EARLY DESIGN EVALUATION OF HOSPITAL BUILDING MORPHOLOGY ON ENERGY PERFORMANCE IN DIFFERENT CLIMATES OF EUROPE

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Approval sheet of the Thesis

This is to certify that we have read this thesis entitled **"Early design evaluation of hospital building morphology on energy performance in different climates of Europe"** and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

EARLY DESIGN EVALUATION OF HOSPITAL BUILDING MORPHOLOGY ON ENERGY PERFORMANCE IN DIFFERENT CLIMATES OF EUROPE

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Globally, sustainability is gaining importance in the construction industry, driven by environmental and economic factors. European directives prioritize improving energy performance in buildings, including hospitals, as they serve as examples of implementing green building principles. Hospital design now focuses on creating a healing environment rather than just functionality. However, limited research exists on thermal requirements of patients in hospitals, necessitating further exploration. The energy performance of buildings is significantly influenced by their geometry. While hospital building morphology has been studied, the impact of climate and orientation in these buildings remains unexplored.

To conduct a thorough analysis of the overall energy performance of the buildings, specific design variables like building shape and orientation are thoughtfully selected. The findings highlight the effectiveness of optimizing the building's geometry in achieving a considered reduction in annual energy demand and enhancing thermal comfort inside the building. Additionally, recommendations are provided regarding the appropriateness of different building typologies for various climate contexts. Simulations using the Design Builder interface for Energy Plus generate a framework for early design decisions, aiding the decision-making process.

Keywords: *morphology, energy optimization, simulation, climate, hospital*

ABSTRAKT

VLERËSIMI I HERSHËM I MODELIT TË MORFOLOGJISË SË SPITALEVE MBI PERFORMANCËN E ENERGJISË NË KLIMA TË NDRYSHME TË EVROPËS

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Në nivel global, qëndrueshmëria po fiton rëndësi në industrinë e ndërtimit, e nxitur nga faktorë mjedisorë dhe ekonomikë. Direktivat evropiane i japin përparësi përmirësimit të performancës së energjisë në ndërtesa, duke përfshirë spitalet, pasi ato shërbejnë si shembuj të zbatimit të parimeve të ndërtesave të gjelbërta. Dizajni i spitalit tani fokusohet në krijimin e një mjedisi shërues dhe jo vetëm në funksionalitetin. Megjithatë, ekzistojnë kërkime të kufizuara mbi kërkesat termike të pacientëve në spitale, gjë që kërkon eksplorim të mëtejshëm. Performanca energjetike e ndërtesave ndikohet ndjeshëm nga gjeometria e tyre. Ndërsa morfologjia e ndërtesave spitalore është studiuar, ndikimi i klimës dhe orientimi në këto ndërtesa mbetet i paeksploruar.

Për të kryer një analizë të plotë të performancës së përgjithshme energjetike të ndërtesave, variabla specifike të projektimit si forma dhe orientimi i ndërtesës janë zgjedhur me kujdes. Gjetjet theksojnë efektivitetin e optimizimit të gjeometrisë së ndërtesës në arritjen e një reduktimi të konsideruar të kërkesës vjetore për energji dhe rritjen e komoditetit termik brenda ndërtesës. Gjithashtu, jepen rekomandime në lidhje me përshtatshmërinë e tipologjive të ndryshme të ndërtesave për kontekste të ndryshme klimatike. Simulimet duke përdorur ndërfaqen Design Builder për Energy Plus gjenerojnë një kornizë për vendimet e hershme të projektimit, duke ndihmuar procesin e vendimmarrjes.

Fjalët kyçe: *morfologjia, optimizimi i energjise, simulimi, klima, spitalet*

To all those who have been my source of inspiration, support, and guidance.

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LIST OF ABREVIATIONS

Acronyms

CU Reference morphology Cube, x=y=z

LP Linked Pavilions

P1 Podium with one tower

PM Podium with Multiple towers

M1C Monoblock with one courtyard

_M1OC _Monoblock with one open courtyard

_M1CC Monoblock with one courtyard covered with glass

M2C Monoblock with two courtyards

_M2OC _Monoblock with two open courtyards

_M2CC _Monoblock with two open courtyards

M4C Monoblock with four courtyards

_M4OC _Monoblock with four open Courtyards

_M4CC _Monoblock with four covered courtyards

Quantitative parameters

RC Relative Compactness

WWR Window to wall ratio

SHGC Solar heat gain coefficient

Se Envelope surface [m^2]

U-value Thermal transmittance [W/m^2. K]

θ i Mean indoor operative temperature [˚C]

θ r Reference indoor operative temperature [˚C]

CHAPTER 1

INTRODUCTION

1.1 Motivation

Globally, there is an increasing focus on advocating sustainability in the construction industry, driven by both environmental and economic considerations. This priority is reflected in the European directives regarding energy performance of buildings, which focus on improving new buildings and rehabilitating existing ones. (Kes McCormick et al.)

Today, public buildings are seen as exemplary structures that embody the benefits of implementing green building principles both in the short and long term (Akvile Cibinskiene et al.).

This trend is evident in the increasing demand for energy-efficient public facilities such as schools, hospitals, offices, and other governmental institutions. There is a noticeable inclination towards reducing primary energy consumption by 25% every five years (Abdelatif Merabtine et al.).

Besides the importance of all buildings, hospitals require special attention due to their critical functionality, energy usage, and need for adaptation to new technologies. Hospitals also have unique requirements for controlling indoor environmental parameters due to the diverse health needs of their users. Therefore, many studies have been conducted to evaluate indoor parameters that affect both patient health and comfort in hospitals (Maria Englezou, Aimilios Michael).

In the last few decades, more attention is given to design spaces with good daylight performance, either to provide useful daylight levels to the occupants which could eventually affect their health and wellbeing, or to reduce the artificial lighting use by using natural lighting. Natural lighting access in healthcare facilities has been correlated to improved physiological and psychological factors. (Marco Neira et al.)

Therefore, this makes it even more important to study daylight performance in hospital building.

Hospital patients have the same thermal needs but disparate metabolic levels, and physical/medical conditions. However, the thermal environments of hospitals are often not designed with these distinctions in mind, nor with a particular focus on patients, but based rather on standard comfort methodologies more often used in offices. The design focus of hospitals has shifted from concentrating on functionality to now providing an appropriate and supportive healing environment for patients.

Each day, numerous individuals encounter the pressure of being in a hospital environment. If environment is not appropriate, it can lead to heightened anxiety, depression, stress, agitation, emotional fatigue, and various other challenges. Although hospitals accommodate multifunctional zones and different occupants, patients admitted to inpatient wards for medical care still have specific demands of the thermal environment based on their individual medical and surgical treatments. Little existing research concentrates on patient subjects in hospitals, supporting the need to explore the complexity of this topic. Thermal discomfort affects hospital patients on many levels (Badr S. Alotaibi et al.)

Previous research has demonstrated the benefits of access to daylight. As an important aspect of indoor environments, interior daylight environments are widely studied among researchers in architecture, technology, science, and medicine (H. Yang et al.). However, large windows may lead to an undesirable rise in indoor temperature, which may cause a noticeable increase in cooling loads. Therefore, the balance between the daylight and the heating and cooling loads is crucial to have a better function. How to maintain this balance is still unclear taking in consideration that the design is variable according to the geographic and climatic status of hospital location (D. Amleh et al.).

1.2 Thesis Objective

Even though the influence of building morphology on energy performance is previously stated, there is a gap regarding this issue when it has to do with hospital and healthcare buildings. Furthermore, this gap is deeper in existing literature on the impact of specific climatic contexts according to energy and thermal performance. Therefore, this research aims to estimate the climate and the morphology influence on hospital building. This will be achieved through simulations. The results will be useful and considered as parameters and guidelines for the design of new hospital buildings in places with similar climatic conditions. This issue will not only affect building comfort, but it will directly impact the occupants' everyday life and provide economic benefits.

1.3 Structure

This research is divided in 6 chapters organized as below:

Chapter 1 will state the problem and present thesis objective;

Chapter 2 consists of literature review;

Chapter 3 includes the methodology followed;

Chapter 4 presents the simulated results;

Chapter 5 presents the discussion and evaluation of main results.

Chapter 6 show the starting point of further research, conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Theoretical background

To create a more effective framework for predicting hospital building performance in the early stages of design, scientific literature is reviewed.

2.1.1 Thermal comfort in hospital building

The primary focus during the design of hospitals is on maintaining hygiene and safety, which sometimes results in thermal comfort being given less priority.

Alotaibi et al. (2021) mentioned in their paper that thermal comfort in healthcare buildings can affect the health of patients, and inadequate design can lead to increased morbidity and mortality. Designing spaces for healthcare patients is complex due to conflicting environmental requirements and interactions among environmental qualities. The research strategy used was DSR, and the study aimed to develop a hospital environmental appraisal thermal comfort tool (HEAT) to optimize healthcare design and improve patient thermal comfort (PTC) demands. The tool was validated through personal interviews and an online survey with healthcare building engineers, facility managers, and other relevant individuals. The goal was to balance evidence and produce a specific design tool to enhance optimal patient thermal environment design decisions.

The work of Priyadarsini and Elkadi (2014) examines the energy performance of three medium-sized healthcare buildings in Victoria, Australia, that operate only during the daytime. The paper aims to provide preliminary understanding of energy consumption in this particular typology in Australia and identifies differences in energy consumption between different functional areas within the facilities.

Comparison with international standards suggests that lower energy consumption is possible. The paper also emphasizes the importance of setting benchmarks for medium-sized health facilities and emphasizes that energy-saving measures should not compromise patient well-being or hospital staff safety.

Alotaibi et al. (2019) stated that hospitals are now designed to provide an appropriate and supportive healing environment for patients, shifting from solely focusing on functionality. However, patients admitted to inpatient wards for medical care still have specific demands for the thermal environment based on their individual medical and surgical treatments. According to authors, thermal discomfort can have adverse effects on the duration and quality of patient sleep and can also hinder or advance bacterial development and infections in hospital environments.

Indoor environmental quality (IEQ) in hospital operating rooms was assessed in a study by Dascalaki et al. (2008) that presents a challenge for designing and operating energy-efficient hospitals. An assessment of 18 ORs at nine major Hellenic hospitals found that indoor air temperature must be maintained within recommended ranges (20–24 8C), according to international regulations and standards, to ensure acceptable conditions. A total of 557 medical personnel participated in an occupational survey, providing data for a subjective assessment.

The study of Khalid et al. (2018) conducted a field survey in three private hospitals in Kuala Lumpur, Malaysia to collect thermal comfort data. The health conditions of patients significantly influenced their thermal preference and comfort, while other characteristics were less impactful. The study estimated the relationship between indoor and outdoor temperatures and found that a change of 4.0 °C in Trm can result in energy savings in the hospitals. All the investigated hospital buildings were air-conditioned.

Gomes et al. (2021) evaluated the thermal behavior and energy retrofitting potential of medical offices in a hospital building using experimental and numerical methods. The case study is the nursing school Francisco Gentil building of the Portuguese Oncology Institute in Lisbon. Two medical offices were monitored for thermal behavior in terms of temperature, heat flow, and irradiance during heating and cooling seasons. Complementary analyses were also performed for thermal comfort and U-values evaluation using a frequency domain approach.

The study found that the best energy retrofit intervention for medical offices in a traditional hospital building is the combination of double reflective glass windows, 6 cm of XPS on the exterior façade, and 7 cm of XPS on the roof. This intervention can result in energy savings of up to 53%. The study included field monitoring of two medical offices, wall U-value and thermal comfort evaluation, frequency domain approach, and building energy simulations.

Lomas and Giridharan (2011) demonstrates how field measurements, thermal modeling, and weather projections can be used to assess building resilience to climate change in the case of UK. It specifically focuses on the thermal comfort conditions in wards and nursing stations of a hospital building with a hybrid ventilation system. The study found that operable windows helped regulate summertime temperatures in the free-running wards, while occupants in the nursing stations experienced high temperatures and dissatisfaction due to the lack of temperature control mechanisms.

The thermal conditions in the hospital ward caused a slightly warm thermal sensation, leading to slightly unacceptable thermal comfort and slightly obstructed work performance for nurses in a paper presented by Derks et al. (2018). The optimal thermal sensation for nurses would be closer to 'slightly cool' than neutral. The paper suggests dividing the ward into separate thermal zones with different set-points for patients and care professionals to create a positive work environment and avenues for energy conservation.

2.1.2 Energy consumption and influencing parameters

The design of a building plays a major role in determining both its construction expenses and its energy consumption expenses.

2.1.2.1 Shape factor and building layout

In addition to the work of Ourghi et al. (2006), the paper by AlAnzi et al. (2008) proposes a simplified analysis method for architects to estimate the energy efficiency impact of building shape during the preliminary design phase for office buildings in Kuwait. The method takes into account building shapes and forms, aspect ratios, window-to-wall ratios, and glazing types. The analysis is based on a comprehensive whole building energy simulation that considers a reference building with a square floor plan. The study shows that as the building's relative compactness increases, the energy use and cooling load decrease. The orientation has an impact on the energy performance of the building, but its effect is almost independent of the building shape, particularly for low window-to-wall ratios.

2.1.2.2 Relative Compactness

Depecker et al. (2001) conducted a study on 14 buildings that shared a common basic structure. They discovered an inverse relationship between energy consumption and compactness (the ratio of external surface area to internal volume) in cold, severe, and sunless winters. However, these findings do not apply to mild climates, where compactness is not recommended. (Depecker et al., 2001).

Werner et al. (2003) investigated the reliability of compactness indicators for energy-related evaluations by conducting extensive thermal simulations on buildings with varying orientations, shapes, glazing percentages, glazing distributions, and orientations. They found a significant correlation between the compactness indicators and simulated heating loads. (Werner et al., 2003)

Albatici et al. (2010) emphasized the importance of considering parameters beyond the shape coefficient or relative compactness. Their study emphasized the need to incorporate factors such as orientation, openings, exposure to atmospheric conditions, and natural elements in the optimization process. The study's results, based on the Italian territory, recommend a bioclimatic approach during the early design phase for improved outcomes. (Albatici et al., 2010)

In a Mediterranean climate study conducted by Muhaisen et al. (2013) in the Gaza Strip, both energy consumption and relative compactness were found to increase at the same rate. The study recommended the implementation of passive solar design strategies, as horizontally arranged residential apartments exhibited superior thermal performance compared to vertically arranged apartments with the same relative compactness. (Muhaisen et al., 2013)

Different studies conducted in various climatic conditions yield diverse results, emphasizing the need to adopt design methods that consider climate factors to achieve enhanced energy performance in buildings.

Boubekri et al. (2017) investigated small, medium, and tall office buildings with different morphologies in the United States. They discovered that heating loads decreased as relative compactness increased. (Boubekri et al., 2017)

Hassan et al. (2020) found that building morphologies with varying relative compactness (RC) had a significant impact on pollutant dispersion. The study revealed a reduction of approximately 30% to 90% at specific points in the studied time sequence, demonstrating the importance of morphology in improving outdoor air quality. (Hassan et al., 2020)

2.1.2.3 Courtyards and orientation

Almhafdy et al. (2013) investigated the use of courtyards in Malaysian hospitals and inventory 32 courtyards in 19 hospitals. The study recorded courtyard functions, design variants, and physical features within the courtyard. The courtyards were found to be creatively manipulated and in square, rectangle, or triangle shapes. The paper also suggests ways to optimize a courtyard's microclimatic and healing performances.

Fifield et al. (2018) investigated in their paper the energy demands and internal temperatures of two 16-bed hospital wards built using modular fast track methods, in Bradford Royal Infirmary, UK. The study shows that the annual energy demand was below the NHS guidelines for new hospital buildings, but there was a risk of overheating in relatively cool UK summer conditions due to the lightweight and well-insulated nature of the building. The authors conclude that this issue needs to be addressed before such buildings can be widely adopted.

Algeciras et al. (2018) explored how the geometry of courtyards affects outdoor thermal conditions in a warm-humid climate by using numerical simulations with the RayMan model. The study focuses on large courtyards in the historical center of Camagüey, changing their height-to-width ratio and orientation. Results show that aspect ratios higher than 1 are preferable as they contribute to better courtyard thermal conditions in summer, reducing the subzones where the mean radiant temperature exceeds 45 °C. Orienting the courtyard's long axis away from the East-West also results in lower mean radiant temperatures, with reductions of up to 15.7 ºC for high aspect ratios.

The design of courtyards can be an effective and sustainable way to improve the thermal and microclimatic conditions of urban areas according to Zamani et al. (2018). Their study focuses on the various factors that impact courtyard design, such as proportion, orientation, geometry, opening characteristics, and materials, as well as components like shading devices, vegetation, and water pools. The research analyzes the impact of these factors on energy consumption, indoor and outdoor temperatures, solar radiation, and natural ventilation across different climates. Based on the reviewed papers, three main categories are identified: 1) those examining the microclimatic function of courtyards, 2) those focused on the thermal function of courtyards, and 3) those that consider an integrative approach by examining both the thermal and microclimatic functions of courtyards. The paper also explores the role of three main climatic factors - solar gain, humidity, and natural ventilation - in each category.

Gómez et al. (2019) investigated in their study the thermal performance of inner courtyards in southern Spain over a two-year period. The objective was to analyze the aspect ratio (AR) and the impact of outdoor temperature on the thermal functions of courtyards to develop passive cooling strategies for urban housing. The study found that while AR is an important factor in maximizing courtyard tempering potential, other parameters such as diurnal temperature range (DTR) and maximum outdoor temperature (MOT) can significantly modify its influence. Courtyards with AR > 3 are effective solutions, particularly in warm regions, to manage microclimates in the summer. Additionally, MOT increase is crucial in establishing tempering potential, and a daily cycle analysis through DTR confirms the thermal buffering effect of courtyards.

2.1.2.4 Integration of daylight and artificial light

The issues related to insufficient energy supply and the phenomenon of global warming are garnering global focus and concern.

The article by Gentile et al. (2022) discusses lessons learned from monitoring 25 international case studies of integrated daylighting and electric lighting in real occupied buildings. The goal was to balance lighting energy use with occupants' needs, and it was achieved through innovative solutions and advanced controls. The adoption of integrative lighting is increasing, and catering to non-visual requirements will drive further innovation. Energy demand for lighting can be significantly reduced through a combination of daylight provision, efficient light sources, and advances in control technology. Daylight contributions must be considered when implementing conventional and integrative lighting controls to meet energy-efficiency benchmarks. Integrative lighting is defined as lighting that integrates both visual and non-visual effects, producing physiological and psychological benefits for humans.

Boer et al. (2022) stated in their work that there are shading and glare protection solutions available for some applications, but they are not ideal for providing both daylight and a view. Lighting design needs to consider multiple criteria for user needs, as visual information is critical for humans. Non-visual perception of light is also important. Cost-effective, daylight-redirecting technologies are needed for both visual and non-visual benefits of daylight. Integrated lighting solutions that address energy use, lighting quality, comfort, and health aspects require new predictive models, simulation engines, and streamlined workflows for comparative analysis.

2.2. Previously related studies

Ourghi et al. (2006) presented a simplified analysis method for predicting the impact of office building shape on annual cooling and total energy use. The method is based on detailed simulation analyses using various combinations of building geometry, glazing type, glazing area, and climate. The study establishes a direct correlation between relative compactness and total building energy use, as well as cooling energy requirements.

This paper presents a simplified analysis tool to evaluate the impact of building shape on total annual energy use for office buildings. The study involves the use of DOE-2 simulation program to model office building models with varying shapes and window configurations, and to vary several parameters such as relative compactness, window sizes, and glazing types. The analysis was performed for buildings located in Tunis and Kuwait. The study finds that higher relative compactness leads to lower cooling loads and total energy use, and a direct correlation is established between relative compactness and total building energy use as well as cooling energy requirement.

Shi et al. (2021) examine in their paper the building layout patterns and energy efficiency of hospitals in the cold climate region of China by analyzing the building layout and energy consumption of 30 hospitals from 2015 to 2017. The study identifies five types of building layouts for comprehensive clinics and three types of layouts for inpatient buildings. The grid courtyard type arrangement for comprehensive clinics and the 'L'-shaped layout for inpatient buildings are found to be the most energy efficient. The study also proposes corresponding energy-saving strategies. The average energy consumption per unit area of Class 3A hospitals in the cold region increased by 5.3% from 2015 to 2017, with higher energy consumption in summer due to heating and cooling demands.

In a later study, presented by Almhafdy et al. (2013) is examined the microclimate performance of a U-shaped courtyard in a Malaysian hospital using simulation analysis. The study aims to substantiate the claim that aspect ratio and orientation are critical design variants for the microclimatic performance of courtyards. The results confirm that the manipulation of courtyard configuration and orientation can impact its microclimate modifying ability. The study was conducted in two parts, calibration and parametric analysis, using IES suite.

In a study by Baci and Dervishi (2023), energy performance of low-rise school building morphology is analyzed. The selected climate is Mediterranean which is expressed by 4 cities in southeastern Europe. The WWR is considered constant as 40% and the glazing area opens as 30%. The study focuses on various design variables, such as the shape and orientation of buildings, which are carefully chosen to analyze the overall energy performance of the entire building. The findings demonstrate the effectiveness of this approach in significantly reducing annual energy demand by up to 33.7% and improving thermal comfort in classrooms by a maximum of 1.15 °C through geometry optimization. Additionally, recommendations are provided regarding the suitability of different building typologies for various climatic conditions. To conduct simulations in diverse climate contexts of Southeast Europe, the Design Builder interface version 6 for Energy Plus is utilized. Overall, the simulation results contribute to establishing a foundational framework for early design decision-making processes.

Table 1: *Reviewed scientific literature concerning early-design evaluation (please, note that WWR is window-to-wall ratio, RC is relative compactness)*

Contribution area	Authors	Description
Shape factor	Ourghi et al. (2006)	A simplified analysis method for predicting the influence of office building shape on annual cooling and total energy use, utilizing detailed simulation analyses and considering factors such as building geometry, glazing type, glazing area, and climate. The study establishes a direct correlation between relative compactness and both total building energy use and cooling energy requirements, demonstrating that higher relative compactness results in lower cooling loads and overall energy consumption.
	Al-Anzi et al. (2007)	The primary factors that significantly impact the energy consumption of office buildings are the window-to-wall ratio (WWR), relative compactness (RC), and the choice of glazing materials. It was observed that in office buildings with RC, regardless of their specific form, the total energy usage was discovered to be inversely proportional in cases where the WWR was low.
	Al-Anzi et al. (2008)	The paper presents a simplified analysis method for estimating the energy efficiency impact of building shape in office buildings, demonstrating that increasing relative compactness reduces energy use and cooling load, while building orientation's effect on energy performance is mostly independent of shape, particularly for low window-to-wall ratios.
Relative compactness	Werner et al. (2003)	The study found a notable association between relative compactness (RC) and simulated heating loads in buildings, considering variations in shape, glazing percentage, glazing distribution, and orientation, highlighting that buildings with identical compactness can still differ in enclosure transparency, orientation, and overall morphology.
	Depecker et al. (2001)	In cold severe and scarcely sunny winters, the energy consumption is inversely proportional to compactness, indicating a weak shape coefficient. However, this relationship does not hold true in mild climates, making it inappropriate to recommend compactness as a determining factor for energy consumption in such conditions.
	Albatici et al. (2010)	In the initial stage of the design process, relying solely on the shape coefficient is insufficient, as a more effective approach involves adopting a bioclimatic perspective that

		considers orientation, openings, exposure to atmospheric agents, and natural elements to optimize energy performance and overall building efficiency.
	Muhaisen et al. (2013)	The thermal response in various geometric shapes is primarily influenced by the surface-to-volume ratio. By increasing the depth ratio in convex shapes, the percentage of shaded facades can be increased, resulting in reduced energy consumption for heating and cooling purposes.
	Boubekri et al. (2017)	Taking climate considerations into account during the design process results in improved energy performance. In three distinct cases, increasing the relative compactness (RC) of office buildings leads to a decrease in heating loads, indicating a positive correlation between RC and energy efficiency.
	Hassan et al. (2020)	The diverse designs of building morphology, characterized by varying relative compactness (RC) indicators, emphasize the significance of considering morphological factors in order to enhance outdoor air quality.
Courtyards, orientation and WWR	Almhafdy et al. (2013)	The study conducted a thorough examination of courtyards in Malaysian hospitals, documenting their functions, design variations, and physical attributes, highlighting creative manipulation with square, rectangle, or triangle shapes, and offering recommendations to enhance the microclimatic and healing performances of courtyards.
	Fifield et al. (2018)	Although the annual energy demand complied with NHS guidelines for new hospital buildings, the lightweight and well-insulated nature of the construction presented a risk of overheating during relatively cool UK summer conditions. Consequently, they emphasized the necessity of addressing this issue before implementing such buildings on a larger scale.
	Algeciras et al. (2018)	Aspect ratios greater than 1 improve courtyard thermal conditions by reducing subzones with excessive mean radiant temperatures, while orienting the courtyard's long axis away from the East-West direction leads to lower mean radiant temperatures, with potential reductions of up to 15.7 ºC for high aspect ratios.
	Zamani et al. (2018)	The climatic function of a courtyard is strongly influenced by its length-to-height ratio, where a ratio below 5 is considered optimal for efficient airflow management. Additionally, vegetation is found to have a greater cooling effect compared to water basins.
	Gómez et al. (2019)	While the aspect ratio is important in maximizing courtyard tempering potential, other factors such as diurnal temperature range (DTR) and maximum outdoor temperature (MOT) can significantly modify its impact. Courtyards with an aspect ratio greater than 3 are effective in managing microclimates during summer, particularly in warm regions.
Daylight and artificial lighting	Gentile et al. (2022)	The combination of daylight provision, efficient light sources, and improved control technology can significantly reduce the energy demand for lighting.
	Boer et al. (2022)	Existing shading and glare protection solutions may not effectively provide both daylight and a view, highlighting the need for comprehensive lighting design that considers multiple criteria to meet user needs. They emphasize the importance of visual information for humans and also recognize the significance of non-visual perception of light.
Thermal comfort	Alotaibi et al. (2021)	Through the use of a research strategy called Design Science Research (DSR), the study developed a hospital environmental appraisal thermal comfort tool (HEAT) to optimize healthcare design and improve patient thermal comfort (PTC) demands.
	Priyadarsini and Elkadi (2014)	The potential for achieving lower energy consumption compared to international standards.
	Alotaibi et al. (2019)	Thermal discomfort can negatively impact patient sleep duration and quality, as well as influence bacterial growth and infections within hospital settings.
	Dascalaki et al. (2008)	The importance of maintaining indoor air temperature within recommended ranges (20-24°C) to ensure acceptable conditions, as per international regulations and standards.
	Khalid et al. (2018)	Patients' health conditions had a significant impact on their thermal preference and comfort, while other characteristics had a lesser influence. The study also estimated the relationship between indoor and outdoor temperatures, showing that a 4.0 °C change in Trm (mean radiant temperature) could lead to energy savings in the air-conditioned hospital buildings that were investigated.
	Gomes et al. (2021)	The study observed that operable windows were effective in regulating summertime temperatures in the free-running wards. However, occupants in the nursing stations experienced high temperatures and dissatisfaction because of the absence of temperature control mechanisms.
	Derks et al. (2018)	The paper recommends dividing the ward into separate thermal zones with different temperature set-points for patients and healthcare professionals. This approach aims to create a positive work environment while also providing opportunities for energy conservation.

2.3. Aim and originality of the study

The studies mentioned above demonstrate that geometry parameters play a crucial role in the energy performance of buildings. However, optimizing the energy performance of hospitals based on morphology is particularly challenging due to the influence of multiple variables. Therefore, this study fills important gaps in our understanding by tackling the complexities associated with morphology-based energy performance optimization of hospitals and contributes valuable insights to the existing knowledge in this field.

None of the simulation-based studies reviewed in the literature considered occupancy schedules that align with the current needs of hospital departments and their schedule throughout the year. Given that hospitals offer support and direct service, they have to be designed properly as central health spaces for community.

The climate region of reviewed scientific litterature's locations influences the heating, ventilation, and air conditioning (HVAC) requirements of buildings.

No prior simulation-based study was conducted in different Eurpean climates, with studies in such climates (Baci and Dervishi, 2023) analyzing only the mediterranean south eastern part of Europe and (Su, 2013; da Graça et al., 2007) relying solely on methods based on real data collection. The impact of a humid climate context representing Europe has also not been studied.

Notably, a study done by Ourghi et al. dates back to 2006 and analyzes an office building and its impact on annual cooling and total energy use, in Kuwait. Eventhough, detailed simulation analyses using various combinations of building geometry, glazing type, glazing area and climate show the direct impact of building in its total energy use.

Shi et al. (2021) analyzed building layout energy consumption of hospitals for two years, but this study represents only the cold climate region of China.

A study by Almhafdy et al. (2013) investigated the use of courtyards in

Malaysian hospitals considering only three shapes. However, some other important energy effecting factors such as orientation and relative compactness are not considered.

Therefore, this paper proposes a comprehensive framework that aims to initiate an analytical and quantitative approach to evaluating the thermal and energy performance of hospital building morphologies in different climatic contexts of Europe. The study focuses on energy performance analysis, considering key design variables such as shape and orientation. The main contribution and significance of this research lie in evaluating and optimizing the energy and thermal performance of various morphologies of hospital buildings, thereby enhancing climatic awareness among designers and architects during the decision-making process.

CHAPTER 3

METHODOLOGY

3.1 Overview

Between many other parameters, the morphology of a building has a predominant effect on energy consumption of a building. As such, the main focus of this research is to underline the impact of morphology on energy performance of hospital buildings. Below is schematically presented in Figure 1.

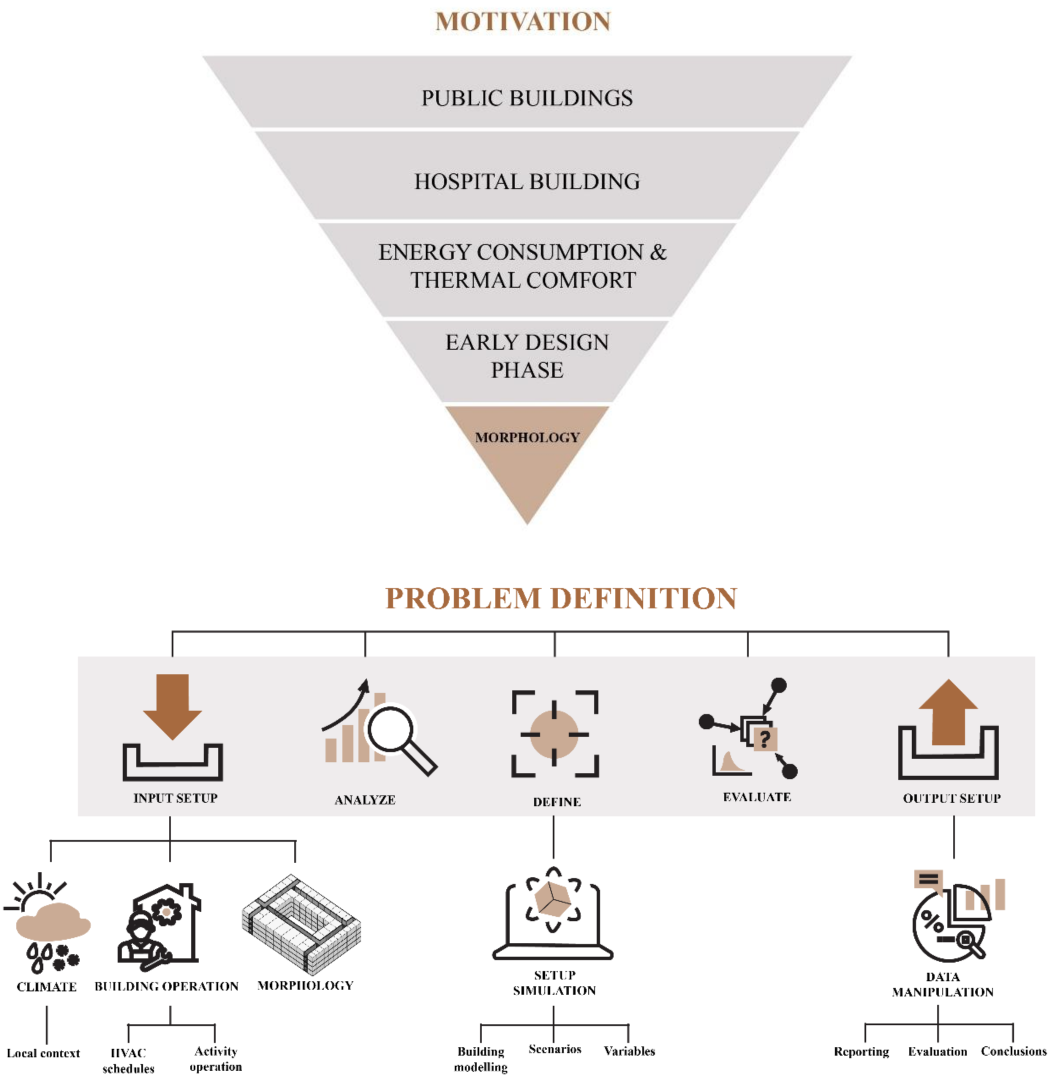


Figure 1: Methodological framework of the study

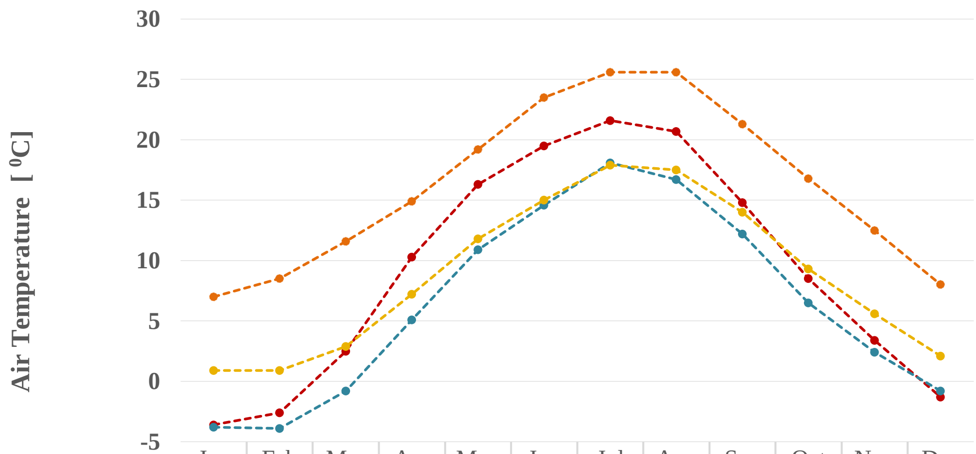
3.2 Climate characterization

The climate in Europe is typically considered to be temperate. According to the Köppen climatic classification, the majority of Western Europe has an oceanic climate, which features cool to warm summers and cool winters with frequent overcast skies. A specific Mediterranean climate, with warm to hot, dry summers, cold to mild winters, and frequent sunny sky, may be found across southern Europe. The climate of Central-Eastern Europe is categorized as humid continental, with warm to hot summers and cold winters. A combination of an oceanic and continental climate can be found in parts of the central European region.

Away from the Mediterranean, most of Europe encounters four distinct seasons. The winter season in the coastal lowlands of the Mediterranean Basin endures from October to February, whereas the summer season has its greatest impact in the dry months, where precipitation can, in some years, become exceptionally uncommon.

Four contrasting climates from different regions of Europe are chosen in order to obtain a deeper knowledge and to create accurate evaluations of the energy performance of hospitals throughout Europe. The locations in Figure 2 were selected based on the variations in temperature, solar radiation, and other characteristics that each area presented. The input climatic data is obtained from "Meteonorm 8". The mean temperatures for the cases of Tirana, Kiev, Tallinn, and Copenhagen are shown in Figure 3.

Figure 2: *Selected locations*



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tirana	7	8.5	11.6	14.9	19.2	23.5	25.6	25.6	21.3	16.8	12.5	8
Kiev	-3.6	-2.6	2.5	10.3	16.3	19.5	21.6	20.7	14.8	8.5	3.4	-1.3
Tallin	-3.8	-3.9	-0.8	5.1	10.9	14.6	18.1	16.7	12.2	6.5	2.4	-0.8
Copenhagen	0.9	0.9	2.9	7.2	11.8	15	17.9	17.5	14	9.3	5.6	2.1

Tirana Kiev Tallin Copenhagen

Figure 3: *Mean outdoor temperatures for the selected locations*

3.2.1 Tirana, Albania

Tirana is the capital and largest city of Albania. It is situated in the middle of the country, surrounded to the east by hills and mountains rising, and to the northwest by a narrow valley looking out over the Adriatic Sea. The city is strongly influenced by a Mediterranean seasonal climate because of its location on the Plain of Tirana and near proximity to the Mediterranean Sea. With 2,544 hours of sunlight annually, it is among of the wettest and sunniest cities in Europe.

According to the Köppen climatic classification, Tirana has a humid subtropical climate (Cfa) and enough summer precipitation to keep it from being classified as having a Mediterranean climate (Csa).

Tirana receives approximately 1,266 millimeters (49.8 inches) of precipitation year on average. Most of the city's precipitation occurs between November and March during the winter, while less occurs between June and September during the summer. The city is one of the wettest in all of Europe in terms of precipitation, including rain and snow.

The average annual temperature varies from 6.7 °C (44.1 °F) in January to 24 °C (75 °F) in July. From May to September, springs and summers are quite warm to hot, frequently exceeding 20 °C (68 °F). The average temperature lowers during the fall and winter, from November to March, and never drops below 6.7 °C (44.1 °F). The city receives around 2500 hours of sun.

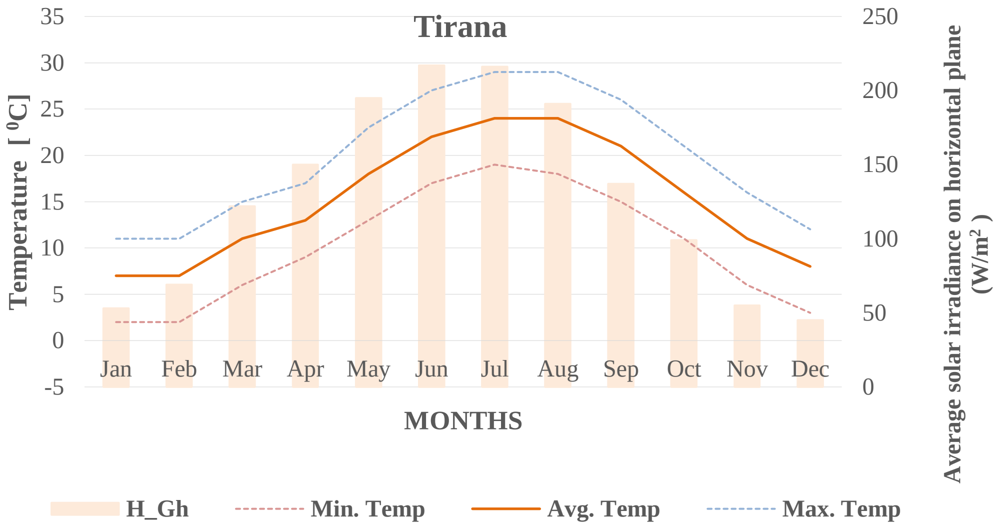


Figure 4: *Annual temperatures and average solar irradiance on horizontal plane for the city of Tirana*

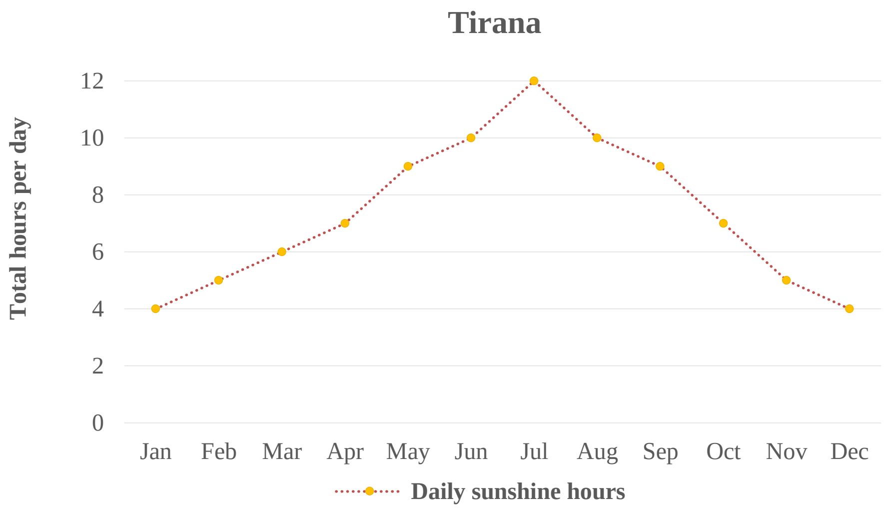


Figure 5: *Average daily sunshine hours during the year for the city of Tirana*

3.2.2 Kiev, Ukraine

Kiev is the capital and largest city of Ukraine. It is situated along the Dnieper River in north-central Ukraine. Kiev experiences warm, humid summers according to Köppen Dfb classification.

June, July, and August are the warmest months, with average temperatures ranging from 13.8 to 24.8 °C (56.8 to 76.6 °F). The three months with the lowest average temperatures—December, January, and February—range from 4.6 to 1.1 °C (23.7 to 30.0 °F).

Snowfall generally occurs from the middle of November until the end of March, with the average number of days without frost exceeding 200.

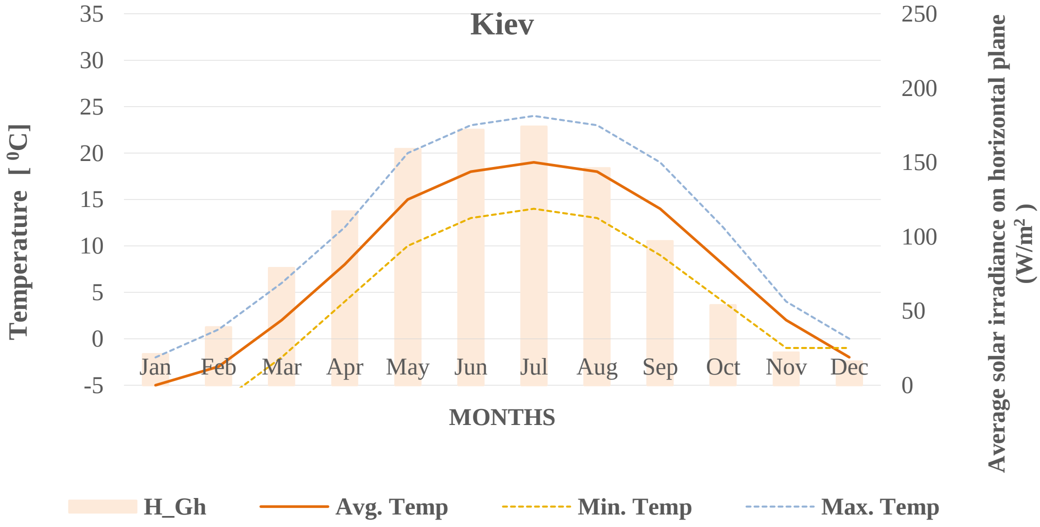


Figure 6: *Annual temperatures and average solar irradiance on horizontal plane for the city of Kiev*

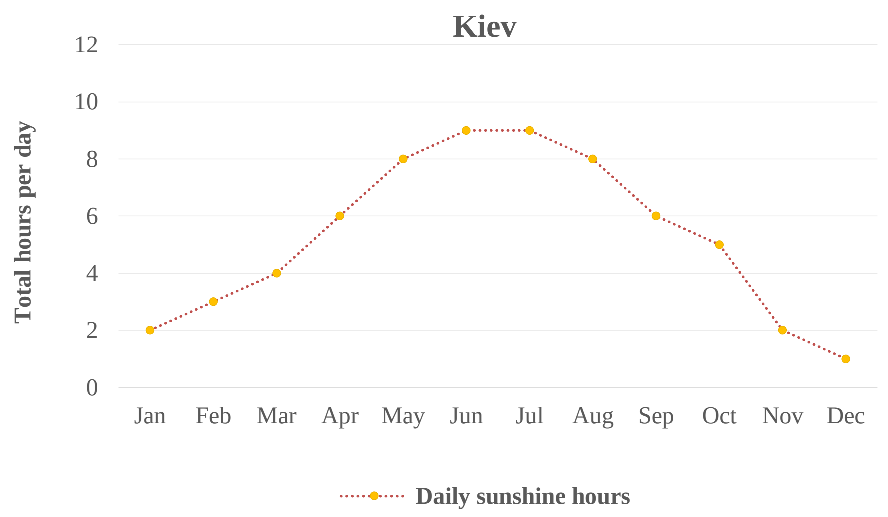


Figure 7: *Average daily sunshine hours during the year for the city of Kiev*

3.2.3 Tallinn, Estonia

Tallinn is the capital and largest city of Estonia. It is located on a bay in northern Estonia, close to the Baltic Sea's Gulf of Finland.

Tallinn has a humid continental climate with mild, rainy summers and cold, snowy winters (Köppen climatic classification Dfb).

Due to its seaside location, winters there are cold but not particularly hard for its latitude. The coldest month is February, with an average temperature of 3.6 °C (25.5 °F). Wintertime temperatures typically stay around freezing, but mild weather periods can occasionally raise them above 0 °C (32 °F) and even over 5 °C (41 °F), while cold air masses can lower them below 18 °C (0 °F) on an average of 6 days each year.

Winters are gray and have limited sunshine, with only 20.7 hours per month in December and 58.8 hours in February. Snowfall is frequent throughout this time.

While nighttime temperatures in the spring are still low, averaging between 3.7

and 5.2 °C (25.3 to 41.4 °F) from March to May, the season gradually warms up as it progresses. Freezing temperatures are prevalent in March and April. In March, snowfall is typical, but it can also happen in April.

The summers are pleasant, with daytime highs of 19.2 to 22.2 °C (66.6 to 72.0 °F) and lows of 9.8 to 13.1 °C (49.6 to 55.6 °F) on average from June to August.

On average, July is the warmest month, with an average temperature of 17.6 °C (63.7 °F). Summer is the sunniest season, with 255.6 hours of sunshine in August and 312.1 hours in July, while precipitation is higher in these months. Partly cloudy or clear days are frequent throughout this time. Due to its high latitude, daylight at the summer solstice lasts longer than 18 hours and 30 minutes.

With a pleasant September average daily mean temperature of 12.0 °C (53.6 °F), fall gradually gets colder and cloudier as it moves toward the end of November. Early in the fall, temperatures frequently surpass 16.1 °C (61.0 °F), with at least one day in September exceeding 21 °C (70 °F). Snowfall may occur in the late fall, when freezing temperatures become more prevalent.

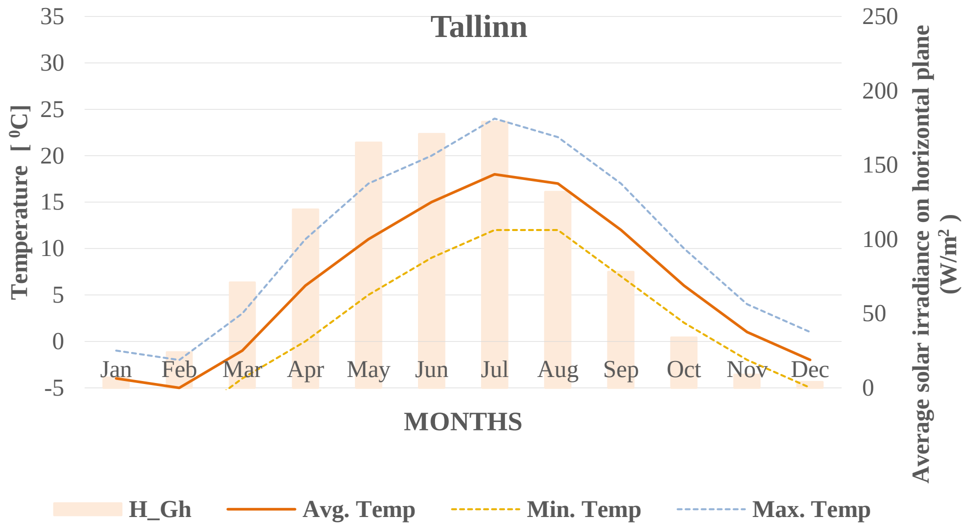


Figure 8: *Annual temperatures and average solar irradiance on horizontal plane for the city of Tallinn*

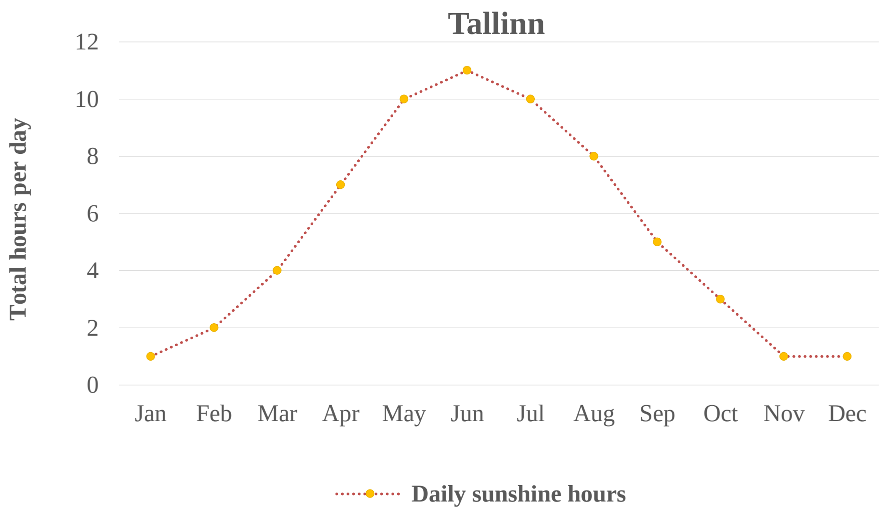


Figure 9: *Average daily sunshine hours during the year for the city of Tallinn*

3.2.4 Copenhagen, Denmark

Copenhagen is the capital and largest city of Denmark.

The climatic zone for Copenhagen is oceanic according to Köppen: Cfb. Low-pressure systems from the Atlantic can affect its weather, causing unpredictable conditions all year long. Precipitation is average, with the exception of a slightly increased rainfall from July to September. While snowfall primarily occurs from late December to early March, rain is also possible while temperatures are often near freezing.

With an average of eight hours of sunshine every day, June is the sunniest month of the year. With a daytime high of 21 °C on average, July is the warmest month.

In comparison, there are often fewer than two hours of sunshine per day in November and just 1.5 hours per day from December through February. In the spring, temperatures rise once more, and from March through May, there is four to six hours of daylight each day. The driest month of the year is February. In the summer, temperatures have been known to go as high as 33 °C (91 °F), and in the winter, unusual meteorological conditions have been known to bring as much as 50 cm of snow to Copenhagen in a 24-hour period.

Copenhagen's northern latitude causes the number of daylight hours to vary greatly from summer to winter. On the summer solstice, there are 17 hours and 32 minutes of daylight since the sun rises at 04:26 and sets at 21:58. On the winter solstice, there are 7 hours and 1 minute of daylight between sunrise and sunset. The difference in day and night length between the summer and winter solstices is consequently 10 hours and 31 minutes.

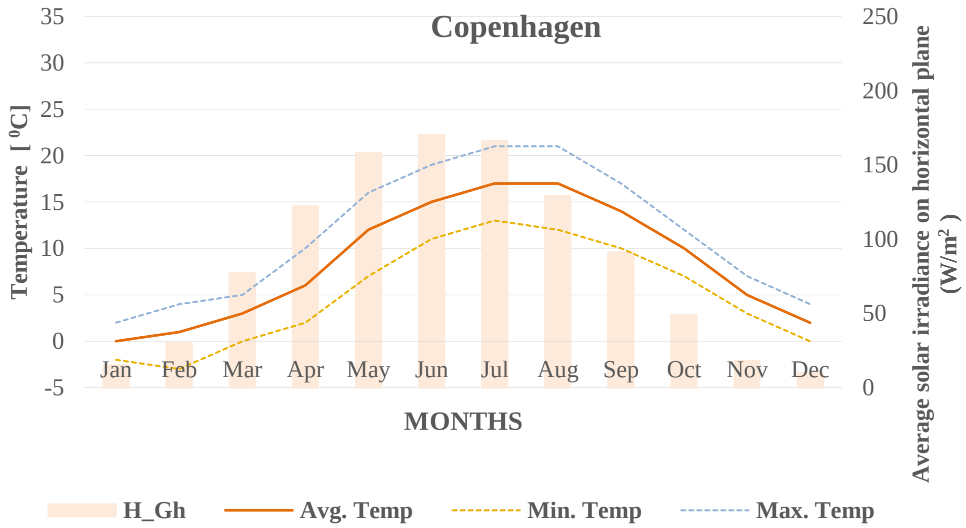


Figure 10: *Annual temperatures and average solar irradiance on horizontal plane for the city of Copenhagen*

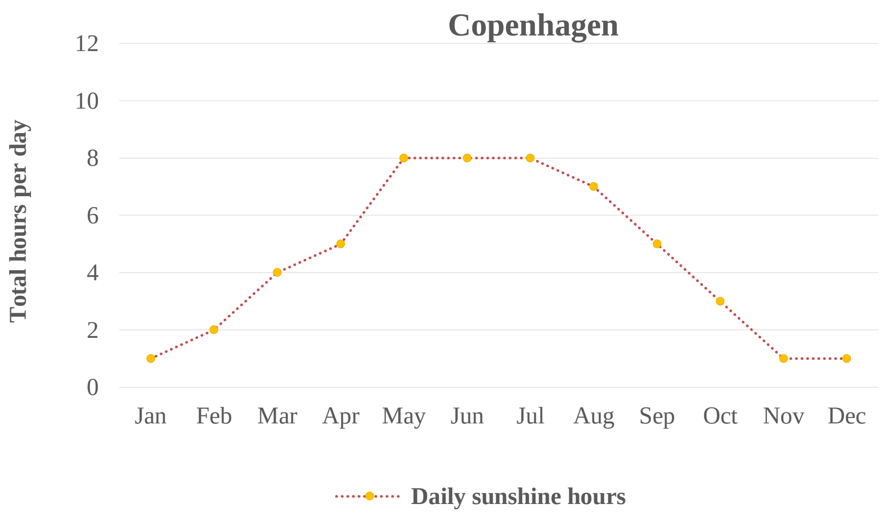


Figure 11: *Average daily sunshine hours during the year for the city of Copenhagen*

3.3 Case study description

Table 2. *Hospital case studies*

NR.	HOSPITAL NAME	LOCATION	AREA	YEAR	LAYOUT
1.	Meppel	Netherlands	23500	2021	Monoblock, two towers
2.	Renovation Graz	Austria	25100	2021	Monoblock, courtyard
3.	Extension Lisbona	Portugal	62000	2019	Monoblock, multi towers
4.	Public Arch Badajoz	Spain	37674	2021	Monoblock
5.	Tambacounda	Senegal	3000	2021	Linked pavilions
6.	Sabadell	Spain	1098	2009	Monoblock
7.	Manta	Ecuador	24100	2018	Monoblock
8.	Amarante	Portugal	21000	2012	Linked pavilions
9.	Goldsboro	USA	403000	2016	Linked pavilions
10.	Renovation Spain	Spain	18000	2010	Linked pavilions
11.	Johanneberg	Sweden	6800	2017	Monoblock, courtyard
12.	Jyvaskyla	Finland	116000	2022	Monoblock, multi towers
13.	Niamey	Niger	34000	2016	Linked pavilions
14.	Reading	UK	10100	-	Monoblock
15.	Shesmedi	South Korea	1249	-	Podium tower
16.	Frenchs Forest	Australia	70000	2018	Linked pavilions
17.	Granollers	Spain	19500	-	Linked pavilions
18.	Broussais	France	10000	2015	Linked pavilions
19.	Zhangjiakou	China	133000	2021	Multi towers
20.	EKH	Thailand	6000	2019	Monoblock, one tower
21.	Pediatric of Tirana	Albania	-	2020-2021	Linked pavilions

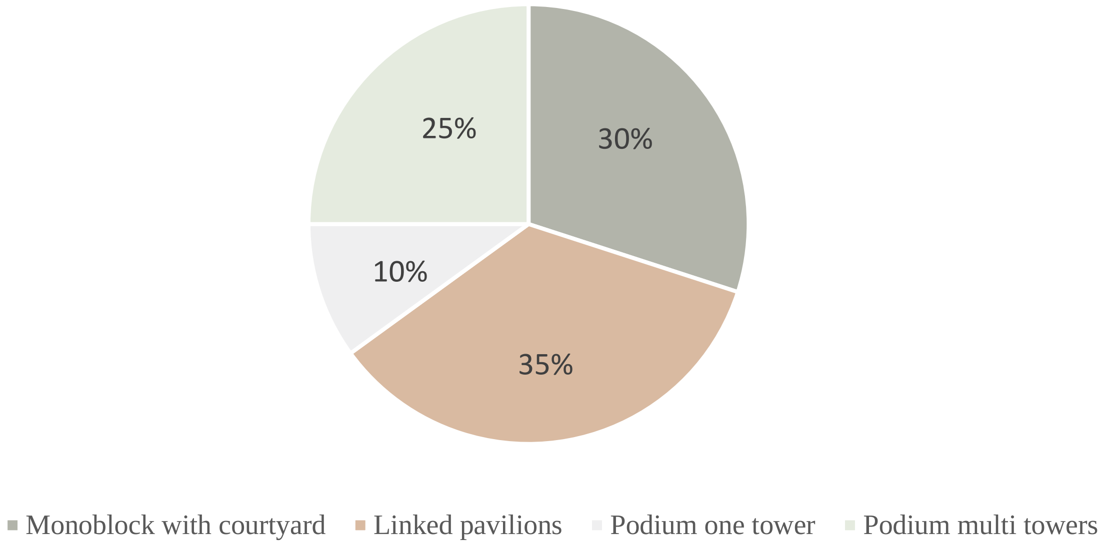


Figure 12. *Case studies found*

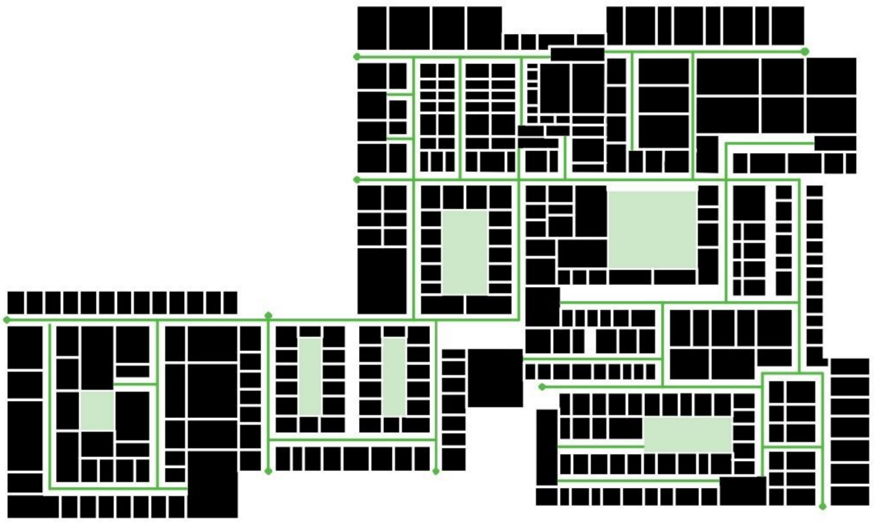


Figure 13*. Meppel Hospital, an example of monoblock morphology with courtyards*

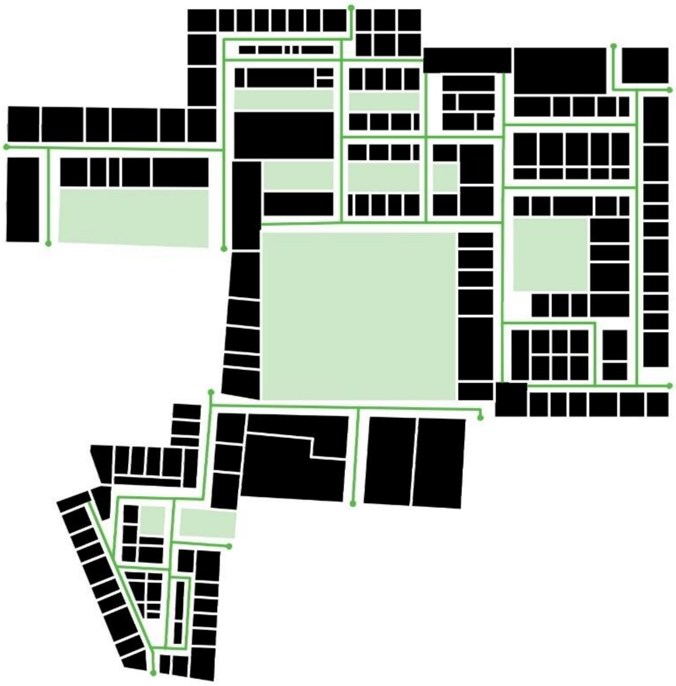


Figure 14*. Renovation Graz Hospital, an example of monoblock with courtyards*

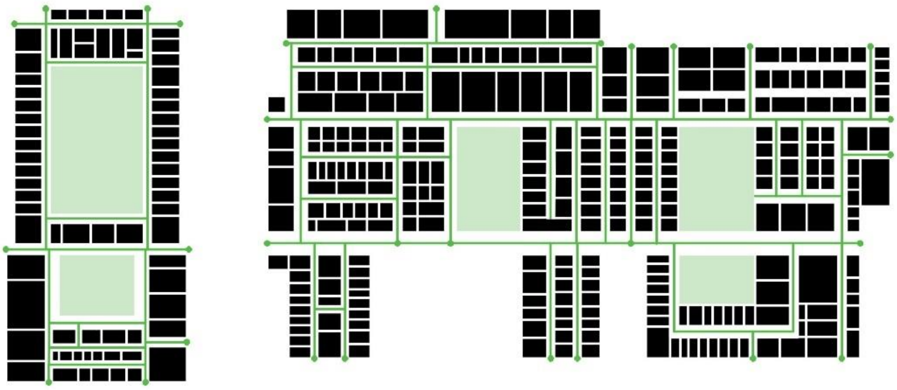


Figure 15*. Extension Lisbona Hospital, an example of linked pavilions and monoblock with courtyards*

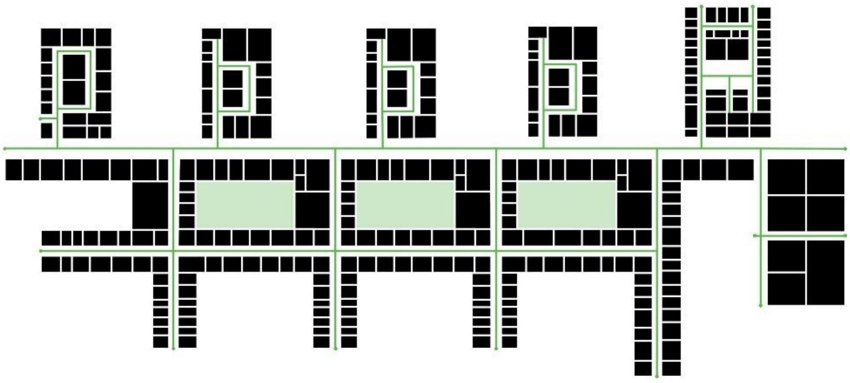


Figure 16. *Goldsboro Hospital, an example of linked pavilions*

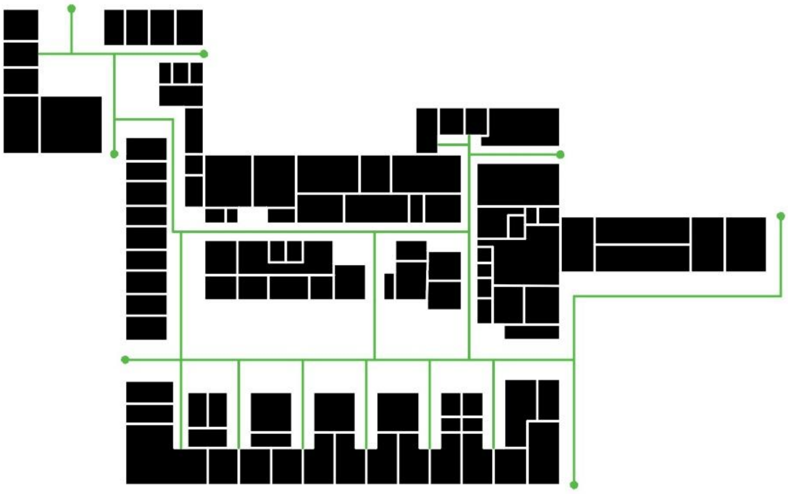


Figure 17. *Reading Hospital, an example of monoblock morphology*

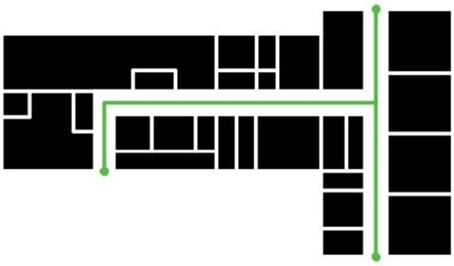


Figure 18. *Johanneberg Hospital, an example of monoblock morphology*

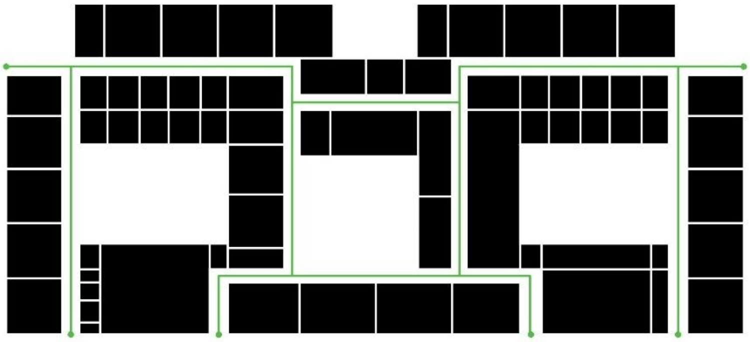


Figure 19. *Broussais Hospital, an example of monoblock with courtyards morphology*

3.4 Hospital Morphologies

The shape of the building has a significant impact on both construction costs and energy costs of buildings. Some studies have investigated the impact of the building shape on its thermal performance for some climates in Europe. No definitive and simple correlations were established between the basic attributes associated with buildings (such as form, window size and glazing type) and their total annual energy use and/or heating/cooling loads.

For the study presented in this paper, a prototypical hospital building is considered. The total floor area for this prototypical building is 8000 m^2.

Several shapes and floor plans have been developed for the prototypical hospital building. The volumetric shapes are illustrated as in Figure 20.

Table 3 gives morphologies description and data. In the Table 4 are the features of each hospital morphology. Table 5 shows the common hospital departments meanwhile Table 6 lists set point temperatures for each space. Figure 21 analyses the relative compactness of selected morphologies.

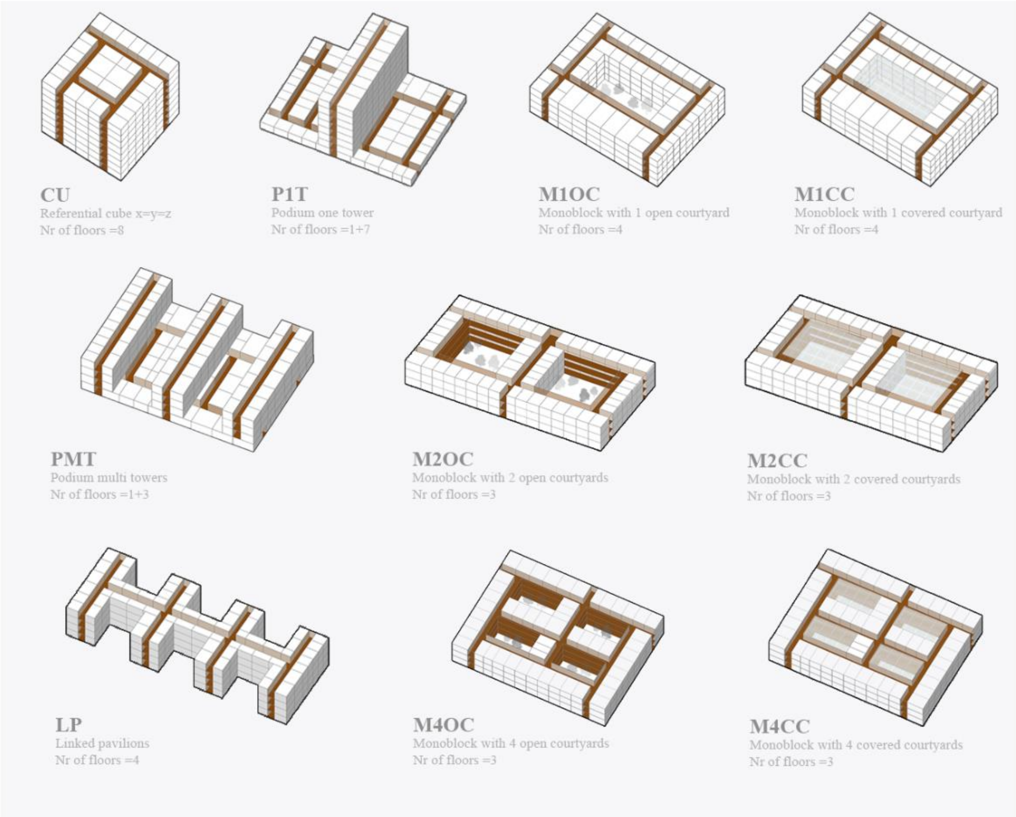


Figure 20: *Hospital morphologies*

Table 3. *Morphologies description and data*

Nr	Shape	Footprint Area		Tot. Area	Nr. floors	Nr. rooms	Nr. courtyard	Courtyard covering	
		ground	*up levels*					*type 1*	*type 2*
1	Cube [**C**]	998.5 m^2	same	**7988 m^2**	8	192	-	-	-
2	Podium with one tower **P1**	3055 m^2	3369 m^2	**7990 m^2**	8	190	-	-	-
3	Podium with multi towers **PM**	3036 m^2	4968 m^2	**8004 m^2**	4	190	-	-	-
4	Linked Pavilions **LP**	1989 m^2	same	**7956 m^2**	4	192	-	-	-
5	Monoblock with one courtyard **M1C** [**M1OC**] [**M1CC**]	1998 m^2	same	**7992 m^2**	4	188	1	open	glass
6	Monoblock with two courtyards **M2C** [**M2OC**] [**M2CC**]	2665 m^2	same	**7995 m^2**	3	144	2	open	glass
7	Monoblock with four courtyards **M4C** [**M4OC**] [**M4CC**]	2640 m^2	same	**7920 m^2**	3	144	4	open	glass

Table 4. *Features of each hospital morphology*

Morphologies	Envelope WWR (%)				Circulation (%)	Skylight roof ratio (%)
	N	E	S	W		
CU	52.99	54.01	52.99	51.83	49	5.5
LP	51.95	53.42	51.89	53.92	36.1	0
P1T	52.56	54.34	53.1	53.39	27.7	0
PMT	51.74	53.45	52.06	53.53	32.4	0
M1OC	54.68	55.03	54.58	54.2	29.9	0
M1CC	53.89	55.06	54.19	53.93	29.9	18.29
M2OC	55.58	55.16	55.8	54.88	36.2	0
M2CC	55.02	53.99	55.36	55.99	36.2	31.97
M4OC	55.63	55.66	55.72	55.05	34.7	0
M4CC	55.12	54.95	54.78	54.71	34.7	22.22

Table 5. *Common hospital departments*

Nr	Common hospital departments	Area for 8000 m^2	
		%	m^2
1	Emergency Unit	10%	800 m^2
2	Outpatients & Diagnostics	32%	2560 m^2
3	Inpatients	16%	1280 m^2
4	Interventions	15%	1200 m^2
5	Therapies	27%	2160 m^2

Table 6. *Temperature ranges in main hospital departments*

Nr	Temperature ranges for thermal comfort in hospitals according to main hospital spaces	Set point temperatures ^{0}C
1	Emergency Unit	22-24 ^{0}C
2	Outpatients & Diagnostics	22-24 ^{0}C
3	Inpatients	22-24 ^{0}C
4	Interventions	22-24 ^{0}C
5	Therapies	22-24 ^{0}C
6	Toilets & Services	22-24 ^{0}C
7	Corridors & Shafts	22-24 ^{0}C

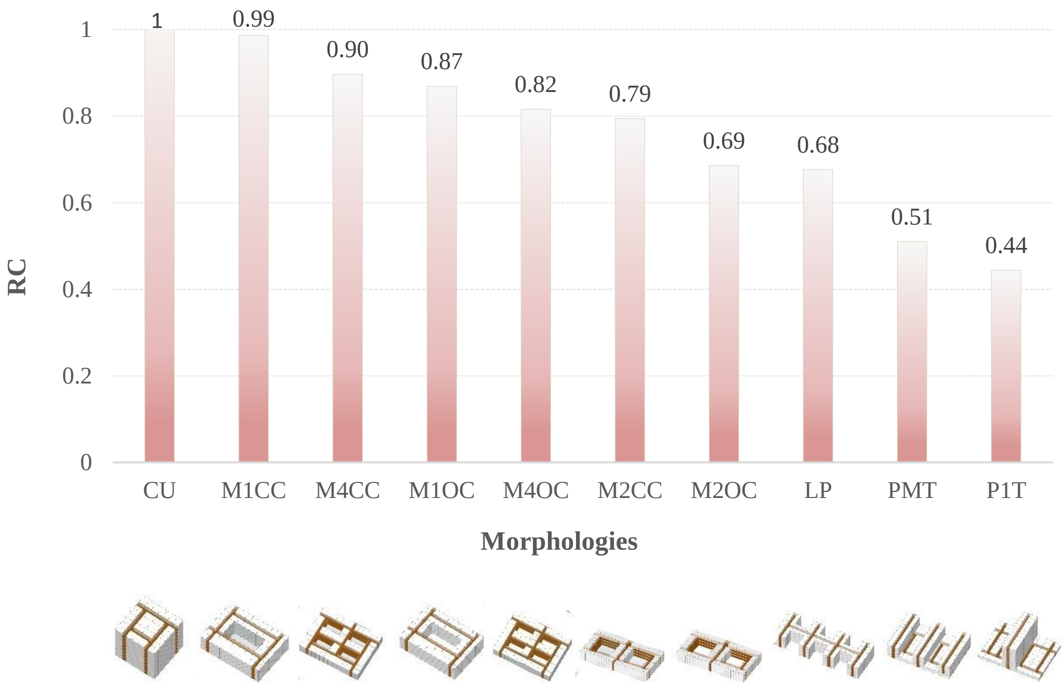


Figure 21: *Relative Compactness of selected morphologies*

3.4.1 Cube

The Cube is the first morphology. The results of the energy simulation are normalized using the results from a reference shape, specifically a cube where x=y=z, for an easier comparison study. The floor plan of this cube is square and shares the same intensity as the 8000 sqm area of the prototypical hospital building.

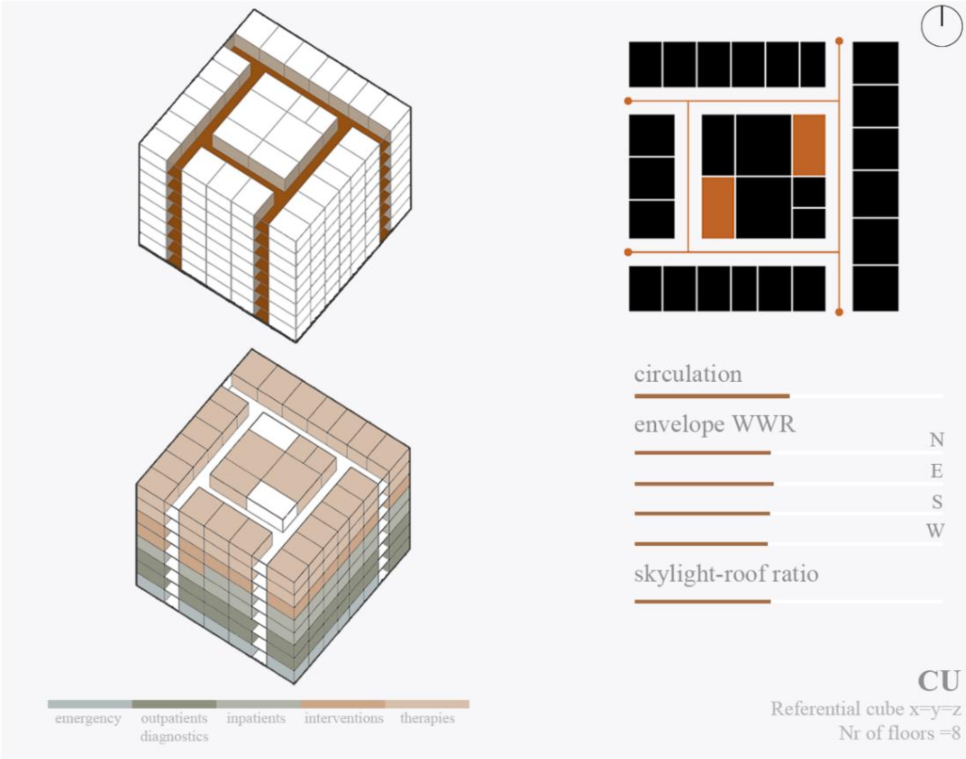


Figure 22: *CU morphology*

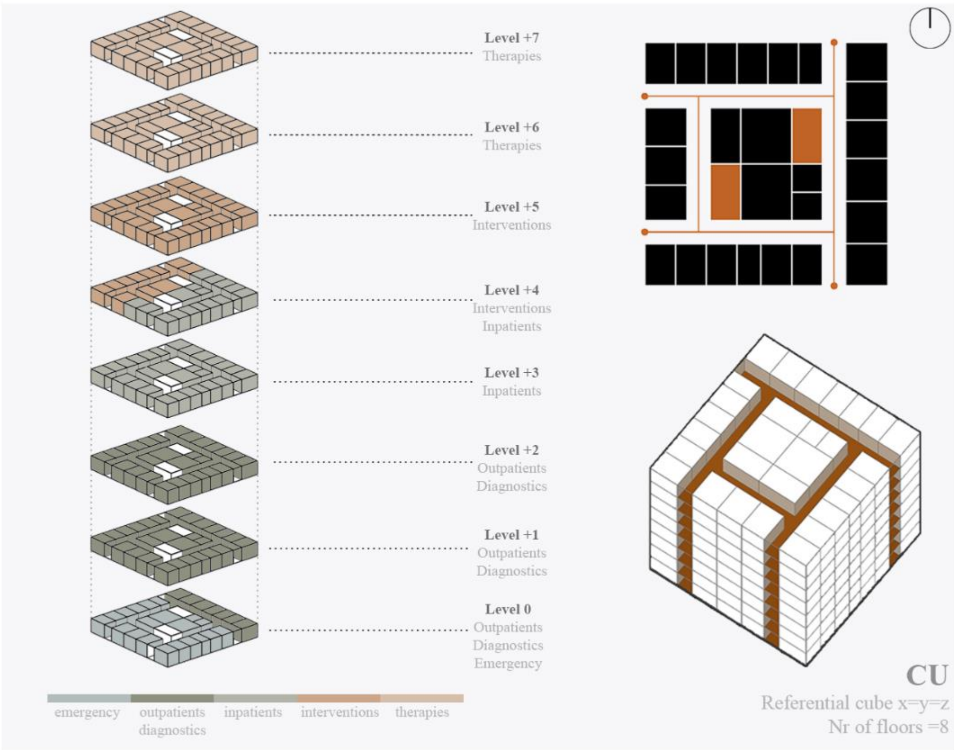


Figure 23: *CU morphology distribution of functions*

3.4.2 Podium with tower

Podium with tower is a morphology very common and widely spread nowdays as the construction sites are becoming more and more narrow. It consists of a rectangular ground level from where the vertical circulation links it with the upper levels of the towers.

3.4.2.1 Podium with one tower

In this morphology, the ground level is considered as a level with common spaces which need direct access to the outside but also do not confuse with the other more private spaces. In general, the tower contains many levels categorized by departments in order that each department takes one or more floors. By this categorization, an easier access and division is present, so that each floor has its own service spaces according to the function of the floor level.

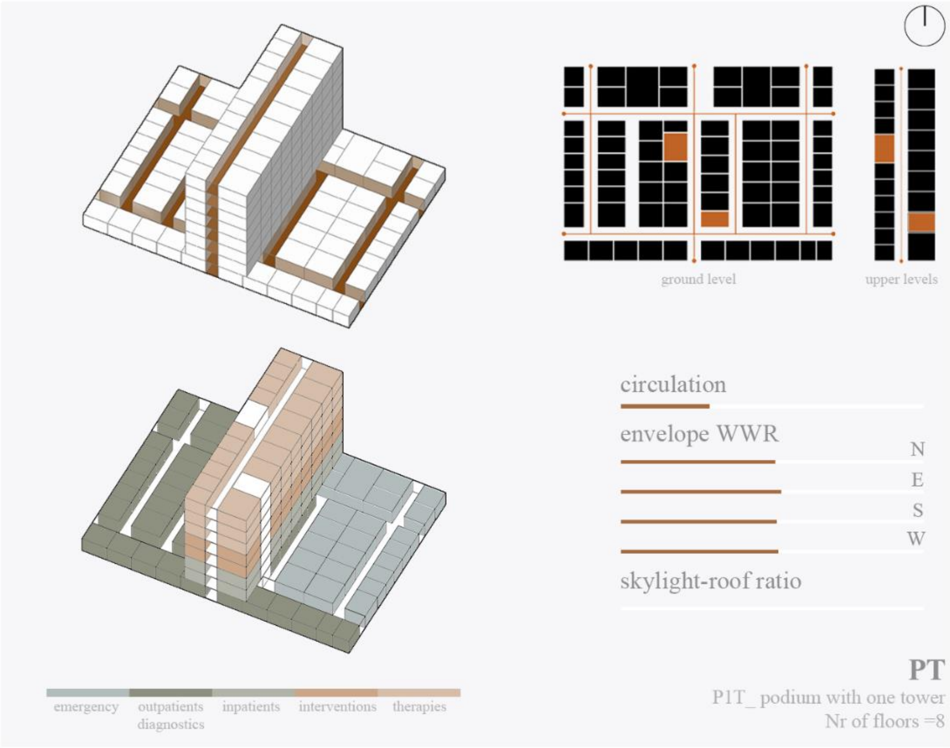


Figure 24: *P1T morphology*

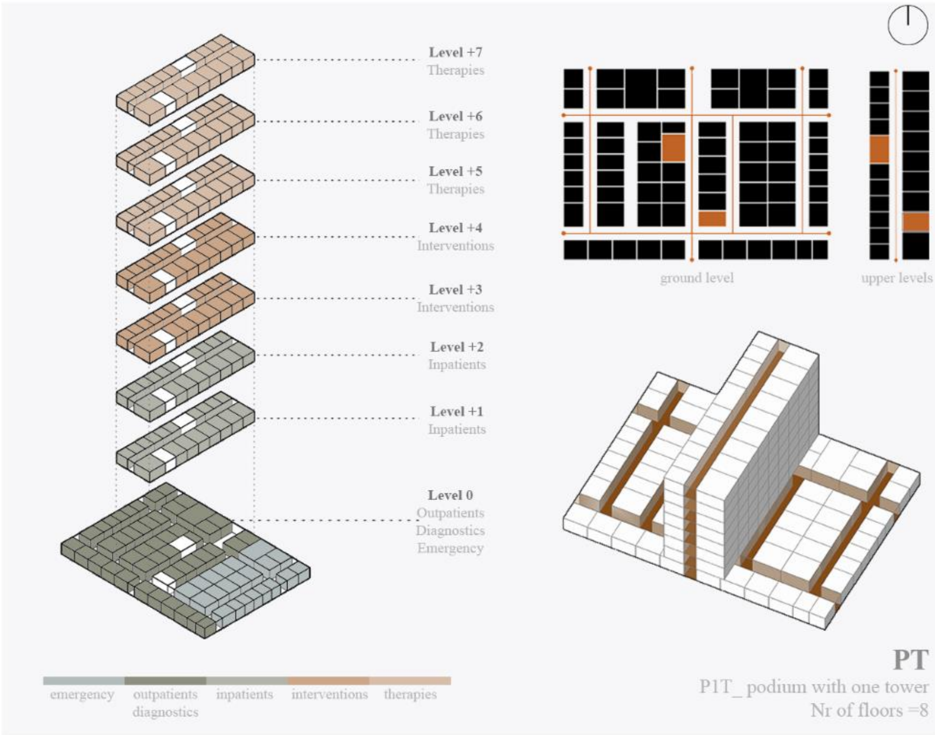


***Figure 25**: P1T morphology distribution of functions*

3.4.2.2 Podium with multi towers

In this case, in the PMT morphology, the ground level is organized by providing direct access to the upper levels. Each shaft serves as a unique vertical link with the upper tower. Every tower shares the same or similar spaces between its floors to provide an easier access for users. The presence of more than one tower is an advantage for both natural light and ventilation as well as a categorization of departments by separated volumes. In this study is taken into consideration the morphology with three towers.

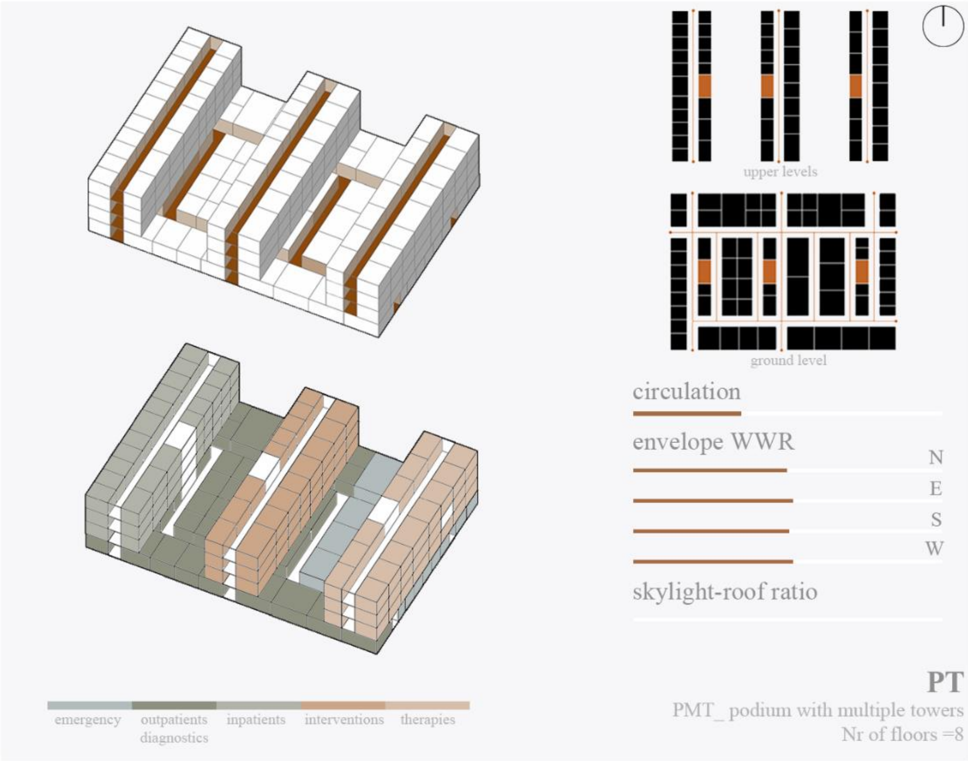


***Figure 26**: PMT morphology*

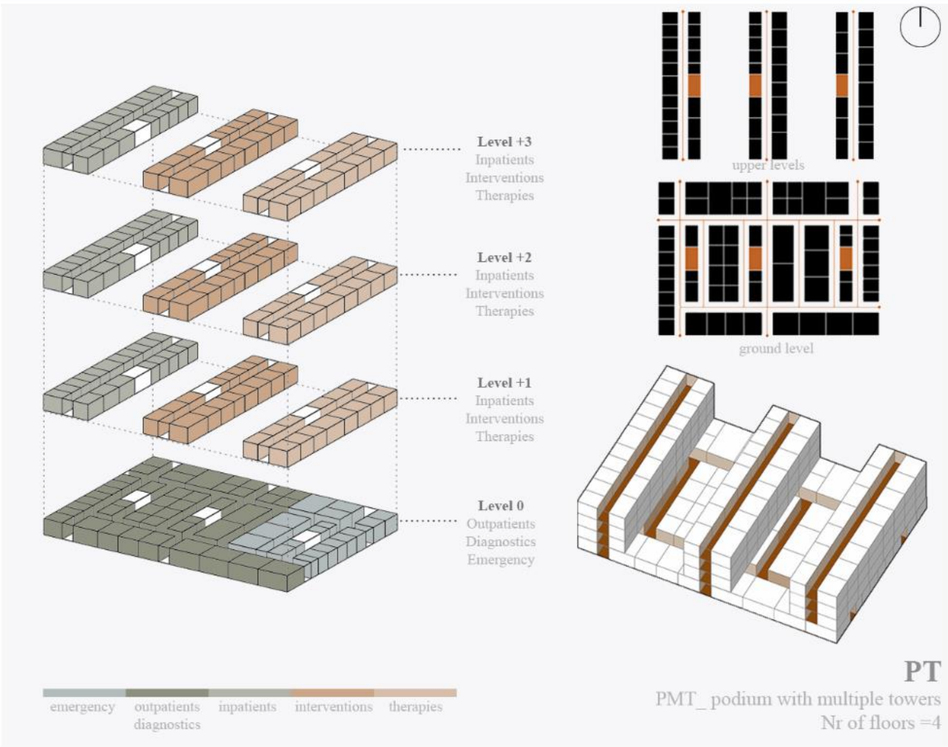


***Figure 27:** PMT morphology distribution of functions*

3.4.3 Linked pavilions

Linked Pavilions, LP, is the morphology that shares the same footprint and area for all the levels. The perimeter of this morphology is larger than its outer rectangle. This means more spaces which benefit from the natural light and ventilation. The courtyards formed between the wings do also serve as an easier categorization of departments with their needed direct exits.

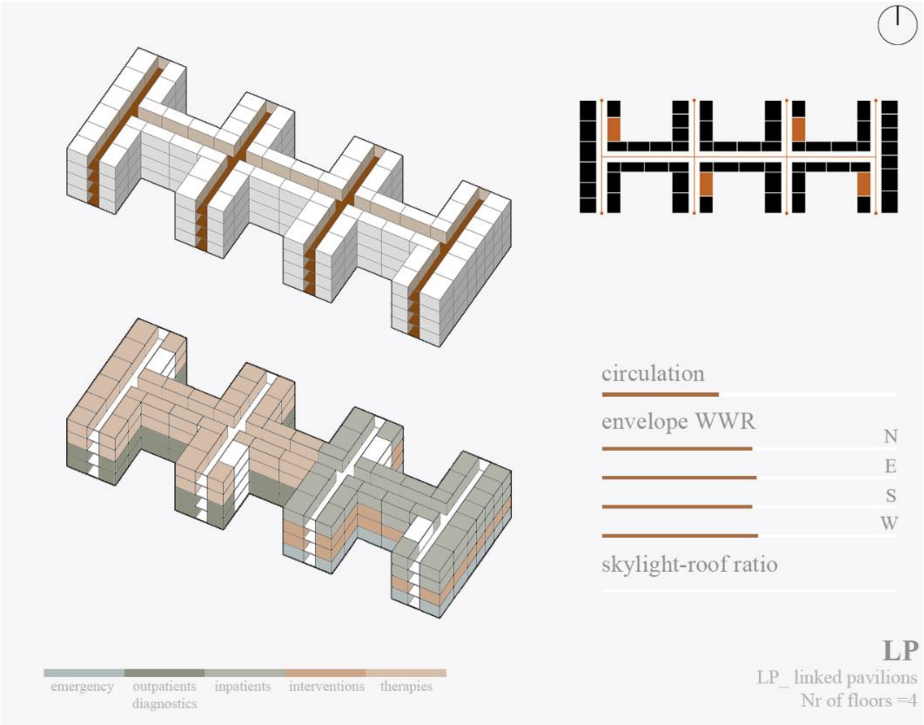


***Figure 28**: LP morphology*

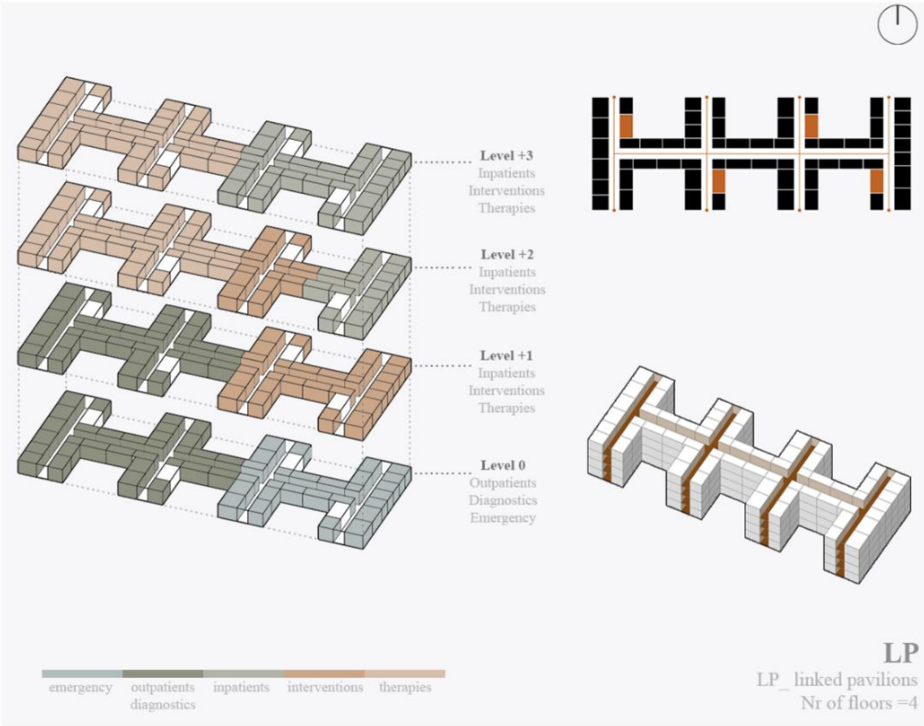


Figure 29: *LP morphology distribution of functions*

3.4.4 Monoblock with courtyard

The other morphologies are monoblocks with courtyards, which have clear internal layouts and compact volumes. The layout is quite flexible, and the circulation area is optimized. The spaces are immediately accessible from corridors and near direct exits.

3.4.4.1 Monoblock with one courtyard

The first morphology, M1C, consist of a volume with a central courtyard which enables easy access and circulation for all the spaces placed around it. The efficacy of this layout, is the access that rooms and corridors have to direct daylight and ventilation.

This morphology is studied in two aspects. One of them is the case when the courtyard is open and the other is when the courtyard is covered with glass.

M1OC, is the monoblock with one open courtyard in which the light and ventilation faces directly the internal façade of each level around the courtyard.

M1CC, is the monoblock with one courtyard closed with glass. In this case, the glass will provide a different microclimate for the spaces placed around the courtyard. Thus, in different selected climates, results are expected to show a difference in values.

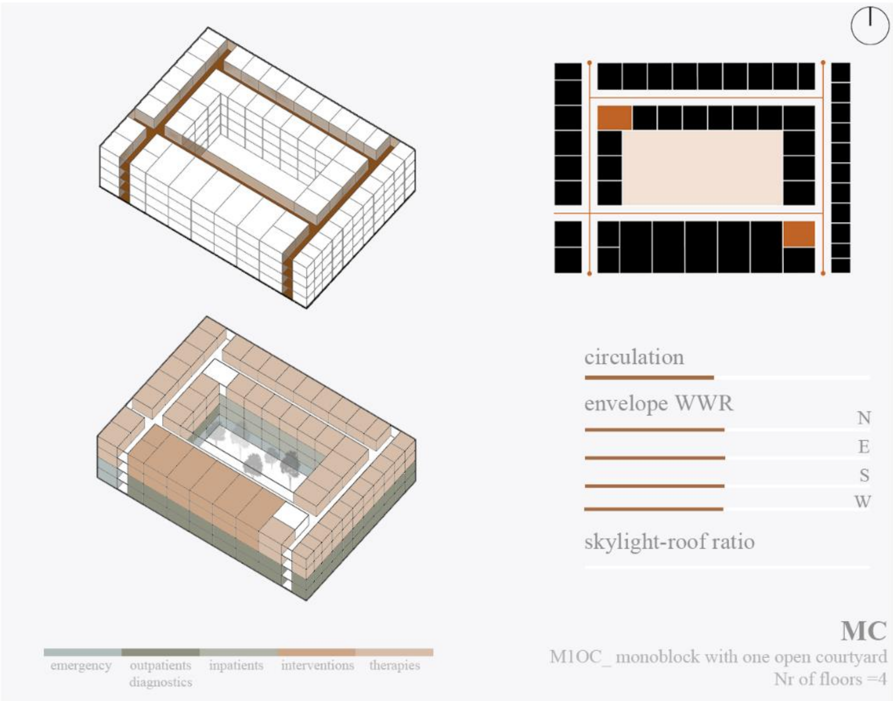


***Figure 30**: M1OC morphology*

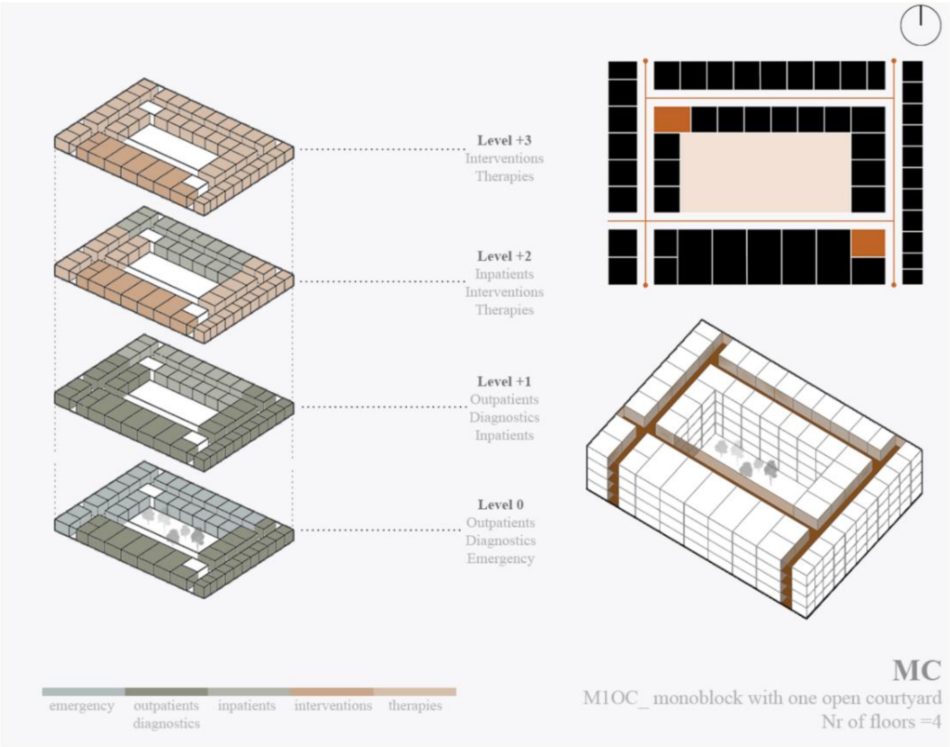


Figure 31: *M1OC morphology distribution of functions*

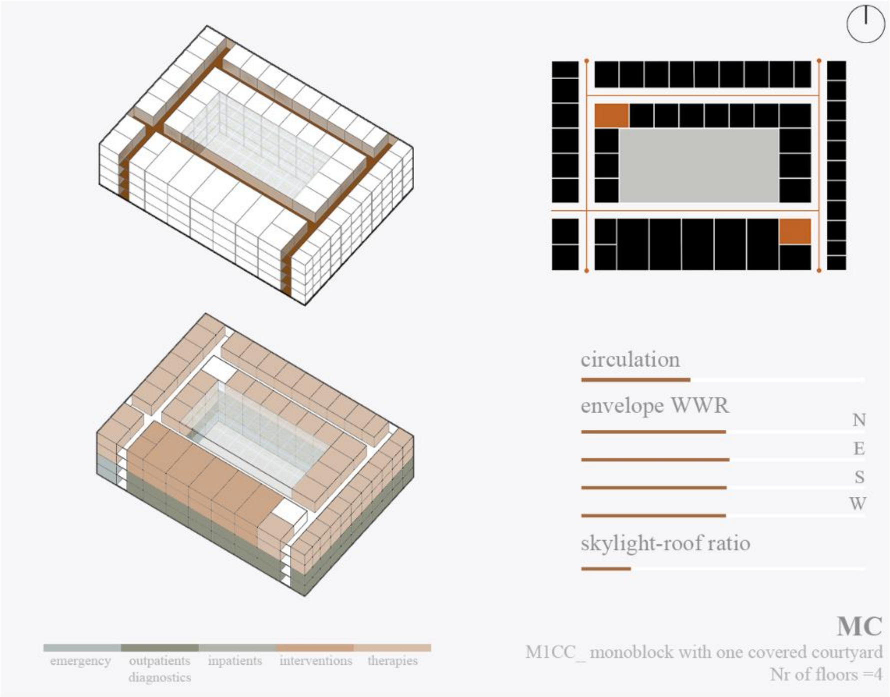


Figure 32*: M1CC morphology*

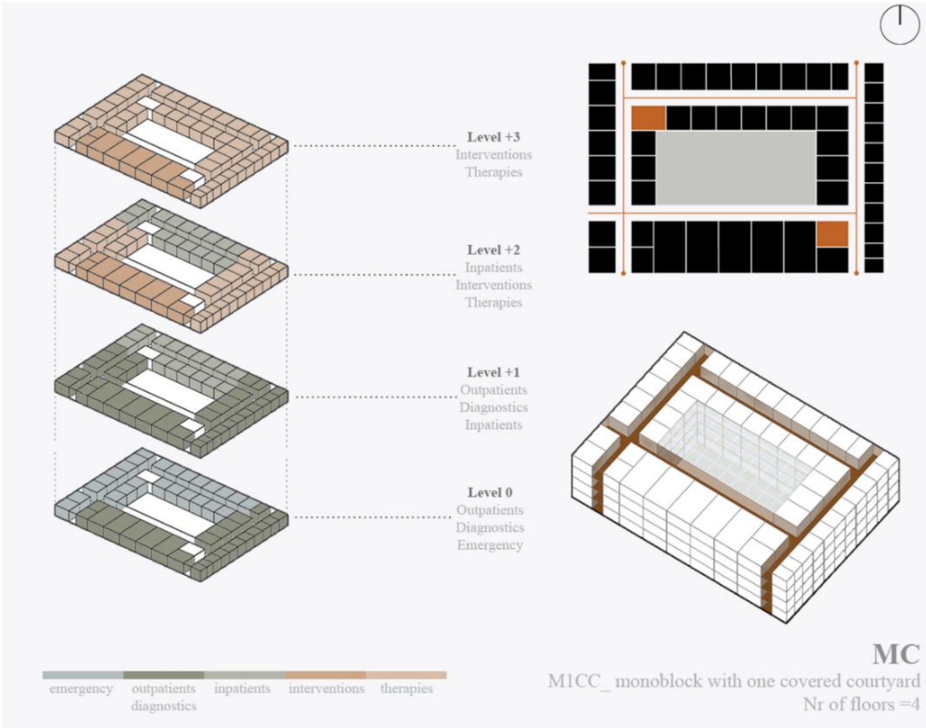


Figure 33*: M1CC morphology distribution of functions*

3.4.4.2 Monoblock with two courtyards

The other morphology consists of a volume with two courtyards. These courtyards simplify the circulation and access of the whole rooms and other spaces. Also, it is provided a central core in which many spaces are placed and directly exposed to the daylight and ventilation by courtyards, M1OC.

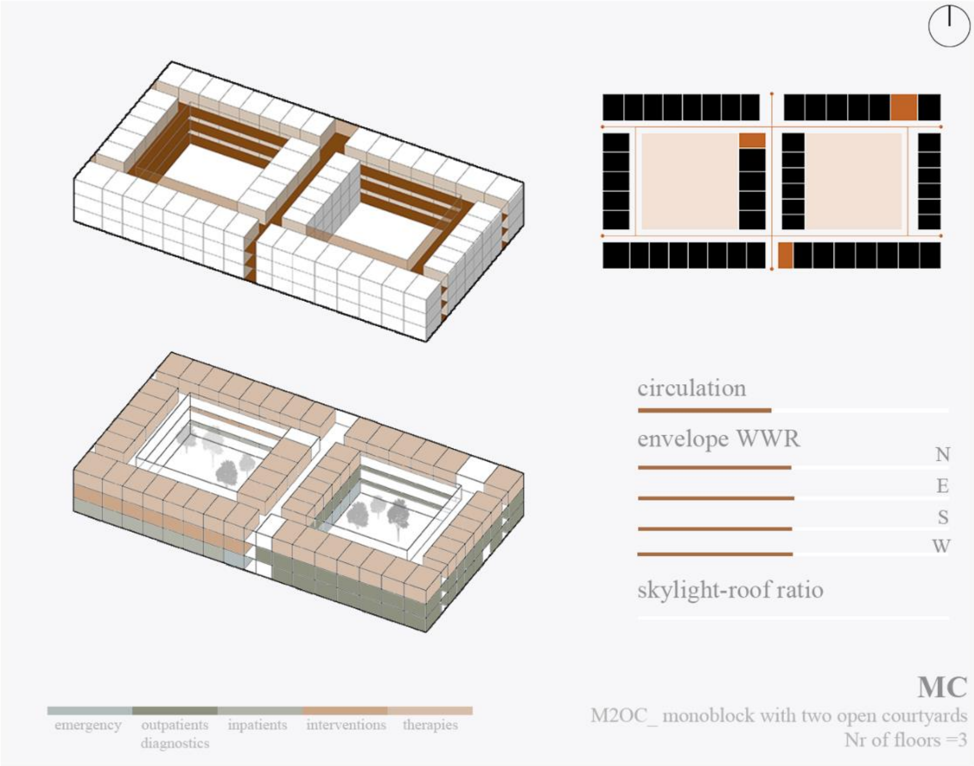


Figure 34: *M2OC morphology*

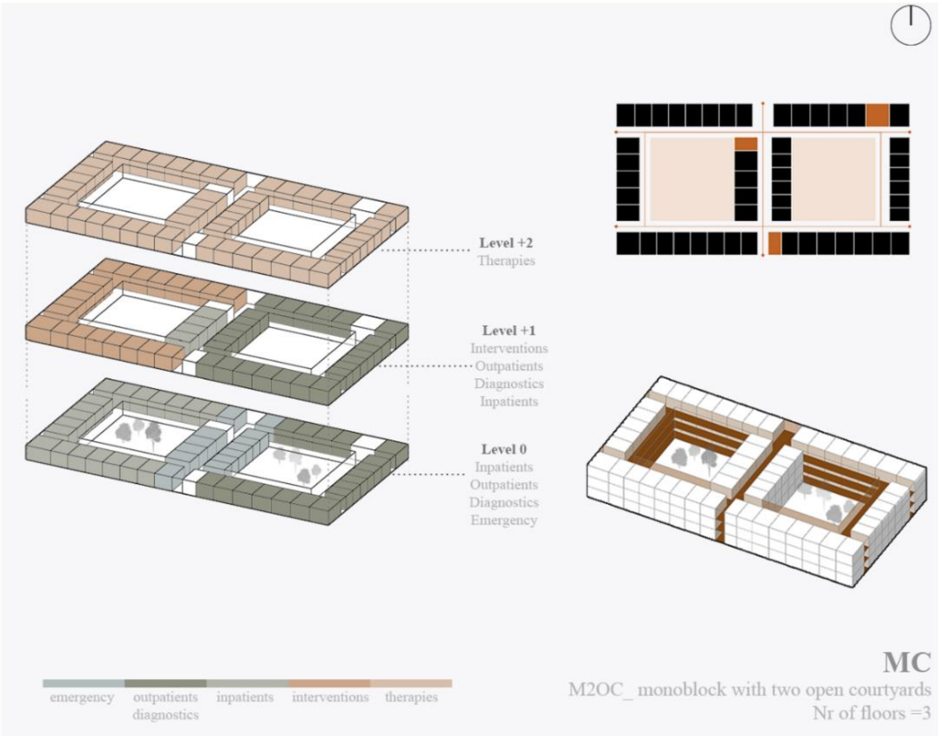


Figure 35: *M2OC morphology distribution of functions*

The second case shows the courtyards covered with glass, M1CC. In this case, comfort and energy is also affected by the presence of glazed covering.

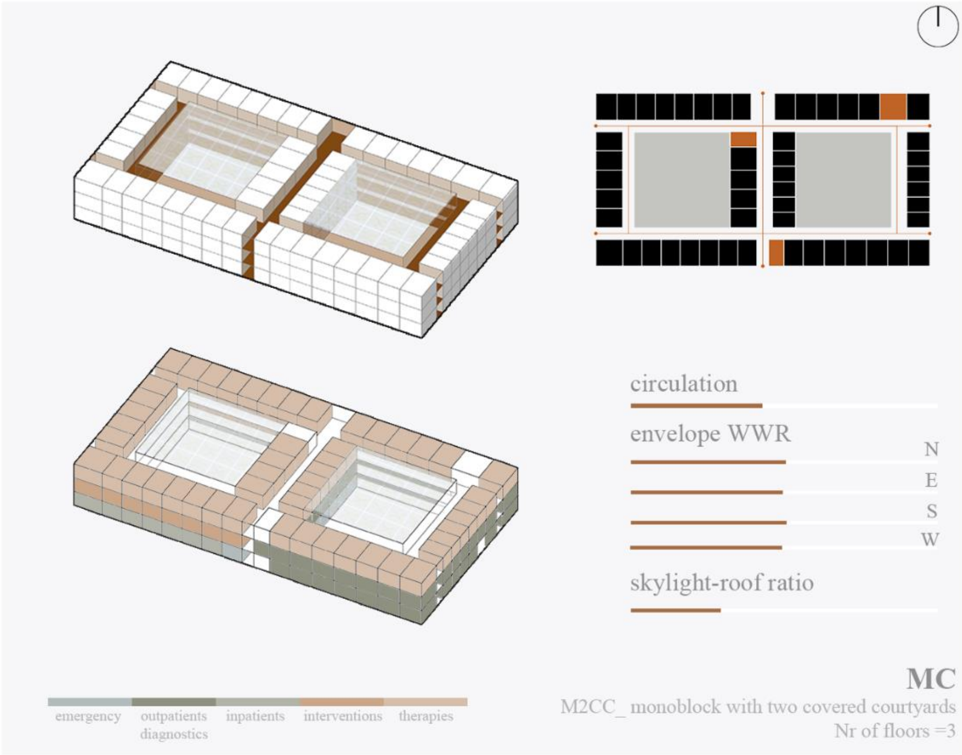


Figure 36: *M2CC morphology*

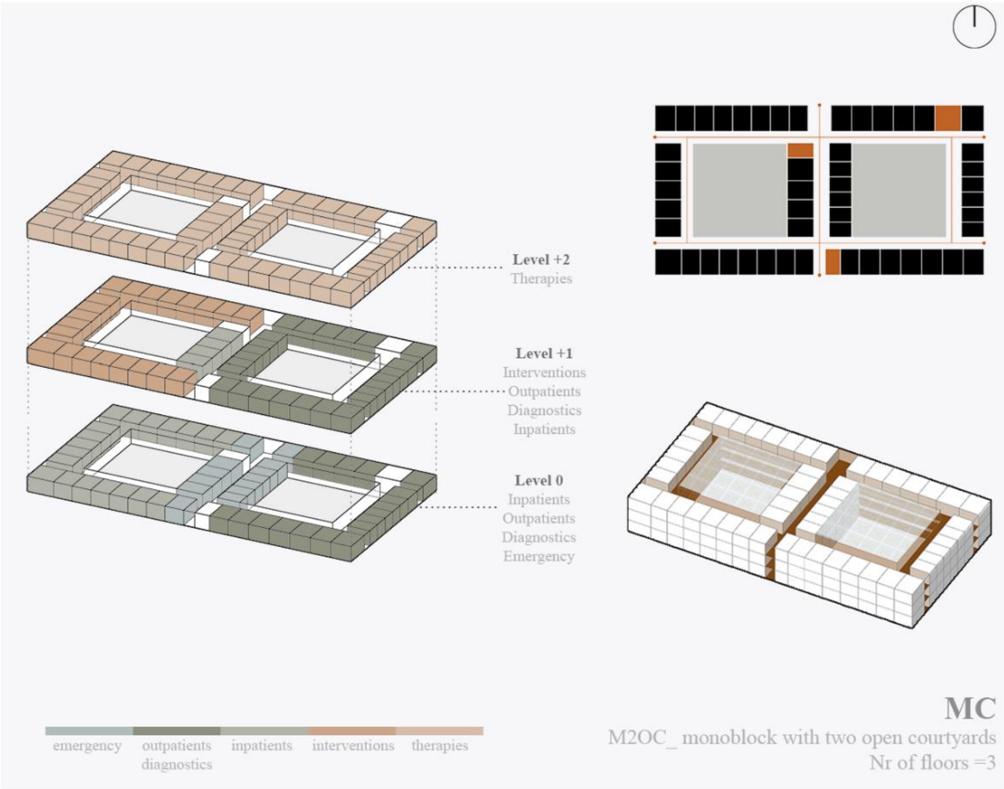


Figure 37*: M2CC morphology distribution of functions*

3.4.4.3 Monoblock with four courtyards

One other morphology that is taken into consideration in this study, is the monoblock with four courtyards, again considered in two aspects, with open courtyards and covered courtyards with glass.

Among selected morphologies, more courtyards mean more spaces with direct access to daylight and ventilation. For this reason, this morphology shows the presence of more corridors around which, in most of the cases, the spaces are distributed.

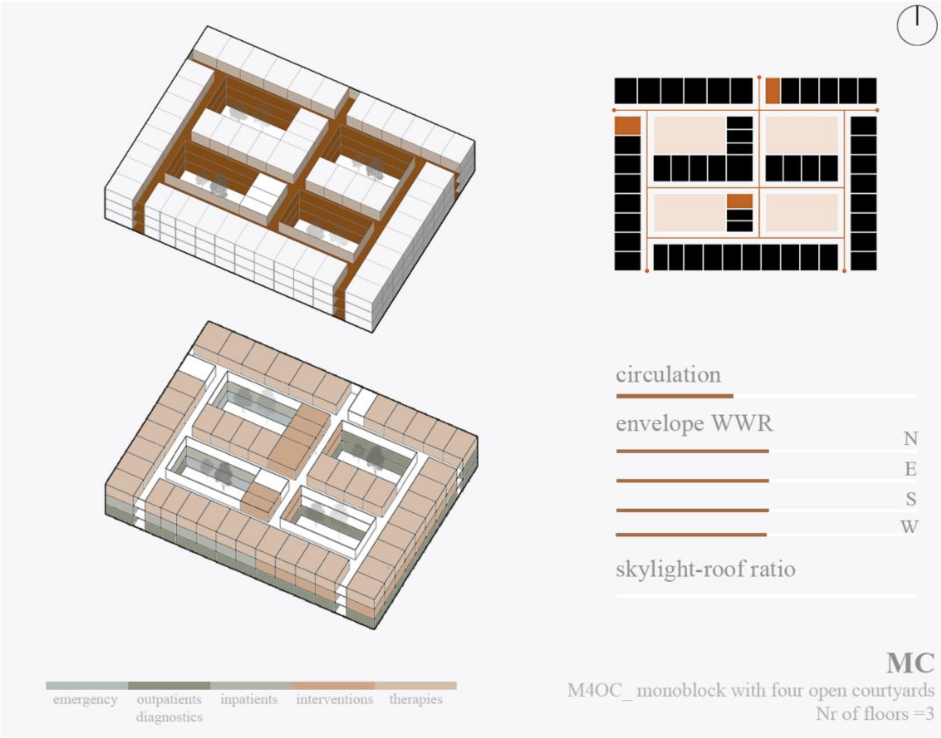


***Figure 38**: M4OC morphology*

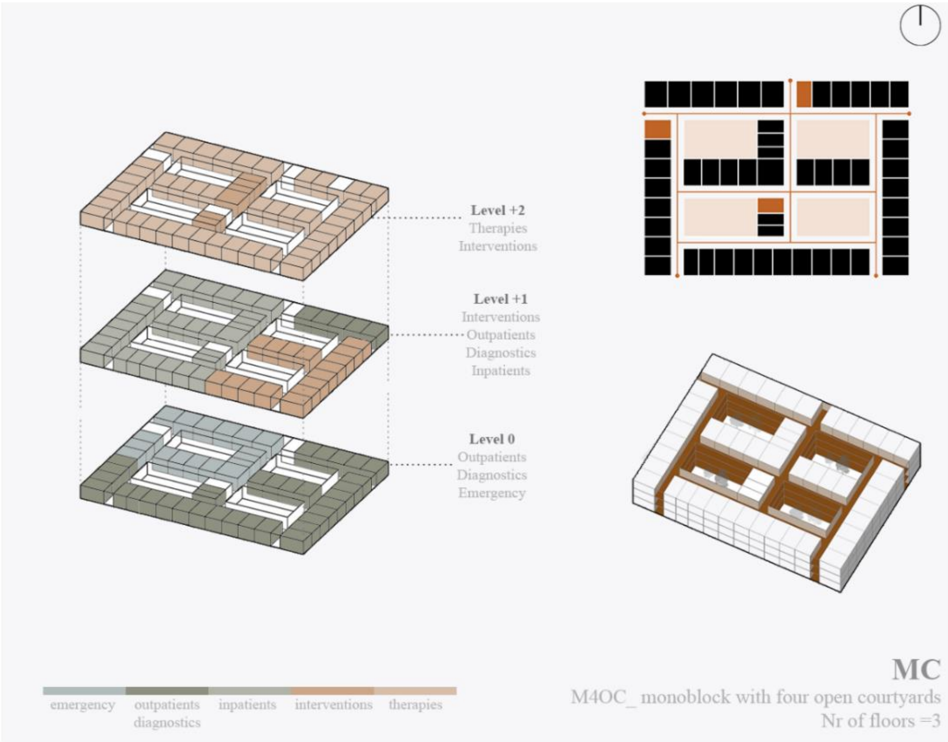


***Figure 39:** M4OC morphology distribution of functions*

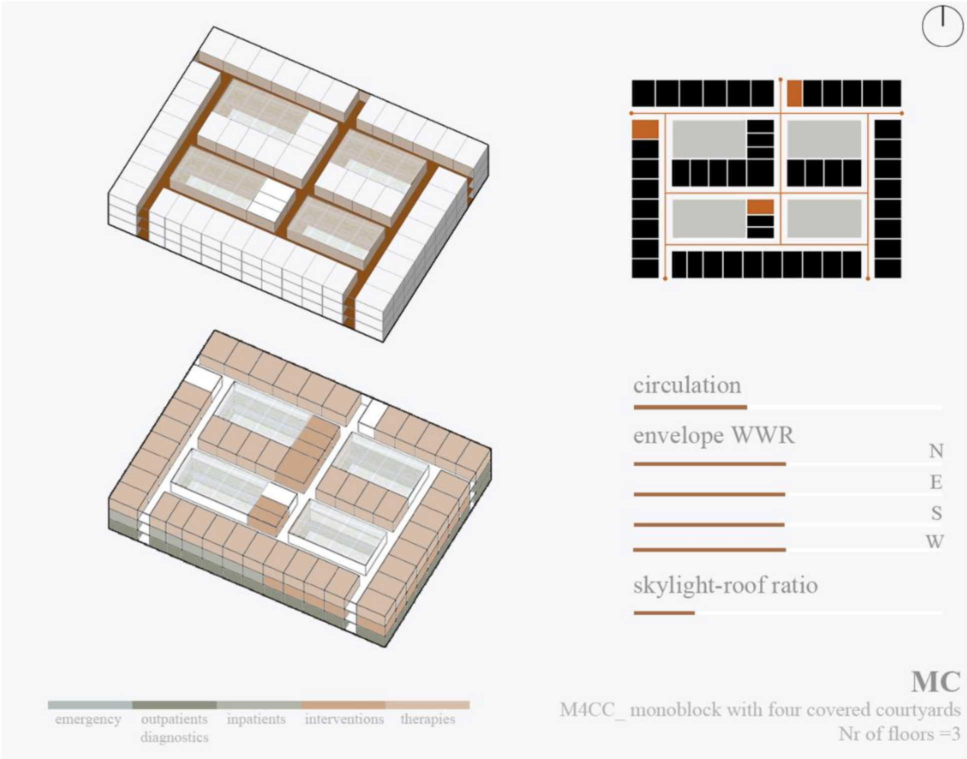


Figure 40: *M4CC morphology*

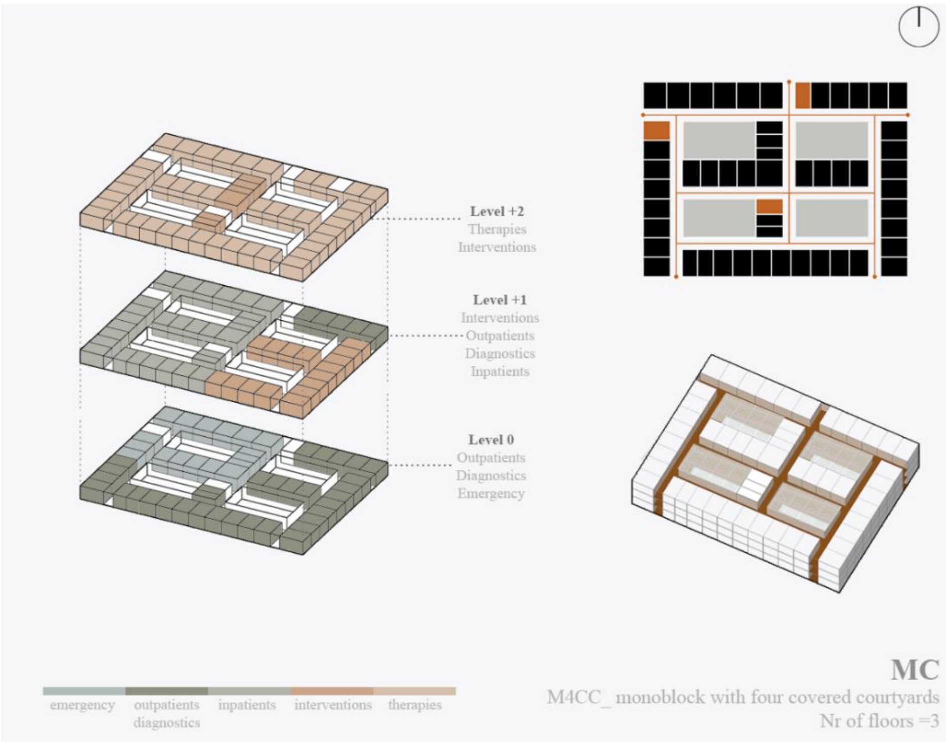


Figure 41: *M4CC morphology distribution of functions*

3.5 Modelling and simulation

3.5.1 Building model

To assess the performance of how various hospital morphologies perform, prototypical hospital buildings are chosen for research purposes. These buildings consist of a floor-to-floor height of 3.95m and a total area of approximately 8000 ± 80 m^2 (intensity). Using Design Builder, seven different hospital building models are created, all with the same spatial composition but different morphologies. The layout consists of five main hospital departments: emergency, outpatients and diagnostics, inpatients, interventions, and therapies, each with circulation spaces and service rooms. Figure 42 shows how these functions are distributed. In all models, the corridor width is set at a constant of 3m.

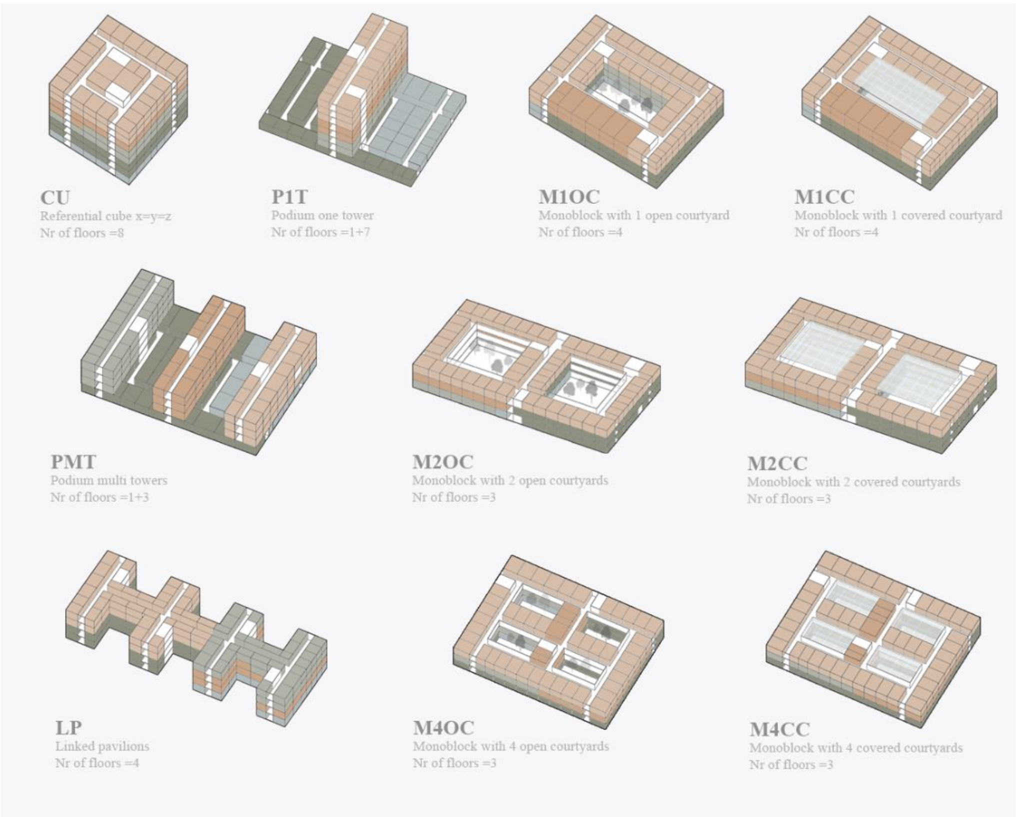


Figure 42: *Functional distribution*

The depicted occupancy schedules in Figure 43, are designed to address the existing requirements and strive to establish a well-distributed network of hospital departments that align with their respective functions.

***Figure 43**: Occupancy schedules*

The construction parameters such as lighting, HVAC template, glazing type and internal loads are set as a constant for all morphologies. Table 7 shows these construction properties. Construction properties are shown in Figure 44.

Table 7. *Construction properties*

		Density [kg/m³]	Conductivity [W/m °C]	Specific heat [J/kg °C]	Thickness [m]
External wall	Stone - granite	2750	3.4	840	0.03
U-value= 0.388	Air gap 30mm				0.03
[W/m²K]	MW Stone Wool (standard board)	40	0.038	840	0.07
	Brickwork	1920	0.72	840	0.25
	Cement plaster	1860	0.72	840	0.02
Internal wall					
U-value= 0.509	Cement plaster	950	0.35	840	0.01
[W/m²K]	Brickwork	1920	0.72	840	0.12
	MW Stone Wool (standard board)	40	0.038	840	0.05
	Brickwork	1920	0.72	840	0.12
	Cement plaster	950	0.35	840	0.01
Insulated roof					
U-value= 0.347	Asphalt - reflective coat	2300	1.2	1700	0.005
[W/m²K]	Roof Screed	1200	0.41	840	0.05
	XPS Extruded Polystyrene - CO2 Blowing	35	0.034	1400	0.08
	Cast Concrete (Lightweight)	1200	0.38	1000	0.10
Ground floor					
U-value= 0.5	Ceramic floor tiles	1700	0.80	850	0.02
[W/m²K]	Floor Screed	1200	0.41	840	0.07
	Cast Concrete	2000	1.13	1000	0.30
	XPS Extruded Polystyrene - CO2 Blowing	35	0.034	1400	0.04
Internal floor	Ceramic floor tiles	1700	0.80	850	0.02
U-value=1.76 [W/ m²K]	Floor Screed	1200	0.41	840	0.07
	Cast Concrete	2000	1.13	1000	0.25

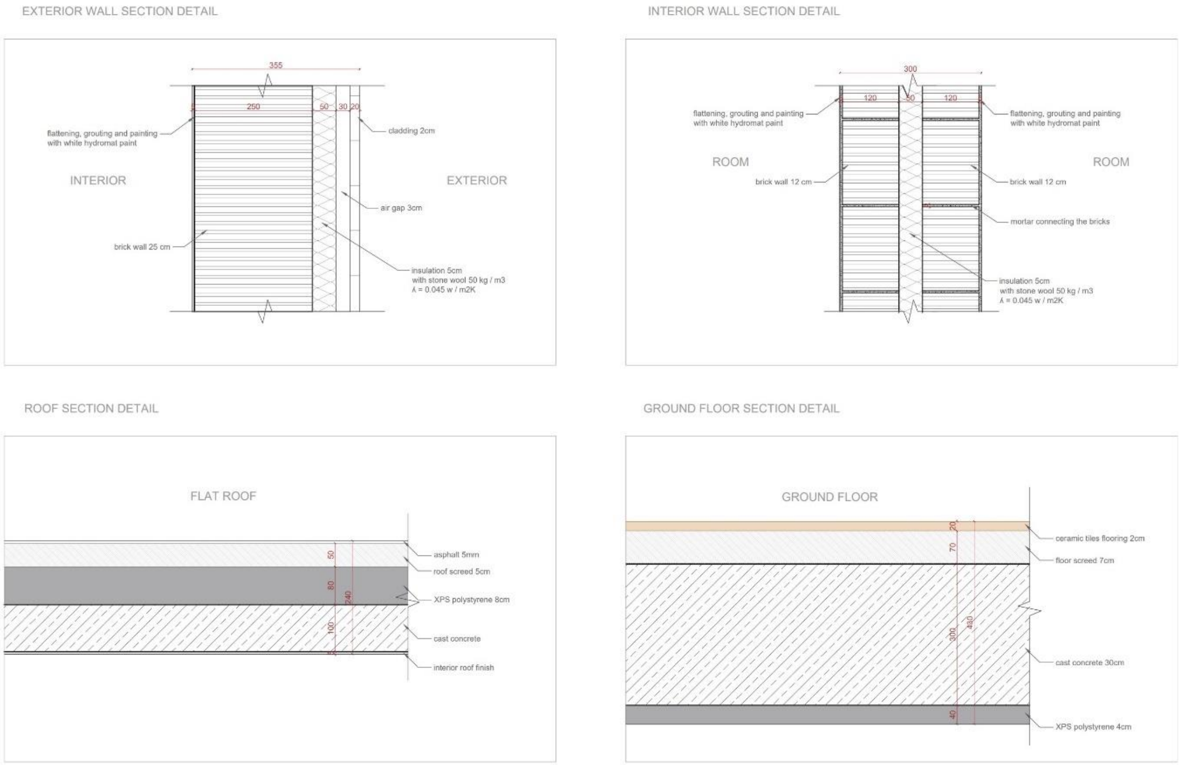


***Figure 44**: Section details of the simulation models*

***Table 8**. Input parameters for HVAC operation*

Input parameters	
Fan coil unit	(4 pipe) water cooled chiller, waterside economizer
Heating/cooling system	Electricity from grid
Coefficient of Performance [CoP]	3.5(cooling) and 2.5(heating)
Heating set back [°C]	12
Cooling set back [°C]	28

Table 9. *Brief for spatial program*

Areas	Size m^2	Fresh Air (L/S-Person)	Air Exchange Rate (Ac/h)	Power density (W/m²-100 lux)	Heating temperature set points °C	Cooling temperature set points °C	Occupancy density [P/m^2]
Emergency	800	60	10	7.8	22	24	0.022
Outpatients, Diagnostics	2560	60	6	6.0	22	24	0.057
Inpatients	1280	60	10	7.8	22	24	0.024
Interventions	1200	60	20	7.8	22	24	0.071
Therapies	2160	60	10	6.0	22	24	0.055
Corridors, Shafts	-	2.5	6	4.0	22	24	-
Toilets, Services	-	2.5	8	2.5	22	24	-

Table 10. *Glazing properties for window to wall ratio 60%*

Glazing properties	
Glazing type	Double Lo E (e2=1) clear 6mm/13mm Air
Frame properties	Aluminum window frame with thermal break
SHGC (Total solar transmission)	0.568
U-value of glass [W/m^2K]	1.761
Opening position	middle
Glazing area opens [%]	30
Airtightness [ac/h]	0.5

3.5.2 Scenarios of the proposed design strategies

In order to calculate the energy usage and thermal comfort of the seven different building shapes, various design parameters are altered. To examine the effect of orientation, the building models are rotated by 90, 180, and 270 degrees to represent east, south, and west, respectively. This process is repeated for different climatic conditions, as shown in Figure 45. Table 11 provides details on the different simulation scenarios that are tested.

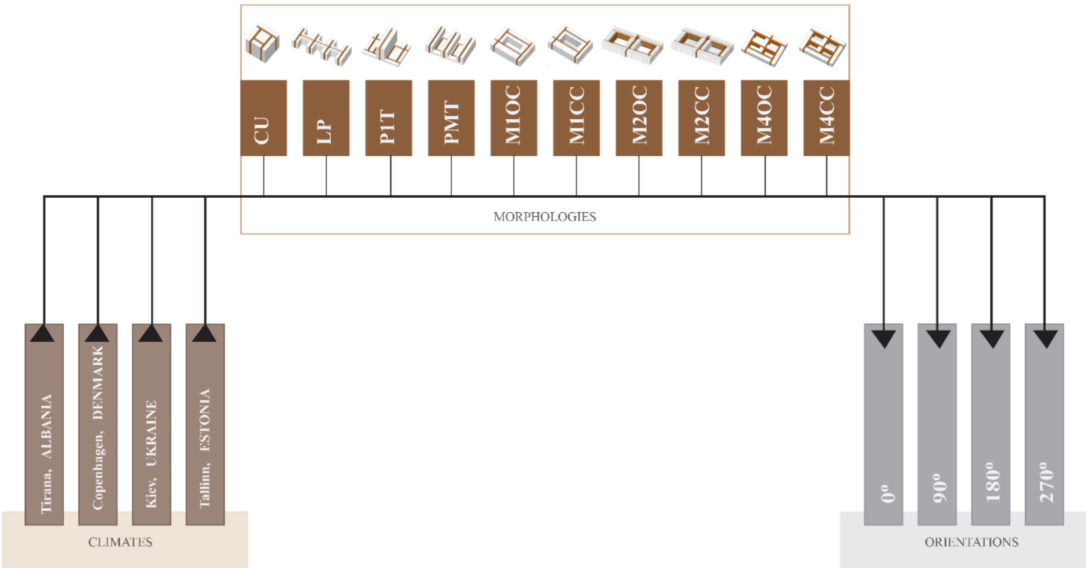


Figure 45:*Simulation scenarios*

Table 11*. Description of the simulation scenarios*

	Code	Scenario	Description
CU	CU	Cube morphology, x=y=z	Block plan morphology considered as a reference shape for an easier comparison study
LP	LP	Linked Pavilions	Linked fragmented pavilions that form courtyards between the wings
PT	P1T	Podium with one Tower	Morphology consists of one block plan of ground level associated by one tower of 7 levels
	PMT	Podium with multiple Towers (3)	Morphology consists of one block plan of ground level associated by three towers of 3 levels
M1C	M1OC	Monoblock with one Open Courtyard	Block plan with one open courtyard surrounded by corridors
	M1CC	Monoblock with one Covered Courtyard	Block plan with one courtyard covered with glass, providing one atrium space, surrounded by corridors
M2C	M2OC	Monoblock with two Open Courtyards	Block plan with two open courtyards, each of them is surrounded by corridors
	M2CC	Monoblock with two Covered Courtyards	Block plan with two courtyards, covered with glass, providing atrium spaces, surrounded by corridors
M4C	M4OC	Monoblock with four Open Courtyards	Block plan with four open courtyards, each of them surrounded by corridors
	M4CC	Monoblock with four Covered Courtyards	Block plan with four courtyards covered with glass, providing atrium spaces, surrounded by corridors

3.5.3 Output variables

To assess the influence of various morphologies on the energy efficiency of a hospital, it is essential to establish the correlation between the annual heating and cooling loads of the hospital building model under ten distinct morphology scenarios and its overall energy consumption. Additionally, the annual simulated energy demand will be compared based on rotation angle for each morphology. This analysis aims to evaluate the impact of different building forms on energy performance and inform decision-making regarding the hospital's design.

By studying the relationship between the annual heating and cooling loads for the hospital building model across the ten morphology scenarios, it becomes possible to identify trends and patterns. This analysis helps determine how variations in morphology affect the building's thermal behavior and energy requirements. For example, certain morphologies may exhibit higher cooling loads due to increased solar heat gain, while others may have higher heating loads due to increased heat loss. Understanding these relationships is crucial for optimizing energy performance.

Furthermore, the assessment of total energy consumption provides a comprehensive view of the building's energy usage. This metric considers both heating and cooling loads, as well as other energy-consuming systems within the hospital. By comparing the total energy consumption across the different morphology scenarios, it becomes apparent which designs are more energy-efficient and can potentially lead to significant energy savings.

Finally, the analysis examines the annual simulated energy demand based on rotation angle for each morphology. The rotation angle refers to the orientation of the building with respect to the sun's path. By investigating the impact of different rotation angles on energy demand, it becomes possible to identify optimal orientations that minimize energy consumption. This analysis considers the varying solar exposure throughout the year and its effect on heating and cooling requirements.

To sum up, evaluating the impact of selected morphologies on the energy performance of a hospital involves analyzing the relationship between annual heating and cooling loads, total energy consumption, and annual simulated energy demand based on rotation angle. This comprehensive assessment enables researchers and designers to make informed decisions to enhance the energy efficiency of hospital buildings.

3.5.4 Simulation software

To conduct simulations for various climatic contexts in Europe, the DesignBuilder interface version 8 for EnergyPlus is chosen due to its validated accuracy. This is confirmed through the BESTest (Building Energy Simulation TEST) procedure developed by the International Energy Agency. The software has previously been used to simulate the thermal comfort of building units in multiple countries (Zhang & Bokel, 2017; Montenegro, Potvin, & Demers, 2012). The local weather files for the different climatic contexts in Europe are generated using the Meteonorm 8 software.

CHAPTER 4

RESULTS

The results generated by computer programs undergo a two-step process of assessment and subsequent conversion into visual representations. Computational calculations involve simulating ten different hospital building designs with each having four distinct orientations, across four diverse climatic conditions. The obtained data elucidates the relationship and interplay between the morphology of the buildings and their overall performance as hospitals.

4.1 Climate of Tirana

The provided figures below depict an examination of yearly energy usage, aiming to assess the influence of Tirana's humid subtropical climate on the suggested building morphologies.

4.1.1. Energy performance

The figures provided below demonstrate the relationship between annual heating and cooling loads for the hospital building model across its ten different morphology scenarios, and the total energy consumption.

In Figure 46, the monthly heating demand is presented for all typologies with 0^0 orientation. Among these scenarios, the M1OC morphology performs poorly in Tirana's humid subtropical climate due to its relatively large surface area of the envelope, including the ground floor slab (Se). On the other hand, the CU morphology shows the best performance, primarily because of the compactness of solid volume contribution to reducing heating energy consumption.

In Figure 47, the monthly cooling demand is shown for all typologies with 0^0 orientation. It is observed that the atrium itself significantly increases the cooling demand of the M1OC morphology, raising concerns about its efficiency when integrated into building plans for this specific context.

Firgure 48 represents the monthly total energy consumption (heating and cooling) demand for all typologies with 0^0 orientation. It is observed that the compactness of buildings increases the energy demand in warm months, meanwhile morphologies with courtyards perform better. In the opposite scenario, the results are as follows; morphologies with courtyards increase more the energy demand in cold months rather than more compact morphologies.

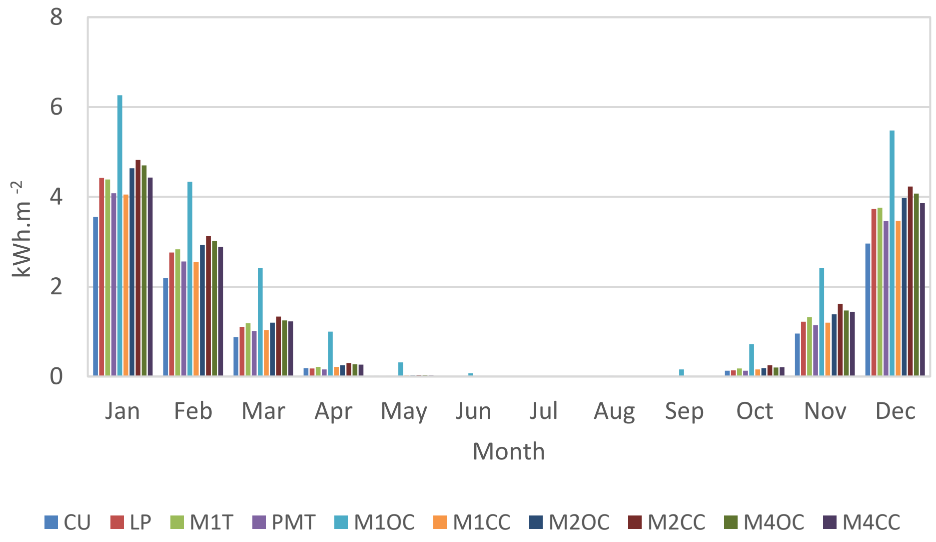


Figure 46. *Comparison of simulated heating demand (kWh.m^{-2}) of 0^0 oriented typologies*

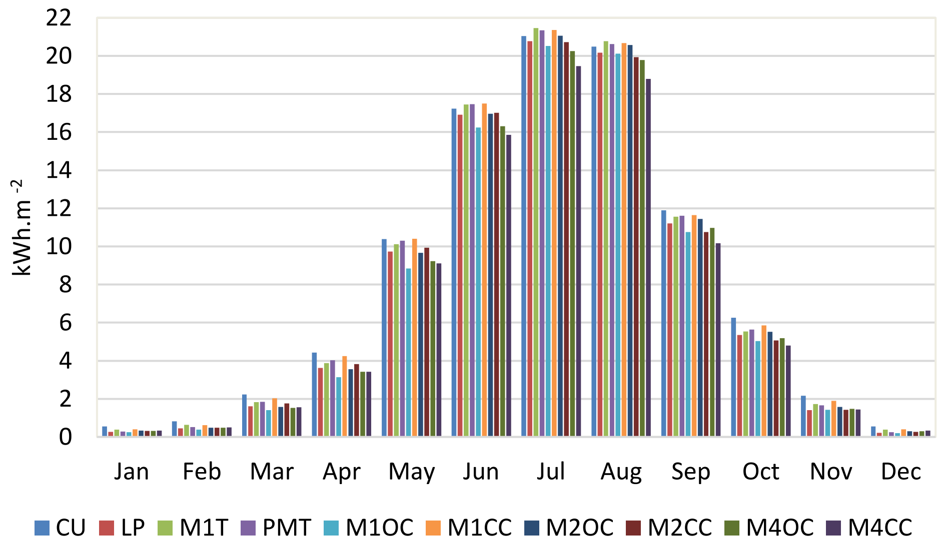


Figure 47. *Comparison of simulated cooling demand (kWh.m^{-2}) of 0^0 oriented typologies*

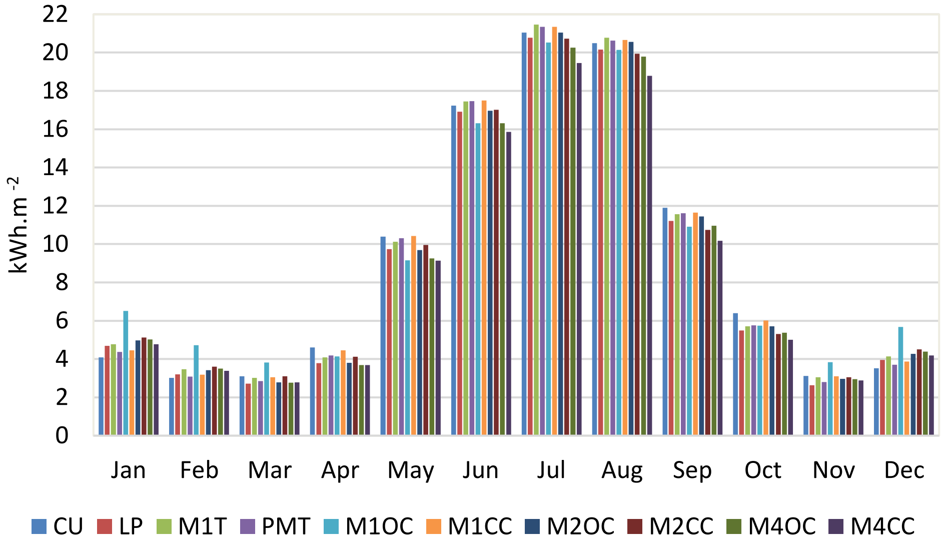


Figure 48. *Comparison of simulated energy demand (kWh.m^{-2}) of 0^0 oriented typologies*

Figure 49 depicts the monthly heating demand for all typologies with 90^0 orientation. On the other hand, Figure 50 illustrates the monthly cooling demand for the same typologies. It is observed that there is a minimal demand for heating from April to October and for cooling from November to March, indicating favorable conditions in Tirana's climate during these months.

Firgure 51 represents the monthly total energy consumption (heating and cooling) demand for all typologies with 90^0 orientation. It is observed that M1OC morphology increases the energy demand regarding cold months while M1CC requires more energy in warm months.

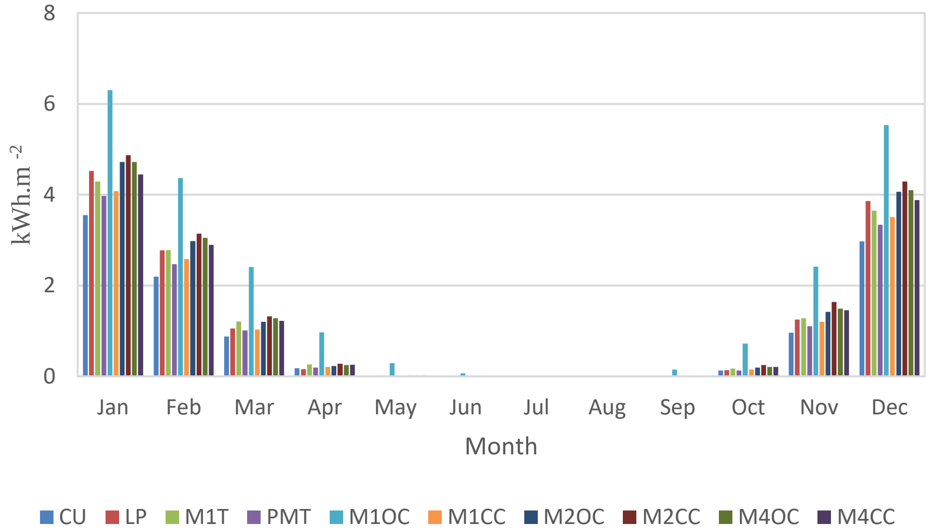


Figure 49. *Comparison of simulated heating demand (kWh.m^{-2}) of 90^{0} oriented typologies*

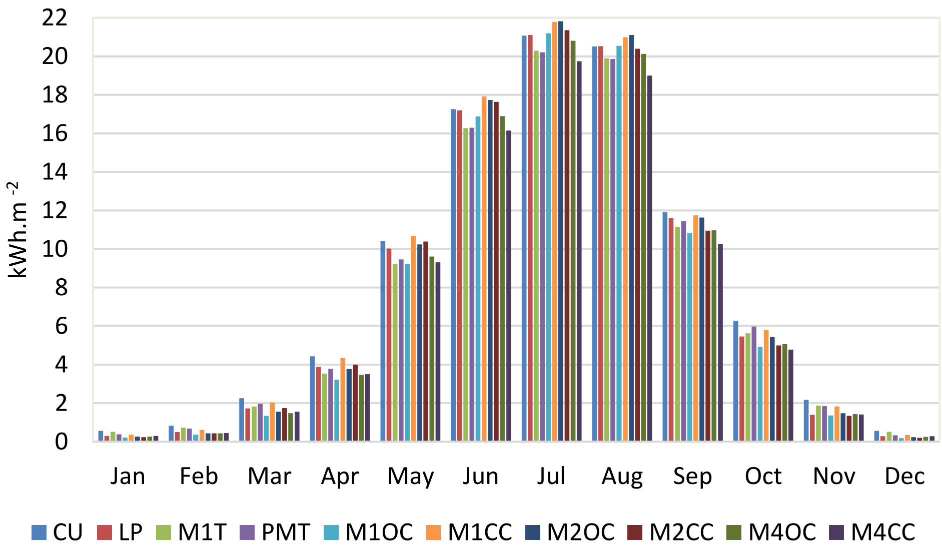


Figure 50. *Comparison of simulated cooling demand (kWh.m^{-2}) of 90^{0} oriented typologies*

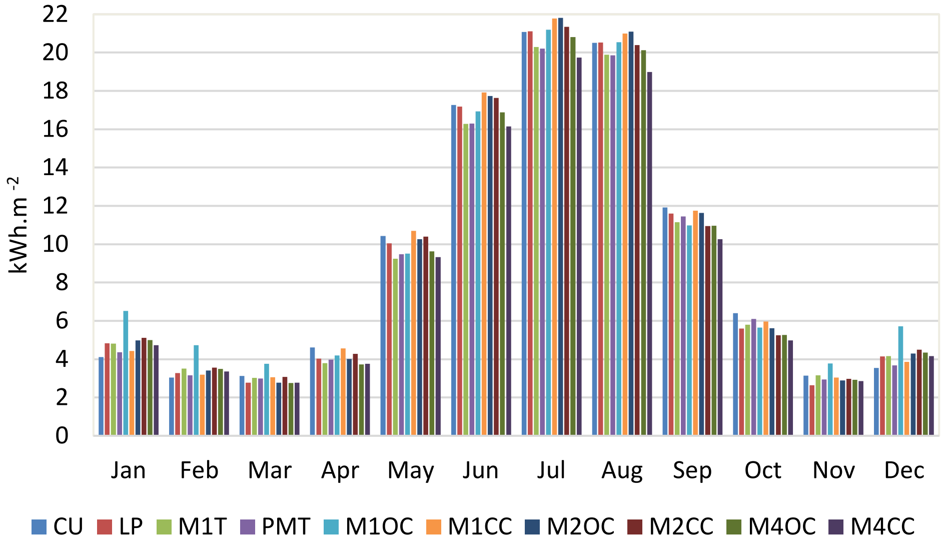


Figure 51. *Comparison of simulated energy demand (kWh.m^{-2}) of 90^0 oriented typologies*

Figure 52 represents the monthly heating demand for all typologies with 180^0 orientation. On the other hand, Figure 53 showcases the monthly cooling demand for the same typologies but with 180^0 orientation. These figures provide insights into the heating and cooling requirements of the different building morphologies throughout the year, considering the specific orientations of the hospitals.

Firgure 54 represents the monthly total energy consumption (heating and cooling) demand for all typologies with 180^0 orientation. It is shown that M1OC morphology increases the energy demand regarding cold months while M1CC and M1T require more energy in warm months.

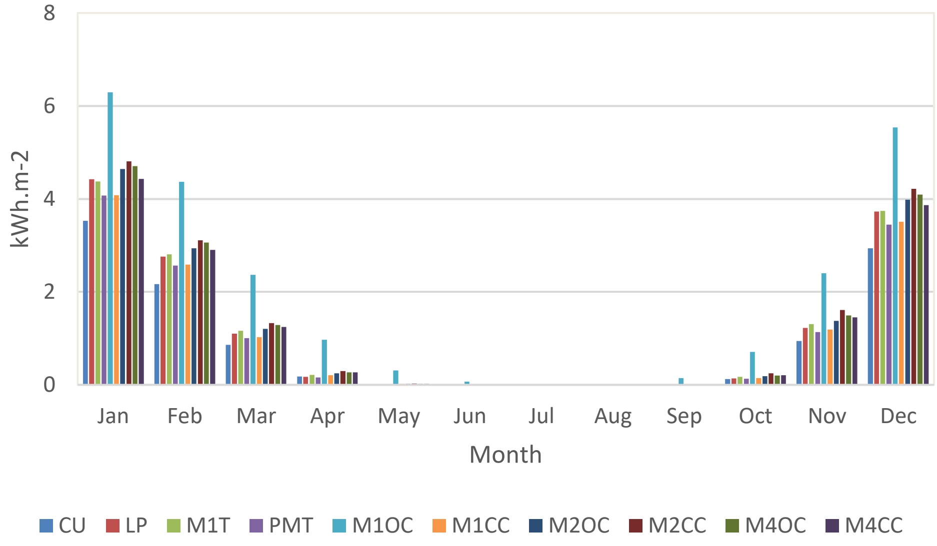


Figure 52. *Comparison of simulated heating demand (kWh.m^{-2}) of 180^{0} oriented typologies*

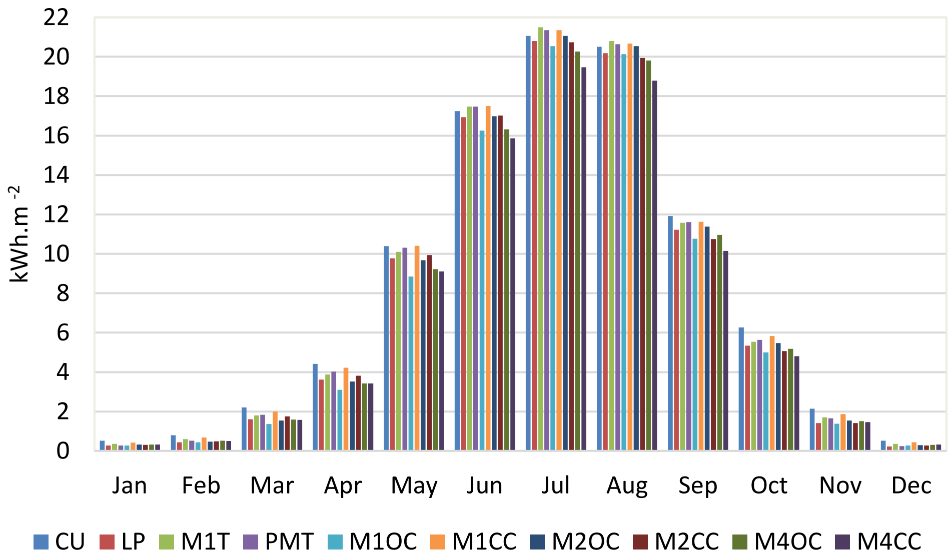


Figure 53. *Comparison of simulated cooling demand (kWh.m^{-2}) of 180^{0} oriented typologies*

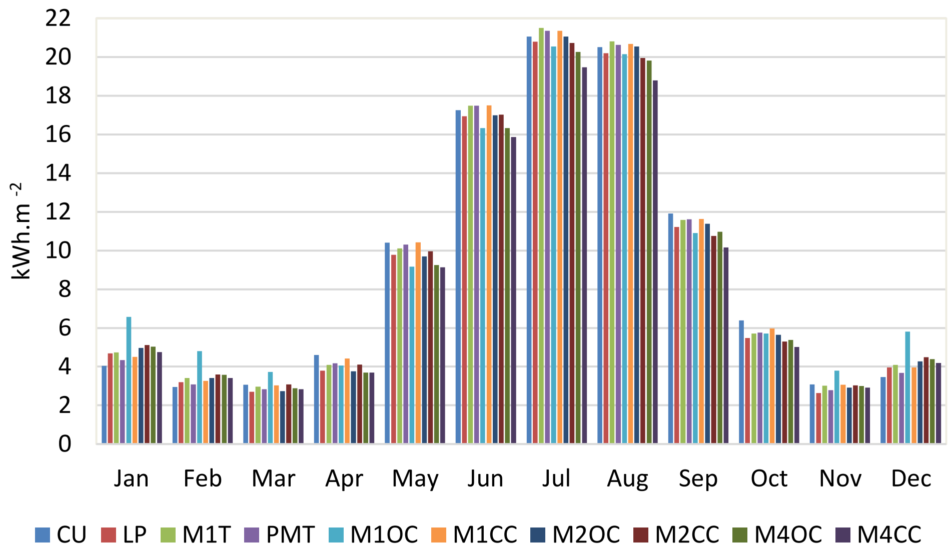


Figure 54. *Comparison of simulated energy demand (kWh.m^{-2}) of 180^0 oriented typologies*

Figure 55 represents the monthly heating demand for all typologies with 270^0 orientation. On the other hand, Figure 56 showcases the monthly cooling demand for the same typologies but with 270^0 orientation. These figures provide insights into the heating and cooling requirements of the different building morphologies throughout the year, considering the specific orientations of the hospitals.

Figure 57 depicts the monthly total energy consumption (including heating and cooling) demand for all typologies oriented at 270^0. The results indicate that the compactness of the morphologies lead to a decrease in energy demand during colder months, whereas these morphologies exhibit higher energy requirements during warmer months.

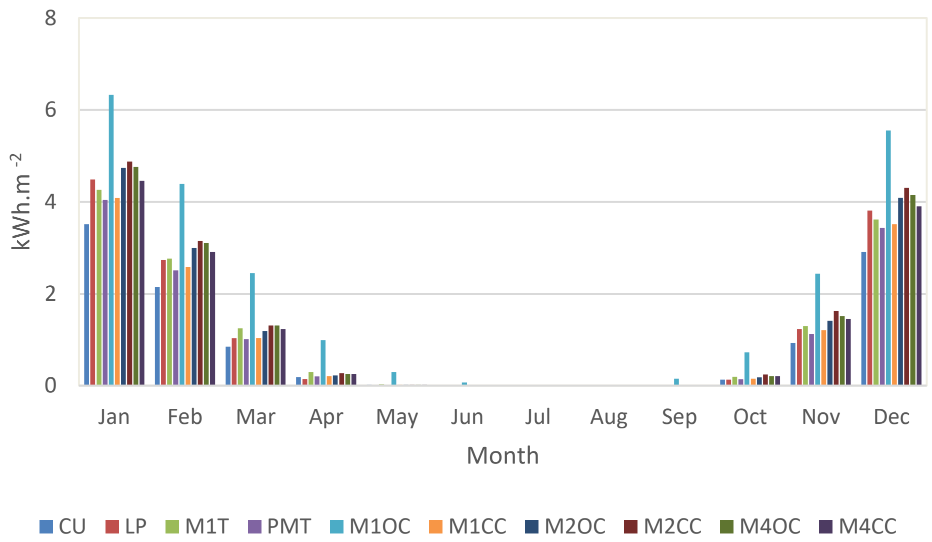


Figure 55. *Comparison of simulated heating demand (kWh.m^{-2}) of 270^0 oriented typologies*

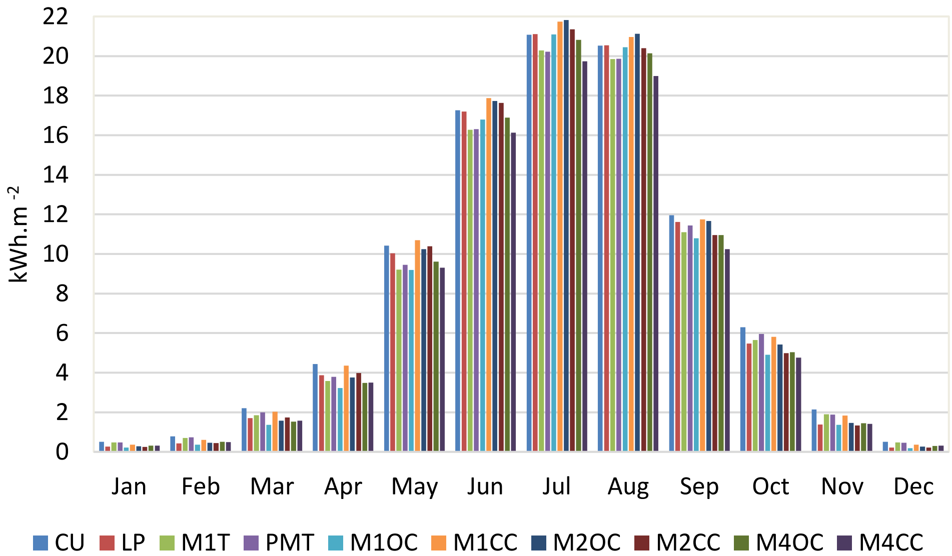


Figure 56. *Comparison of simulated cooling demand (kWh.m^{-2}) of 270^0 oriented typologies*

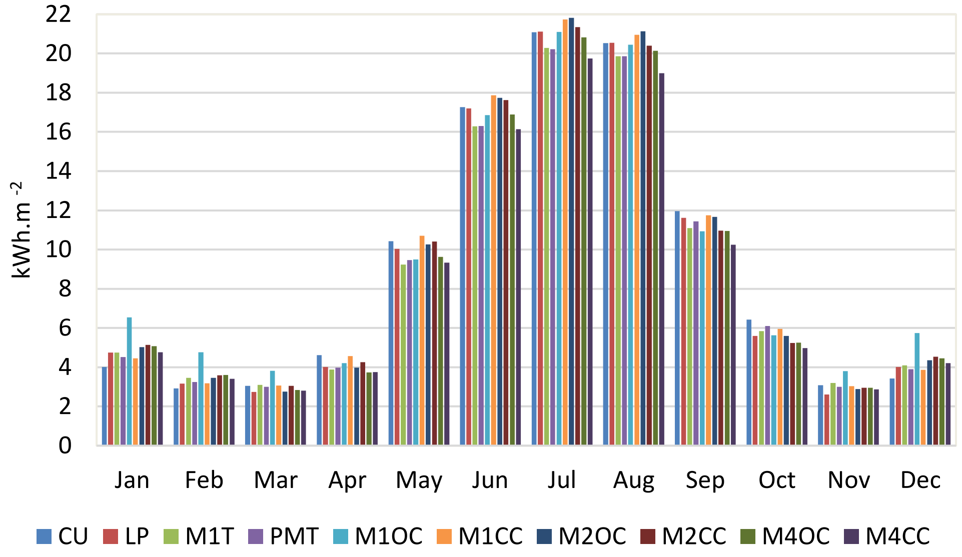


Figure 57. *Comparison of simulated energy demand (kWh.m^{-2}) of 270^{0} oriented typologies*

4.2 Climate of Copenhagen

The figures presented below illustrate an analysis conducted on annual energy consumption, with the objective of evaluating the impact of Copenhagen's oceanic climate on selected building morphologies.

4.2.1. Energy performance

The figures provided below demonstrate the relationship between annual heating and cooling loads for the hospital building model across its ten different morphology scenarios.

In Figure 58, the monthly heating demand is presented for all typologies with 0^{0} orientation. Among these scenarios, the M1OC morphology performs poorly in Copenhagen's climate during the whole year regarding heating demand. On the other hand, the CU morphology shows the best performance, because of the compactness of the building that contributes in reducing heating energy consumption.

In Figure 59, the monthly cooling demand is shown for all typologies with 0^0 orientation. It is observed that the compactness of the building itself significantly increases the cooling demand of the CU morphology, raising concerns about its efficiency when integrated into building plans for this specific context.

Figure 60 illustrates the monthly energy consumption (including heating and cooling) for all building typologies oriented at 0^0 degrees. The findings reveal that morphologies with higher compactness experience reduced energy demand during colder months, but demonstrate increased energy requirements during warmer months.

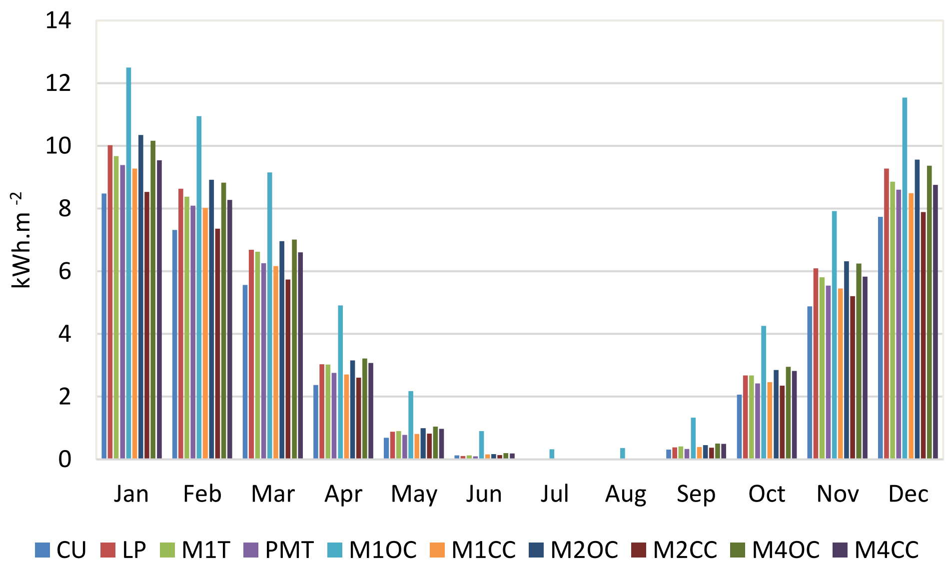


Figure 58. *Comparison of simulated heating demand (kWh.m^{-2}) of 0^0 oriented typologies*

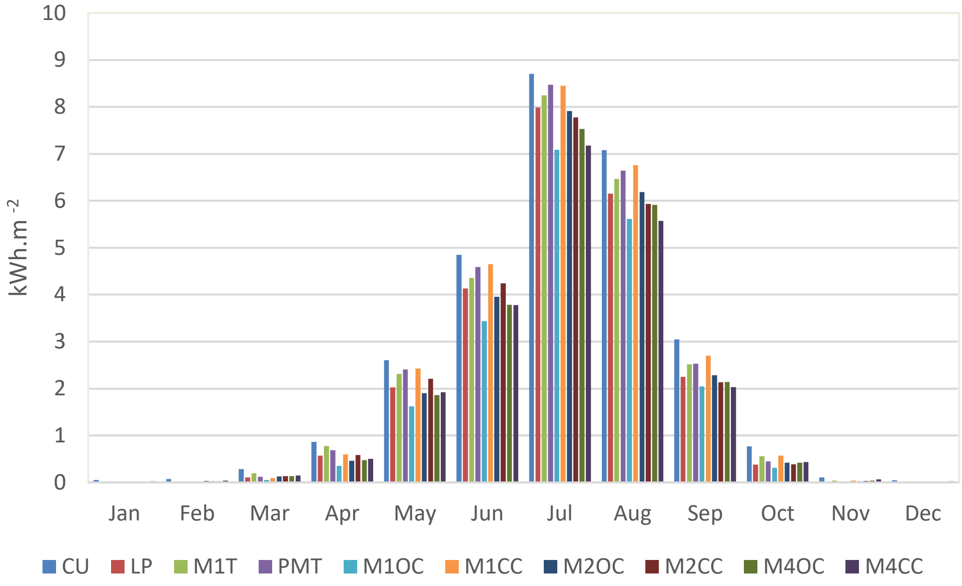


Figure 59. *Comparison of simulated cooling demand (kWh.m^{-2}) of 0^{0} oriented typologies*

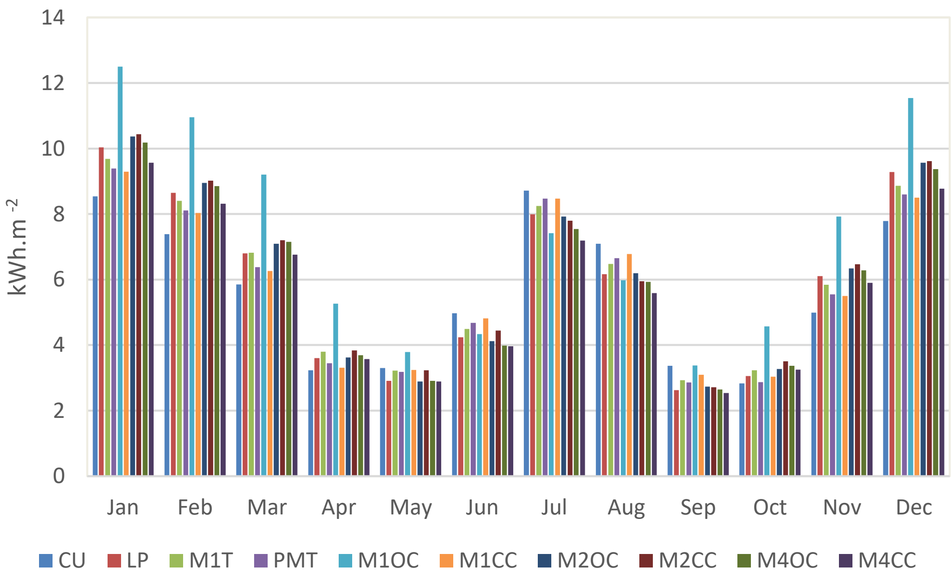


Figure 60. *Comparison of simulated energy demand (kWh.m^{-2}) of 0^{0} oriented typologies*

Figure 61 depicts the monthly heating demand for all typologies with 90^{0} orientation. On the other hand, Figure 62 illustrates the monthly cooling demand for the same typologies. It is observed that, the M1OC morphology performs poorly in

Copenhagen's climate during the whole year regarding heating demand also in this orientation. On the other hand, the CU morphology shows the best performance.

In Figure 63, the monthly cooling demand is shown for all typologies with 90^0 orientation. It is observed that the compactness of the building itself significantly increases the cooling demand of the CU morphology.

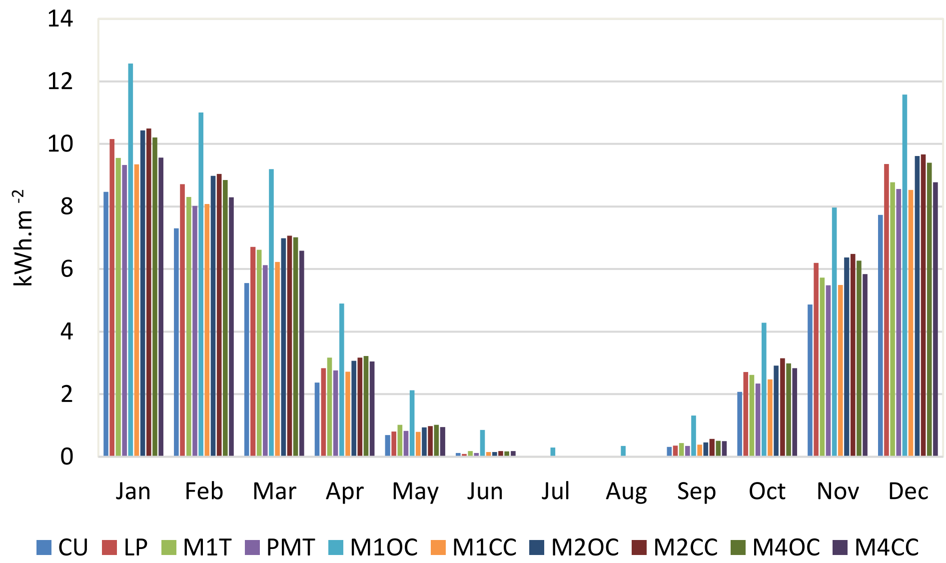


Figure 61. *Comparison of simulated heating demand (kWh.m^{-2}) of 90^0 oriented typologies*

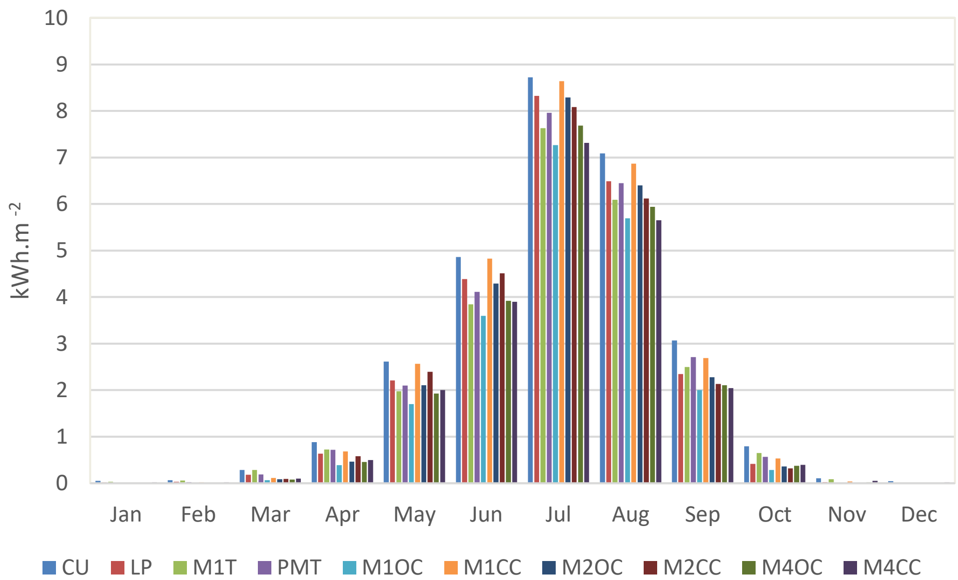


Figure 62*. Comparison of simulated cooling demand (kWh.m^{-2}) of 90^0 oriented typologies*

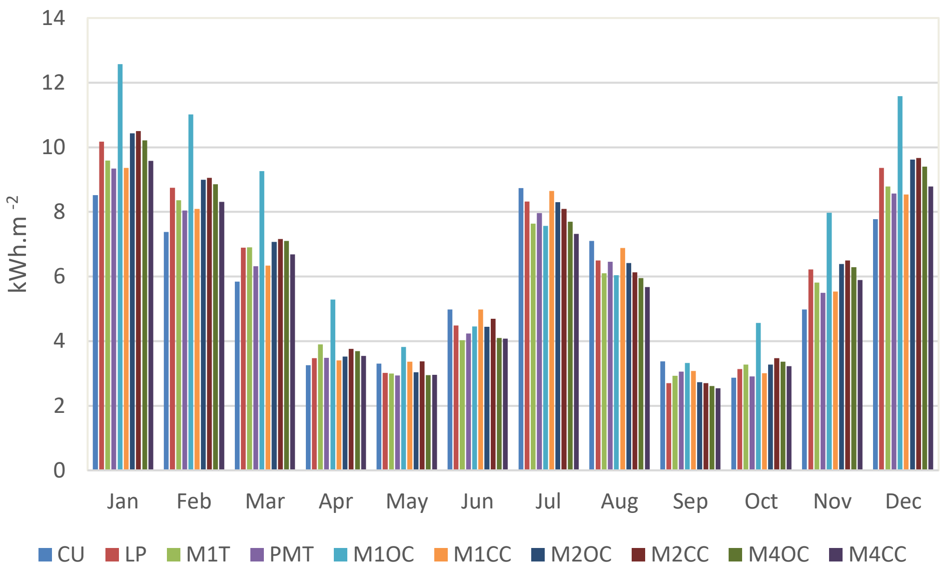


Figure 63. *Comparison of simulated energy demand (kWh.m^{-2}) of 90^{0} oriented typologies*

Figure 64 represents the monthly heating demand for all typologies with 180^{0} orientation. On the other hand, Figure 65 showcases the monthly cooling demand for the same typologies but with 180^{0} orientation. These figures provide insights into the heating and cooling requirements of the different building morphologies throughout the year, considering the specific orientations of the hospitals.

Figure 66 represents the monthly total energy consumption (heating and cooling) demand for all typologies with 180^{0} orientation. The findings indicate that the cooling demand of the CU morphology is significantly affected by the compactness of the building.

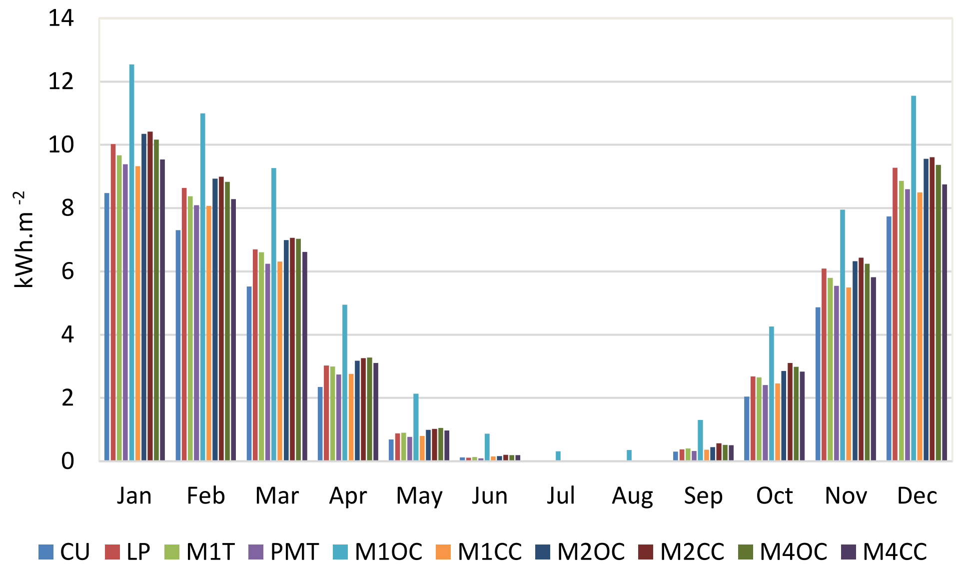


Figure 64. *Comparison of simulated heating demand (kWh.m^{-2}) of 180^{0} oriented typologies*

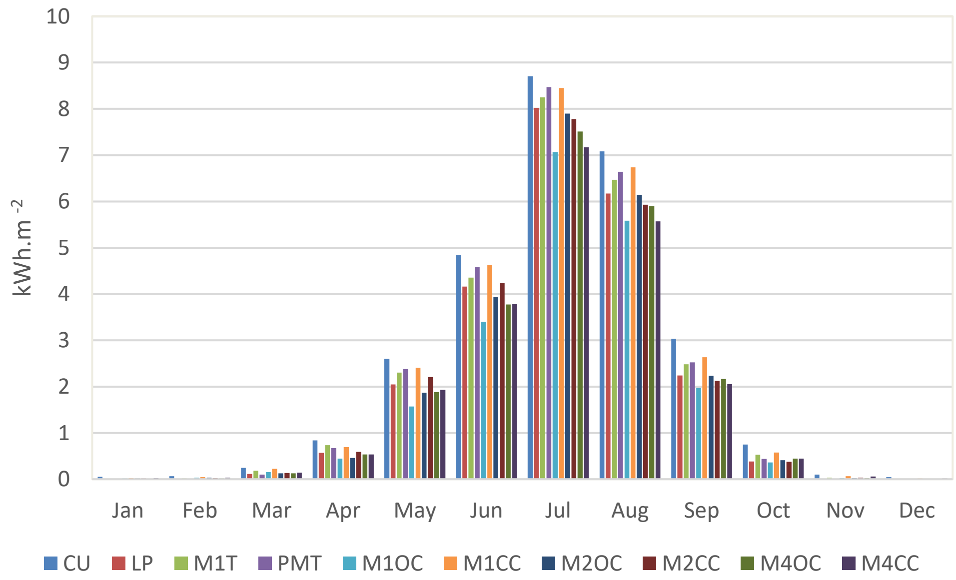


Figure 65. *Comparison of simulated cooling demand (kWh.m^{-2}) of 180^{0} oriented typologies*

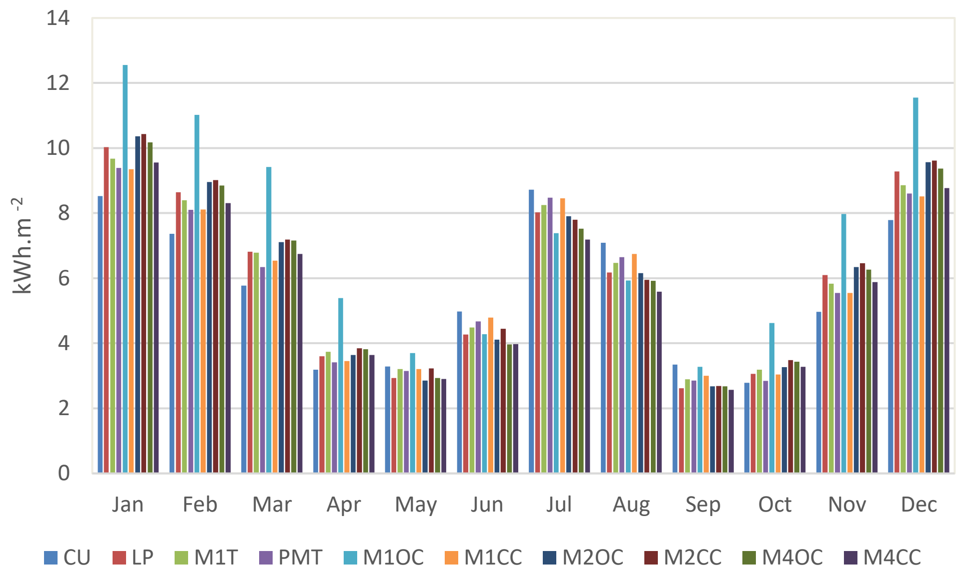


Figure 66 . *Comparison of simulated energy demand (kWh.m^{-2}) of 180^{0} oriented typologies*

Figure 67 represents the monthly heating demand for all typologies with 270^{0} orientation. On the other hand, Figure 68 showcases the monthly cooling demand for the same typologies but with 270^{0} orientation. These figures provide insights into the heating and cooling requirements of the different building morphologies throughout the year, considering the specific orientations of the hospitals.

Figure 69 shows the total energy demand for selected morphologies according the climate of Copenhagen. The findings indicate that the cooling demand of the CU morphology is significantly affected by the compactness of the building.

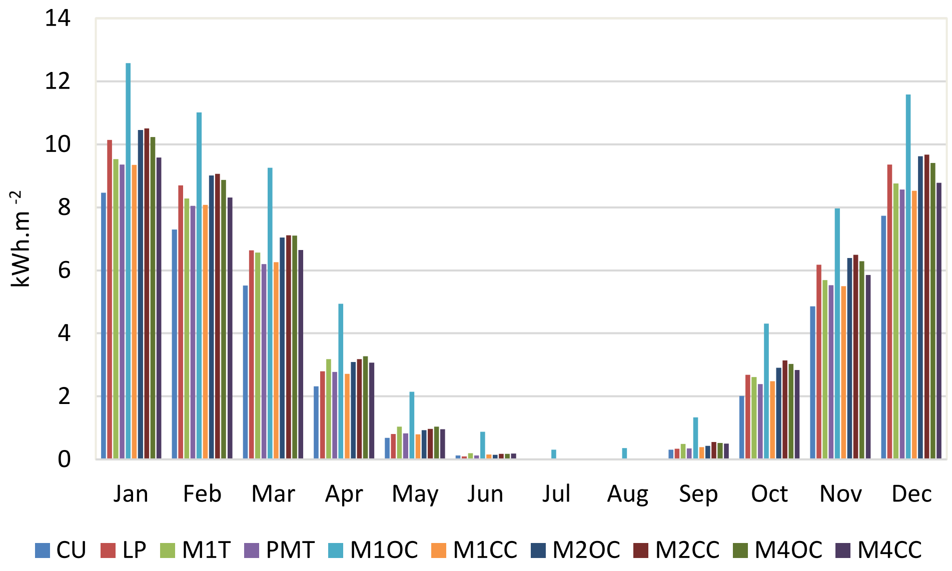


Figure 67. *Comparison of simulated heating demand (kWh.m^{-2}) of 270^{0} oriented typologies*

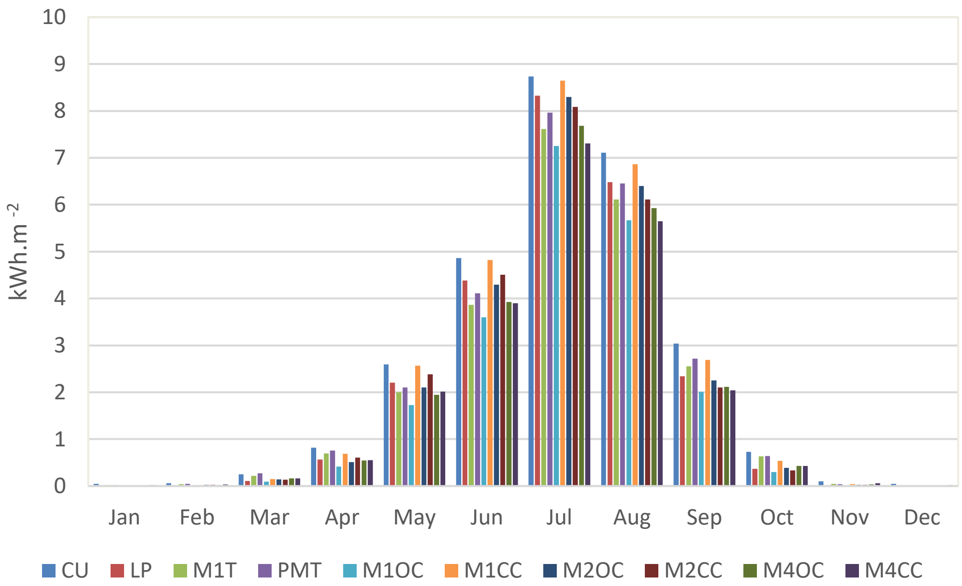


Figure 68. *Comparison of simulated cooling demand (kWh.m^{-2}) of 270^{0} oriented typologies*

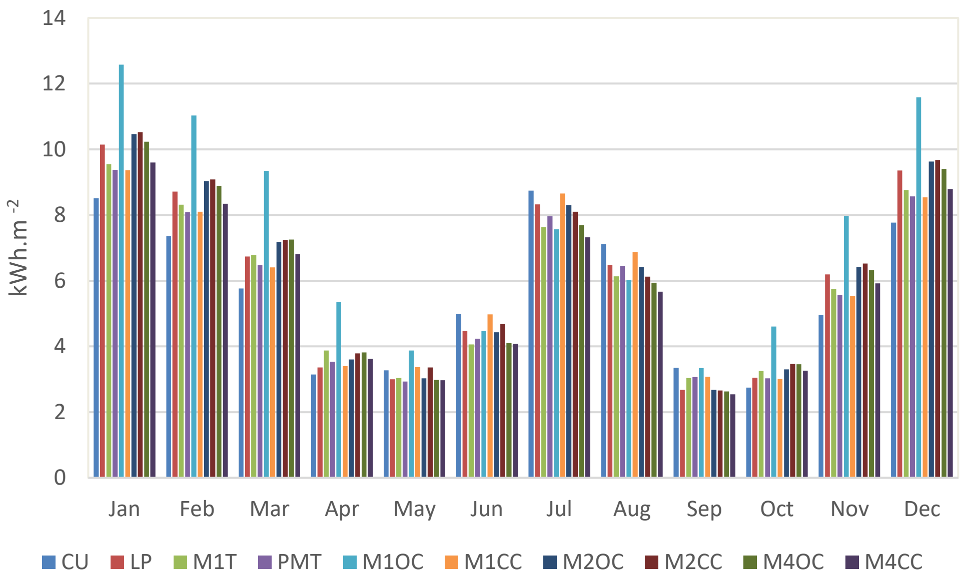


Figure 69. *Comparison of simulated energy demand (kWh.m^{-2}) of 270^{0} oriented typologies*

4.2 Climate of Kiev

The provided figures below depict an examination of yearly energy usage, aiming to assess the influence of Kiev's warm humid climate on the suggested building morphologies for different orientations.

4.2.1. Energy performance

The figures presented below demonstrate the relationship between annual heating and cooling consumption in the ten morphology scenarios of the hospital building model. Figure 70 compares the monthly heating demand for all typologies with 0^{0} orientation, while Figure 71 illustrates the monthly cooling demand for the same typologies. The climatic context of the locations where the typologies are situated results in a low cooling demand from May to September and the most cooling demand from October to April.

Figure 72 illustrates the monthly energy consumption (including heating and cooling) for all building typologies. The findings reveal that morphologies with higher compactness experience reduced energy demand during colder months, but demonstrate increased energy requirements during warmer months.

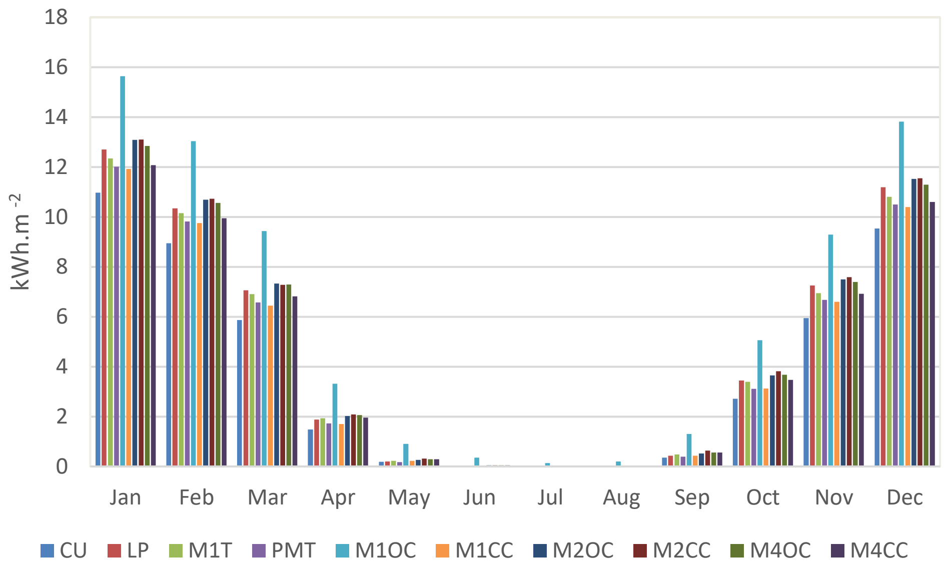


Figure 70. *Comparison of simulated heating demand (kWh.m^{-2}) of 0^0 oriented typologies*

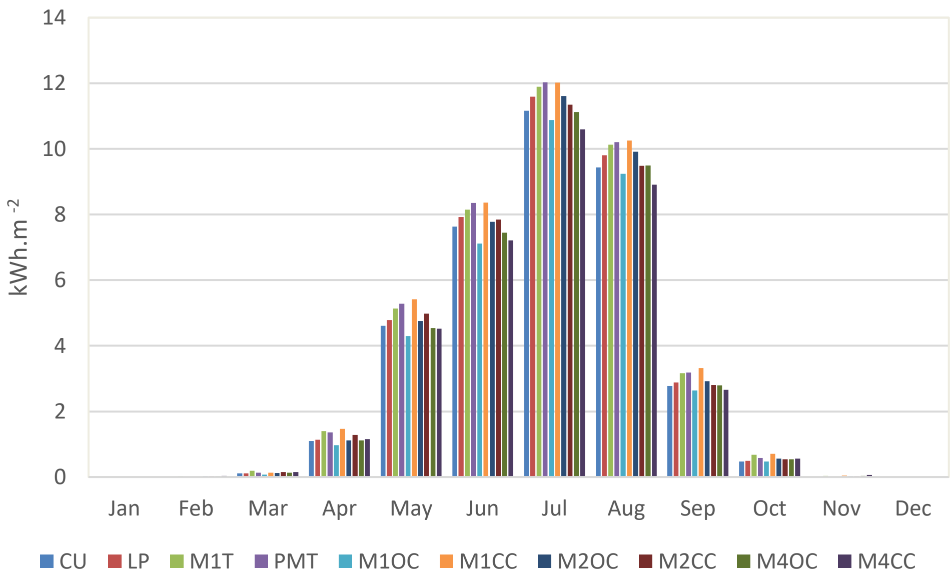


Figure 71. *Comparison of simulated cooling demand (kWh.m^{-2}) of 0^0 oriented typologies*

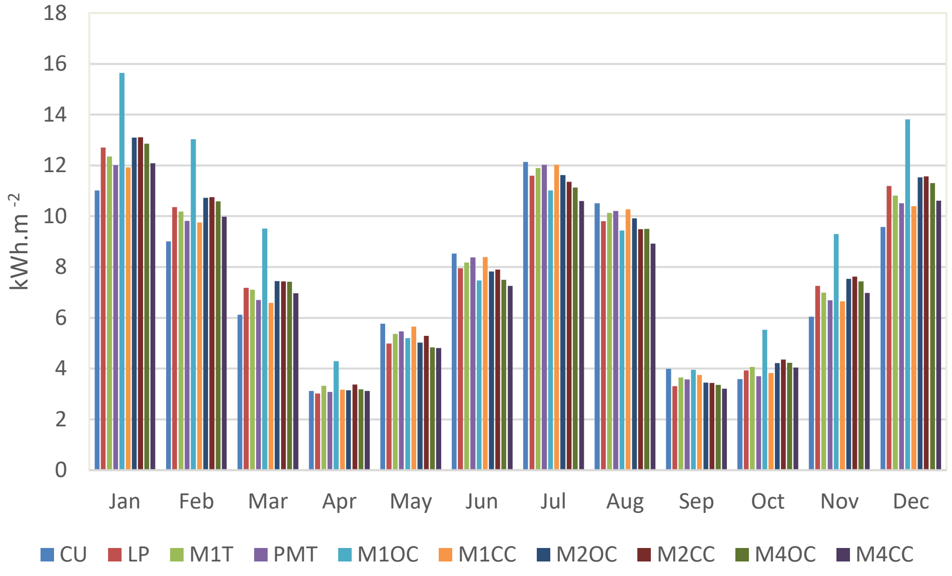


Figure 72. *Comparison of simulated energy demand (kWh.m^{-2}) of 0^0 oriented typologies*

Figure 73 depicts the monthly heating demand for all typologies with 90^0 orientation. On the other hand, Figure 74 illustrates the monthly cooling demand for the same typologies. The specific climatic conditions of the locations where the typologies are situated lead to a minimal cooling demand from May to September, while the highest cooling demand occurs from October to April.

Figure 75 provides a visual representation of the monthly energy consumption, encompassing both heating and cooling, for all building typologies. The results indicate that morphologies characterized by higher compactness exhibit lower energy demand during colder months but show an increase in energy requirements during warmer months.

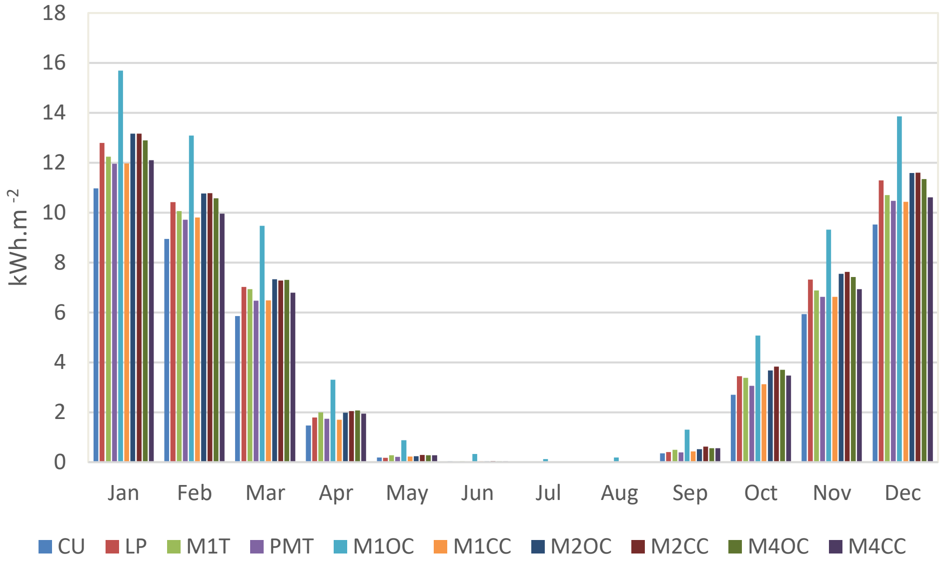


Figure 73. *Comparison of simulated heating demand (kWh.m^{-2}) of 90^0 oriented typologies*

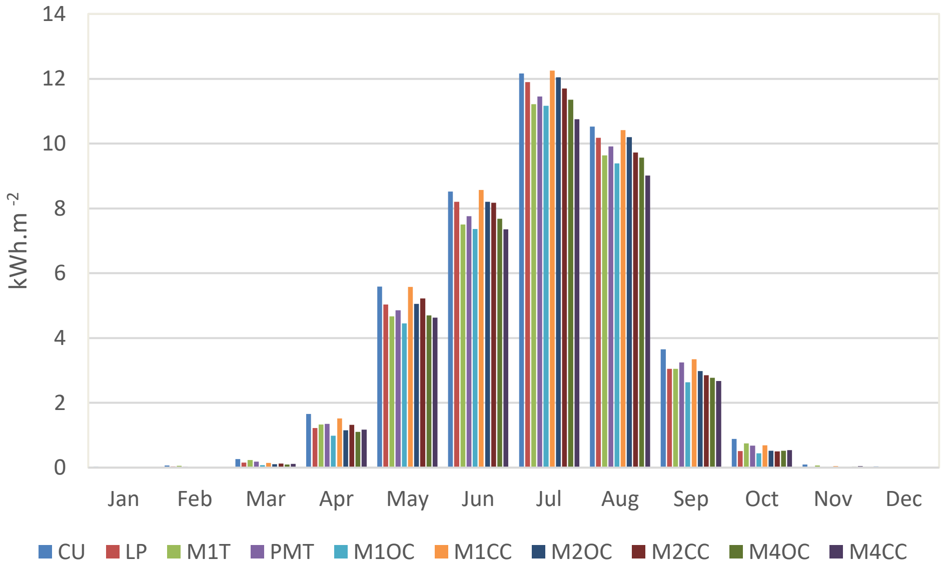


Figure 74. *Comparison of simulated cooling demand (kWh.m^{-2}) of 90^0 oriented typologies*

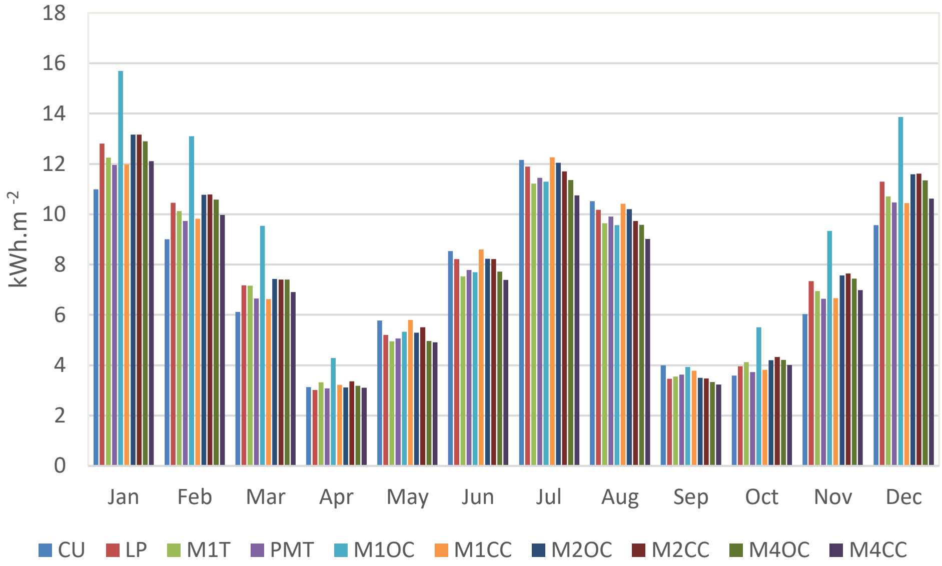


Figure 75. *Comparison of simulated energy demand (kWh.m^{-2}) of 90^0 oriented typologies*

Figure 76 represents the monthly heating demand for all typologies with 180^0 orientation. On the other hand, Figure 77 showcases the monthly cooling demand for the same typologies but with 180^0 orientation. These figures provide insights into the heating and cooling requirements of the different building morphologies throughout the year, considering the specific orientations of the hospitals.

Figure 78 provides a visual representation of the monthly energy consumption, encompassing both heating and cooling, for all building typologies. The results indicate that the lowest total energy demand is during April, September and October.

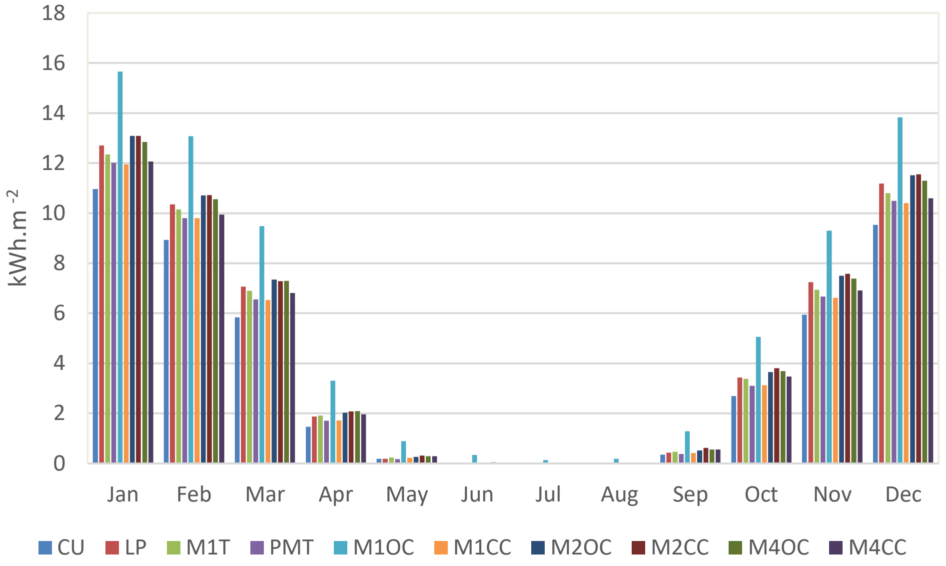


Figure 76. *Comparison of simulated heating demand (kWh.m^{-2}) of 180^{0} oriented typologies*

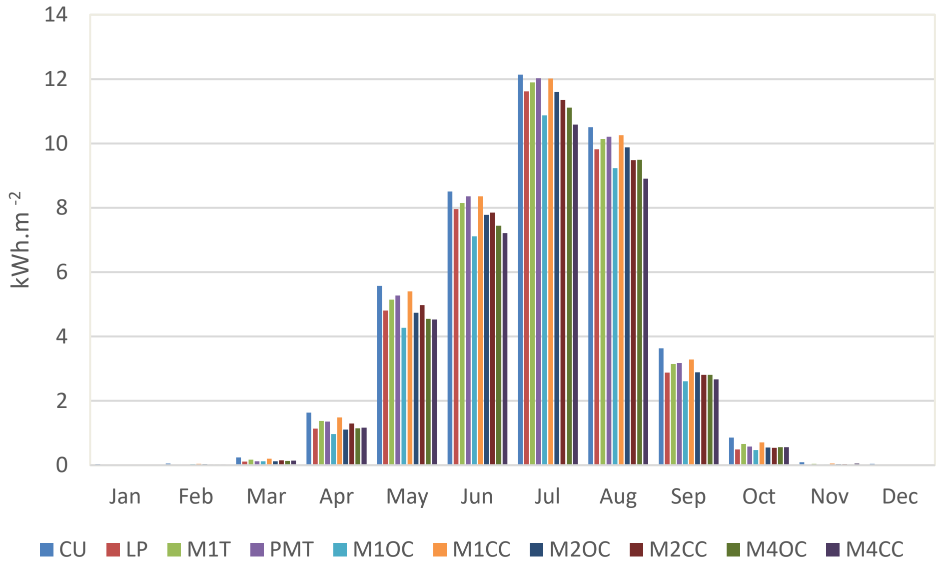


Figure 77. *Comparison of simulated cooling demand (kWh.m^{-2}) of 180^{0} oriented typologies*

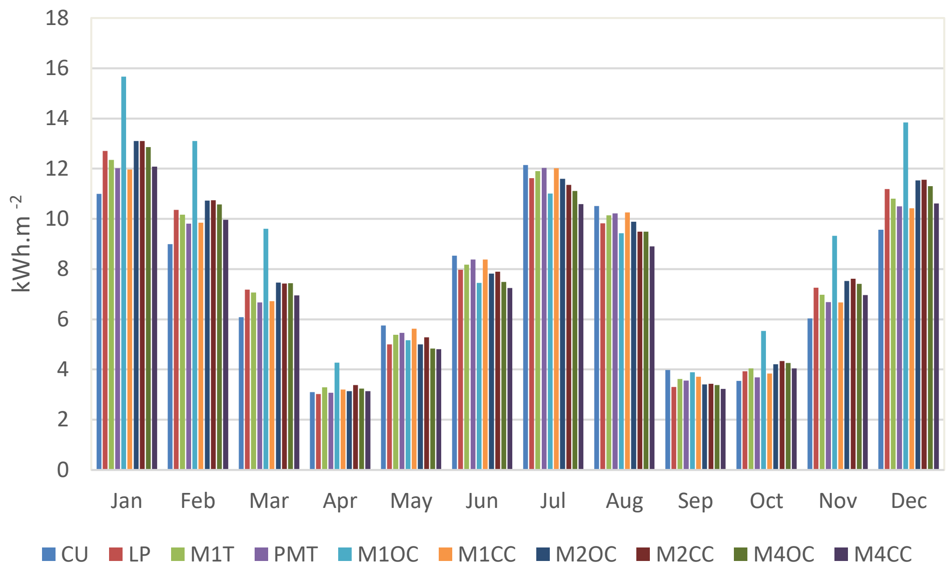


Figure 78. *Comparison of simulated energy demand (kWh.m^{-2}) of 180^0 oriented typologies*

Figure 79 illustrates the monthly heating demand for all building typologies oriented at 270^0, while Figure 80 displays the monthly cooling demand for the same typologies and orientation. These figures offer valuable information regarding the heating and cooling needs of various building morphologies throughout the year, taking into account the specific orientations of the hospitals.

In addition, Figure 81 presents a graphical representation of the monthly energy consumption, including both heating and cooling, for all building typologies. The findings suggest that morphologies with higher compactness demonstrate reduced energy demand during colder months, but experience an increase in energy requirements during warmer months.

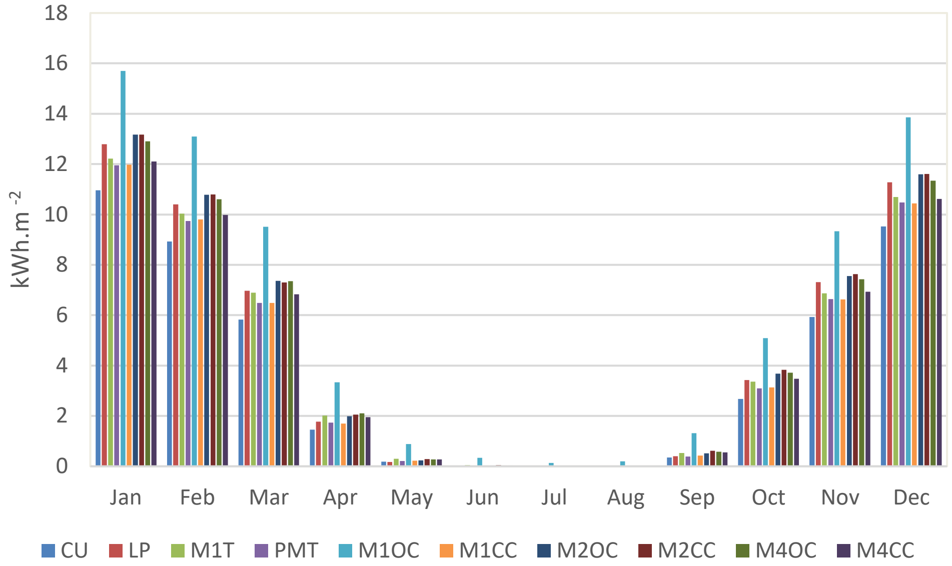


Figure 79. *Comparison of simulated heating demand (kWh.m^{-2}) of 270^{0} oriented typologies*

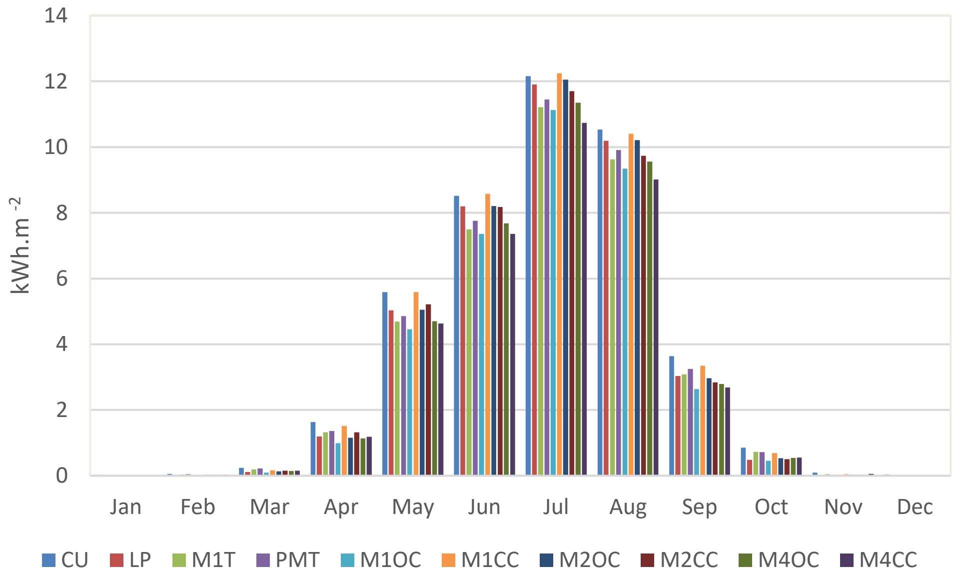


Figure 80. *Comparison of simulated cooling demand (kWh.m^{-2}) of 270^{0} oriented typologies*

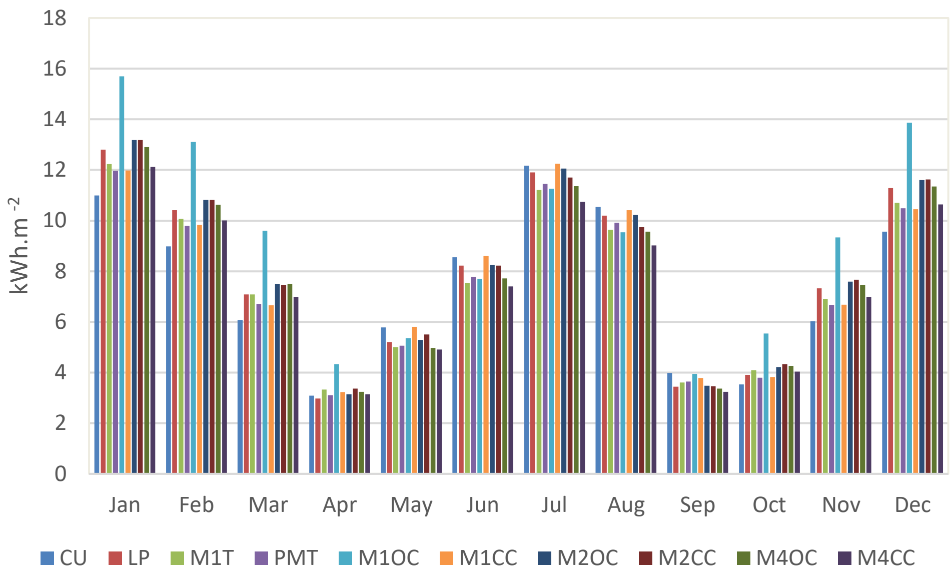


Figure 81. *Comparison of simulated energy demand (kWh.m^{-2}) of 270^{0} oriented typologies*

4.2 Climate of Tallinn

The provided figures below depict an examination of yearly energy usage, aiming to assess the influence of Tallinn's humid continental climate on the suggested building morphologies.

4.2.1. Energy performance

The following figures showcase the relationship between the annual heating and cooling consumption across the ten morphology scenarios of the hospital building model. Figure 82 provides a comparison of the monthly heating demand for all typologies with a 0^{0} orientation, while Figure 83 presents the monthly cooling demand for the same typologies. The specific climatic conditions of the locations where the typologies are situated contribute to a lower cooling demand from May to September, with the highest cooling demand occurring from October to April.

Furthermore, Figure 84 depicts the monthly energy consumption, encompassing both heating and cooling, for all building typologies. The results indicate that morphologies require less energy in total during April, May, June and September.

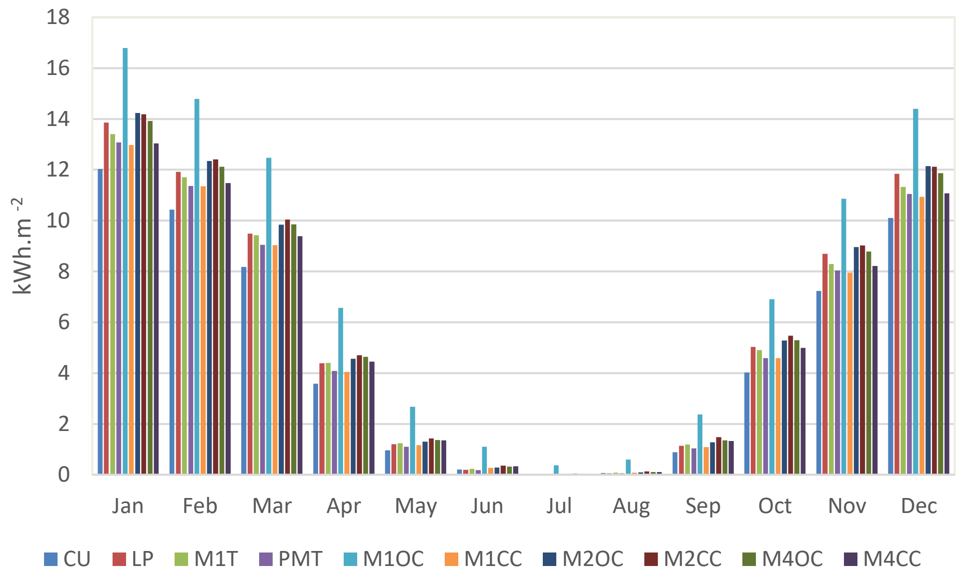


Figure 82. *Comparison of simulated heating demand (kWh.m^{-2}) of 0^0 oriented typologies*

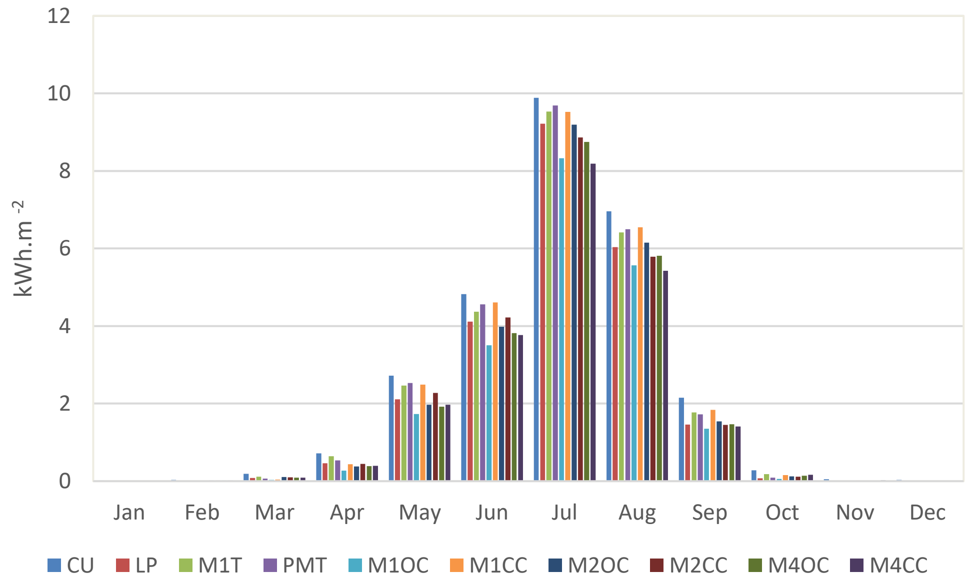


Figure 83. *Comparison of simulated cooling demand (kWh.m^{-2}) of 0^0 oriented typologies*

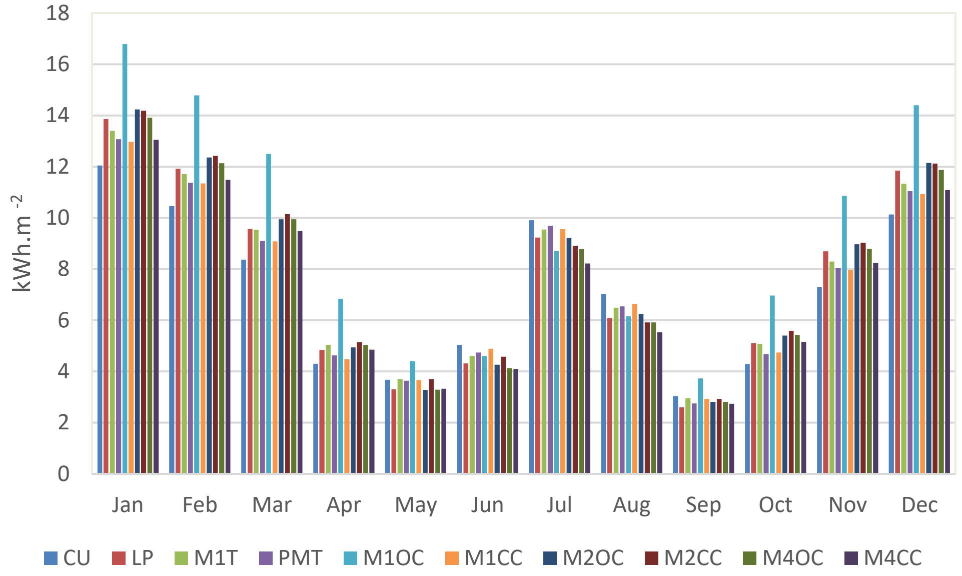


Figure 84. *Comparison of simulated energy demand (kWh.m^{-2}) of 0^0 oriented typologies*

Figure 85 depicts the monthly heating demand for all typologies with 90^0 orientation. On the other hand, Figure 86 illustrates the monthly cooling demand for the same typologies. The specific climatic conditions of the locations where the typologies are situated contribute to a lower cooling demand from May to September, with the highest cooling demand occurring from October to April.

Furthermore, Figure 87 depicts the monthly energy consumption, encompassing both heating and cooling, for all building typologies. The results indicate that morphologies require less energy in total during April, May, June and September.

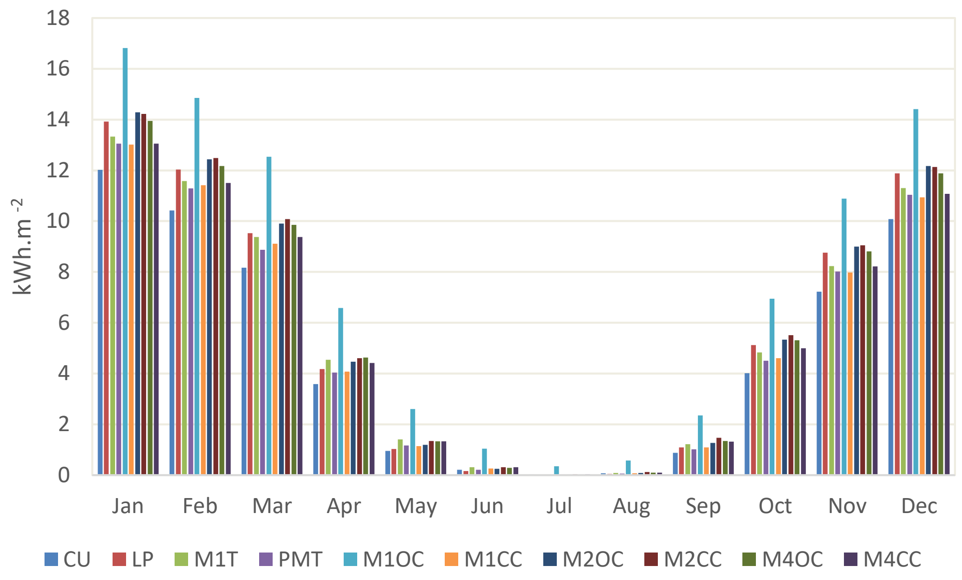


Figure 85. *Comparison of simulated heating demand (kWh.m^{-2}) of 90^{0} oriented typologies*

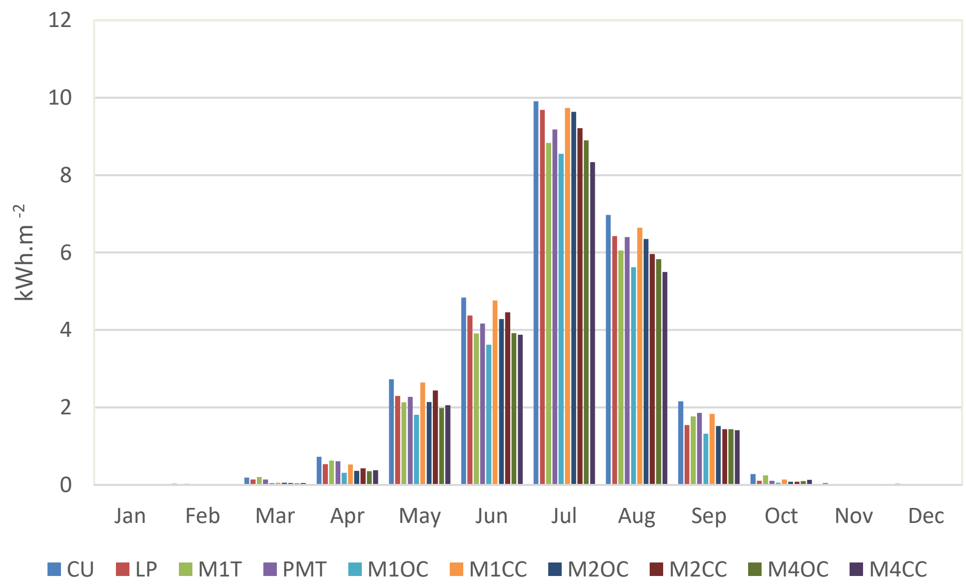


Figure 86. *Comparison of simulated cooling demand (kWh.m^{-2}) of 90^{0} oriented typologies*

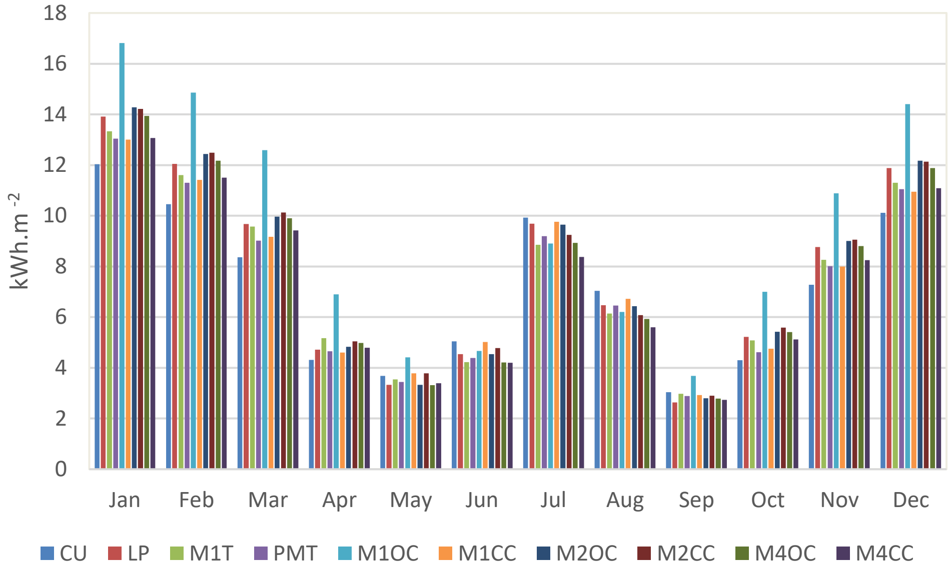


Figure 87. *Comparison of simulated energy demand (kWh.m^{-2}) of 90^0 oriented typologies*

Figure 88 showcases the monthly heating demand for all typologies oriented at 180^0, while Figure 89 illustrates the monthly cooling demand for the same typologies.

Moreover, Figure 90 provides a visual representation of the monthly energy consumption, incorporating both heating and cooling, for all building typologies. The results suggest that morphologies characterized by higher compactness exhibit reduced energy demand during colder months. However, they experience an increase in energy requirements during warmer months.

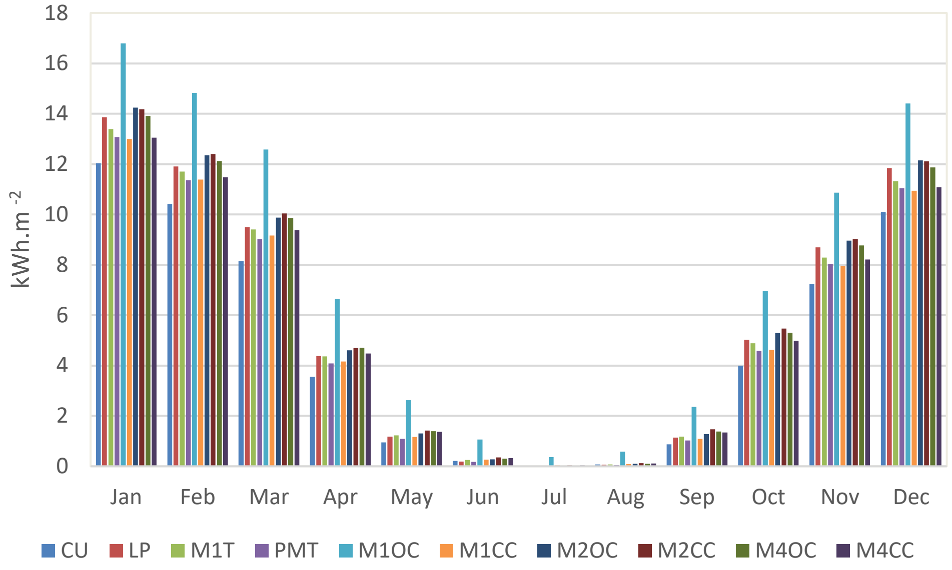


Figure 88. *Comparison of simulated heating demand (kWh.m^{-2}) of 180^0 oriented typologies*

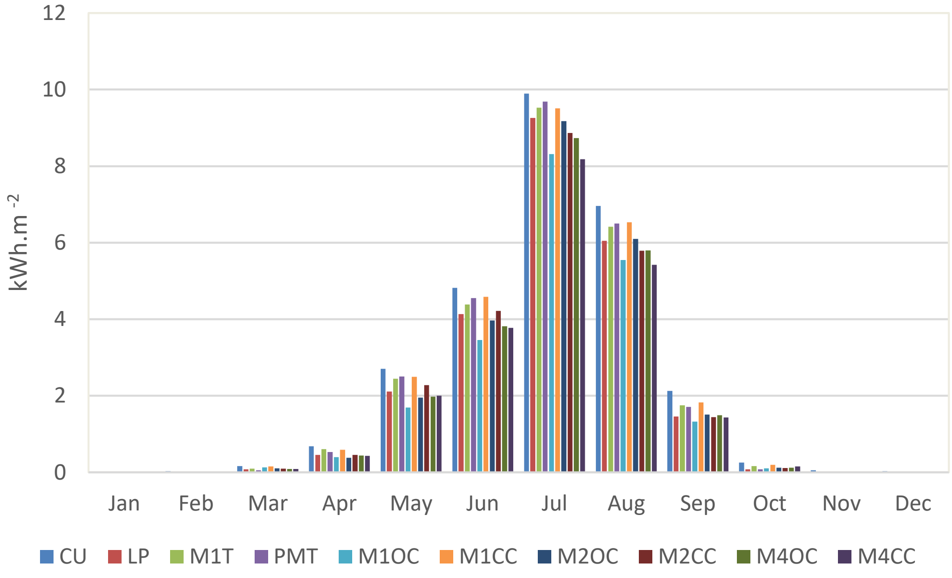


Figure 89. *Comparison of simulated cooling demand (kWh.m^{-2}) of 180^0 oriented typologies*

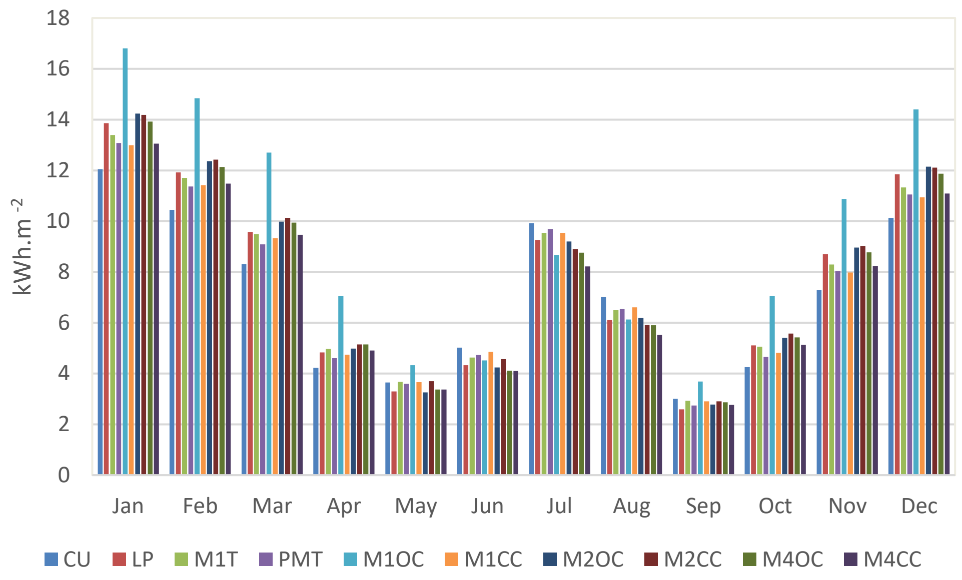


Figure 90. *Comparison of simulated energy demand (kWh.m^{-2}) of 180^{0} oriented typologies*

Figure 91 depicts the monthly heating demand for all typologies with 270^{0} orientation. On the other hand, Figure 92 illustrates the monthly cooling demand for the same typologies. The specific climatic conditions of the locations where the typologies are situated contribute to a lower cooling demand from May to September, with the highest cooling demand occurring from October to April.

Furthermore, Figure 93 depicts the monthly energy consumption, encompassing both heating and cooling, for all building typologies. The results indicate that morphologies require less energy in total during April, May, June and September.

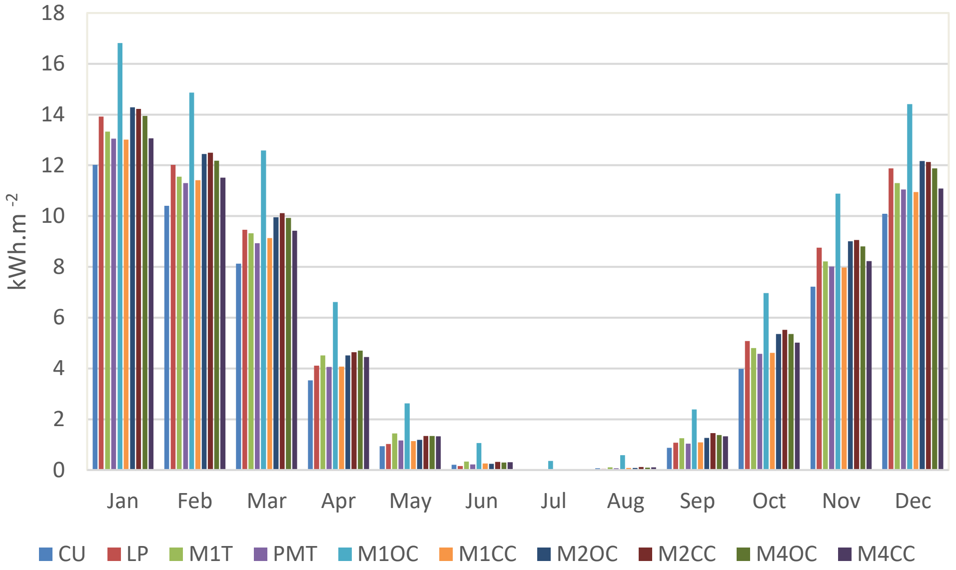


Figure 91. *Comparison of simulated heating demand (kWh.m^{-2}) of 270^0 oriented typologies*

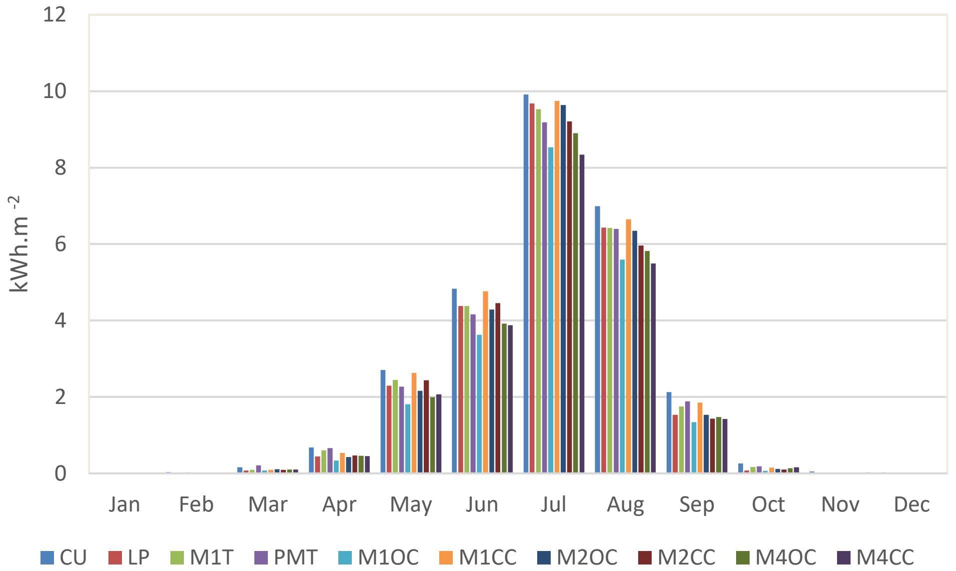


Figure 92. *Comparison of simulated cooling demand (kWh.m^{-2}) of 270^0 oriented typologies*

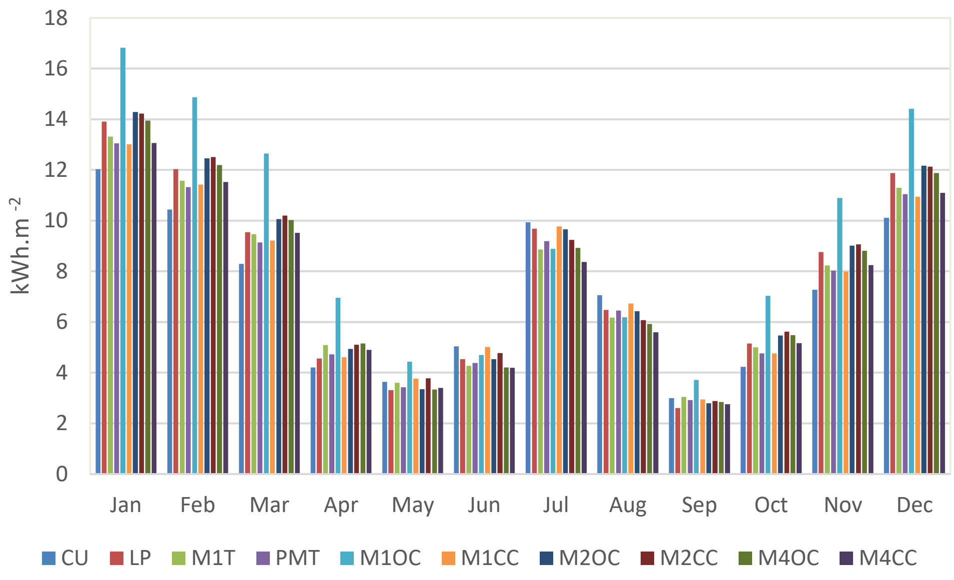


Figure 93. *Comparison of simulated energy demand (kWh.m^{-2}) of 270^0 oriented typologies*

CHAPTER 5

DISCUSSIONS

5.1 Climate of Tirana

5.1.1 Energy Performance

Figure 94 illustrates the annual simulated energy demand comparison based on rotation angle. The findings indicate that there is an increasing trend in energy demand when the building is rotated by 90° and 270°. The impact of orientation is less significant in typologies with more squared layouts, specifically CU and M4CC.

For the P1T typology, rotating the building by 90° results in an energy consumption decrease of 4.5 kWh.m-2Y-1, while rotating it by 270° also leads to a 4.5 kWh.m-2Y-1 decrease. On the other hand, when the typologies are rotated by 180°, slight changes are observed, with a difference of approximately ±0.1 kWh.m-2Y-1 in energy consumption.

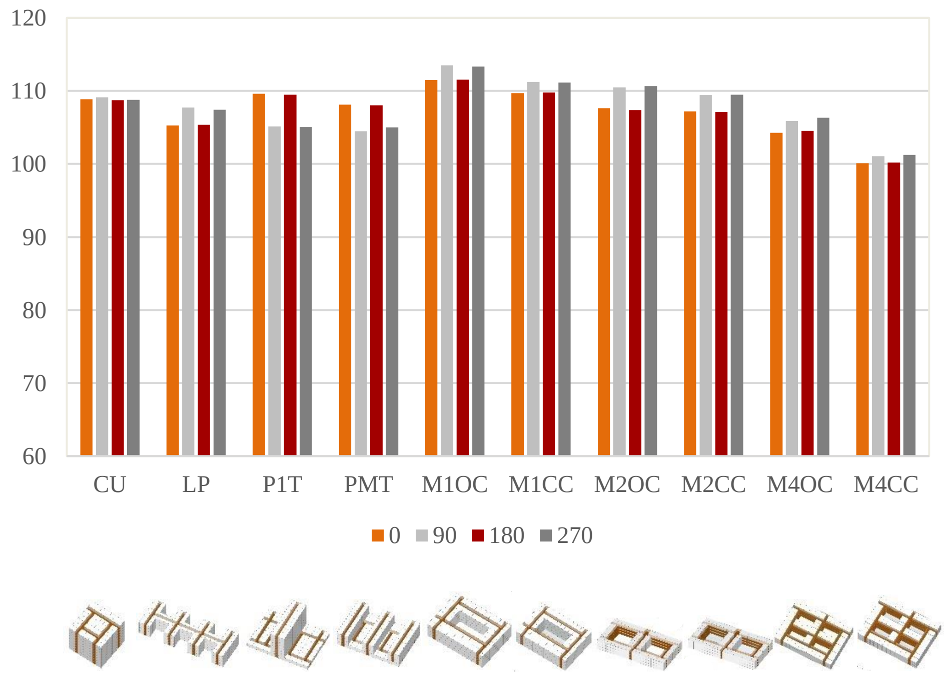


Figure 94. *Comparison of annual simulated energy demand (kWh.m^{-2} y^{-1})*

Table 12 provides a summary of the simulation results for all scenarios within the climate of Tirana. It reveals that selecting the appropriate building morphology for this specific climatic context can potentially result in a maximum reduction of 16.94% in total energy consumption. However, the M4CC typology exhibits the poorest performance in terms of energy loads, raising concerns about the suitability of block plans organized around a central covered atrium for Tirana's humid subtropical climate.

The presence of courtyards, whether open (OC) or closed (CC), enhances the morphology's effectiveness by approximately ± 2%. Linked pavilion typology LP also incorporate multiple open courtyards. However, the longitudinal plan of this typology only performs better in specific orientations, namely when rotated by 0 and 180 degrees. The presence of a sky-lit atrium in the core of each unit in MC further decreases its performance, making it necessary to analyze if the courtyard have to be opened or covered for specific climates.

Table 12. *Simulation results obtained for all the scenarios in the climate of Tirana*

		Annual heating demand			Annual cooling demand			Annual energy demand		
		Total heating [kWh]	Heating Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total cooling [kWh]	Cooling Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total energy [kWh]	Total energy/ Conditioned area [kWh/m2]	Total morphology effectiveness [%]
	CU	73195.79	10.87	-	660136.67	98.02	-	733332.46	108.89	-
	LP	87984.27	13.57	**-24.81**	594770.76	91.70	**6.45**	682755.03	105.27	**12.21**
	P1T	96307.03	13.88	**-27.72**	664118.27	95.72	**2.34**	760425.29	109.60	**8.23**
	PMT	85362.68	12.55	**-15.48**	649988.01	95.56	**2.50**	735350.69	108.11	**9.60**
0	M1OC	160588.46	23.18	**-113.29**	611916.67	88.33	**9.88**	772505.13	111.51	**6.48**
	M1CC	95222.31	12.69	**-16.78**	727749.48	97.00	**1.03**	822971.78	109.70	**8.14**
	M2OC	100729.57	14.58	**-34.18**	642780.23	93.06	**5.06**	743509.81	107.64	**10.03**
	M2CC	131459.87	15.70	**-44.50**	765873.17	91.49	**6.66**	897333.04	107.20	**10.44**
	M4OC	102801.56	15.00	**-38.02**	611664.55	89.25	**8.95**	714466.11	104.25	**13.15**
	M4CC	112649.13	14.34	**-31.93**	673874.02	85.77	**12.49**	786523.15	100.11	**16.94**
	CU	73280.94232	10.88	-	661757	98.26	-	735037.94	109.14	-
	LP	89308.28846	13.77	**-26.55**	609452.56	93.96	**4.37**	698760.84	107.73	**1.29**
	P1T	94821.64121	13.67	**-25.61**	634626.98	91.47	**6.91**	729448.62	105.14	**3.67**
	PMT	83210.37599	12.23	**-12.44**	627430.85	92.25	**6.12**	710641.23	104.48	**4.27**
90	M1OC	161001.6681	23.24	**-113.59**	625276.09	90.26	**8.14**	786277.75	113.50	**-3.99**
	M1CC	95886.60479	12.78	**-17.46**	738624.51	98.45	**-0.20**	834511.12	111.23	**-1.92**
	M2OC	102408.0942	14.83	**-36.26**	660857.64	95.67	**2.63**	763265.74	110.50	**-1.25**
	M2CC	132397.8081	15.82	**-45.36**	783669.3	93.62	**4.72**	916067.11	109.43	**-0.27**
	M4OC	103662.9976	15.13	**-39.01**	622146.54	90.78	**7.61**	725809.54	105.90	**2.96**
	M4CC	112980.2534	14.38	**-32.16**	681123	86.70	**11.77**	794103.26	101.08	**7.39**
	CU	72479.29333	10.76	-	659870.53	97.98	-	732349.82	108.74	-
	LP	87922.70193	13.56	**-25.96**	595472.21	91.81	**6.30**	683394.91	105.36	**3.11**
	P1T	95684.1946	13.79	**-28.15**	663957.43	95.70	**2.33**	759641.62	109.49	**-0.69**
	PMT	85114.79114	12.51	**-16.28**	649837.62	95.54	**2.49**	734952.41	108.06	**0.63**
180	M1OC	160640.0118	23.19	**-115.47**	612091.99	88.35	**9.82**	772732	111.54	**-2.58**
	M1CC	95725.73471	12.76	**-18.56**	727824.53	97.01	**0.98**	823550.27	109.77	**-0.95**
	M2OC	100826.9509	14.60	**-35.64**	641021.99	92.80	**5.28**	741848.94	107.40	**1.23**
	M2CC	130960.726	15.64	**-45.37**	765707.92	91.47	**6.64**	896668.64	107.12	**1.49**
	M4OC	103741.173	15.14	**-40.65**	612788.88	89.41	**8.74**	716530.05	104.55	**3.85**

	M4CC	113182.309	14.41	**-33.86**	674158.52	85.81	**12.42**	787340.83	100.22	**7.84**
	CU	71903.97781	10.68	-	660793.3	98.12	-	732697.27	108.79	-
	LP	88062.55724	13.58	**-27.17**	608566.17	93.83	**4.37**	696628.72	107.40	**1.28**
	P1T	95151.92452	13.71	**-28.46**	633756.63	91.35	**6.90**	728908.55	105.06	**3.43**
	PMT	84795.37475	12.47	**-16.77**	629606.01	92.57	**5.66**	714401.38	105.03	**3.45**
270	M1OC	162084.1548	23.40	**-119.14**	623133.93	89.95	**8.32**	785218.08	113.34	**-4.18**
	M1CC	95936.3802	12.79	**-19.77**	737976.3	98.37	**-0.26**	833912.68	111.15	**-2.17**
	M2OC	102407.9047	14.83	**-38.86**	662003	95.84	**2.32**	764410.91	110.66	**-1.72**
	M2CC	132271.2751	15.80	**-48.00**	784225.59	93.68	**4.52**	916496.86	109.48	**-0.64**
	M4OC	104889.2567	15.30	**-43.35**	623724.6	91.01	**7.24**	728613.85	106.31	**2.28**
	M4CC	113502.937	14.45	**-35.32**	681954.09	86.80	**11.53**	795457.03	101.25	**6.93**

5.2 Climate of Copenhagen

5.2.1 Energy Performance

Figure 95 illustrates the comparison of annual simulated energy demand, focusing on rotation angle and its impact on energy consumption. The results show that when the building is rotated by 90° and 270°, there is an increasing trend in energy demand. The largest impact of orientation is observed in the typology with one courtyard, namely M1OC.

For the P1T typology, rotating the building by 90° leads to a decrease in energy consumption of 1.72 kWh.m-2Y-1, while a rotation of 270° results in a 1.85 kWh.m-2Y-1 increase. However, when the typologies are rotated by 180°, there is a slight decrease in energy consumption, with an approximate value of ±0.3 kWh.m-2Y-1.

The additional data provided includes the outdoor and indoor temperatures during peak hours for different orientations. The temperature differentials (ΔT) between the outdoor and indoor environments are also listed.

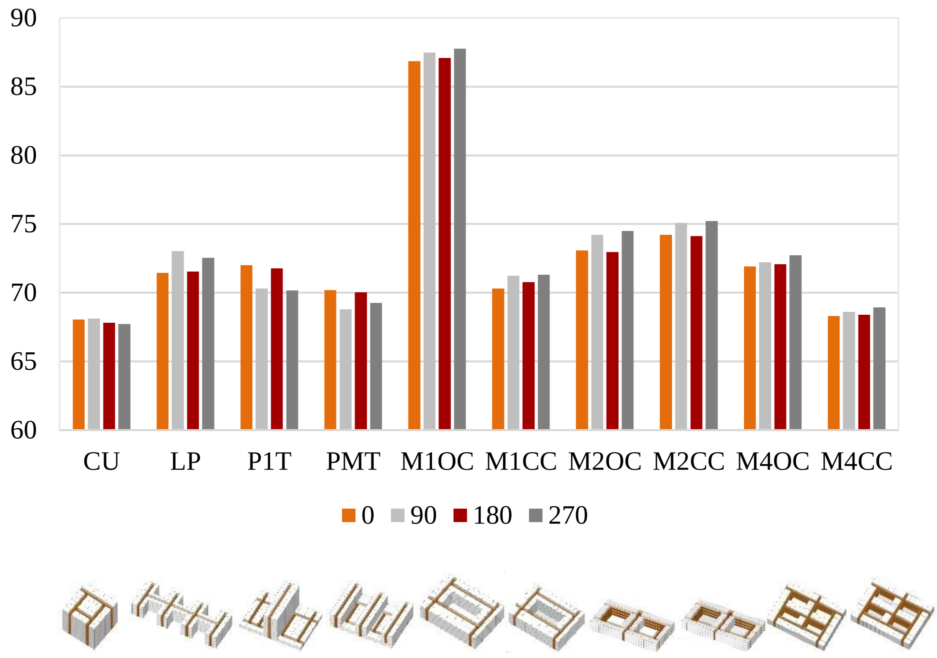


Figure 95. *Comparison of annual simulated energy demand (kWh.m^{-2} y $^{-1}$)*

Table 13 provides a summary of the simulation results obtained for all scenarios in the oceanic climate of Copenhagen. The analysis reveals that selecting the appropriate building morphology for this particular climatic context can potentially lead to a maximum reduction of 29.58% in total energy consumption.

Among the simulated typologies, M1OC exhibits the worst performance in terms of energy loads, raising doubts about the suitability of organic typologies with a high Se (surface of the envelope) and low relative compactness for the climate of Copenhagen. However, in a cold climate like Copenhagen, where the need for cooling is limited to June and partially in May, July, and August, the focus shifts to the impact on heating loads. Adopting the M1OC typology in regions with similar climate results in a waste of at least 10.6 kWh/m2.

The presence of courtyards, whether open (OC) or closed (CC), enhances the morphology's effectiveness by approximately 24.32% for the M1C morphology. %. Linked pavilion typology LP also incorporate multiple open courtyards.

However, the longitudinal plan of this typology only performs better in specific orientations, namely when rotated by 0 and 180 degrees. The presence of a sky-lit atrium in the core of each unit in MC further decreases its performance, making it necessary to analyze if the courtyard have to be opened or covered for specific climates.

Table 13. *Simulation results obtained for all the scenarios in the climate of Copenhagen*

		Annual heating demand			Annual cooling demand			Annual energy demand		
		Total heating [kWh]	Heating Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total cooling [kWh]	Cooling Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total energy [kWh]	Total energy/ Conditioned area [kWh/m2]	Total morphology effectiveness [%]
0	CU	266505.00	39.57	-	191752	28.47	-	458257	68.04	-
	LP	310101.63	47.81	**-20.82**	153323.78	23.64	**16.97**	463425.41	71.45	**-5.01**
	P1T	322798.53	46.53	**-17.58**	176859.64	25.49	**10.47**	499658.16	72.02	**-5.84**
	PMT	301155.52	44.28	**-11.89**	176230.51	25.91	**9.00**	477386.03	70.19	**-3.15**
	M1OC	459525.06	66.33	**-67.63**	142259.05	20.53	**27.88**	601784.11	86.87	**-27.66**
	M1CC	330042.49	43.99	**-11.17**	197488.74	26.32	**7.54**	527531.23	70.32	**-3.34**
	M2OC	343620.06	49.75	**-25.71**	161116.82	23.33	**18.08**	504736.89	73.07	**-7.39**
	M2CC	424764.75	50.74	**-28.23**	196466.77	23.47	**17.57**	621231.51	74.21	**-9.07**
	M4OC	339726.40	49.57	**-25.27**	153118.16	22.34	**21.53**	492844.56	71.91	**-5.69**
	M4CC	366077.90	46.60	**-17.75**	170575.34	21.71	**23.74**	536653.24	68.31	**-0.39**
90	CU	266206.55	39.53	-	192527.07	28.59	-	458733.62	68.11	-
	LP	311096.8	47.96	**-21.35**	162557.07	25.06	**12.33**	473653.87	73.03	**-7.21**
	P1T	322091.02	46.42	**-17.45**	165645.85	23.88	**16.48**	487736.87	70.30	**-3.21**
	PMT	298877.84	43.94	**-11.17**	169101.82	24.86	**13.03**	467979.66	68.80	**-1.01**
	M1OC	460387.31	66.46	**-68.13**	145650.65	21.02	**26.45**	606037.96	87.48	**-28.43**
	M1CC	331789.44	44.23	**-11.89**	202607.6	27.01	**5.53**	534397.04	71.23	**-4.58**
	M2OC	344895.4	49.93	**-26.32**	167830.99	24.30	**15.01**	512726.4	74.23	**-8.98**
	M2CC	425521.1	50.83	**-28.60**	196280.02	24.26	**15.15**	628570.99	75.09	**-10.24**
	M4OC	340610.55	49.70	**-25.73**	153521.58	22.52	**21.22**	494945.82	72.22	**-6.03**
	M4CC	366087.25	46.60	**-17.89**	170850.85	22.00	**23.03**	538944.22	68.60	**-0.71**
180	CU	265692.18	39.45	-	190989.63	28.36	-	456681.81	67.81	-
	LP	310097.7	47.81	**-21.19**	153930.82	23.73	**16.31**	464028.52	71.54	**-5.51**
	P1T	322061.08	46.42	**-17.67**	175905.97	25.35	**10.59**	497967.05	71.77	**-5.85**
	PMT	300734.81	44.22	**-12.08**	175635.91	25.82	**8.94**	476370.72	70.04	**-3.29**
	M1OC	460528.02	66.48	**-68.51**	142884.93	20.63	**27.27**	603412.95	87.10	**-28.45**
	M1CC	332138.55	44.27	**-12.22**	198889.02	26.51	**6.52**	531027.57	70.78	**-4.38**
	M2OC	344057.9	49.81	**-26.26**	159932.27	23.15	**18.35**	503990.16	72.96	**-7.60**
	M2CC	424330.39	50.69	**-28.49**	196280.02	23.45	**17.32**	620610.41	74.14	**-9.33**
	M4OC	340506.42	49.68	**-25.94**	153521.58	22.40	**21.01**	494028	72.08	**-6.31**
	M4CC	366520.8	46.65	**-18.26**	170850.85	21.75	**23.32**	537371.65	68.40	**-0.87**
270	CU	264900.45	39.33	-	191286.91	28.40	-	456187.36	67.74	-
	LP	309571.41	47.73	**-21.35**	160919.67	24.81	**12.65**	470491.08	72.54	**-7.09**
	P1T	321747.39	46.37	**-17.90**	165113.61	23.80	**16.21**	486861	70.17	**-3.60**
	PMT	300325.95	44.16	**-12.26**	170841.06	25.12	**11.57**	471167.02	69.27	**-2.27**
	M1OC	461922.61	66.68	**-69.52**	146115.69	21.09	**25.74**	608038.31	87.77	**-29.58**
	M1CC	331968.08	44.25	**-12.50**	203037.55	27.06	**4.71**	535005.62	71.31	**-5.28**
	M2OC	344057.9	50.03	**-27.20**	169028.08	24.47	**13.84**	514606.57	74.50	**-9.99**
	M2CC	424330.39	50.89	**-29.37**	203789.04	24.34	**14.29**	629752.5	75.23	**-11.06**
	M4OC	342266.94	49.94	**-26.97**	156242.79	22.80	**19.73**	498509.73	72.74	**-7.39**
	M4CC	367185.99	46.74	**-18.82**	174316.22	22.19	**21.88**	541502.21	68.92	**-1.76**

5.3 Climate of Kiev

5.3.1 Energy Performance

Figure 96 demonstrates the comparison of annual simulated energy demand in relation to rotation angle. The results indicate a slight increase in energy demand when the building is rotated by 90° and 270. The P1T typology shows the most significant impact of orientation, with energy consumption increasing by 2.47 kWh.m-2Y-1 when rotated 90° and 2.61 kWh.m-2Y-1 when rotated 270°. However, when the typologies are rotated by 180°, there is a slight decrease in energy consumption, with a maximum value of 0.1 kWh.m-2Y-1.

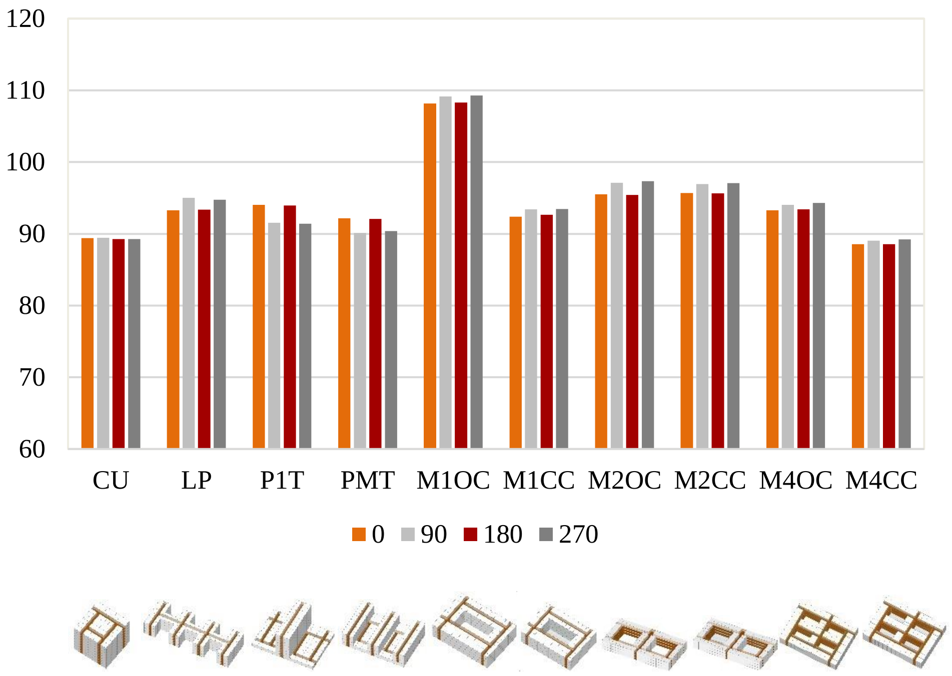


Figure 96. *Comparison of annual simulated energy demand (kWh.m^{-2} y $^{-1}$)*

Table 14 presents a summary of the simulation results obtained for all scenarios in the humid continental climate of Kiev. The selection of an appropriate morphology can potentially reduce up to 22.43% of the total energy consumed. However, the

M1OC typology exhibits the poorest performance in terms of energy loads, raising concerns about the suitability of organic typologies with high surface area (Se) and low relative compactness for the climate of Kiev. In a cold climate like Kiev, where cooling needs are limited to June and partially to May, July, and August, the focus shifts to the impact on heating loads. Adopting the M1OC typology results in a minimum wastage of 21.02 kWh/m2 in regions with a similar climate. The presence of courtyards, whether open (OC) or closed (CC), enhances the morphology's effectiveness in the range of 17% to 18%.

Linked pavilion typology LP also incorporate multiple open courtyards.

However, the longitudinal plan of this typology only performs better in specific orientations, namely when rotated by 0 and 180 degrees. The presence of a sky-lit atrium in the core of each unit in MC further decreases its performance, making it necessary to analyze if the courtyard have to be opened or covered for specific climates.

Table 14. *Simulation results obtained for all the scenarios in the climate of Kiev*

		Annual heating demand			Annual cooling demand			Annual energy demand		
		Total heating [kWh]	Heating Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total cooling [kWh]	Cooling Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total energy [kWh]	Total energy/ Conditioned area [kWh/m2]	Total morphology effectiveness [%]
0	CU	309994.45	46.03	-	292041.85	43.36	-	602036.3	89.39	-
	LP	353616.29	54.52	**-18.45**	251374.31	38.76	**10.62**	604990.6	93.28	**-4.35**
	P1T	369208.10	53.22	**-15.61**	283132.38	40.81	**5.89**	652340.48	94.02	**-5.18**
	PMT	346764.36	50.98	**-10.76**	279952.83	41.16	**5.08**	626717.19	92.14	**-3.08**
	M1OC	502139.60	72.48	**-57.47**	247311.74	35.70	**17.67**	749451.34	108.18	**-21.02**
	M1CC	379857.03	50.63	**-10.00**	313224.11	41.75	**3.72**	693081.14	92.38	**-3.35**
	M2OC	391185.10	56.63	**-23.04**	268519.34	38.87	**10.35**	659704.44	95.51	**-6.84**
	M2CC	478419.32	57.15	**-24.17**	322399.68	38.51	**11.18**	800819	95.67	**-7.02**
	M4OC	383978.05	56.03	**-21.72**	255440.5	37.27	**14.05**	639418.55	93.30	**-4.37**
	M4CC	413724.49	52.66	**-14.41**	281864.28	35.88	**17.26**	695588.77	88.54	**0.96**
90	CU	309602.97	45.97	-	292761.97	43.47	-	602364.93	89.44	-
	LP	354771.4	54.70	**-18.98**	261499.55	40.32	**7.25**	616270.95	95.01	**-6.23**
	P1T	367825.56	53.02	**-15.33**	267327.06	38.53	**11.36**	635152.62	91.55	**-2.36**
	PMT	344435.09	50.64	**-10.16**	268478.49	39.47	**9.19**	612913.59	90.11	**-0.75**
	M1OC	503117.54	72.62	**-57.98**	253128.28	36.54	**15.94**	756245.82	109.16	**-22.05**
	M1CC	381359.13	50.83	**-10.58**	319583.53	42.60	**2.01**	700942.67	93.43	**-4.46**
	M2OC	392653.92	56.85	**-23.66**	278261.88	40.28	**7.33**	670915.79	97.13	**-8.60**
	M2CC	479599.49	57.29	**-24.63**	331949.85	39.65	**8.78**	811549.34	96.95	**-8.39**
	M4OC	385150.3	56.20	**-22.25**	259335.16	37.84	**12.95**	644485.45	94.04	**-5.14**
	M4CC	413961.03	52.66	**-14.55**	285537.32	36.34	**16.39**	699498.35	89.04	**0.45**
180	CU	309500.13	45.96	-	291641.74	43.30	-	601141.87	89.26	-
	LP	353581.52	54.51	**-18.62**	252043.47	38.86	**10.26**	605624.98	93.37	**-4.61**
	P1T	368893.71	53.17	**-15.70**	282774.64	40.76	**5.88**	651668.36	93.93	**-5.23**
	PMT	346557.33	50.95	**-10.87**	279713.01	41.12	**5.03**	626270.34	92.08	**-3.16**
	M1OC	502725.28	72.57	**-57.91**	247518.64	35.73	**17.49**	750243.92	108.30	**-21.33**
	M1CC	381354.64	50.83	**-10.61**	313893.87	41.84	**3.38**	695248.51	92.67	**-3.82**
	M2OC	391546.65	56.68	**-23.35**	267574.54	38.74	**10.54**	659121.18	95.42	**-6.91**
	M2CC	478121.84	57.12	**-24.29**	322343.52	38.51	**11.08**	800465.36	95.62	**-7.13**
	M4OC	384463.04	56.10	**-22.07**	255631.25	37.30	**13.86**	640094.29	93.40	**-4.64**
	M4CC	413857.85	52.68	**-14.63**	281767.89	35.86	**17.18**	695625.73	88.54	**0.80**
270	CU	308869.97	45.86	-	292215.5	43.39	-	601085.47	89.25	-
	LP	353843.05	54.55	**-18.95**	260714.28	40.20	**7.36**	614557.32	94.75	**-6.16**
	P1T	367372.4	52.95	**-15.46**	266800.91	38.46	**11.37**	634173.32	91.41	**-2.42**
	PMT	345169.97	50.75	**-10.66**	269484.45	39.62	**8.68**	614654.42	90.37	**-1.25**

M1OC	504140.87	72.77	**-58.68**	252820.36	36.49	**15.89**	756961.23	109.27	**-22.43**
M1CC	381539.4	50.86	**-10.89**	319753.06	42.62	**1.77**	701292.45	93.48	**-4.74**
M2OC	393208.36	56.93	**-24.12**	279111.43	40.41	**6.87**	672319.79	97.33	**-9.06**
M2CC	480026.52	57.34	**-25.04**	332523.51	39.72	**8.45**	812550.03	97.07	**-8.76**
M4OC	386108.31	56.34	**-22.84**	260246.86	37.97	**12.48**	646355.17	94.31	**-5.67**
M4CC	414598.16	52.77	**-15.07**	286197.01	36.43	**16.04**	700795.17	89.20	**0.06**

5.4 Climate of Tallinn

5.4.1 Energy Performance

Figure 97 depicts the comparison of annual simulated energy demand in relation to the rotation angle, indicating that there is an increase when the building is rotated 90° and 270. The orientation has not as significant impact on longitudinal typologies as in three other climates, however P1T and PMT, with energy consumption experiencing a maximum decrease of 1.62 kWh.m-2Y-1 when rotated 90° and 1.72 kWh.m-2Y-1 when rotated 270°.

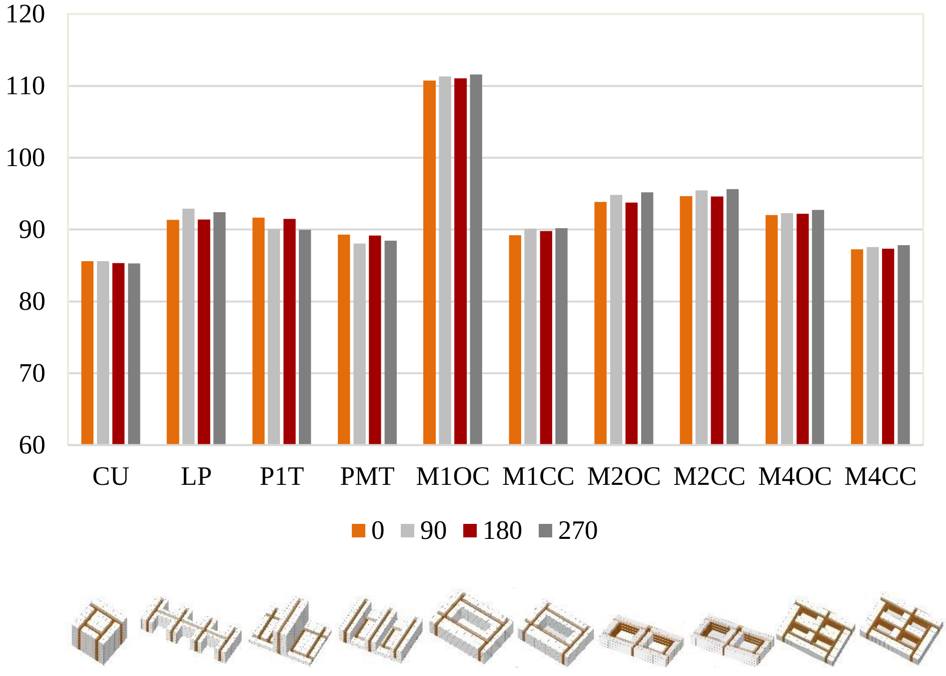


Figure 97. *Comparison of annual simulated energy demand (kWh.m^{-2} y $^{-1}$)*

Table 15 presents a summary of the simulation results obtained for all the scenarios in the cold climate of Tallinn. The selection of the proper morphology can lead to a maximum reduction of 30.84% in total energy consumption. Among the studied typologies, M1OC performs the worst in terms of energy loads, raising concerns about the suitability of block plans centered around an opened atrium for the climate of Tallinn.

The presence of courtyards, whether open (OC) or closed (CC), enhances the morphology's effectiveness in the range of 24% to 26%.

Linked pavilion typology LP also incorporate multiple open courtyards.

However, the longitudinal plan of this typology only performs better in specific orientations, namely when rotated by 0 and 180 degrees. The presence of a sky-lit atrium in the core of each unit in MC further decreases its performance, making it necessary to analyze if the courtyard have to be opened or covered for specific climates.

Table 15. *Simulation results obtained for all the scenarios in the climate of Tallinn*

		Annual heating demand			Annual cooling demand			Annual energy demand		
		Total heating [kWh]	Heating Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total cooling [kWh]	Cooling Conditioned area [kWh/m2]	Morphology effectiveness [%]	Total energy [kWh]	Total energy/ Conditioned area [kWh/m2]	Total morphology effectiveness [%]
0	CU	388695.84	57.71	-	187669.97	27.87	-	576365.81	85.58	-
	LP	439717.66	67.79	**-17.47**	152885.7	23.57	**15.41**	592603.36	91.37	**-6.76**
	P1T	459113.78	66.17	**-14.66**	176960.94	25.51	**8.47**	636074.72	91.68	**-7.13**
	PMT	432614.28	63.60	**-10.21**	174820.51	25.70	**7.76**	607434.79	89.31	**-4.36**
	M1OC	622650.67	89.88	**-55.73**	144459.15	20.85	**25.17**	767109.82	110.73	**-29.39**
	M1CC	476477.75	63.51	**-10.04**	192641.4	25.68	**7.85**	669119.15	89.19	**-4.22**
	M2OC	485934.49	70.35	**-21.89**	162179.67	23.48	**15.74**	648114.16	93.83	**-9.64**
	M2CC	597414.31	71.37	**-23.66**	194816.67	23.27	**16.48**	792230.98	94.64	**-10.59**
	M4OC	477227.92	69.63	**-20.65**	153541.22	22.40	**19.60**	630769.14	92.04	**-7.54**
	M4CC	516715.27	65.77	**-13.96**	168778.64	21.48	**22.91**	685493.91	87.25	**-1.95**
90	CU	388250.43	57.65	-	188178.64	27.94	-	576429.07	85.59	-
	LP	439457.33	67.75	**-17.53**	163043.6	25.14	**10.03**	602500.93	92.89	**-8.53**
	P1T	459491.04	66.23	**-14.88**	165367.83	23.84	**14.69**	624858.87	90.06	**-5.23**
	PMT	430479.75	63.29	**-9.79**	168395.4	24.76	**11.39**	598875.15	88.05	**-2.87**
	M1OC	623233.86	89.96	**-56.06**	147923	21.35	**23.58**	771156.87	111.32	**-30.06**
	M1CC	478041.33	63.72	**-10.53**	197949.43	26.39	**5.57**	675990.76	90.10	**-5.28**
	M2OC	486313.23	70.40	**-22.13**	168822.13	24.44	**12.53**	655135.36	94.84	**-10.81**
	M2CC	597353.02	71.36	**-23.78**	201524.55	24.07	**13.84**	798877.57	95.43	**-11.50**
	M4OC	477650.67	69.69	**-20.90**	154730.99	22.58	**19.20**	632381.66	92.27	**-7.81**
	M4CC	516494.95	65.74	**-14.04**	171221.89	21.79	**22.00**	687716.84	87.54	**-2.27**
180	CU	387819.68	57.58	-	186767.32	27.73	-	574587	85.32	-
	LP	439575.8	67.77	**-17.69**	153313.75	23.64	**14.76**	592889.55	91.41	**-7.14**
	P1T	458582.51	66.10	**-14.78**	176219.55	25.40	**8.41**	634802.06	91.50	**-7.25**
	PMT	432215.29	63.55	**-10.35**	174266.39	25.62	**7.61**	606481.68	89.17	**-4.51**
	M1OC	623910.04	90.06	**-56.40**	145394.9	20.99	**24.32**	769304.94	111.05	**-30.16**
	M1CC	479042.1	63.85	**-10.89**	194562.28	25.93	**6.48**	673604.38	89.79	**-5.24**
	M2OC	486485.06	70.43	**-22.31**	647626.63	23.33	**15.88**	647626.63	93.76	**-9.90**
	M2CC	597068.19	71.33	**-23.86**	194799	23.27	**16.09**	791867.19	94.60	**-10.88**
	M4OC	477989.43	69.74	**-21.12**	153999.57	22.47	**18.97**	631989	92.21	**-8.09**

	M4CC	517197.41	65.83	**-14.32**	169076.45	21.52	**22.40**	686273.85	87.35	**-2.39**
270	CU	387084.87	57.47	-	187210.27	27.80	-	574295.14	85.27	-
	LP	437974.8	67.53	**-17.49**	161573.67	24.91	**10.38**	599548.47	92.44	**-8.40**
	P1T	459252.98	66.19	**-15.17**	164878.33	23.76	**14.51**	624131.31	89.96	**-5.50**
	PMT	431704.23	63.47	**-10.43**	169951.1	24.99	**10.11**	601655.33	88.46	**-3.74**
	M1OC	624670.49	90.17	**-56.89**	148242.01	21.40	**23.02**	772912.49	111.57	**-30.84**
	M1CC	478253.4	63.75	**-10.91**	198452.87	26.45	**4.84**	676706.26	90.20	**-5.78**
	M2OC	487187.76	70.53	**-22.72**	170236.54	24.65	**11.34**	657424.31	95.18	**-11.61**
	M2CC	597988.56	71.44	**-24.29**	202454.03	24.19	**12.99**	800442.59	95.62	**-12.14**
	M4OC	479157.5	69.91	**-21.64**	156388.5	22.82	**17.91**	635546	92.73	**-8.75**
	M4CC	517549.1	65.88	**-14.62**	172576.46	21.97	**20.98**	690125.55	87.84	**-3.01**

CHAPTER 6

CONCLUSIONS

5.5 Conclusions

It is proposed a new comprehensive framework that aims to assess the thermal and energy performance of hospital building morphologies in different climatic contexts. The study employs an analytical and quantitative approach, considering various design variables such as shape and orientation. This approach contributes to enhancing designers' and architects' understanding of climate-related considerations during the decision-making process, ultimately optimizing the energy and thermal performance of diverse hospital morphologies.

The current approach builds upon previous methodologies and introduces novel and valuable insights. Through our analysis, we discovered the following key findings:

• In the humid subtropical climate of Tirana, the hospital models exhibited the highest energy demand. Tallinn's humid continental climate ranked second, displaying a similar performance to Kiev with only a 2 $kWh.m^{-2}$ average difference. The hypothetical hospital models in the oceanic climate of Copenhagen showcased the lowest energy demand, approximately 9 $kWh.m^{-2}$ lower than in Tirana.

• The M1OC typology was found to be unsuitable for locations with greater heating needs but can be suitable for hot climates where cooling demands are higher. However, further optimization of courtyard dimensions is required for improved performance in cold climates. Typologies with high Se (Solar exposure) had the lowest ranking in oceanic and humid continental climates, while M1OC and M2OC ranked highest across all four climates.

• In climatic regions similar to the selected climates, significant energy consumption reduction through morphology selection can be achieved. Proper morphology selection can lead to a maximum reduction of 11.4 $kWh.m^{-2}$ in the humid subtropical climate of Tirana, 18.83 $kWh.m^{-2}$ in the oceanic climate of Copenhagen, 19.64 $kWh.m^{-2}$ in the warm humid climate of Kiev, and 25.15 $kWh.m^{-2}$ in the humid continental climate of Tallinn.

• When comparing the annual simulated energy demand based on rotation angle, a trend of increased energy demand was observed when the building was rotated 90° and 270°. This orientation had the most significant impact on typologies with longitudinal layouts in climates like Tirana and Kiev.

In conclusion, the proposed framework provides a valuable approach to evaluating the thermal and energy performance of hospital building morphologies in different climates. The findings highlight the importance of morphology selection and orientation in optimizing energy efficiency, enabling designers and architects to make informed decisions based on climatic considerations.

5.6 Recommendations for future research

In general, the findings underscore the significant thermal and energy advantages resulting from the influence of morphology. The model development process and analysis align with relevant scientific studies and experiments, taking into consideration climatic conditions, construction properties, HVAC systems, and internal loads, which ensure optimal performance of the model. However, to further investigate the research topic, it is recommended to conduct experimental studies on building geometries. Therefore, several areas are identified as priorities for future investigation, including:

• incorporating internal space organization as a variable in simulation-based research,

• involving shading strategies into the results,

• optimizing the aspect ratio of morphologies,

• considering other WWR such as 45%, 75%,

• Thermal comfort and daylight analysis of one room for each hospital department,

• analyzing the models for different orientations such as 45^0, 135^0, 225^0, 315^0 which correspond to four other orientations as North-East, South-East, South-West, North-West,

• further refining the dimensions of courtyards in each typology, again whether they are covered or uncovered.

Overall, the study represents a well-documented and effective step towards an analytical approach. It emphasizes that if architects carefully consider and evaluate building shape during the early stages of design, it can not only reduce energy consumption in hospital buildings but also minimize their environmental impact.

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