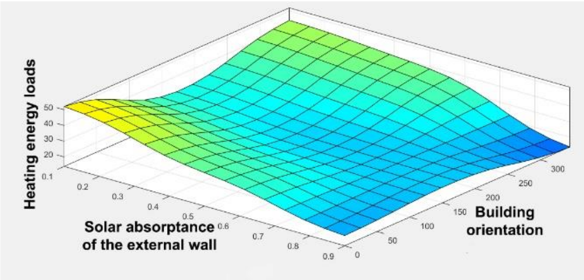

Cooling energy loads
Bedroom
window to wall ratio
Window type

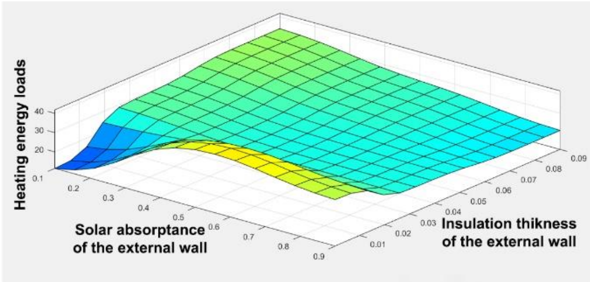

Cooling energy loads
Window type
Insulation thikness
of the external wall

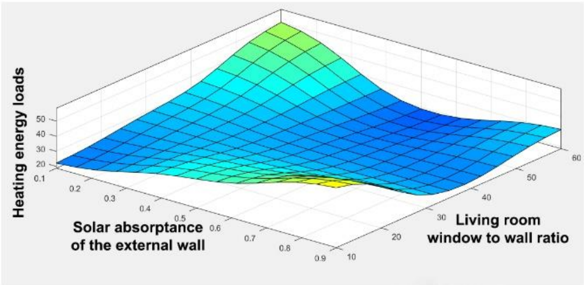

Cooling energy loads
Window type
Solar absorptance
of the external wall

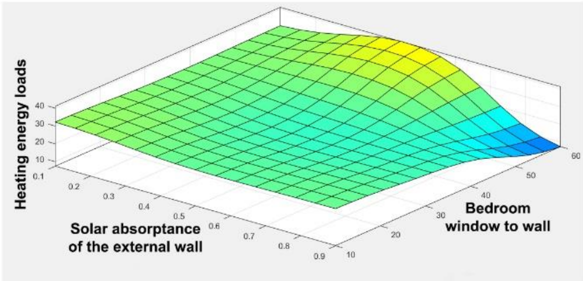

Cooling energy loads
Window type
Living room
window to wall ratio

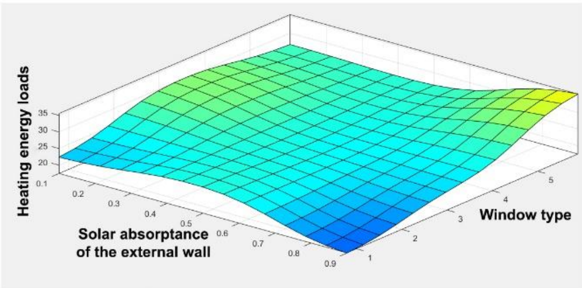

Cooling energy loads
Window type
Building
orientation

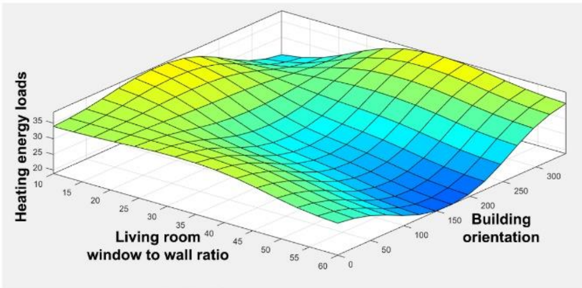

Heating energy loads
Solar absorptance of the external wall
Building orientation

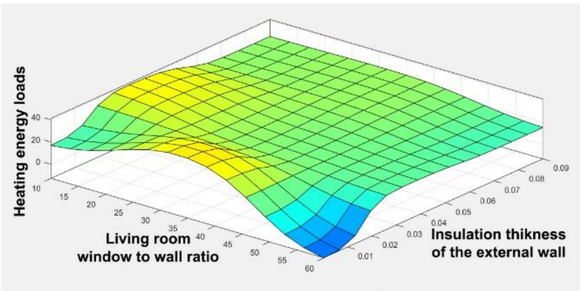

Heating energy loads
Solar absorptance of the external wall
Insulation thikness of the external wall

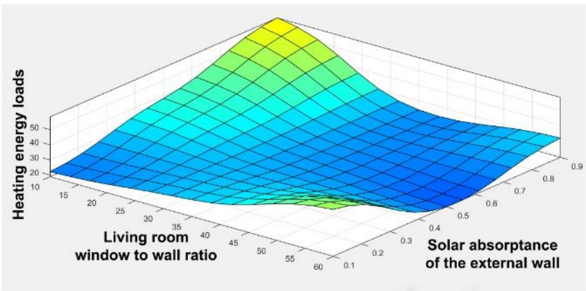

Heating energy loads
Solar absorptance of the external wall
Living room window to wall ratio

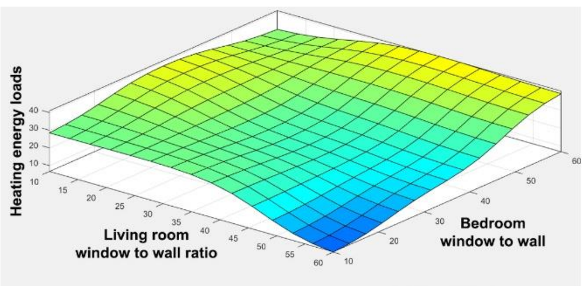

Heating energy loads
Solar absorptance of the external wall
Bedroom window to wall

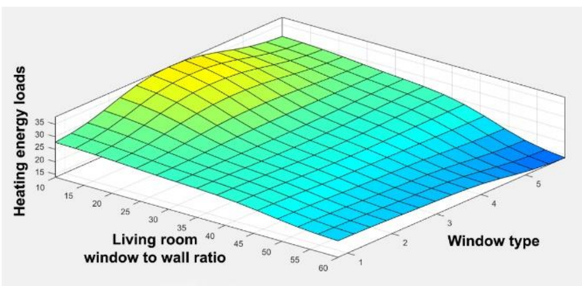

Heating energy loads
Solar absorptance of the external wall
Window type

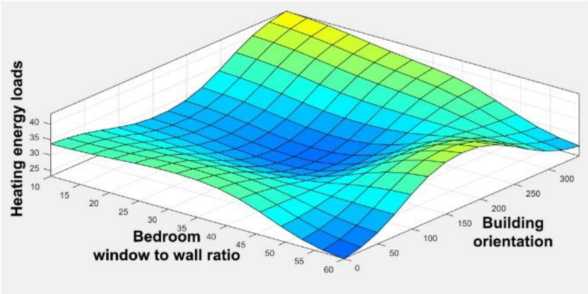

Heating energy loads
Living room window to wall ratio
Building orientation

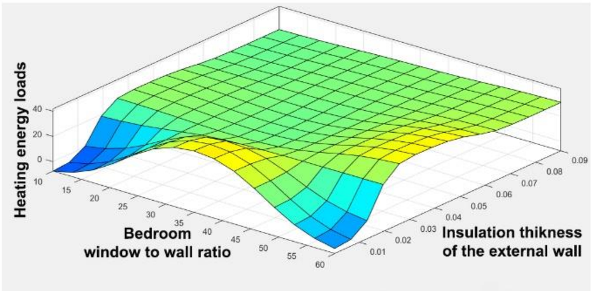

Heating energy loads
Living room window to wall ratio
Insulation thikness of the external wall

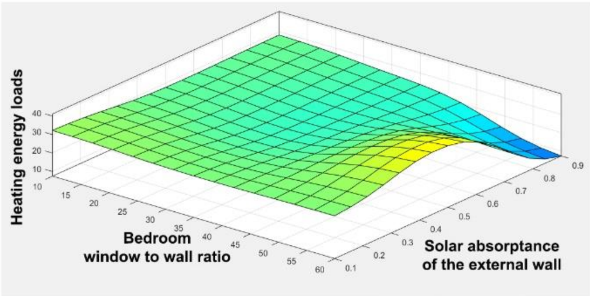

Heating energy loads
Living room window to wall ratio
Solar absorptance of the external wall

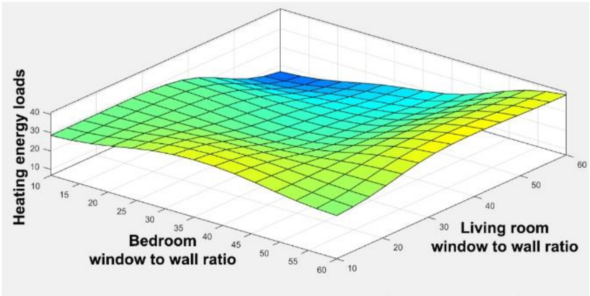

Heating energy loads
Living room window to wall ratio
Bedroom window to wall

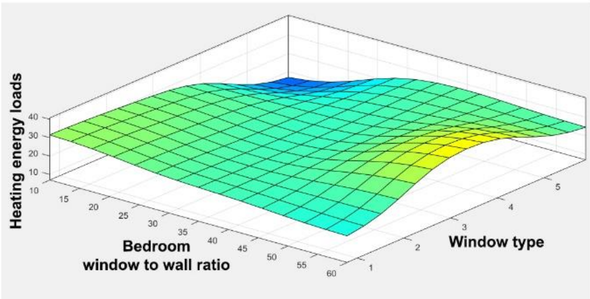

Heating energy loads
Living room window to wall ratio
Window type


Heating energy loads
Bedroom
window to wall ratio
Building
orientation


Heating energy loads
Bedroom
window to wall ratio
Insulation thikness
of the external wall


Heating energy loads
Bedroom
window to wall ratio
Solar absorptance
of the external wall


Heating energy loads
Bedroom
window to wall ratio
Living room
window to wall ratio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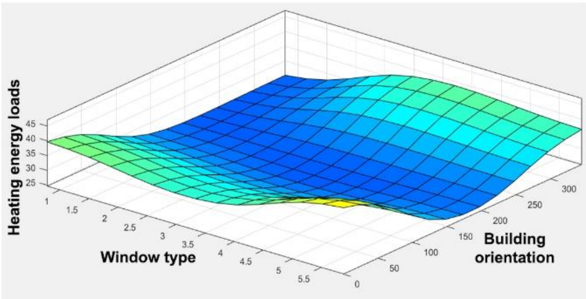
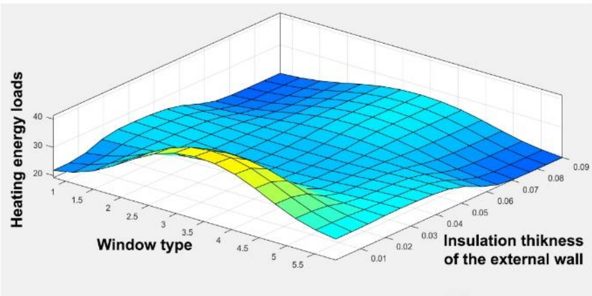
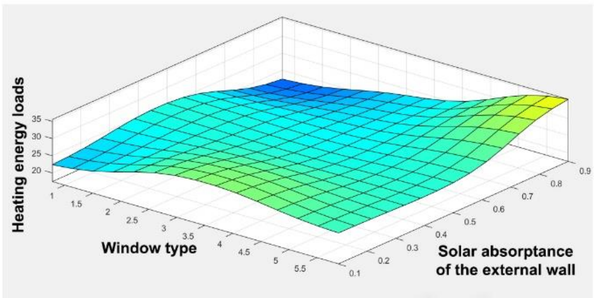
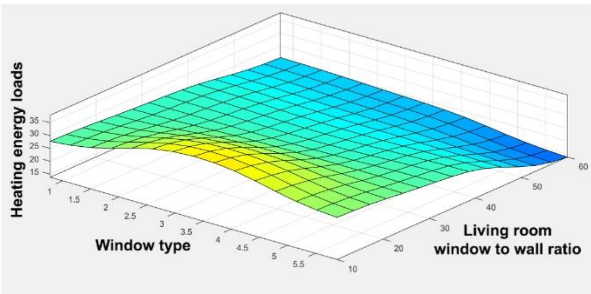
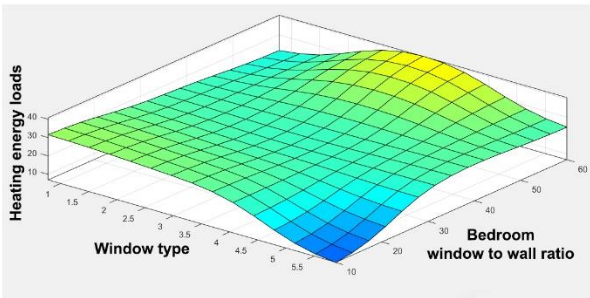
Bedroom
window to wall ratio
Window type

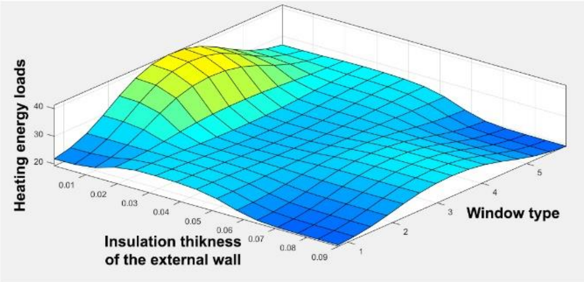

Heating energy loads
Window type
Building
orientation

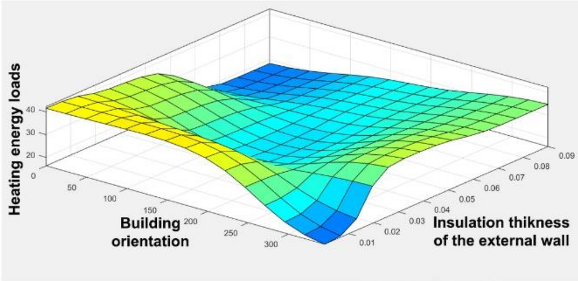

Heating energy loads
Window type
Insulation thikness
of the external wall

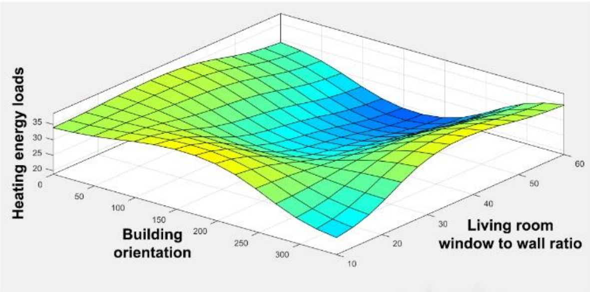

Heating energy loads
Window type
Solar absorptance
of the external wall

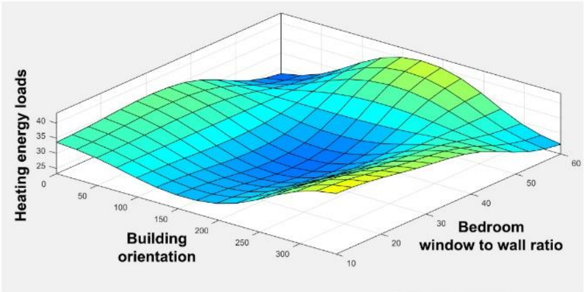

Heating energy loads
Window type
Living room
window to wall ratio

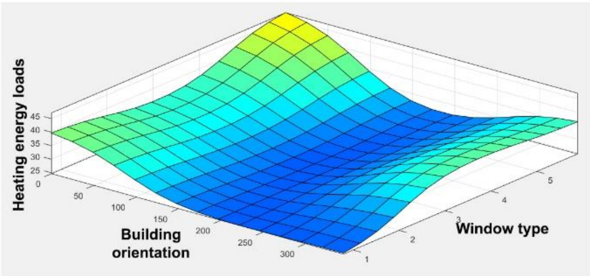

Heating energy loads
Window type
Bedroom
window to wall ratio

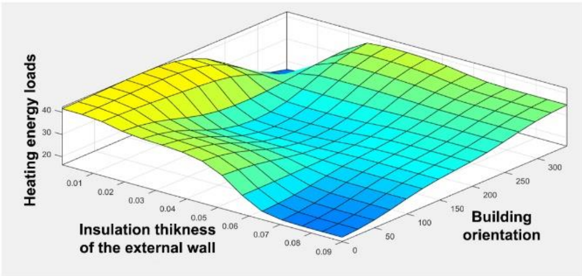

Heating energy loads
Insulation thikness
of the external wall
Window type

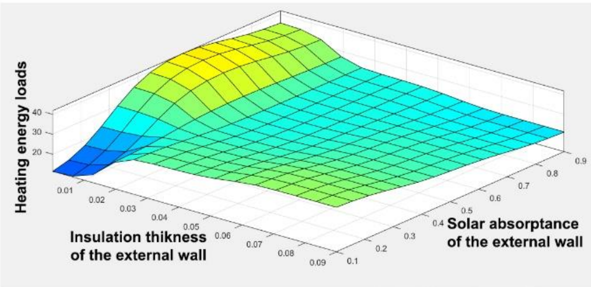

Heating energy loads
Building
orientation
Insulation thikness
of the external wall

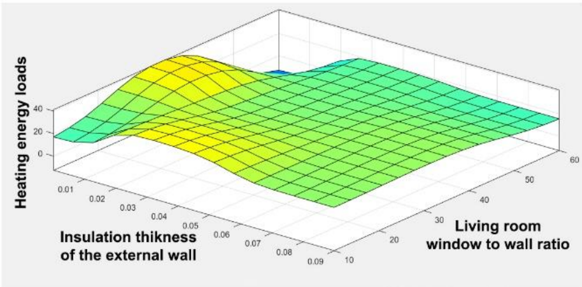

Heating energy loads
Building
orientation
Living room
window to wall ratio

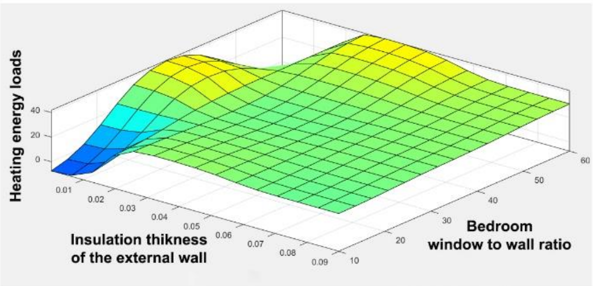

Heating energy loads
Building
orientation
Bedroom
window to wall ratio


Heating energy loads
Building
orientation
Window type


Heating energy loads
Insulation thikness
of the external wall
Building
orientation


Heating energy loads
Insulation thikness
of the external wall
Solar absorptance
of the external wall


Heating energy loads
Insulation thikness
of the external wall
Living room
window to wall ratio


Heating energy loads
Insulation thikness
of the external wall
Bedroom
window to wall ratio

Appendix c: author's research work

➢ Peer-reviewed journal articles:

- Semahi s., Djebri B., 2013, La conception des logements à haute performance énergétique (HPE) en Algérie-proposition d'un outil d'aide à la conception dans les zones aride et semi-aride, revue des énergies renouvelables, volume 16, n°3, CDER, Alger, pp.551-568.
- Semahi, S., Zemmouri, N., Singh, M. K., & Attia, S. (2019). Comparative bioclimatic approach for comfort and passive heating and cooling strategies in Algeria. *Building and Environment*, *161*, 106271.
- Semahi, S., Benbouras, M. A., Mahar, W. A., Zemmouri, N., & Attia, S. (2020). Development of Spatial Distribution Maps for Energy Demand and Thermal Comfort Estimation in Algeria. Sustainability, 12(15), 6066.

➢ Un-refereed publications:

- Semahi, S., Zemmouri, N., & Attia, S.: Evaluation of thermal comfort potential of passive heating and cooling strategies in Algeria. Presented at the 2019 Doctoral Seminar on Sustainability Research in the Built Environment (DS²BE-2019). Leuven, Belgium.
- Semahi, S., Benbouras, M.A., Attia,S. (2019), Atlas of spatial distribution for energy demand and thermal comfort estimation in Algeria, SBD Lab, Liège, Belgium, ISBN: 978-2-930909-16-5, https://orbi.uliege.be/handle/2268/238864
- Semahi, S., Zemmouri, N., Hamdy, M. & Attia, S. (2021) Passive envelope design optimization of residential buildings using NSGA-II in different Algerian climatic zones, Building Simulation 2021 Conference (BS2021), Bruges, Belgium.

➢ Refereed Conference Proceeding:

- BENABDELFATTAH Med., SEMAHI S., DJEBRI B., KEHILA Y., 2014, Le développement d'un document de travail à bord dédie à conception des logements hpe en Algérie dans les zones arides et semi-arides, Le 3ème Congrès de l'Association Marocaine de Thermique, Agadir, Maroc.
- SEMAHI s., DJEBRI B., ZEMMOURI N., 2014, La conception des logements à haute performance énergétique (HPE) en Algérie. Développement d'un guide d'aide à la conception pour les zones arides et semi-arides, Séminaire International Sur L'architecture Et Les Arts Islamiques En Algérie, L'Université

Des Sciences Islamiques Emir Abdelkader Et L'université Constantine 3, Constantine, Algérie.

- SEMAHI S., DJEBRI B., ZEMMOURI N., 2014, La conception des logements à haute performance énergétique (HPE) en Algérie. Développement d'un guide d'aide à la conception pour les zones arides et semi-arides, Colloque international défis et perspectives de l'habitat en Algérie, EPAU, Alger. Algérie.
- SEMAHI S., ZEMMOURI N., DJEBRI B., 2016, La conception bioclimatique des bâtiments en Algérie-Développement d'un guide d'aide à la conception pour les zones semi-arides, 4ème Conférence Internationale des Energies Renouvelables (CIER), Hammamet, Tunisie.