ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ СОФИЯ

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DESIGN OF BUILDINGS UNDER GLOBAL WARMING USING CLIMATE SCENARIOS

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Keywords: *climate scenarios, global climate models, regional climate models, RCP 4,5, RCP 6, RCP 8,5, heating and cooling energy demand, dry cooling load, passive measures*

ABSTRACT

Designing buildings that will exist and be inhabited for at least 50 – 100 years in the face of climate change is an exciting and non-trivial challenge. Currently, when designing the “Energy Efficiency” part, it is usual to use climatic data (solar and temperature), obtained from measurements in a limited number of meteorological stations on the territory of Bulgaria in the past 30-year climatic periods. This makes the newly designed buildings suitable for the past and not the future with the expected significant change in temperatures, air humidity, and other climatic parameters. Considering different possible trajectories of human behavior that lead to different climate consequences, the Intergovernmental Panel on Climate Change IPCC defined four climate scenarios under which corresponding global and regional climate models were created. They can be used to investigate the behavior of newly designed buildings in the warmer climate of the late 21st century. This methodology was applied to the study of a newly designed building in Bulgaria. The heating energy in the period 2061 – 2080 with climate scenario RCP 4,5 (90 %) will decrease by about 32 %. The cooling energy demand will increase by about 150 % and the dry cooling load – by about 170 % due to the substantial increase in summer outdoor temperatures. Adding active blinds to the design reduces the increase in dry cooling load to 93 %.

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1. Introduction

At the beginning of the 21st century, our planet's climate began to change more and more due to the increased amount of greenhouse gases of anthropogenic origin. They are released mainly while burning fossil fuels, the primary energy source satisfying humanity's energy needs. One of the most severe manifestations of climate change is the increase in global average temperatures, which is illustrated in Fig. 1 for the period 1850 – 2022. An increase in average temperatures is observed on all continents, and Europe is one of the fastest-warming continents due to its specific position in the Northern Hemisphere (Fig. 2) [1].

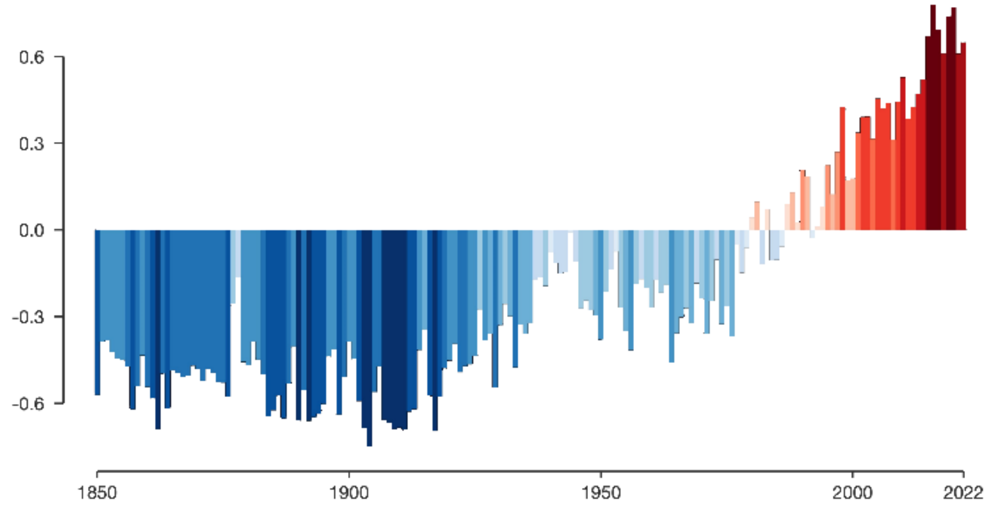


Figure 1. Relative temperature changes for the world from 1850 to 2022 compared to the average for the period 1971 – 2000 in °C [2]

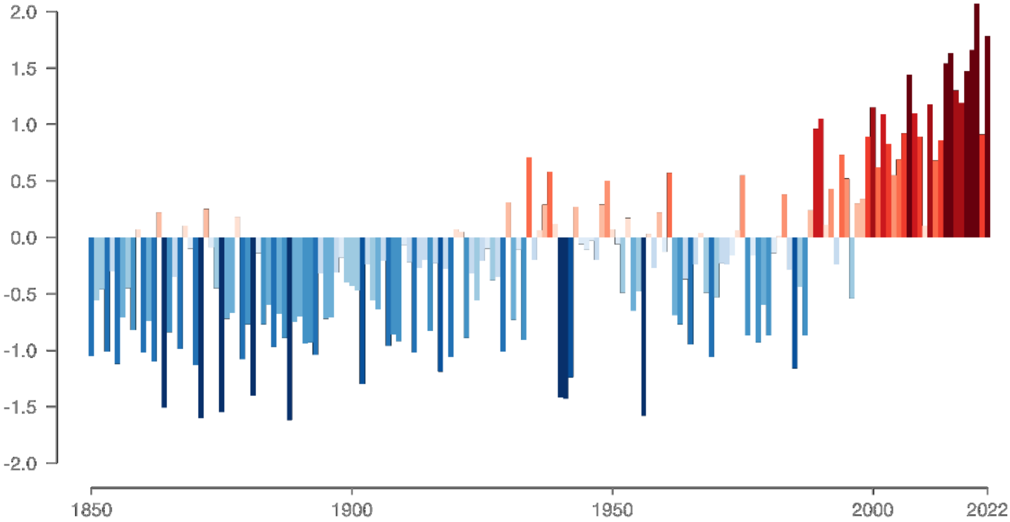


Figure 2. Relative temperature changes for Europe from 1850 to 2022 compared to the average for the period 1971 – 2000 in °C [2]

All this calls into question the methodology for designing future buildings, which are expected to have a life of at least 50 – 100 years in the future [3]. Currently, when designing the "Energy Efficiency" part, the climatic data specified in Ordinance No. RD-02-20-3 of November 9, 2022, on the technical requirements for the energy characteristics of buildings are used [4]. These data were published for the first time in Ordinance No. RD-16-1058 of December 10, 2009 on energy consumption indicators and energy characteristics of buildings [5] and are based on temperature measurements in a limited number of meteorological stations in the territory of Bulgaria in the previous 30-year climatic period (1961 – 1990). Thus, all newly designed buildings are adapted to the much cooler climate of past periods (see Fig. 3 for Bulgaria), and not to the expected temperatures in the future.

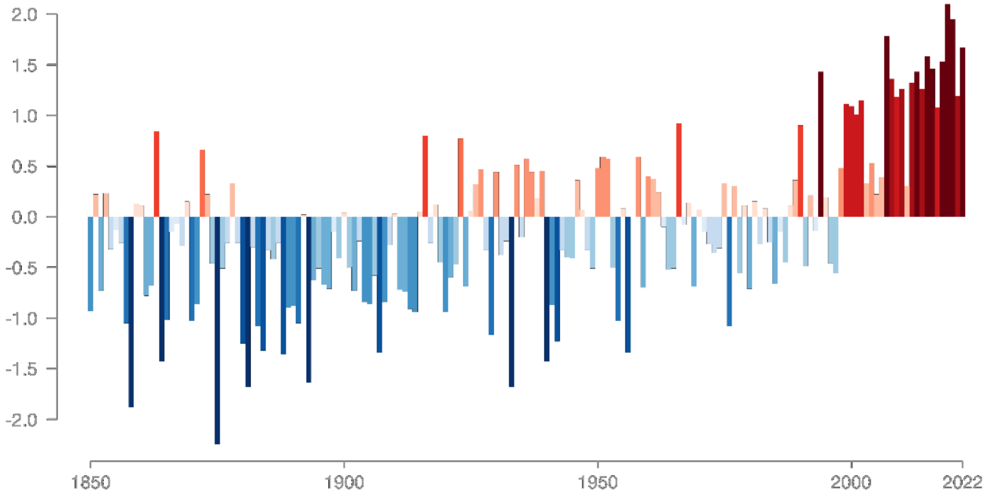


Figure 3. Relative temperature changes for Bulgaria from 1850 to 2022 compared to the average for the period 1971 – 2000 in °C [2]

Higher temperatures in the future will affect the annual values of heating and cooling degrees. The former will decrease gradually, and the latter will increase [6]. In connection with the application of the principles of the circular economy, an increase in the normative life of buildings to 100 or 150 years can be expected, which means that in their design, the features of the climate must be taken into account not only for the next 50 years but for 100 – 150 years.

This necessitates another multidisciplinary approach in the design of buildings, where knowledge of scenarios for the climatic future is needed even today. In turn, the development of scenarios for the climate future needs inputs from multiple scientific fields.

2. Climate scenarios – meaning and application

Modeling the future of our planet's climate involves elements of uncertainty. The reasons for this are various, but one of the most important is the uncertainty of how far humanity will be aware of the problem, whether and how it will plan measures to solve it, and how successful they will be. In 2014, the Intergovernmental Panel on Climate Change (IPCC) developed various scenarios for the future of Earth's climate [7]. These are called Representative Concentration Pathways (RCP) and were provided in the Fifth Assessment Report of the IPCC. Four scenarios represent model trajectories of greenhouse gas concentration (Fig. 4) and radiation pressure [8], which are used in climate models. Radiation pressure is the difference in W/m^2 per unit time (hour) between incoming and outgoing radiation in the atmosphere and is the primary driver of climate change.

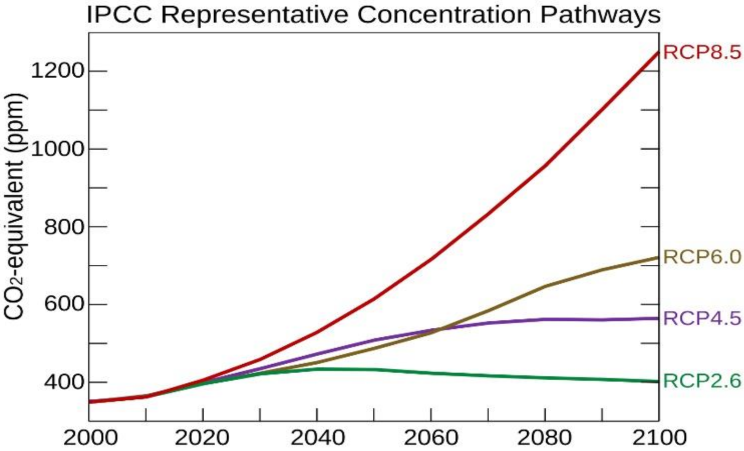


Figure 4. Model trajectories of greenhouse gases translated into carbon equivalent under the four climate scenarios from 2000 to 2100 [7]

2.1. Overview of climate scenarios

Here is a brief overview of the scenarios developed by the IPCC and their meaning [7]:

RCP 2,6 is the most optimistic scenario for a radiation pressure of 2,6 W/m^2 in 2100, which assumes a sharp reduction in greenhouse gas emissions and stabilization of concentrations by the middle of the century. This scenario is associated with strict emission reduction policies and intensive adaptation measures. In this scenario, limiting global warming to below 2 °C relative to pre-industrial levels is possible. Unfortunately, this scenario is unrealistic to expect to happen, as action on it should have been launched around 2015 and is already well advanced.

RCP 4,5 is characterized by a radiation pressure of 4,5 W/m^2 in 2100. This is a scenario with a moderate reduction in emissions, which, however, fails to stabilize greenhouse gas concentrations by 2100. This scenario assumes significant but achievable efforts to reduce emissions, which may lead to more moderate warming (by 2 – 3 °C).

RCP 6,0 is a scenario with a radiative forcing of 6 W/m^2 in 2100, in which emissions continue to rise until mid-century and then begin to decline. Still, total greenhouse gas concentrations continue to increase until 2100. In this scenario, moderate to significant warming (by 2 – 4 °C) is expected, requiring considerable adaptation measures.

RCP 8,5 is the most pessimistic scenario, with a radiation pressure of 8,5 W/m^2 in 2100, where emissions will continue to increase throughout the century without any significant restrictions. Extreme and continued exponential warming (by 4 – 6 °C or more) is predicted, which would have catastrophic consequences for the climate and require aggressive and desperate measures for adaptation and survival.

Global and regional climate models are built based on the RCP scenarios, which predict the development of a large set of climate factors and parameters (amount of greenhouse gases, radiation pressure, temperatures, humidity, solar radiation, etc.).

2.2. Global and regional climate models

Global climate models (Global Climate Models, GCM) [8] are computer models for simulating Earth's climate. They are crucial to climatology and are used to study various aspects of the climate, including how it may change due to human activity and greenhouse gases.

Global models are based on the fundamental laws of physics, chemistry, and fluid dynamics and integrate multiple sub-systems of the climate system, for example, atmospheric processes (such as cloudiness and precipitation), ocean currents, ice cover, vegetation, etc.

These models are used to produce climate forecasts at various temporal and spatial scales, from decades to centuries, and from global to regional scales. Their disadvantages are related to insufficient accuracy and spatial resolution (resolution). The outputs of these models are typically represented as probability distributions and scaled spatially and temporally to regional climate models for more detailed predictions.

Regional climate models (Regional Climate Models, RCM) [9] are computer models that provide detailed information about climate conditions in specific geographic areas under different climate scenarios, offering higher spatial and temporal resolution. This is important because climatic conditions can vary dramatically over short distances due to location, topography, and microclimatic effects. RCMs have applications in designing energy-efficient buildings because they provide information on the climate conditions by 2100 in which they will exist.

The development of climate scenarios and global and regional models is an ongoing process that is refined over time to match reality better.

3. Methodology

When designing new buildings, the main emphasis is placed on energy efficiency and managing future operating costs related to maintaining an optimal microclimate and comfort inside the building. Designers' attention is directed to analyzing energy costs – site and source energy, selection of primary energy sources, their carbon footprint, and applicable methods to reduce the building's energy consumption and carbon emissions. This approach involves looking at different strategies and techniques that can be implemented to optimize energy efficiency and decrease environmental impact.

Pursuing low- and zero-emission buildings represents a significant challenge that requires the application of high-quality software solutions and computational simulations. These tools are vital for determining the energy needs of buildings, integrating renewable energy sources, and evaluating their efficiency in operational terms. Leading global engineering and certification organizations such as ASHRAE, CIBSE, LEED, and BREEAM attach particular importance to the development of energy models of buildings already in the design phase, using highly efficient and science-based computational simulation software. This approach is essential for achieving sustainable solutions in building construction.

3.1. Description of the software used

The essential advantage of the computational simulations lies in the use of regional climate data, realized based on the base climate scenarios, considering different percentage probabilities of their realization. These simulations provide valuable data for analyzing the building's current and future energy consumption in various climatic conditions. This publication uses the Integrated Environmental Solutions Virtual Environment (IES VE) software [10].

Understandably, it uses a different methodology for calculating energy consumption according to Bulgarian legislation but applies more modern ways of modeling the climatic parameters of the environment around the building. This makes the information obtained particularly valuable. Advantageously, the software can work with different sets of climate data for the specific location – this gives the designer an idea of what the behavior and energy needs of the newly designed building will be under different external conditions, for example, expected in the future according to climate scenarios.

The energy model analyzes the energy consumption of the designed building based on the selected climate scenario for a certain period. Thus, for the chosen location, it is possible to compare the different RCP climate scenarios with three different percentage probabilities of their realization (10 %, 50 %, and 90 %) for different 20-year periods (2041 – 2060, 2061 – 2080, 2081 – 2100). This provides an opportunity for an informed and detailed analysis of the condition of the building during the selected period.

Version 2023.2.0.0 of the Integrated Environmental Solutions Virtual Environment (IES VE) software was used for this development. An earlier version of it was approved by BREEAM, making it the first product with such approval for producing energy models to certify buildings in the design phase.

The product includes integrated computational and analytical tools for building design and reconstruction.

3.2. Working principle

The tools integrated into the software perform the following functionalities:

- Three-dimensional geometric modeling of the building, with added thermophysical parameters of the materials used in the building;
- Three-dimensional geometric modeling of the environment around the investigated building, for example, other surrounding buildings in the vicinity;
- Calculation of the trajectory of the sun on the sky throughout the year, taking into account the geographical location of the building (according to its coordinates), modeling of the penetration of solar radiation through the building envelope, a study of local shading and that from the surrounding buildings.

Energy consumption calculation and data analysis.

Analyses of the energy consumption of the building were carried out, working with the same data on building elements, work schedule, number of occupants, load from lighting and appliances, types of HVAC installations, and microclimate conditions in the premises, and only the climate data changed. The file BGR_Sofia.156140_IWEC.epw (originating from Energy Plus [11]), which contains monthly meteorological data (temperature, humidity, wind speed, solar radiation, and other climatic factors), was used to evaluate the building's behavior under historical climate data) for a whole year, but selected as representative from those measured in different years at station 156140 of Sofia Airport from 1980 to 2000. Thus, the data for January in the representative year are from January 1997, for February – from the same year month in 1992, for March – from 1995, etc.

The same format is also used to describe climate data for future representative years for different climate scenarios. The file used BGR_Sofia.156 1 40_RCP45_2061-2080_90%.epw was generated by IES [10] and contains climate data representative of the period 2061 – 2080 under the RCP 4,5 climate scenario.

3.3. Object of the study

The object of the research is an administrative building with offices, shops, underground floors, and two levels of underground garages in the eastern part of the city of Sofia. It consists of one underground, ground, and six above-ground levels, with the first above-ground level being the reception/lobby, which houses retail outlets, and the remaining six levels are office premises.

The orientation of the main facades of the building is north-south. The source of heating and cooling for the building is a separate VRF-type heat pump unit with a hydrobox for each separate office – in the specific case, two offices per level. The ventilation systems are highly efficient recuperative air handling units. Figure 5 shows a view of the building in a virtual environment, with adjacent buildings added to the model, which can influence the solar load by shading the building.

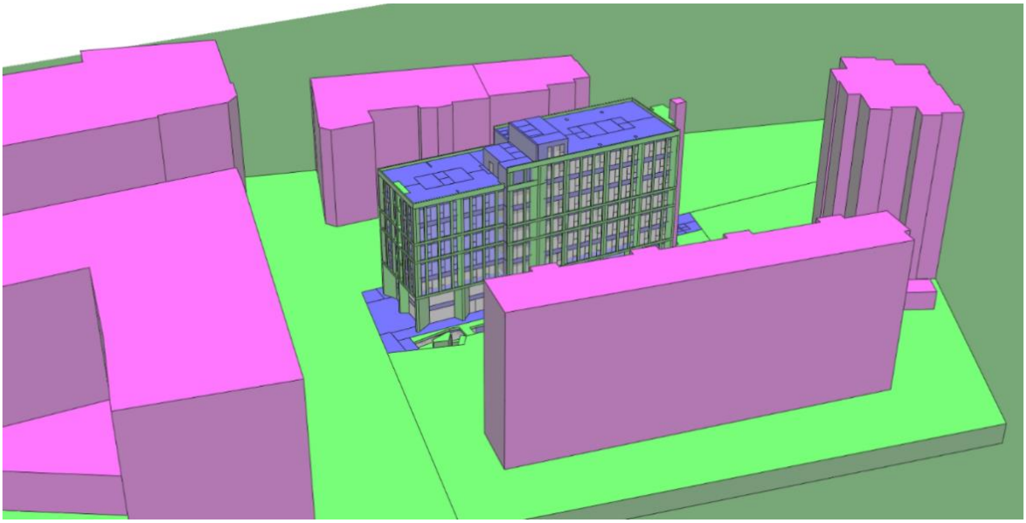


Figure 5. View of the southern facade of the investigated building and the environment around it. Nearby buildings are shown in purple. The image is generated in the IES VE environment

The heating and cooling schedule coincides with building hours, 8 A.M. to 6 P.M. on weekdays. Room temperature control uses a setpoint with an amplitude of ±1 °C while the plants operate from 6 A.M. to 10 P.M. In this way, the parameters are guaranteed during extended working hours, and in the rest of the day and on weekends, a temperature set point with a decrease of -5 °C is used for the heating season, and a set point with an increase of +5 °C for the cooling period.

The object is modeled according to the requirements for heat transfer coefficients of external enclosing elements of Ordinance No. RD-02-20-3 of November 9, 2022, on the technical specifications for the energy characteristics of buildings.

The facade of the building is mostly glass with aluminum frames with two different types of glazing. The first of them allows better solar transmittance and is located on the northern and eastern facades (U = 1,00 W/m^{2}K; g = 0,36; shading coefficient = 0,42), while the second is located on the south and west facades and aims to limit the transmittance of sunlight (U = 1,00 W/m^{2}K; g = 0,32; shading coefficient = 0,36).

Two simulations were prepared for the present study:

- **with historical climate data** (BGR_Sofia.156140_IWEC.epw) – for the period from 1980 to 2000;

- **with data on climate scenario RCP 4,5 for the period 2061 – 2080** with a probability of the predicted model coming true with 90 % accuracy (BGR_Sofia.156140_RCP45_2061-2080_90%.epw).

Let us recall that RCP 4,5 is a scenario in which significant but achievable efforts to reduce emissions are implemented, which may lead to more moderate warming (by 2 – 3 °C). Of the possible climate scenarios, this is the most favorable. The rest (RCP 6,0 and RCP 8,5) are less favorable. For the RCP 2,6 scenario, all relevant deadlines for action are omitted, and therefore, it is impossible.

4. Results

4.1. Result of IES VE software

The results of the calculations of the IES VE software are formed into an energy report on the annual energy consumption for all the needs of the building and their distribution by month, as well as the carbon footprint for each type of energy required for the set climate data. With the help of the analytical tool in the software, climatic and building data – such as loads, energy consumption, carbon footprint, and information about specific rooms – can be analyzed and visualized.

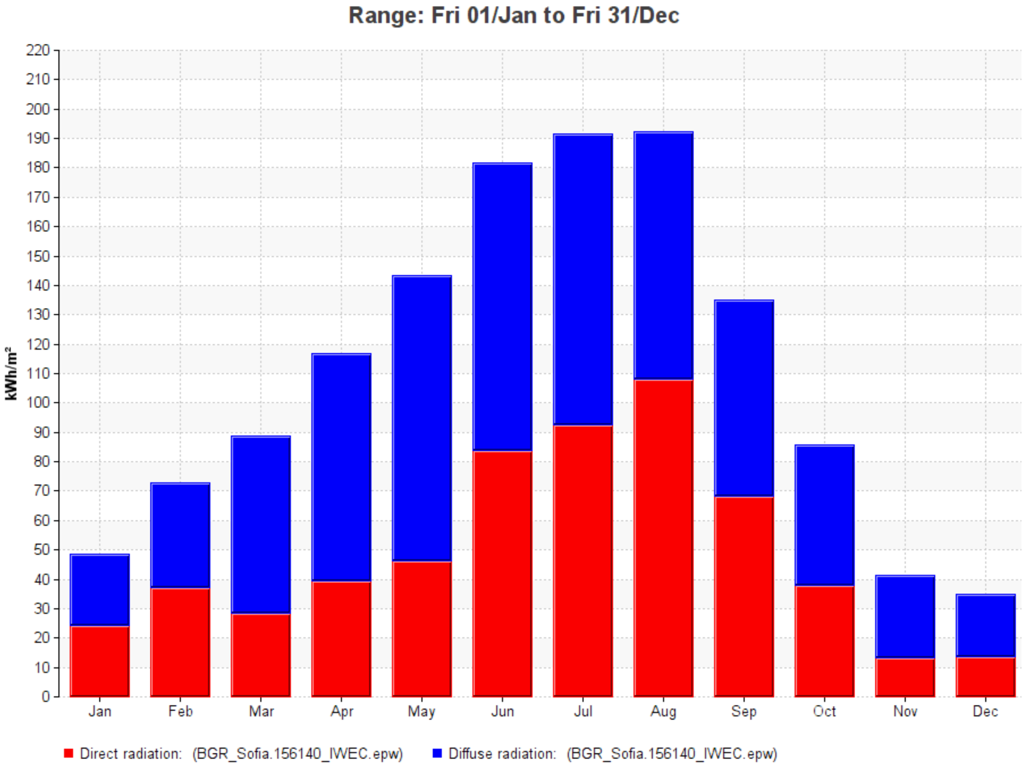


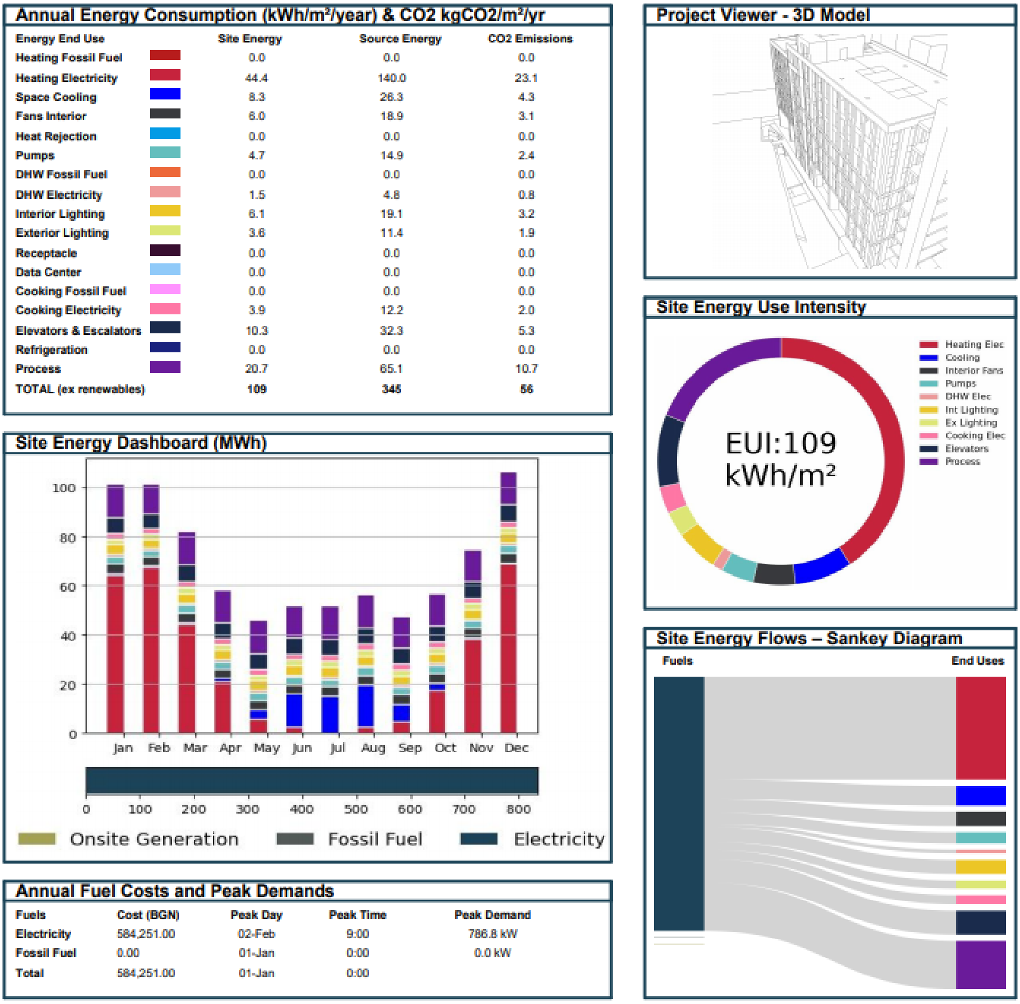
Figure 6. Using historical data, the amount of direct and diffuse horizontal solar irradiation by month. The image is generated in the IES VE environment

4.1.1. Simulations with historical climate data

For the present development, simulations were first performed with historical climate data representative of the 1980 – 2000 period.

Figure 6 shows the direct and diffuse horizontal solar irradiation for the entire year period by months in one direction and by hours in the other, in W/m^2. The annual amount of solar irradiation is 593,33 kWh/m^2 for direct and 739,91 kWh/m^2 for diffuse component. Their annual sum is 1333,24 kWh/m^2. Diffuse irradiation prevails over direct irradiation by 22 %.

The energy consumption report using historical data shows that the amount of total energy required for the building amounts to 109 kWh/m^2, including 44,4 kWh/m^2 for heating and 8,3 kWh/m^2 for cooling (including loads for conditioning the fresh air), visualized by month in one of the graphs included in Fig. 7. Thus, the predicted energy in this building for heating and cooling is 48,3 % of the total energy required.



Annual Energy Consumption (kWh/m²/year) & CO2 kgCO2/m²/yr

Energy End Use	Site Energy	Source Energy	CO2 Emissions
Heating Fossil Fuel	0.0	0.0	0.0
Heating Electricity	44.4	140.0	23.1
Space Cooling	8.3	26.3	4.3
Fans Interior	6.0	18.9	3.1
Heat Rejection	0.0	0.0	0.0
Pumps	4.7	14.9	2.4
DHW Fossil Fuel	0.0	0.0	0.0
DHW Electricity	1.5	4.8	0.8
Interior Lighting	6.1	19.1	3.2
Exterior Lighting	3.6	11.4	1.9
Receptacle	0.0	0.0	0.0
Data Center	0.0	0.0	0.0
Cooking Fossil Fuel	0.0	0.0	0.0
Cooking Electricity	3.9	12.2	2.0
Elevators & Escalators	10.3	32.3	5.3
Refrigeration	0.0	0.0	0.0
Process	20.7	65.1	10.7
TOTAL (ex renewables)	109	345	56

Annual Fuel Costs and Peak Demands

Fuels	Cost (BGN)	Peak Day	Peak Time	Peak Demand
Electricity	584,251.00	02-Feb	9:00	786.8 kW
Fossil Fuel	0.00	01-Jan	0:00	0.0 kW
Total	584,251.00	01-Jan	0:00	

Figure 7. Energy report for the building using historical climate data representative of 1980 – 2000. Image generated in IES VE environment

4.1.2. Simulation with data for the RCP 4,5 climate scenario for the period 2061 – 2080

The simulation with data for the RCP 4,5 climate scenario is produced with the same building model, the only change being the climate file – for the RCP scenario 4,5, with a 90 % chance of happening.

Figure 8 shows graphs of direct and diffuse horizontal solar radiation by months and hours for the whole year in W/m^2 according to the predictions of the scenario and IES. The annual amount of solar irradiation is 730,26 kWh/m^2 for direct and 876,84 kWh/m^2 for diffuse component. Their sum is 1607,1 kWh/m^2, which is about 20,5 % above the value for the period 1980 – 1999 and represents a significant increase in solar energy reaching the Earth's surface. This will naturally lead to higher surface air temperatures, as shown in the RCP 4,5 climate scenario.

The energy consumption report under the RCP 4,5 scenario shows that the total energy required for the building amounts to 107 kWh/m^2, including 30,2 kWh/m^2 for heating and 21,0 kWh/m^2 for cooling (including fresh air conditioning loads). The projected total energy for heating and cooling of this building is 47,4 % of the total required energy – the percentage is close to the one obtained in the calculations using historical data (Fig. 9).

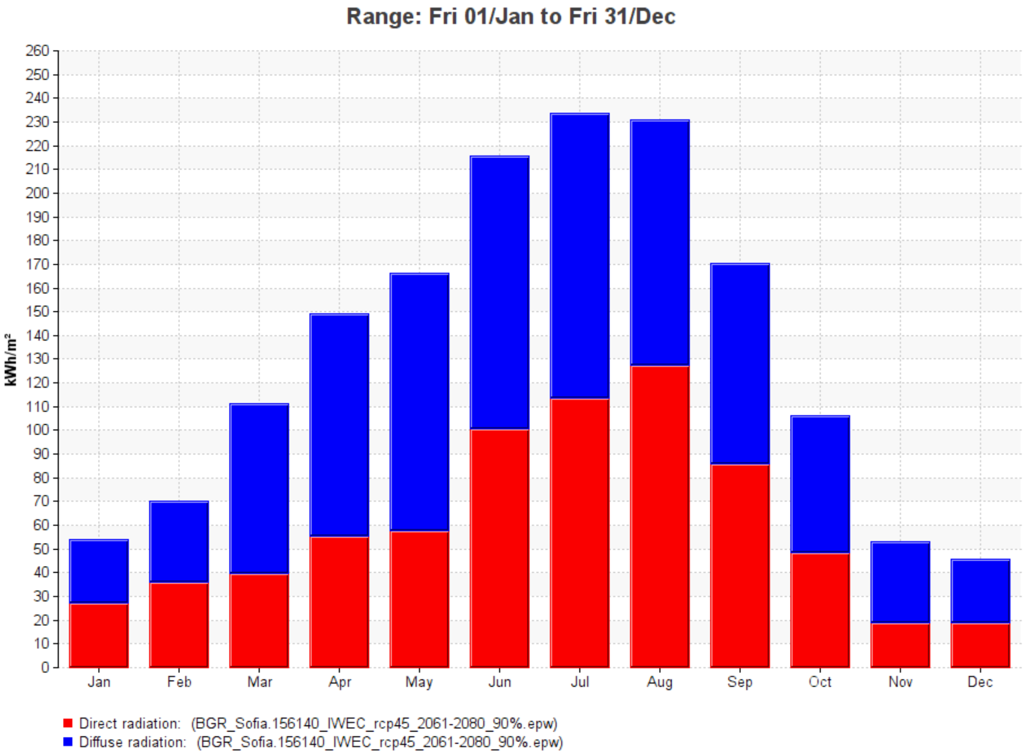
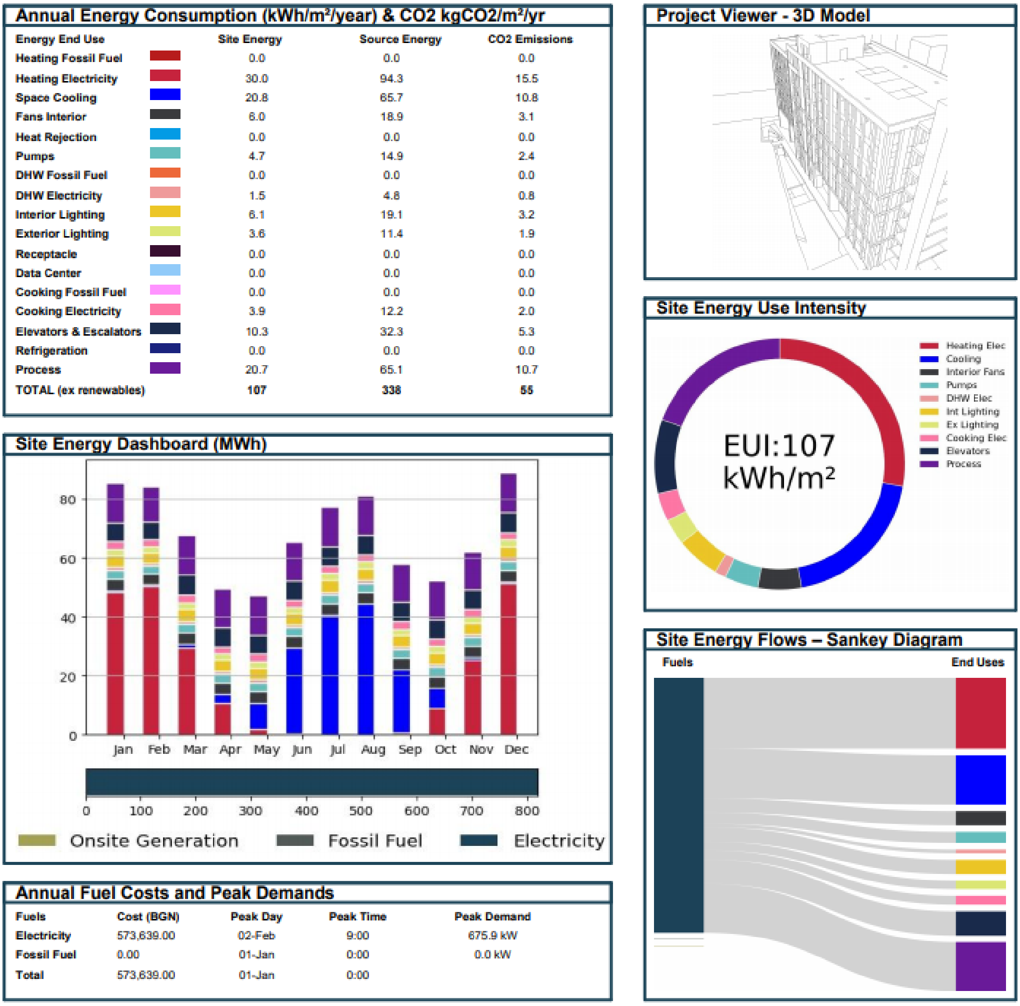


Figure 8. Amount of direct and diffuse solar radiation for all months in the year, with an hourly distribution using the climate scenario RCP 4,5 (90 %). The image is generated in the IES VE environment

4.2. Significance of results

The balance of the calculations made for the specific building in the climatic conditions of the city of Sofia is that the energy consumption of the building in an annual aspect remains in the same order. However, the computational model clearly shows that cooling energy consumption under the RCP 4,5 scenario used for the period 2061 – 2080 increases by 153 % – from 8,3 kWh/m^2 to 21,0 kWh/m^2. A significant cooling consumption increase is observed in the summer and transitional seasons.



Annual Energy Consumption (kWh/m²/year) & CO2 kgCO2/m²/yr

Energy End Use		Site Energy	Source Energy	CO2 Emissions
Heating Fossil Fuel	🟥	0.0	0.0	0.0
Heating Electricity	🟥	30.0	94.3	15.5
Space Cooling	🟦	20.8	65.7	10.8
Fans Interior	⬛	6.0	18.9	3.1
Heat Rejection	🟦	0.0	0.0	0.0
Pumps	🟩	4.7	14.9	2.4
DHW Fossil Fuel	🟧	0.0	0.0	0.0
DHW Electricity	🟥	1.5	4.8	0.8
Interior Lighting	🟨	6.1	19.1	3.2
Exterior Lighting	🟨	3.6	11.4	1.9
Receptacle	🟪	0.0	0.0	0.0
Data Center	🟦	0.0	0.0	0.0
Cooking Fossil Fuel	🟪	0.0	0.0	0.0
Cooking Electricity	🟥	3.9	12.2	2.0
Elevators & Escalators	⬛	10.3	32.3	5.3
Refrigeration	🟦	0.0	0.0	0.0
Process	🟪	20.7	65.1	10.7
TOTAL (ex renewables)		**107**	**338**	**55**

Project Viewer - 3D Model

Site Energy Use Intensity

Site Energy Dashboard (MWh)

Site Energy Flows – Sankey Diagram

Annual Fuel Costs and Peak Demands

Fuels	Cost (BGN)	Peak Day	Peak Time	Peak Demand
Electricity	573,639.00	02-Feb	9:00	675.9 kW
Fossil Fuel	0.00	01-Jan	0:00	0.0 kW
Total	573,639.00	01-Jan	0:00	

Figure 9. Energy report for the building using climate scenario RCP 4,5 (90 %). The image is generated in the IES VE environment

At the beginning of summer, the outside temperature rises dramatically, eliminating the potential for applying free-cooling or natural ventilation. The temperature graphs for the period from June 14 to June 20 are shown in Fig. 10 and Fig. 11. The two graphs look at the outside air temperature, the approximate comfort temperature of 22 °C to 25 °C depicted in white, the outside temperature above 25 °C in red and below 22 °C in blue. The areas in red show in which periods of the day the building will have a cooling load compared to the external conditions, and the areas in blue show a heating load. There are possibilities for free cooling when designing buildings with occupancy during working hours from Monday to Friday. This type of cooling uses colder outside air without needing energy to lower its temperature by forcing it through mechanical ventilation or designing a natural ventilation solution.

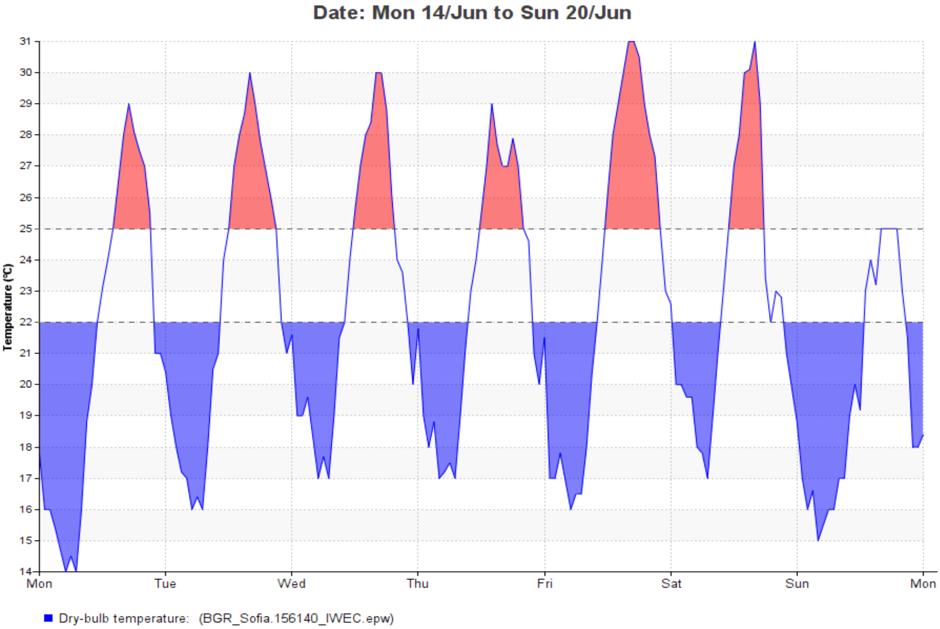


Figure 10. Outdoor air temperature for the period 14 – 20 June in a simulation with historical data. The image is generated in the IES VE environment

When considering the temperatures in Fig. 10, it is clearly seen that the selected period has a balanced amplitude about the relatively comfortable temperatures in an office space. Accordingly, the external conditions provide a theoretical possibility to implement natural ventilation and free cooling of the building, which would reduce the costs of mechanical ventilation in transitional periods and cooler summer days. These measures can lead to significant energy savings combined with active or passive shading.

The temperature amplitude for the same period in a simulation with the RCP 4,5 climate scenario in Fig. 11 drastically reduces the possibility of natural ventilation of the premises at the beginning of the summer season. On the contrary, the premises need mechanical cooling, which will require more energy in view of the extreme peak temperature levels above +35 °C.

As a final aspect, we should consider the energy required for heating and cooling for the two different periods. The energy reports produced with the various climate models clearly show a decrease in heating energy and an increase in cooling energy under the RCP 4,5 climate scenario. The difference in consumption for the two calculation files is displayed in Fig. 12 and Fig. 13. In blue are the cooling and heating loads for historical data, and in red for the RCP 4,5 climate scenario.

The heating load of the building is equal to 1642,63 MWh in one year. In the simulation with the RCP climate scenario 4,5, this value is reduced to 1117,36 MWh. This drop equals to about 32 % of heating energy compared to the original simulation.

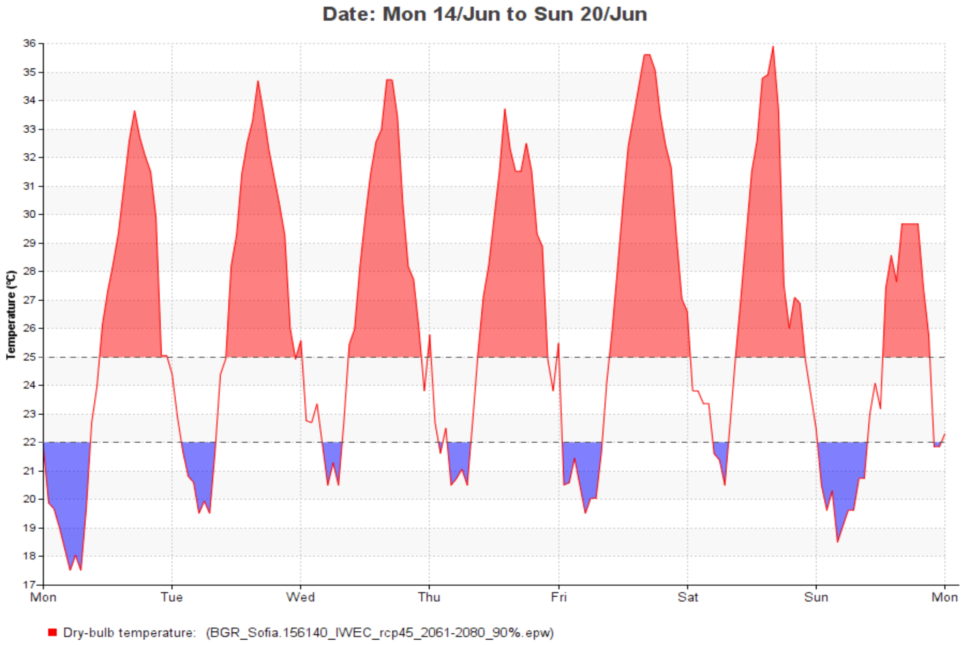


Figure 11. Outdoor air temperature for the period 14 – 20 June in simulation with climate scenario RCP 4,5 (90 %). The image is generated in the IES VE environment

Respectively, the dry cooling load of the building in the simulation with historical data amounts to 167,79 MWh, and this load increases to 459,51 MWh when adapting the climate data for RCP 4,5. The percentage increase amounts to nearly 174 % of the original load.

After analyzing the data on the increased values of solar radiation, the outdoor temperature for the summer period and the cooling load, the unprofitable implementation of natural ventilation and free cooling, as well as the drastically increased loads and energy consumption for cooling, the need for active and passive shading of the facade glazing elements of the building becomes obvious. Through additional simulation of the RCP climate scenario 4,5 (90 %), the possibility of integrating active blinds to reduce solar radiation load through the glazing is investigated. The energy report shows a reduction in cooling site energy of 5,2 W/m^2. At the same time, the dry cooling load is reduced from 459,51 MWh to 324,61 MWh, a significant reduction of approximately 29 % of the required cooling site energy (Fig. 14).

4.3. Significance of the results for design today

By integrating climate scenarios into software tools such as IES VE, we can orientate ourselves on the necessary measures to achieve energy efficiency of the building not only for the near future but also for more distant periods in time. The measures are passive and active.

Passive measures focus on using natural resources, and energy flows without active mechanical equipment. These include design and construction solutions that reduce the need for artificial heating, cooling, and lighting. Examples of passive measures include good thermal insulation, strategic positioning of the building to maximize the use of natural light and ventilation, choosing materials with high thermal mass, planting plants for shade and cooling, etc.

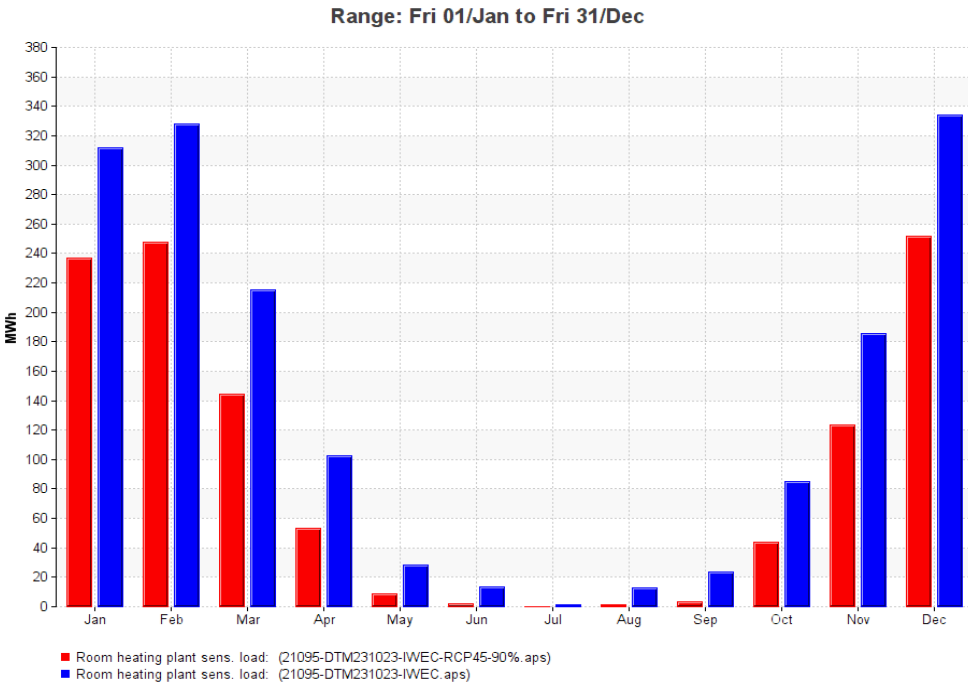


Figure 12. Comparison of building heating load in annual aspect, distributed by months. The image is generated in the IES VE environment

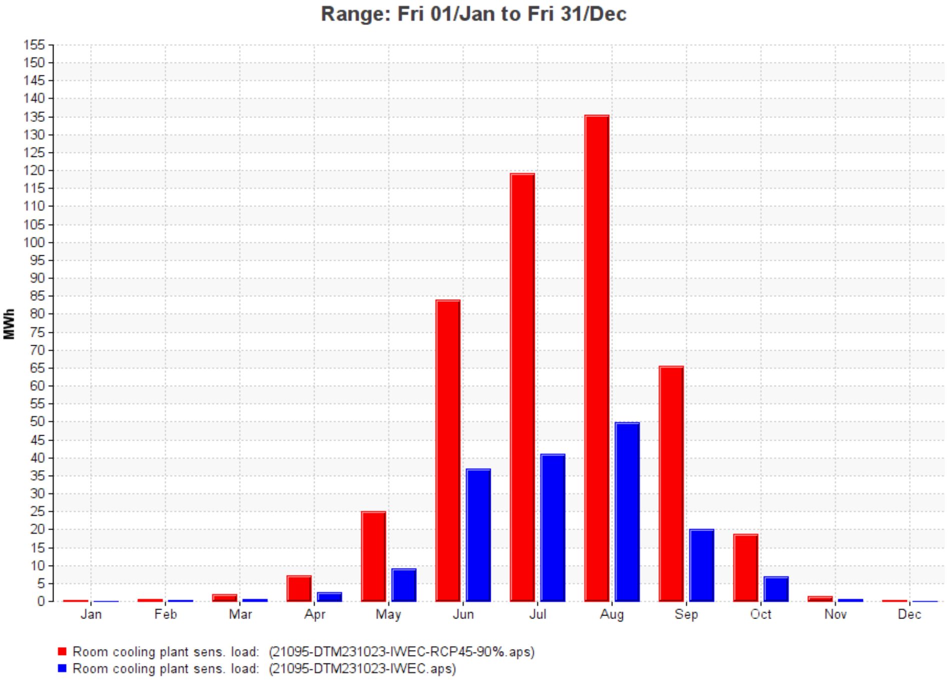
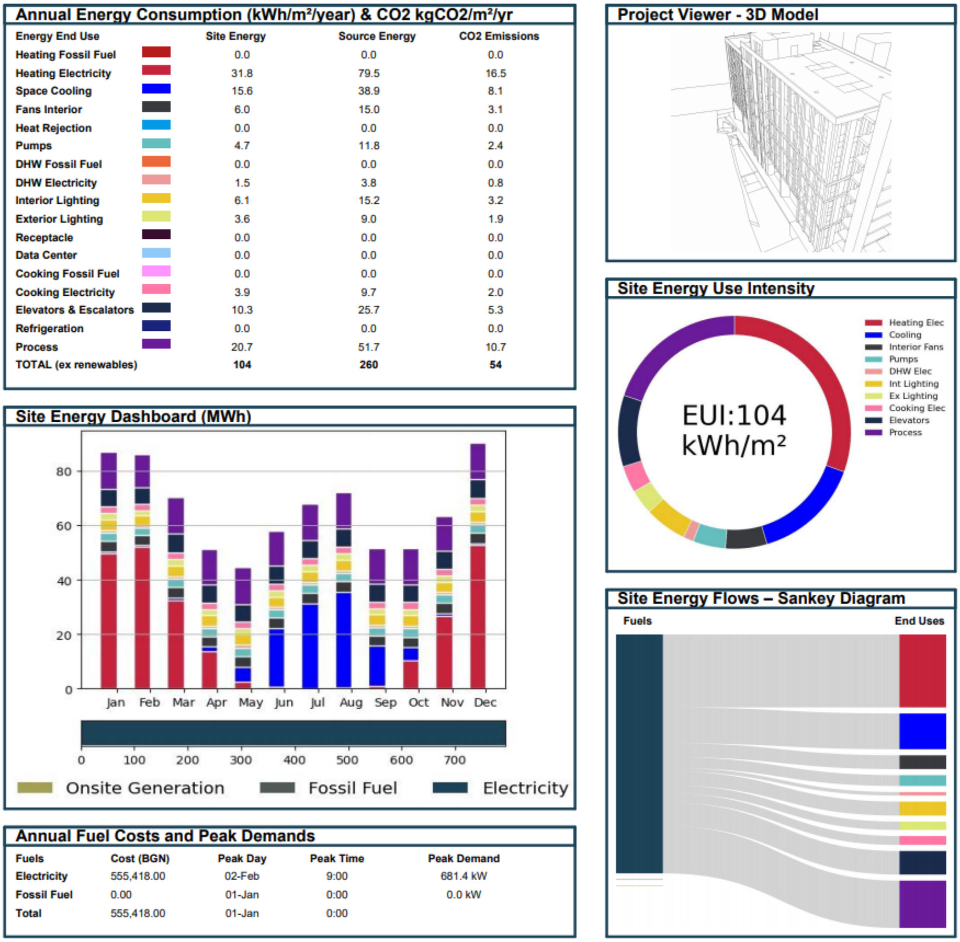


Figure 13. Comparison of the dry cooling load of the building in annual aspect, distributed by months. The image is generated in the IES VE environment



Annual Energy Consumption (kWh/m²/year) & CO2 kgCO2/m²/yr

Energy End Use		Site Energy	Source Energy	CO2 Emissions
Heating Fossil Fuel	🟥	0.0	0.0	0.0
Heating Electricity	🟥	31.8	79.5	16.5
Space Cooling	🟦	15.6	38.9	8.1
Fans Interior	⬛	6.0	15.0	3.1
Heat Rejection	🟦	0.0	0.0	0.0
Pumps	🟩	4.7	11.8	2.4
DHW Fossil Fuel	🟧	0.0	0.0	0.0
DHW Electricity	🟥	1.5	3.8	0.8
Interior Lighting	🟨	6.1	15.2	3.2
Exterior Lighting	🟨	3.6	9.0	1.9
Receptacle	⬛	0.0	0.0	0.0
Data Center	🟦	0.0	0.0	0.0
Cooking Fossil Fuel	🟪	0.0	0.0	0.0
Cooking Electricity	🟥	3.9	9.7	2.0
Elevators & Escalators	⬛	10.3	25.7	5.3
Refrigeration	🟦	0.0	0.0	0.0
Process	🟪	20.7	51.7	10.7
TOTAL (ex renewables)		**104**	**260**	**54**

Annual Fuel Costs and Peak Demands

Fuels	Cost (BGN)	Peak Day	Peak Time	Peak Demand
Electricity	555,418.00	02-Feb	9:00	681.4 kW
Fossil Fuel	0.00	01-Jan	0:00	0.0 kW
Total	555,418.00	01-Jan	0:00	

Figure 14. Energy report for the building using the climate scenario RCP 4,5 (90 %) combined with shading with external blinds. The image is generated in the IES VE environment

Active measures include using mechanical and electrical systems to improve the building's energy efficiency. They usually require an external energy source, including solar panels to produce electricity, photovoltaic systems, heat pumps, high-efficiency heating, ventilation, air conditioning systems, and automated building management systems that optimize energy use. Among all the measures to achieve energy efficiency in buildings, the passive ones have the longest life and the lowest price.

The projected rise in temperatures that occurs when comparing historical climate data from 1981 – 2000 and those under RCP 4,5 climate scenarios (90 %) shows that the proportion of energy for heating and energy for cooling is changing over time – the first decreases, and the second increases – by 153 % (from 8,3 to 21,0 kWh/m^2). Therefore, investors, designers, and future users of such buildings must pay considerable attention to passive cooling methods.

In 60 – 80 years, in the context of ongoing climate change and potential increases in average global temperatures, passive measures to protect buildings from overheating will be even more critical [12]. Here are some possible passive strategies that can be effective:

- **Building orientation and design:** Optimizing building orientation and design to maximize the use of natural light and minimize direct solar radiation can reduce the need for artificial cooling. It also affects the optimized use of natural lighting in the premises [13].

- **Green roofs and walls:** Integrating green roofs and vertical gardens reduces building temperatures, improves air quality, and enhances biodiversity. They offer extra thermal insulation, lower heat radiation, and increase thermal inertia, allowing gradual heat release and air filtration.
- **Shading elements:** The use of shading elements such as canopies, blinds, and vegetation, can reduce the impact of direct solar radiation [14].
- **Advanced thermal insulation**: Using highly efficient thermal insulation materials will be vital to keeping buildings cool. This may include new, innovative materials more effective at holding off heat.
- **Compact shape**: It directly impacts the building's heat exchange with the environment. A more compact shape leads to smaller heat gains and losses, and a more complex shape – leads to a more significant transfer through the building envelope and, from there to more considerable heat losses in winter and unwanted heat gains in summer [15].
- **Well-designed natural ventilation**: Well-designed natural ventilation is crucial for maintaining fresh air flow and minimizing air conditioning use. Utilizing the “chimney effect” [16], where hot air rises and exits through higher openings, allows warm air to be replaced by cool, fresh air through facade openings like windows.
- **Use of high thermal mass materials**: In building construction, high thermal mass materials can help absorb heat during the day and release it at night, resulting in more uniform indoor temperatures. This stabilizes the temperature in the building, and sudden climatic changes outside are not felt so strongly. This improves comfort in the premises and reduces the need for active cooling systems in them.
- **Use of light colors and reflective surfaces in facades:** Light colors and mirrored surfaces reflect more solar radiation, which helps reduce indoor temperatures.
- **Planning and zoning of the urban environment**: Urban planning and zoning, which includes creating sufficient green areas and water bodies, can help reduce the “urban heat island” effect and improve the microclimate.
- **Window shading devices**: Since the sun is higher in the sky in summer than in winter, shading devices can easily prevent the sun's rays from entering the building. Such an element can even be creeping vegetation on the facade, as well as various types of visors, blinds, slats, shutters, etc.
- **Degree of glazing of the facade**: The degree, type, location, and characteristics of the transparent elements greatly influence the energy efficiency of the buildings due to the high value of the heat transfer coefficient of the glazed parts.
- **Air space between the top floor and the roof** acts as an air chimney for convection ventilation. In this way, in the presence of openings in the roof or its construction with porous materials, the heated air from the interior comes out naturally and is replaced by fresh air from the outside [17].

Most of these methods of protecting buildings from overheating are relatively cheap and easy to implement, especially regarding new construction or renovation. The listed passive measures should already be considered in the initial design stages. Not all can be implemented in one project, but all should be familiar to designers.

It is important to note that the effectiveness of these measures may vary depending on the specific climatic and geographical conditions and the specific characteristics of the building.

Integrating climate scenarios in architectural design and using software tools such as IES VE [9] are essential to achieve energy efficiency in buildings in the future. Passive measures that utilize natural resources and energy flows offer long-term, low-cost solutions, while active measures involving mechanical and electrical systems contribute to optimizing energy efficiency. It is important to emphasize that successfully implementing these measures requires well-thought-out design and planning, considering current and future climate conditions. In this context, architects must be well informed about the different possibilities and use innovative approaches to create buildings that are energy efficient and sustainable in the long term.

5. Conclusions

Designing buildings in the context of ongoing climate change presents a significant challenge, especially in light of the common practice in Bulgaria of using outdated climate data. These data do not adequately reflect the future climatic conditions where the design will function for buildings today. In this regard, the climate scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) provide critically important models for predicting future climate conditions.

The publication analyzes the four key climate scenarios (RCP 2,6, 4,5, 6,0, and 8,5), highlighting their relevance for modeling different potential climate change scenarios. Each of these scenarios presents different projections of the rate of temperature increase and the possible consequences for the global climate. Furthermore, the article explores the importance of global and regional climate models in the context of climate change prediction and their impact on architectural design. Particular attention is paid to the significance of the higher resolution of these models, the integration of diverse scientific disciplines, and the application of artificial intelligence to refine the models.

The paper also discusses the methodology for assessing the energy needs of buildings using modern software tools such as IES VE. These tools provide an opportunity for a complex analysis of the energy consumption of buildings under different climatic conditions and scenarios. An analysis of the energy consumption of a building in Sofia was carried out, comparing historical data with predictions for future climatic conditions.

The calculations results highlight a significant increase in the energy demand for cooling in the period 2061 – 2080 with moderate climate scenario RCP 4,5 (90 %) by about 150 % and the dry cooling load – by about 170 % in the considered example due to the substantial increase in summer outdoor temperatures. Adding active blinds to the design reduces the increase in dry cooling load to 93 %. At the same time, the energy used for heating in the future will decrease by about 32 %.

In this aspect, the importance of integrating climate scenarios in the building design process and developing different strategies for adapting buildings to the adverse conditions of very high outdoor summer temperatures is growing. These strategies include passive and active measures to increase the energy efficiency of buildings. The present work highlights the growing need for a multidisciplinary approach to building design, considering expected climate changes. Sustainable construction and energy efficiency are becoming increasingly important in the context of global warming, and technological advances in simulation and analysis software tools play a key role in adapting architectural design to the challenges presented by future climate change.

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ПРОЕКТИРАНЕ НА СГРАДИ В УСЛОВИЯ НА ГЛОБАЛНО ЗАТОПЛЯНЕ С ИЗПОЛЗВАНЕ НА КЛИМАТИЧНИ СЦЕНАРИИ

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Ключови думи: *климатични сценарии, глобални климатични модели, регионални климатични модели, RCP 4,5, RCP 6, RCP 8,5, потребление на енергия за отопление и охлаждане, сух охладителен товар, пасивни мерки*

РЕЗЮМЕ

Проектирането на сгради, които ще съществуват и ще бъдат обитавани в следващите поне 50 – 100 години в условията на климатични промени, е интересно и нетривиално предизвикателство. В момента обичайно при проектиране на част „Енергийна ефективност“ се използват климатични данни (соларни и температурни), които са получени от измервания в ограничен брой метеорологични станции на територията на България в отминали 30-годишни климатични периоди. Това прави новопроектираните в момента сгради подходящи за миналото, а не за бъдещето, при очакваната значителна промяна на температурите, влажността на въздуха и други климатични параметри. С отчитане на различни възможни траектории на човешко поведение, които водят до различни последствия за климата, Междуправителствената група по изменение на климата IPCC дефинира 4 климатични сценария, по които бяха създадени съответни глобални и регионални климатични модели. Те могат да бъдат използвани, за да се изследва поведението на новопроектирани сгради в по-топлия климат в края на 21 век. Тази методика е приложена при изследване на новопроектирана сграда в България. Топлинната енергия в периода 2061 – 2080 г. при климатичен сценарий RCP 4,5 (90 %) ще намалее с около 32 %. Потребността от енергия за охлаждане ще се увеличи с около 150 %, а сухият охладителен товар – с около 170 % поради значителното повишаване на летните външни температури. Добавянето на активни щори към проекта намалява увеличението на сухия охладителен товар до 93 %.

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