ON THE EVALUATION OF THE IMPACT OF CLIMATE CHANGE ON THE ENERGY PERFORMANCE OF PREFABRICATED AND CONVENTIONAL BUILDINGS

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ABSTRACT

Climate change has a major impact on the urban built environment both regarding the buildings' energy demand, but also with respect to the higher probability of confronting extreme events such as heatwaves. To propose adaptation strategies, a growing scientific attention is paid on the accurate evaluation of the building's future energy performance. Yet, most relevant studies focus on the analysis of traditional construction solutions involving onsite construction processes and buildings made of reinforced concrete and brick masonry; yet prefabricated structures are far less evaluated in terms of their performance under the future climatic conditions. The aim of the study is (a) to evaluate via dynamic simulations the energy performance of a prefabricated building, considering both current and future climatic conditions and (b) to compare the obtained results with the respective outcome for a similar conventional building, made of reinforced concrete and brick masonry. Dynamic energy performance simulations with the EnergyPlus simulation tool are conducted for a one-story, family building, located in the city of Thessaloniki, Greece both for present and future periods. Different wall configurations and various insulation levels are examined. To generate the future climate dataset as a necessary input for the energy performance simulations, the study employs dynamical downscaling approaches. The regional climate model RegCM4 is used under the RCP4.5 scenario. Emphasis is paid on the buildings' energy performance in the near future; therefore, the generated future weather dataset refers to the period 2041-2060. Finally, EnergyPlus simulations are conducted for all the conventional and the prefabricated building scenarios for a reference period, corresponding to the current conditions and the future period and the acquired simulation results are presented and discussed.

KEYWORDS _ *climate change, dynamic energy performance simulations, prefabricated buildings*

INTRODUCTION

Climate change significantly affects the urban built environment regarding the higher probability of confronting extreme events such as heatwaves and flash floods but also with respect to the outdoor and indoor thermal comfort conditions and the buildings' energy demand. Especially for the buildings' energy performance, climate change may reduce the heating energy requirements, but it severely exacerbates the cooling energy needs, suggesting serious impacts on peak electricity demand, energy generation and energy supply (Berardi et al. 2020). In parallel, high indoor and outdoor air temperatures because of climate change, strongly aggravate the citizens' thermal comfort, constituting an important risk of their health and well-being. Given the severe social, economic and environmental extensions of the above-mentioned effects, it is of imperative importance to accurately evaluate the energy needs of buildings both under current and future climatic conditions so as to have a global perspective of the buildings' performance during their whole lifecycle and propose suitable design and adaption strategies.

When it comes to the assessment of climate change and the definition of future climate projections, the models that are used by the scientific community are the General Circulation Models (GCMs), driven by different scenarios that represent the main driving forces of future emissions (economic, technological and population growth) (Liang et al. 2008). Yet, these models provide climate information on the global scale and with a large spatial and temporal resolution. Consequently, the direct use of their output on dynamic building energy performance simulations tools would not be possible, as the latter require climatic parameters at an hourly resolution. To acquire compatible, future climate data, the GCMs should be downscaled and to this aim, there are two main approaches, involving dynamical and statistical downscaling methods (Kostopoulou et al. 2007).

While the statistical downscaling methods develop statistical relationships between observed climatic variables and larger (GCM) scale variables, such analogue methods regression analysis, or stochastic methods, the dynamical downscaling employ Regional Climate Models (RegCMs), driven by the output of a GCM, to dynamically extrapolate the effects of large-scale climate processes to regional or local scales of interest. Both methods have been widely used in previous studies assessing climate change effect in buildings energy use (Tsoka et al. 2021) and there is also an important number of studies analysing the various advantages and disadvantages of each approach (Ekström et al.2015). In this context, Tootkaboni et al. (2021) and Berardi et al. (2020) suggested that the statistical downscaling methods may provide adequate information to comparatively assess the long-term changes in energy building performance but still, the dynamical downscaling method is found to be more reliable given its finer resolution.

To continue, most of the existing relevant studies that assess the climate change impact on buildings' heating and cooling energy needs focus on conventional construction methods such as on-site processes and buildings made of reinforced concrete and brick masonry (Li et al.2012, Berardi et al. 2020) rather than on prefabricated buildings. It is true that for many years, prefabricated buildings were regarded as of inferior quality or designated for temporary constructions and this consideration explained both their low penetration in the building industry in various Mediterranean countries for many years (Apaydin,2011) and also the reduced scientific literature. Yet, during the last decade, a considerable change is noticed on the presence of prefabricated buildings in the market as they can compete the conventional ones in every aspect of performance, i.e., structural, energy, hygrothermal, acoustic, fire, environmental, etc. (Liu et al. 2022)

In this context and to assist the gap in the existing literature, the present study aims to evaluate via dynamic simulations, the current and future heating and cooling energy demand of a prefabricated building and compare the obtained results to the respective energy demand of a conventional building with similar geometrical characteristics, made of reinforced concrete and brick masonry.

METHODOLOGY

Description of the case study building

The study concerns a small, single-family building, presented in Figure 1. It has one storey and covers an area of 47.32 m². The plan is rectangular, expanded along the south-north axis, with openings only on the south and north walls. The roof is inclined and is covered with clay tiles. Below the inclined roof of the building, there is a horizontal slab, made of reinforced concrete, above which a thick layer of 10.0 cm of thermal insulation (XPS) is positioned. The floor of the house, in contact with the ground, is constructed with reinforced concrete and is insulated with a 10 cm thick XPS layer. The windows comprise of PVC frame with a double, low-e glazing. The U-value of the transparent elements is equal to 2.0 W/(m² K). The energy performance of the building is evaluated for two different configurations of the vertical elements involving both conventional and prefabricated construction methods. More precisely, the first configuration involves conventional walls, composed of bearing masonry made of hollow clay bricks, as a representative of the conventional construction; the second scenario involves the use of the new module developed through the SU.PR.I.M. research project, as a representative of the prefabricated building alternative (Tsikaloudaki et al. 2020). The prefabricated building element has the form of a composite panel. It consists of two lightly reinforced concrete plates, 5cm thick each, which are positioned on either side of vertical (and occasionally diagonal) metal hollow elements. The distance between the vertical hollow metal elements is about 0.70 m – 1.00 m and the gap is filled in with expanded polystyrene. The prefabricated panels are connected to each other and to the metal columns/beams of the structural organization with anchors, especially designed for this construction.

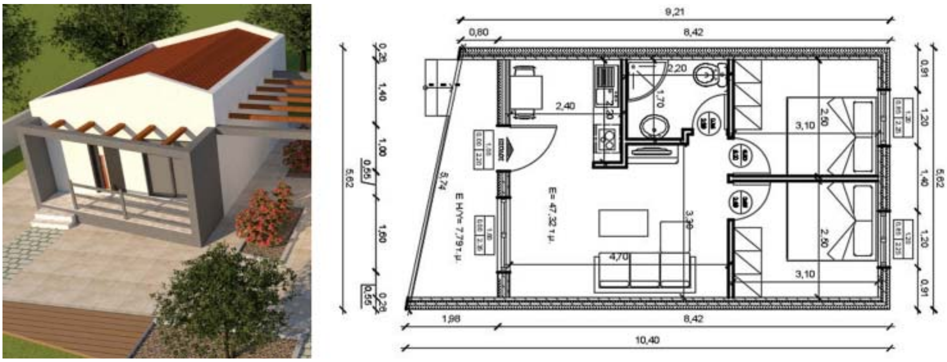


Figure 1: External 3D view and plot of the examined house

Simulation scenarios and parameters

The energy performance of both building alternatives is assessed with EnergyPlus, a dynamic simulation software, that is commonly used for such purposes. The energy analysis concerns the annual heating and cooling needs of the buildings for different insulation levels, assumed to be the same in the two wall alternatives and equal to 5 cm, 10 cm, 15 cm and 20 cm of XPS. In terms of the climate conditions, it is considered that the two examined building types are located in the city of Thessaloniki, Greece and their energy performance is evaluated both for current and future climatic conditions. The procedure for the generation of the respective hourly weather datasets is described in the next section.

In terms of the operational schedules of the house, involving occupancy, lighting, equipment, heating and cooling setpoints and infiltration rates, they have been set according to the respective values provided by the Technical Guides of the recast of the Hellenic Building Energy Performance

Regulation. Furthermore, in order to simulate in a more realistic way the performance of the building during summer, it has been considered that the occupants will naturally ventilate the building during the cooling period, provided that the outdoor air temperature is lower than the indoor one by at least 1.0°C. The simulations were conducted on an annual basis and the ideal load HVAC system has been employed in the model. The Domestic Hot Water (DHW) needs were also calculated, for all climatic zones of Greece, according to the Hellenic Regulation for Building Energy Performance, EN 15316-3.2 and EN 15316-3.3. Finally, for all the examined buildings, energy performance simulations have been performed for the heating and cooling setpoints of 20°C and 26°C respectively, following the Provisions of the National Building Energy Performance Regulation.

Generation of current and future climatic weather datasets

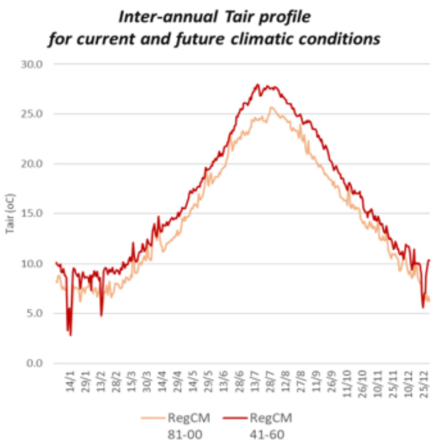
In this study, the generation of the future weather file is based on dynamic downscaling methods. More precisely, the regional climate model, RegCM4 (version 4.4.5.1) is used. The spatial resolution of the model is 25x25km. The simulation is driven by HadGEM2 general circulation model (GCM) and for the future projections the model is using RCP4.5 scenario, which is an intermediate pathway with no exceedance of radiative forcing at a stabilization level of ~4.5 W/m^2. The main physics parameterizations of the model are described in detail in the work of Velikou et al. (2019). To evaluate the energy performance of the conventional and the prefabricated construction both under current and future climatic conditions, two weather files are created according to the RegCM4 output (a) an hourly weather file, corresponding to the present-day climatic conditions and issues by the reference simulation period 1981-2000 (i.e., RegCM 81-00) and (b) an hourly weather file, reflecting the future climatic conditions for the period 2041-2060 (i.e., RegCM 41-60).

To this aim and for every simulation run of the RegCM4, five meteorological parameters are extracted. These parameters include the air temperature, the relative humidity, the wind speed, and the global solar radiation. At the next step, RegCM4 extracted data for periods of 1981–2000 and 2041–2060 are organized and averaged for the 20-years period to generate a single weather file of 8760 values for each period. In parallel, given that the RegCM4 simulation output included 3-hourly temporal resolution data, linear interpolation was used to estimate the hourly values for each meteorological parameter for both periods of 1981-2000 and 2041-2060. A similar approach has been also followed by Berardi et al. (2021). Finally, the obtained 8760 hourly values of each meteorological parameter and for both periods, have been introduced in Elements tool, an open-source platform for editing and creating custom EPW weather files, compatible with Energy Plus dynamic building energy modelling.

RESULTS AND DISCUSSION

Evaluation of climate change and future air temperature

Figure 2 presents the inter-annual profile of the estimated Tair values for the present and future climate conditions, while in Figure 3 the respective mean monthly values are depicted. The analysis of the air temperature between the present day and the future weather dataset on a daily basis throughout the year, suggests that the generated datasets follow a similar profile, with the future ones presenting higher Tair values, depicting thus the impact of climate change on the created weather files. More precisely, the range of the daily Tair fluctuates between 2.7°C to 25.62°C for the present-day climatic conditions (i.e., RegCM_81-00) and between 2.83°C to 27.9°C for the future period (i.e., RegCM_41-60). Moreover, as seen in Figure 3, future projections forecast a mean monthly temperature increase between 1.1°C-1.5°C and 2.1°C-2.8°C during the heating and cooling period respectively, while the mean annual temperature rise reaches 1.7°C. Peak maximum values, overpassing 2.5°C, are estimated for the months of July and September suggesting serious risks in terms of the potential, buildings energy use.



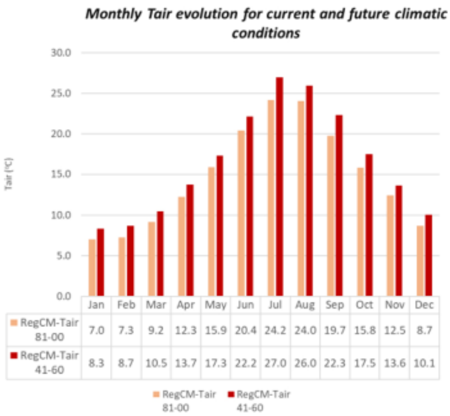


Figure 2: Estimated, inter-annual Tair values for the reference (81-00) and the future period (41-60);
Figure 3: Estimated mean Tair values for the reference (81-00) and the future period (41-60)

The energy performance of the examined buildings under current and future climatic conditions

The annual heating and cooling energy demand of the examined buildings of conventional (i.e., ETICS building) and prefabricated construction (i.e., PREFAB. building), for the reference period and future climatic conditions are shown in Figure 4 and Figure 5 respectively. Simulation results are presented in pairs with respect to the thermal insulation thickness and the wall configuration.

Focusing on the simulation results for the present-day climate, the energy needs of the prefabricated building are always lower, compared to the respective values for the conventional ETICS construction. The difference on total energy needs ranges between 4% and 18%, with the heating loads being reduced by 3% to 17.5% with respect to the thickness of thermal insulation. Moreover, for both construction methods, the heating energy demand dominates over the cooling energy needs, which is expected due to the geographical position and the climate of the region. In fact, the maximization of thermal resistance of the walls leads to the minimization of heat losses during winter, but it does not cause an equivalent decrease of the cooling needs, as the solar heat gains, its major component, stem mainly from the transparent building elements. Again, the difference on the heating needs between the two examined construction types is not the same for every thickness of thermal insulation; as the thermal insulation thickness increases, its impact on heating load reduction weakens.

In terms of the estimated, future energy performance, the obtained simulation results suggest an increasing trend in cooling energy requirements and a reduction in the heating needs for both construction types, with the projected changes varying according to the insulation level. For both conventional and prefabricated buildings, regardless of the insulation level, the cooling energy needs are more than doubled, due to the higher future, summer Tair values. Yet, for the future period 2041-2060, prefabricated buildings present lower, total annual energy needs, compared to the conventional ones, with the difference ranging between 4% and 16%, according to the insulation level. In terms of the annual heating energy demand, the examined ETICS buildings need 14.74-26.77 $KWh/m^2/y$, depending on the insulation level, while the respective values for the prefabricated constructions varying between 14.09 and 20.88 $KWh/m^2/y$. Again, differences in the cooling energy needs are of lower importance due to the climatic zone that the buildings are located, as previously explained. Still, the prefabricated buildings present lower cooling energy demand compared to the conventional ETICS buildings with the estimated deviations ranging between 1.5% and 6%.

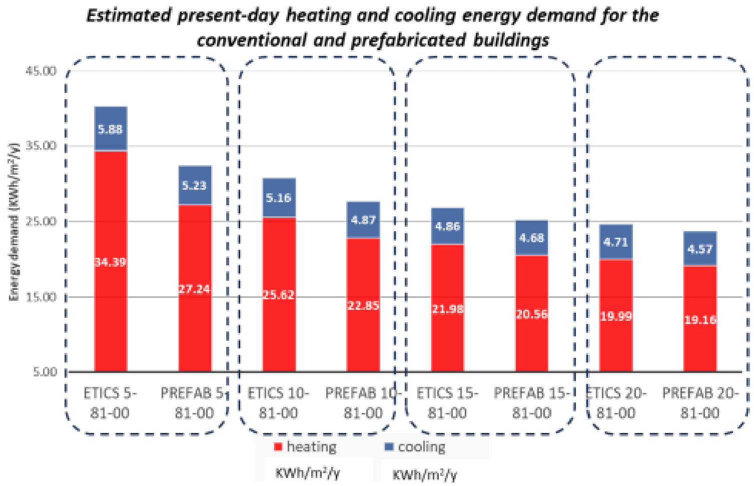


Figure 4: Estimated, annual heating and cooling energy needs for the different, examined wall configurations, for the present-day climatic conditions

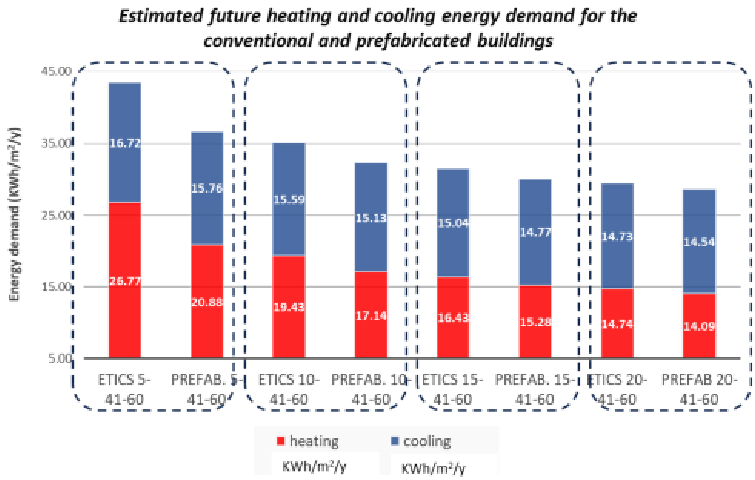


Figure 5: Annual heating and cooling energy needs for the different, examined wall configurations, for the future climatic conditions

CONCLUSION

This study aimed at the evaluation of the climate change impact on the heating and cooling energy demand of prefabricated buildings compared to conventionally constructed buildings, made of reinforced concrete and brick masonry. Dynamic downscaling approaches have been implemented to forecast future climate conditions for the period 2041-2060, for the area of Thessaloniki and the EnergyPlus simulations have been conducted for the energy performance analysis. Tha analysis suggested an average annual Tair increase of 1.7°C is expected for the period 2041-2060 compared to the reference period of 1981-2000, representing current climatic conditions; peak monthly rise is expected in July and September, suggesting considerable changes in the peak cooling energy demand, compared to the present-day conditions.

Future higher Tair values result in a reduction of the heating energy demand both for prefabricated and conventional buildings, but the cooling energy demand is significantly exacerbated and becomes more than double. Yet, despite the future increase on the total annual energy demand, the analyzed, prefabricated buildings have been found more efficient compared to the conventional ones, since they will need 4%-16% lower energy for heating and cooling purposes.

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