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Assessing the Impacts of Climate Change on Industrial Building Energy Performance

[1] B.Sc. **Melike Eksi**, [2] B.Sc. **Beytullah Emre Kavak,** [3] B.Sc. **Ahmet Eren Kargi** and *[4] Dr. **Sadik Yigit**
FMV Isik University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey [1,2,3,4]
E-mail [1]: melikeeksiii@gmail.com, E-mail [2]: beytullahemrekavak@gmail.com, E-mail [3]: ahmetekargi@gmail.com,
E-mail [4]: sadik.yigit@isikun.edu.tr

Abstract
Buildings are responsible for a significant portion of global greenhouse gas emissions and are a critical component in achieving climate neutrality. Researchers have focused on finding energy-efficient building envelope designs to reduce the energy consumption of buildings. However, the majority of studies did not take climate change into consideration. It is clear that more studies should be carried out to investigate the energy performance of buildings under climate change conditions. This paper provides a brief review of relevant studies and highlights the need for further investigation. Specifically, this study analyses the energy performance of a prefabricated industrial building, considering climate change conditions, using Energy Plus simulation software. The results of the study demonstrate that, due to climate change, the heating energy demand of buildings is predicted to significantly decrease. The results of this study are expected to inform strategies for reducing the carbon footprint of industrial buildings in a changing climate.
Keywords: Climate Change; Industrial Buildings; Heating Energy; Energy Performance.

1. Introduction

Buildings have a significant impact on the environment as they consume a large amount of energy and resources during construction and operation, and they can also contribute to air and water pollution. Some of the specific ways that buildings can affect the environment include energy consumption, resource consumption, water pollution, and air pollution. Inefficient buildings waste a lot of energy, which contributes to greenhouse gas emissions and climate change, and they are responsible for a significant portion of global energy consumption (Yigit and Ozorhon, 2019). Materials such as concrete, steel, and wood are used in construction and can have negative impacts on the environment due to the energy and resources required to produce them (Li et al., 2019; Amen, 2021; Aziz Amen, 2022; Amen et al., 2023; Amen & Nia, 2020). Chemicals used for cleaning and maintenance, as well as sewage and other waste, can contribute to water pollution, while emissions from heating and cooling systems, and the use of paints and other materials that release pollutants into the air can contribute to air pollution (Spiru and Simona, 2017). To minimize the negative effects of buildings on the environment, it is essential to consider their environmental impacts during the design, construction, and operation phases. Recently, there has been a growing concern about the future energy performance of buildings in light of climate change. It is crucial to analyse how changes in performance due to climate change can affect buildings' life cycle costs and carbon emissions. To this end, researchers have directed their efforts towards analyzing the impact of climate change on the energy performance of buildings.

Shady Attia and Camille Gobin investigated the impact of climate change on the number of overheating hours in a newly constructed nearly zero-energy building (nZEB) in Belgium. The study used thermal comfort models to simulate indoor temperatures under different climate scenarios for the years 2050 and 2080. The results showed that the number of overheating hours exceeded the acceptable upper threshold of discomfort hours in residential buildings in all climate scenarios. In particular, the worst thermal comfort scenario was found in the living rooms of the building, where overheating hours could reach over 1,400 hours per year under certain climate scenarios in 2080. The study concludes that overheating in naturally ventilated nZEBs cannot be avoided using passive design measures, and that active cooling may be necessary to address overheating risks. However, the use of active cooling will result in an increase in carbon emissions and hinder the energy transition. The study also highlights the need for a Belgian climate change adaptation strategy and plan for the building sector's energy transition and suggests that future research should investigate the uncertainties derived from regional weather files and the urban heat island effect (Attia and Gobin, 2020).

Berardi and Javarfur investigated the effects of climate change on the heating and cooling energy demand of buildings in Toronto, Ontario, using statistical and dynamical downscaling methods to generate several future weather files. The results showed a decrease in heating energy use intensity and an increase in cooling energy use intensity by 2070, depending on the building typology. The study also emphasized the importance of considering future weather files for building design to maximize energy efficiency, reduce GHG emissions, and limit the cost of future changes. Future research should take into account the effects of urban heat islands and extreme weather

conditions, as well as investigate other cities with different climate conditions. The study also suggests the development of higher temporal and spatial resolution climate models for Canada (Berardi and Jafarpur, 2020). Another research examined the effect of climate change on operational parameters such as base load and heating hours in two extreme climates (polar and temperate-hot). The findings revealed that in 2050, the base load was 29% and 28% of the reference value for the polar and temperate-hot climates, respectively. The variation in the number of heating hours was insignificant in the colder climate but substantial in the warmer climate. Furthermore, in the temperate-hot climate, 75% of the heating hours had a demand that was less than 15% of the peak demand in the reference year. This could have a negative impact on the efficiency of heating systems at various levels. This study did not take into account cooling demand in residential buildings, but it suggests that similar methodologies could be used to evaluate the impact of climate change on cooling demand in tropical and subtropical climates and determine if the increase in cooling demand could enhance the feasibility of such systems (Andrić et al. 2017).
Based on the literature survey, it can be seen that there are several studies focused on building energy optimization methods (Caglayan et al. 2020a; Caglayan et al. 2020b) and the application of machine learning methods to speed up optimization processes (Yigit, 2021). However, it is seen that there is a limited number of studies focused on evaluating the energy performance of buildings under climate change conditions. In addition, most of the studies examine fictitious buildings due to a lack of information and data. Therefore, this study aims to evaluate the energy performance of a real industrial facility considering climate change. This research seeks to assess how a building performs in terms of energy consumption in the context of climate change. To achieve this, the objective was to create a 3D model of the building using Revit and then simulate its energy usage through Energy Plus. The findings of this study are expected to serve as a valuable resource for designers and professionals in the construction industry, providing them with insights into the energy efficiency of buildings and helping them make informed decisions about future building projects.

2. Methodology

A real industrial facility located in Turkey was selected as a reference building to compare its current and future energy performance. Weather data for the years 2050 and 2080 were acquired using current weather data and CCWorldWeatherGen software. The reference building was modelled and simulated using EnergyPlus for the years 2022, 2050, and 2080. The obtained results are compared to observe performance changes due to climate change. Each step of the process is described in detail in the following sections. The framework of the methodology is presented in the Figure 1.

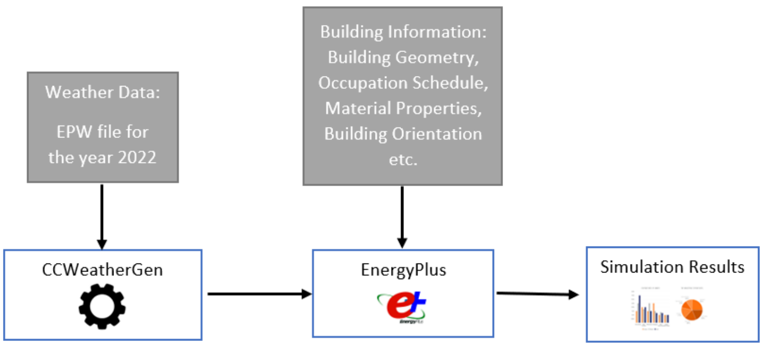

Figure 1. Structure of the Study.

2.1. Reference Building

In this study, a precast reinforced concrete manufacturing facility in Duzce province in north-western Turkey that produces sandwich panels was selected as the reference building. The total floor area of the facility is approximately 35,000 m2, and its volume is approximately 16,000 m2. It was constructed in two separate sections: the production building and the administrative building. The building is oriented in a north-south direction. During the weekdays, the facility is in use and operating hours are from 8:00 AM to 6:00 PM. The facility selected as the reference building is presented in Figure 2.

Figure 2. Industrial Facility.

The sandwich panel used in the factory consists of an outer surface, insulation layer, and inner surface. The inner and outer surfaces are 0.4 and 0.5 mm, respectively, and the panel thickness is 50 mm. The inner and outer surfaces are made of aluminium and galvanized steel, respectively. The insulation layer is the part that gives the panel its thickness and creates its physical properties. The insulation layer creates a new macromolecular structure called polyisocyanurate (PIR) by allowing the main components of the polyurethane (PUR) foam to react differently. General properties of the panels used in the industrial facility are presented in Table 1.

Table 1. Properties of the Sandwich Panels

Properties	Values
Density	39-40 kg/m3
Thermal Conductivity Coef.	0.022 W/mK
Fire Reaction Class	Bs2d0
Panel Thickness	50 mm
Coating Type	Polyester, PVDF, PVC, Plastisol
Inner and Outer Metal	Galvanized Steel, Aluminum

2.2. Simulation Model

A commercial software called Design Builder was used to create the 3D simulation model of the building. Design Builder is a commercial building energy simulation software that enables users to design, analyse, and optimize the energy performance of buildings. It can evaluate the energy efficiency of different building design options and optimize the building's energy performance through the use of energy-efficient technologies and strategies. The 3D simulation model of the industrial facility is presented in Figure 3.

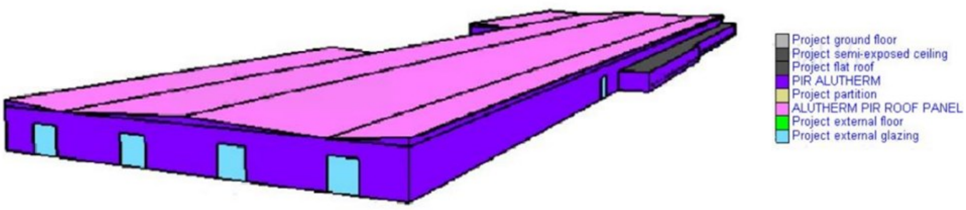

Figure 3. 3D model of the Industrial facility.

2.3. Climate Information and Data

The population of Duzce is 395,679. 68.8% of this population lives in city centre. The area of the province is 2492 km2. Duzce is a province located in the Western Black Sea Region in Turkey. It lies between 40° - 42° north latitude and 30 -33 east longitude. Duzce has an altitude of 150 m. Duzce province is under the influence of the humid and not too harsh climate seen in the coastal areas of the Black Sea Region. Table 2 shows the temperature values according to the months. The annual average temperature is 13.3 °C, the average annual total precipitation is 822.6 kg/m2, and the average relative humidity is 75.2%.

Table 2. Average Monthly Temperature (°C).

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
3.7	5.1	7.7	12.1	16.5	20.3	22.4	22.3	18.6	14.1	9.4	5.7

The weather data for the year 2022 were obtained from weather stations. However, it was necessary to acquire the weather data in the simulations for the years 2050 and 2080. The data for the year 2022 and CCWorldWeatherGen were used to predict weather data for the years 2050 and 2080. Morphing is a method used for designing weather data in building thermal simulations that accounts for future changes in climate. This technique combines current observed weather data with climate model projections to create weather time series that capture the average weather conditions of future climate scenarios while maintaining realistic sequences. The method also downscales climate model projections to the resolutions required for building thermal simulations. An example of this method is its application to CIBSE design weather years and climate change scenarios for the UK. The heating degree days calculated from the weather series adjusted for future climates show a significant decrease compared to present day, consistent with results calculated directly from the climate model, confirming the morphing technique's accuracy in transforming weather sequences.

3. Analysis and Results

Climate change has various environmental impacts, including changes in energy consumption. This study conducted an energy analysis of a manufacturing plant in Duzce using data obtained from the plant and a simulation program. The study found that rising temperatures resulting from climate change could decrease the factory's heating energy requirements. Specifically, the study revealed that by 2080, the factory's annual heating energy needs would be three times lower than in 2022, measured in kilowatt hours. Figure 4 shows monthly actual energy consumption data for 2022. When examining the figure, it is apparent that energy consumption is highest during the months with lower temperatures in the region where the factory is located. The highest energy consumption occurred in January, at 163,603 kilowatt hours (KWh). Energy consumption steadily decreased from January to May, reaching a low of 3,512 KWh in May. There was no heating energy consumption between June and August due to high air temperatures. Energy consumption remained at 0 KWh during these months. As seen in Figure 4, energy consumption began to increase again in September, reaching 2,072 KWh. The last four months saw a gradual increase, with energy consumption reaching 37,244 KWh in November. However, there was a sharp increase in December, with energy consumption reaching 129,053 KWh.

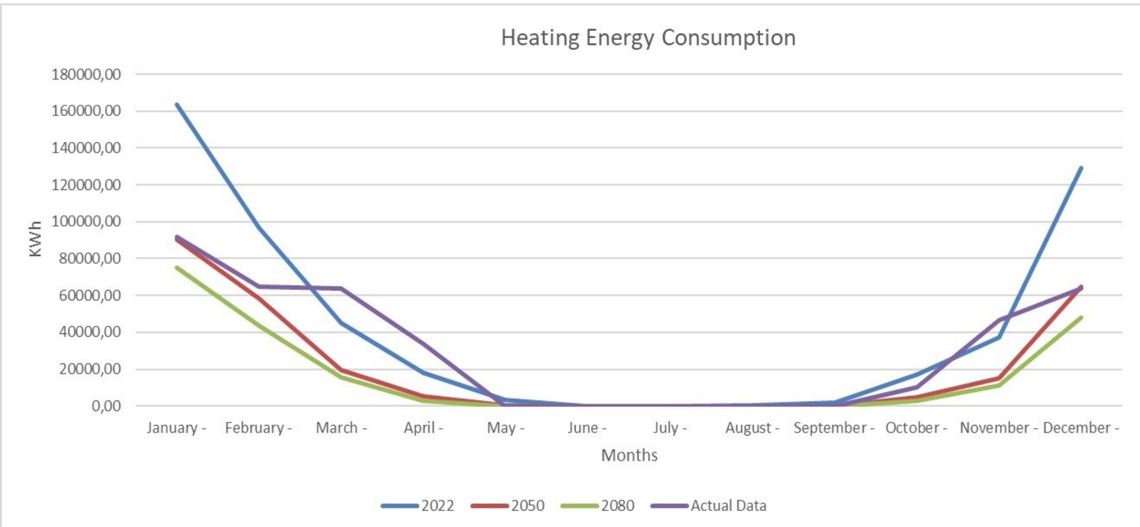

Figure 4. Monthly Heating Energy Consumption.

Figure 5 also demonstrates simulation data for the energy consumption of the factory in the years 2022, 2050, and 2080. The effect of climate change is clearly visible in the figure for the years 2050 and 2080 compared to the actual and simulated energy consumption in 2022. Figure 5 shows that there is a significant difference between the current energy consumption and the predicted energy consumption, with the latter being noticeably lower due to the effect of rising temperatures. As can be seen in the data, the energy consumption required for heating decreased as the years progressed.

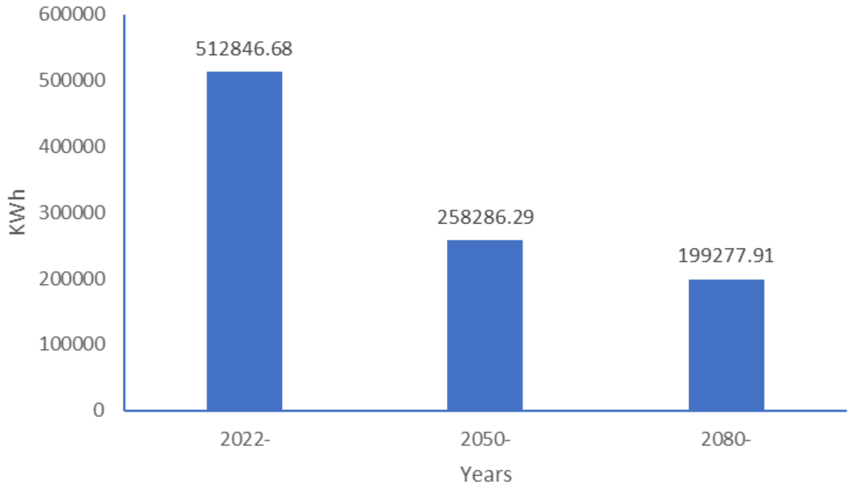

Figure 5. Yearly Simulated Heating Energy Consumption.

4. Discussions

The findings of this study align with previous research that has highlighted the importance of considering climate change in building energy performance analysis. The study conducted by Attia and Gobin (2020) in Belgium found that the number of overheating hours in a nearly zero-energy building exceeded the acceptable threshold under different climate scenarios. This suggests that passive design measures may not be sufficient to address overheating risks in the future, and active cooling systems may be necessary, which can increase carbon emissions and hinder the energy transition. Similarly, Berardi and Javarfur (2020) investigated the effects of climate change on heating and cooling energy demand in buildings in Toronto, Ontario. They observed a decrease in heating energy use intensity and an increase in cooling energy use intensity by 2070, depending on the building typology. These studies emphasize the need to consider future climate scenarios in building design and energy efficiency strategies.

The present study contributes to the existing literature by evaluating the energy performance of a real industrial facility under climate change conditions. By using actual weather data and climate projections for the years 2050 and 2080, the researchers were able to assess the potential energy savings in heating energy demand. The results showed a significant decrease in heating energy requirements over time. This finding has important implications for the carbon footprint of industrial buildings, as reduced energy consumption can contribute to the mitigation of greenhouse gas emissions.

However, it is important to note that the study focused solely on heating energy demand and did not consider cooling demand. As mentioned in the paper, if the facility fails to provide the necessary thermal comfort levels, the installation of a cooling system may be required, which could offset the energy savings achieved in heating. Therefore, future studies should consider both heating and cooling demands to provide a comprehensive analysis of the overall energy performance of buildings under climate change conditions. Furthermore, the study highlights the need for more research in this area. The authors noted that there is a limited number of studies focused on evaluating the energy performance of buildings under climate change conditions, and most of the existing studies examine fictitious buildings due to a lack of information and data. Therefore, the findings of this study contribute to filling this research gap by providing insights into the energy efficiency of a real industrial facility. The results can serve as a valuable resource for designers and professionals in the construction industry, helping them make informed decisions about future building projects and strategies to reduce the carbon footprint of industrial buildings.

5. Conclusions

This study aims to evaluate the impact of climate change on the energy performance of buildings. To achieve this, an industrial facility located in the Duzce region was selected as a reference building. Weather data for the years 2050 and 2080 were generated using current weather data and the CCWorldWeatherGen software. The results showed that climate change has a significant impact on the building's heating energy consumption. The findings suggest that energy costs will be reduced in the near future. However, further studies are needed to predict and evaluate the thermal comfort of the facility. If the facility fails to provide the necessary thermal comfort levels, it may be necessary to install a cooling system. In this case, the energy saved on heating might be consumed for cooling purposes. The results also demonstrate that conducting future performance analyses of buildings should take climate change into consideration to obtain a more accurate assessment of their life cycle costs (LCC).

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Conflict of Interests
The authors declare no conflict of interest.

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