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Energy and environmental performance based decision support process for early design stages of residential buildings under climate change

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ABSTRACT

Building design decisions have high impacts on energy and environmental performance of buildings. Especially, conscious decisions in earlier design stages are more significant due to lifespan impact of buildings. Deficiencies in systematic approach for design decision support to increase energy and environmental performance of buildings are projected as the major problems of this study. Decisions for performance-based design should be made in terms of the most effective design parameters peculiar for each project. This study exemplifies the act of design decision support in early design stage of a residential building in Turkey. The relation between design parameters and annual energy consumption for heating, cooling and annual operational CO_2 emissions is examined by global sensitivity analyses for the present, 2020s, 2050s and 2080s weather conditions. Design process requires the assessment of the uncertainties in building performance caused both by design parameters and climate change. The results indicate that the decisions about solar heat gain coefficients (SHGC), and heat transfer coefficients (U) of transparent surfaces on building envelope have the highest impacts on energy and environmental performance of residential buildings in hot-humid climatic conditions.

1. Introduction

Increasing energy demand together with environmental problems resulting from global warming and climate change have accelerated the global attraction about energy and environmental issues. These problems are mainly solved by decreasing energy consumption and greenhouse gas (GHG) emissions. Therefore, significant consideration is given to the building sector to diminish the global problems. For instance, residential buildings are accounted for 35.11% of energy consumption in Turkey (The Ministry of Energy & Natural Resources, 2014). Moreover, the total CO_2 equivalent GHG emissions increased 122% from 1990 to 2015, while energy consumption covers 71.6% of total releases (Turkish Statistical Institute, 2017). It is emphasized that the decisions in earlier stages of design are even more significant to reach projected performance goals (US Energy Information Administration, 2011).

The concept of sustainable design has become a global medium, by which architects aim to meet human needs while preserving the environment. Accordingly, many countries have already established laws and institutions towards reducing the effects of climate change, increasing energy savings and reducing CO_2 emissions. However, architects, in practice, may not have full of knowledge, or comprehend all parameters simultaneously, since the design and construction are imperfect processes with a variety of inherent uncertainties. Hence, the importance of design decision support arises, as well.

The realities of global warming and increasing energy demand have revealed the need for holistic environmental solutions. Building design is a complex process; including not only aesthetical issues but also many factors to be thought to meet physical, environmental and user-centered requirements. The quality criteria for sustainable building design has a wide range from conventional performance indicators to the most recent subjects such as nearly zero energy consumption, energy plus structuring and carbon zero buildings/cities. Many legislative regulations exist to increase the building performance of already existing and new buildings (European Union [EU], 2002). In this sense, there are plenty of very recent studies scrutinizing energy performance assessment. The design decision support approaches are also one of the intensive topics related to the improvement of building energy performance, especially for early design stages (Tavares & Martins, 2007; Vullo, Passera, & Lollini, 2018).

The recent literature on design decision support for architects focuses on the link between two main study areas: professional experiences gained from previous works and decision support information provided by the digital analysis tools. Hence, creating a link between professionals and systematic knowledge received from building performance simulations has become significant for building design stages

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Table 1
Overview of the studies about the relation between climate change and building energy and environmental performance.

Publication Date	Authors	Country	Project Phase	Building Type	Building Simulation Tools	Energy Performance	Climate Change	CO_2 Emission	Uncertainty/Sensitivity Analyses	Design Support
2007	Paulo Filipe de Almeida Ferreira Tavares, Antonio Manuel de Oliveira Gomes Martins	Portugal	early design stage	public		x			x	x
2009	Pieter de Wilde, Wei Tian	Netherlands	existing	office		x	x		x	x
2010	S. K.Firth, K. J.Lomas, A. J. Wright	UK	design stage	housing		x		x	x	
2010	Lisa Collins, Sukumar Natarajan, Geoff Levermore	UK	existing	housing		x	x	x	x	
2010	Xiaoming Wang, Dong Chen, Zhengen Ren	Australia	existing	housing		x	x		x	
2010	Pieter de Wilde, Wei Tian	UK	hypothetical	office	x	x	x		x	
2010	Merve Tuna, Gülsu Ulukavak Harputlugil, Gülser Çelebi	Turkey	hypothetical	housing	x	x				x
2011	Christina J. Hopfe, Jan L.M. Hensen	Netherlands	existing	office	x	x			x	x
2011	Mady Olonscheck, Anne Holsten, Jürgen P.Kropp	Germany	existing	housing	x	x	x	x		
2012	Clara Spitz, Laurent Mora, Etienne Wurtz Arnaud Jay	France	experimental	housing	x	x			x	
2012	Yusuf Yıldız, Koray Korkmaz, Türkan Göksal Özbalta, Zeynep Durmuş Arsan	Turkey	hypothetical	housing	x	x			x	x
2013	Xu Han, Jingjing Pei, Junjie Liu, Luyi Xu	China	existing	eco-community		x		x	x	
2013	Saad Dawood, Tracey Crosbie, Nashwan Dawood, Richard Lord	UK	early design stage	housing	x	x		x		x
2013	M. Kavgic, D. Mumovic, A. Summerfield, Z. Stevanovic, O. Ecim-Djuric	Serbia	existing	housing		x		x	x	
2015	I. Andrić, C. Silva, A. Pina, P. Ferrão, J. Fournier, B. Lacarrière, O. Le Corre	Portugal	existing	housing	x	x	x	x		
2016	Ramkishore Singh, I.J. Lazarus, V.V.N. Kishore	India	hypothetical	office	x				x	
2016	T.van Hooff, B. Blocken, H.J.P. Timmermans, J.L.M.Hensen	Netherlands	hypothetical	housing	x	x	x			
2016	Kuo-Tsang Huang, Ruey-Lung Hwang	Taiwan	hypothetical	housing	x	x	x			
2016	Vahid M.Nik, Erika Mata, Angela Sasic Kalagasidis Jean-Louis Scartezzini	Sweden	existing	housing	x	x	x			
2016	I. Andrić, N. Gomes A.Pina P. Ferrão, J. Fournier, B. Lacarrière, O.Le Corre	Portugal	existing	housing	x	x	x			
2016	Andrea Invidiata, Enedir Ghisi	Brazil	existing	housing	x	x	x			
2017	Saleh N.J. Al-Saadi, Khalifa S. Al-Jabri	Oman		housing	x	x				
2018	Pascal Vullo, Alessio Passera, Roberto Lollini, Alessandro Prada, Andrea Gasparella	Italy	early design stage	school	x	x				x
2018	Aslıhan Şenel Solmaz, Fahriye Halıcıoğlu, Suat Günhan	Turkey	existing	school	x	x			x	x

(Dawood, Crosbie, Dawood, & Lord, 2013; Hopfe, Struck, Ulukavak Harputlugil, Hensen, & Wilde, 2005).

The demand for including sensitivity analyses into building performance has also increased depending on the needs for more accurate results and ability to conduct more sophisticated analyses (Hopfe & Hensen, 2011). Therefore, building performance simulation tools for design support and retrofitting are incorporated in uncertainty and sensitivity analyses. Especially, Spitz, Mora, Wurtz, and Jay (2012) have carried out different types of sensitivity analyses to make even more precise analyses to reduce the uncertainties.

Climate is another significant indicator due to its effects on building energy performance and climate-specific decisions should also be taken during building design phases. There are several researches that have conducted sensitivity analyses to identify the most influential parameters on energy performance of the buildings by focusing on different climates (Table 1). It is shown that the building envelope measures such as heat transmission, thermal mass, solar heat gain through windows can be employed to reduce building energy consumption (Singh, Lazarus, & Kishore, 2016). Especially, the solar heat-gain coefficient (SHGC) values are indicated to be more significant than the thermal transmittance (U) values of glazing units in hot-humid climates (Al-Saadi & Al-Jabri, 2017; Yıldız, Korkmaz, Göksal Özbalta, & Durmuş Arsan, 2012).

Besides, the measurements to reduce GHG emissions and the effects of global warming have been taken worldwide to fight against environmental deterioration (Department of Energy, 2011; The Ministry of Environment & Urbanization, 2012). These attempts have accelerated research focusing on the impacts of building parameters and design decisions over the amount of CO_2 releases arising from the buildings (Collins, Natarajan, & Levermore, 2010; De Wilde & Tian, 2010; Firth, Lomas, & Wright, 2010; Han, Pei, Liu, & Xu, 2013; Kavgic, Mumovic, Summerfield, Stevanovic, & Ecim-Djuric, 2013). In fact, the consideration of global warming and climate change issues are also hot topics observed in the very recent studies on decision support and building performance analyses. In addition, energy demand and environmental performance of buildings may differ depending on the future weather conditions (De Wilde & Tian, 2009, 2010; Wang, Chen, & Ren, 2010). Nik, Mata, Kalagasidis, & Scartezzini (2016) emphasize the significance of window and insulation retrofitting for energy efficient buildings considering the impacts of climate change. In addition, Huang and Hwang (2016) studied the effects of SHGC and overhang shading as input parameters to decrease energy consumption. Similarly, van Hooff, Blocken, Timmermans, & Hensen (2016) focus on the external shading as the most significant parameter on energy loads of the buildings. Andrić et al. (2016) predict 22.3–52.4% increase on heating demand by 2050s for the case located on hot humid climate, while Invidiata and Ghisi (2016) estimate 56%–112% increases in annual energy consumption by 2050s considering the climate change conditions for Brazil. In all the climate change-oriented publications, the common point is the decrease in annual heating loads as well as the increase in annual cooling loads. Besides, it is pointed out that the passive energy efficiency methods can improve the energy performance characteristics up to 50%. In terms of the relation between climate change and the future GHG emission predictions, Olonscheck, Holsten, & Kropp (2011) predicted reduction of GHG emissions around 60–78% by 2050s compared to 2010. On the other hand, Andric et al. (2015) claim that the changing climate, by itself, could decrease annual CO_2 emissions from 8% up to 34% in the 2050s compared to 2010 due to the changing weather parameters. In Table 1, a brief summary of the publications related to the impacts of climate change on building energy and environmental performance characteristics are presented.

The recent studies in Turkey have also followed the similar patterns to evaluate the energy performance by simulation tools and emphasized the importance of case-specific design decisions to reduce the annual energy consumption of residential buildings (Tuna, Ulukavak Harputlugil, & Celebi, 2010). In addition, the aim is to integrate not only sensitivity analyses but also the optimization of climate change related decision support and preparation of design guides to increase the energy efficient and environment friendly buildings (Senel Solmaz, Halicioglu, & Gunhan, 2018). Measures on natural ventilation, window area, and SHGC of glazing may create the highest impacts on building annual cooling consumption (Yıldız et al., 2012).

It may be concluded from the literature that the impacts of climate change on the design process and analyzing sensitivities of different design parameters on energy and environmental performance of the buildings are determined to be more corroborated. Besides, the existing studies have shown that collecting systematic knowledge is significant for generating energy and environmental performance improvement proposals. Providing design decision support with the help of these systematic experiences is a secondary subject to be studied elaborately.

There are many studies focusing on the multifaceted problems of climate change issues, building energy performance and GHG emissions simultaneously. However, it has been noticed that there are deficiencies in the number of studies focusing on these global issues in terms of the building sector in Turkey. Therefore, this study mainly aims to assess the sensitivities on residential building performance caused by design parameters by determining the most significant parameters on annual energy consumption for heating, cooling and annual operational CO_2 emissions in hot humid climatic region of Turkey for recent and future climate conditions. The objectives to accomplish the aim of the study are stated as follows:

- Investigating the integration and importance of building performance practice in early stages of residential building design
- Evaluating the impacts of climate change on building energy and environmental performance characteristics
- Revising sensitivity analyses on design decision process integrated with building performance simulations
- Synthesizing the correlation between building energy and environmental performance criteria and design parameters, as well as classification of these parameters according to significance levels on performance criteria
- Generating three different proposals with respect to the most effective parameters to provide more systematic design decision support

2. Description of the case building

Housing industry plays an important role for energy efficiency in buildings. In Turkey, residential buildings with two or more dwellings cover around 63% of the total number of buildings officially registered between the years of 2002–2017 (Turkish Statistical Institute, 2018). Accordingly, a mid-rise residential building is selected as the case study. It was in early design phase, designed by a medium-sized architectural office in Izmir. The building is specified after the meetings held with the office, and several discussions with the architect.

The ground floor of the mid-rise building is designated for commercial use, and upper levels are planned as housing units. The location of the block is in Cigli district, Izmir, with 1.2 m elevation above sea level, as well as 60° directed to the north. The climatic conditions for the studied area are hot, humid in summer and rainy in winter, as a representation of the Mediterranean climate. Summers are hot and dry in contrast to mild and rainy winters, as well (Turkish State Meteorological Service, 2015).

The residential block has wider facades in the north-west and south-east elevations as indicated in Fig. 1. Moreover, window-wall ratios are considerably high, which could cause major heat gains and losses from the building envelope. The selected building is a seven-story dwelling, where the main entrance is rotated to the south-west. The building has twelve flats with 767.88 m^2 total floor area in each residential level. Moreover, the floor-to-ceiling height is 2.80 m, while the ground floor's height is 4.21 m. The total height is 21.49 m along with walkable flat

Fig. 1. Site plan of the residential case building.

roof on top.

Technical drawing of the building is presented in Fig. 2. It indicates that, there are twelve housing units on each floor, aligned around a central hall. The units have one bedroom and a living room facing outside in every plan schema. On the other hand, bathrooms, entrance halls and kitchens are the spaces with blind facades, except for kitchens of the corner units.

The specifications about the building envelope and thermal properties of the materials are discussed with the architect and arranged according to the initial decisions taken during preliminary design. Thermophysical properties of the building components are defined in consistence with Thermal Insulation Regulations in Buildings (Turkish Standards Institute, 2008).

Turkey is separated into four climatic zones according to TS 825 in order to specify different heat transfer coefficient (U value) limitations for building components of the envelope. Therefore, the U value of exterior walls and external floors with 0,70 W/m^{2}K, 0,45 W/m^{2}K with roofs, and windows having U value of 2,4 W/m^{2}K are the maximum rates specified for the climate zone of İzmir. In fact, U values of exterior walls and roof defined by the architect are 0,61 W/m^{2}K and 0,452 W/m^{2}K, respectively. The detailed information about the building components is demonstrated in Table 2.

Table 2
Thermophysical properties of the building components.

BUILDING COMPONENTS	POSITION	LAYER NAME	THICKNESS (m)	U VALUES (W/m^2.K)
EXTERIOR WALL	OUTSIDE	Artificial stone tile	0.02	0.61
		EPS Expanded Polystyrene	0.03	
		Brickwork	0.195	
		Plaster (coarse)	0.02	
	INSIDE	Gypsum plaster	0.01	
FLOOR GENERAL	OUTSIDE	Gypsum plaster	0.01	0.85
		Plaster (coarse)	0.01	
		Hollow concrete block	0.32	
		Cement screed	0.05	
		Polystyrene	0.005	
	INSIDE	Flooring blocks	0.012	
FLOOR WET CORE	OUTSIDE	Gypsum plaster	0.01	1.23
		Plaster (coarse)	0.01	
		Hollow concrete block	0.32	
		Cement screed	0.05	
	INSIDE	Ceramic tile	0.015	
FLAT ROOF	OUTSIDE	Ceramic tile	0.015	0.452
		Cast concrete	0.04	
		XPS Extruded Polystyrene	0.04	
		Bituminous membrane sheet	0.006	
		Cement screed	0.04	
		Cast concrete	0.04	
		Hollow concrete block	0.35	
		Plaster(coarse)	0.01	
	INSIDE	Gypsum plaster	0.01	
PARTITION WALL 1	OUTSIDE	Gypsum plaster	0.01	0.985
		Plaster (coarse)	0.02	
		Brickwork	0.195	
		Plaster (coarse)	0.02	
	INSIDE	Gypsum plaster	0.01	
PARTITION WALL 2	OUTSIDE	Gypsum plaster	0.01	1.541
		Plaster (coarse)	0.02	
		Brickwork	0.085	
		Plaster (coarse)	0.02	
	INSIDE	Gypsum plaster	0.01	
EXTERNAL GLAZING	OUTSIDE	Generic clear	0.004	2.3
		Air gap	0.012	
	INSIDE	Generic clear	0.004	
DOORS		Wooden door	0.035	2.25

3. Research methodology and materials

The main purpose of the analyses is to support the design process by providing additional information about the impacts of input variables, and to observe uncertainties about different climate scenarios.

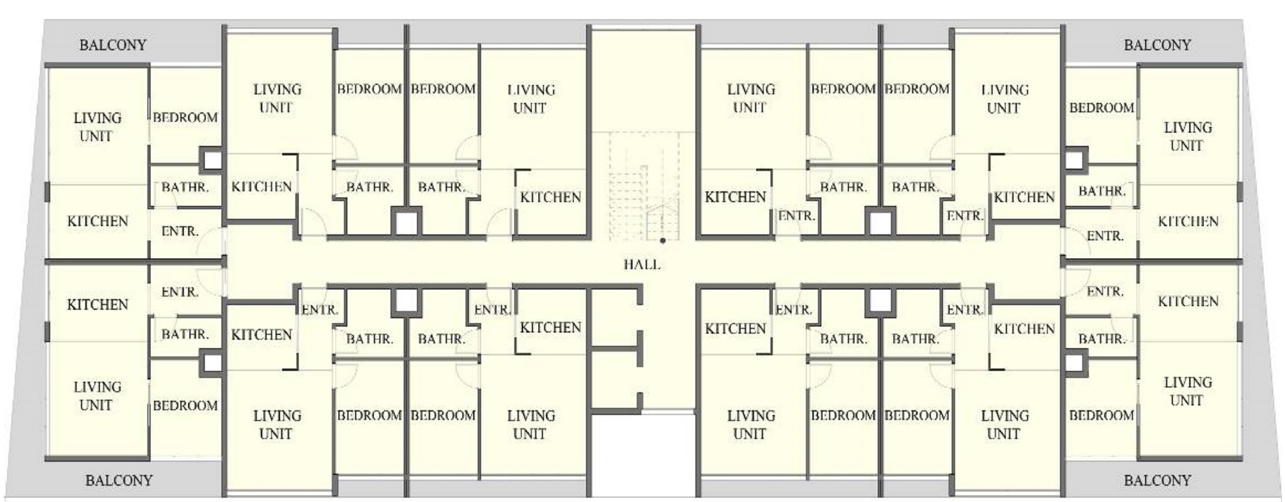

Fig. 2. Typical schematic plan of the residential floor.

Case Study

↓

Pre-Processing

- Input parameter decisions for the top and intermediate floors
- Weather file generation for 2020s, 2050s, 2080s (CCWeatherGenerator)
- 200 sample matrix generation for each floor (SimLab)

↓

Simulation

- Digital modelling of the case building (DesignBuilder)
- 200x2x4 EnergyPlus file generation of model (Matlab)
- 200x2 energy simulation for each climate prediction (EnergyPlus)
- Annual energy consumption for heating and cooling and CO_2 emission (output) compilation (Excel)

↓

Post-Processing

- Sensitivity analysis of the outputs (SimLab)
- Proposals for design decision support

Fig. 3. Visualization of the design decision support process.

Therefore, important information about the sensitivities of output parameters due to changing design variables and projected weather conditions are numerically visualized by the analysis results, as well. There are several methods applied in this study to analyze the building performance for design decision process in early stages with respect to changing climate conditions. The general structure of the research methodology is separated into three parts as pre-processing, simulation, and post-processing (Fig. 3).

3.1. Pre-processing

There are many uncertainties affecting the energy and environmental performance of buildings. The parameters are specified for the case study, according to the interviews conducted with the architectural office, as well as concentrating on building envelope, internal partitions, floors and roof.

Accordingly, 45 design parameters are selected for three groups of inputs; as design, physical and scenario variables. The maximum and minimum values depending on thermal and physical characteristics of input parameters are specified based on the common materials in the building sector in Turkey (Supplementary material, Table S 1). For example, concrete, adobe, hollow brick, autoclaved aerated concrete (AAC) and solid brick are the materials considered for exterior walls.

The roof and intermediate level variables are studied separately, regarding diverse thermal performance of different levels. The material thickness and conductivity of thermal insulation material for the roof are chosen different than the intermediate floor, in terms of design and physical parameters.

Different thermal responses of facade orientations are also considered during the parameter selection process. Table S 1, given as the Supplementary material, indicates that north-east (N-E), north-west (N-W), south-east (S-E) and south-west (S-W) elevations are studied individually, due to positioning of the building. Besides, annual energy consumption performance includes conditioning, i.e. mechanical heating and cooling, except ventilation, characteristics of the building.

For modeling the climate conditions of Izmir, weather information used in the current study is The International Weather Files for Energy Calculations (IWEC) data files. Besides, future climate data are employed from the HadCM3 climate model to evaluate the impacts of climate change on building energy consumption (Johns et al., 2004). The significant parameters in HadCM3 for creating future weather data contain various parameters such as; relative humidity, wind speed, dry bulb temperature, horizontal solar radiation, total sky cover and total precipitation rate. The emission scenarios used in HadCM3 are Special Report on Emissions Scenario (SRES) A1, A2, B1, and B2 scenarios. The SRES A2 scenario follows a storyline that describes less trade and more self-reliance, slow technological change and consolidated economic regions (Nakicenovic et al., 2000).

The current weather file of Izmir (TUR_Izmir.172180_IWEC.epw) is provided from the website of the software and used for weather data generation (Energy Plus, 2015). The Climate Change World Weather File Generator (CCWorldWeatherGen) is selected to generate climate change weather files for the residential building. It is a software used for projected weather data generation of various locations around the world with reference to existing climate change scenarios. Hence, three probabilistic weather files of Izmir are obtained for overlapping 30-year time periods of the 2020s (2011–2040), 2050s (2041–2070) and 2080s (2071–2100).

The minimum and maximum values of each design parameter according to the regulations in Turkey, are specified in SimLab that provides free development model for sensitivity and uncertainty analyses (SimLab, 2015). As a first step, design and physical parameters are combined simultaneously during sample generation process, while projected weather data as the scenario parameter is handled discretely. Latin Hypercube Sampling (LHS) is selected as the statistical sampling method. In fact, the results of the current studies have shown that, it is the most proper technique for increasing complexity. In addition, it is accepted as one of the most reliable methods for identifying the sensitivities of parameters (Kristensen & Petersen, 2016). Accordingly, the number of samples for building simulations are determined as 200×43 sample matrix for the intermediate and 200×45 sample matrix for top floors.

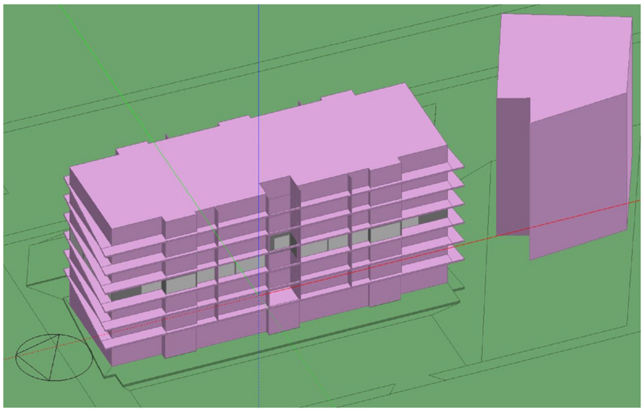

Fig. 4. Visual from the digital building simulation model.

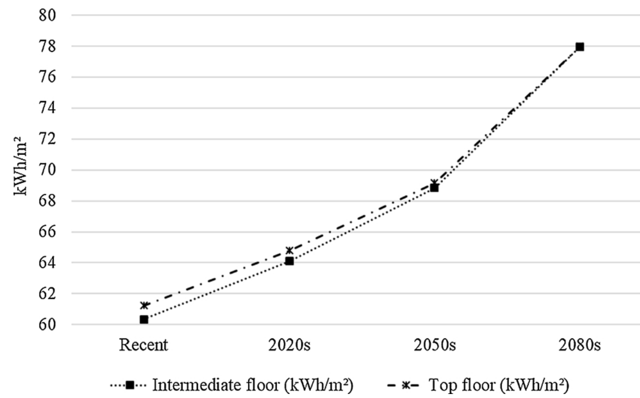

Fig. 5. Annual total energy consumption comparison of different floors.

3.2. Simulation

Digital modeling of the case building is provided by the simulation software, DesignBuilder v4.2, executing building energy, CO_2, lighting and comfort performance analyses. Annual energy consumption for heating and cooling calculations are conducted through EnergyPlus algorithms within the program.

There are certain steps followed, during digital modeling of the building. Initially, the entire floor is reduced into seven zones including six living units and a zone for circulation. Afterwards, the building is modelled in DesignBuilder for energy analyses. At the same time, natural gas for heating and electricity for cooling are denoted as HVAC system of the building.

Two different versions of the simulation model are created, indicating the top floor and intermediate floor. The intermediate floor is selected as the fourth floor of the building (Fig. 4). The main purpose of studying only certain floors was to investigate the impacts of different levels on building energy demand. Therefore, the adjacent surfaces of different floors are assumed as adiabatic, so that the temperature of the adjacent zones are assumed to be the same as well as preventing the heat transfer between adjacent surfaces.

Annual energy consumption for heating and cooling of the building and annual operational CO_2 emissions are specified as the output parameters for sensitivity analyses. IDF files are simulated to calculate outputs for each climatic data representing the present, the 2020s, 2050s and 2080s, separately.

3.3. Post-processing

Post-processing section includes the examination of input and output parameter correlations as well as the generation of design decision support proposals. Initially, uncertainties in energy and environmental performance of the building according to climate scenarios are examined. The Monte Carlo method is selected for the configuration process. After the specification of input and outputs, Standardized Rank Regression Coefficient (SRRC) is determined as an indicator to identify the sensitivity of each design parameter, which is based on a non-linear relation between the output and input parameters (Helton, Johnson, Sallaberry, & Storlie, 2006). Eventually, sensitivity analyses are conducted to clarify the most effective design parameters on the energy and environmental performance of the building. Sensitivity analysis results are evaluated through annual heating, cooling, total energy consumptions in addition to annual operational CO_2 emissions. Finally, more detailed energy performance analysis of the most sensitive parameter is conducted to create different design proposals. Each proposal included the application of different material types and individual examination of each facade to observe the building performance characteristics.

4. Results and discussion

4.1. Simulation results

Annual total energy consumptions of the building have shown a significant increase from recent years to the 2080s. For instance, the intermediate floor has total energy consumption around 60 kW h/m² per year at present, although it is around 78 kW h/m² per year in the 2080s, with 29.2% increase. Both floors consume similar amounts of energy per year within the years. Although the energy needed for the top floor is higher at the present, the energy consumption values of both floors get closer to each other starting from the 2050s, as shown in Fig. 5.

The results indicate that, both floors follow similar performance patterns throughout the years (Fig. 6). Annual mean values of heating consumption represent significant amounts of decrease from present to the 2080s. The decline in annual heating consumption points out the effects of global warming, along with the changes in the thermal behavior of the building.

Fig. 6 indicates that, the amount of annual heating consumption of the top floor gets higher than the intermediate floor in the 2080s. However, there has been so severe decrease in the amount of annual heating consumption of the intermediate floor throughout the years. Furthermore, there is an increase in the mean values of annual cooling consumptions from present to the 2080s, which is around 30 kW h/m² for both floors.

Annual heating and cooling consumptions are balanced between the 2020s and 2050s for the top floor. Moreover, energy consumption for cooling on the intermediate floor is higher than heating, starting in recent years (Fig. 6). The changes in heating and cooling requirements of the building visualize the increases in heat gains arising from the effects of global warming.

It is also concluded that, the major changes in annual heating and cooling consumption correlations have huge impacts on the environmental characteristics of the case building. The amount of CO_2 emissions from the intermediate level has always been slightly higher than the top level starting from present to the 2080s (Table 3). In other words, excessive raises in energy consumption for cooling creates higher electricity oriented operational CO_2 emissions, while the heating energy diminishes. Moreover, huge amounts of increases are observed in operational CO_2 emissions until the 2080s. For instance, the recent mean CO_2 emission value is around 30 $kgCO_2e/m^2$ for the top floor, then it shows around 72% rise until the 2080s (Fig. 6). The results indicate that, the more the temperature rises, the more carbon equivalent gases are released to the atmosphere from the studied residential block.

The effect of annual cooling consumption is more than the annual heating consumption on operational CO_2 emissions of the building. Table 3 conveys the changes in building performance regarding the impacts of climate change. In other words, excessive raises in energy

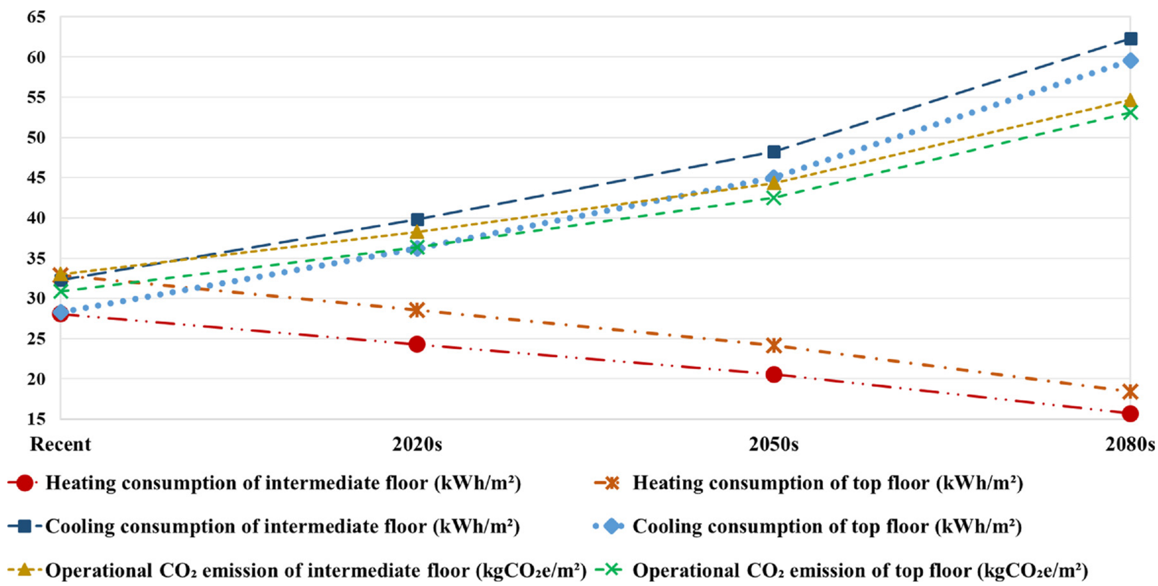

Fig. 6. Annual performance properties of the intermediate and top floors.

consumption for cooling creates higher electricity oriented operational CO_2 emissions, while the heating energy diminishes.

4.2. Sensitivity analysis results

After a general evaluation of the analysis results, the performance simulation results have been utilized for sensitivity analysis to observe the relation between the outcomes and the input parameters. Then, the most sensitive variables are listed for proposing better design decision options separately for the intermediate and top floors.

The most prominent parameters are related to the transparent surfaces of the building envelope since the floors consist of extended openings on exterior walls (Figs. S 1, S 2, S 3, S 4). It can be seen from Table 4 that, the most sensitive parameters for energy consumption for annual heating and cooling are SHGC values of windows on S-W, N-E, S-E and N-W facades, respectively. The same order of sensitivity is valid for the following years.

Annual energy consumption of the top floor includes insulation material conductivity for the roof, instead of SHGC value of N-W windows as one of the effective parameters on energy performance of the building, which differs from the intermediate floor results. Environmental performance characteristics of both floors are mostly affected by same parameters, namely SHGC values of transparent surfaces on different facades. The sensitivities of same parameters are prominent for future climate scenarios, as well.

Overall examination of the figures indicates that, the sensitivities of input parameters on outputs increase from present to the 2080s. For instance, the most prominent parameter, SHGC value of S-W windows, has an impact factor of 0.62 for annual heating consumption in recent years, while it is around 0.67 in the 2080s.

The comparison between recent and the 2080s results reveals the changes in the intermediate floor performance indicators during specified period. Initially, sensitivities on the annual heating consumption do not indicate any changes in the order of parameters, while sensitive parameters of annual cooling consumption and operational CO_2 emission characteristics have differences. In fact, the sensitivity of U values loses its importance, while shading, insulation material thickness, exterior wall material conductivity variables gain more importance as the SHGC values still stay at top priority, over the years. Furthermore, sensitivities of the top floor for annual cooling and heating consumption follow similar patterns to the intermediate floor, whereas the effects of S-W window SHGC value on operational CO_2 emission increases towards the 2080s (Figs. S 3 and S 4). It can be concluded that, the improvements in initial design strategies can also increase the building performance characteristics.

4.2.1. Proposals for design decision support

The specification of the most sensitive parameters on the performance of the case building has provided overall systematic and scientific knowledge for creating different design decision support proposals. Since SHGC values of windows are the most important factors on annual energy consumption and operational CO_2 emissions of the building, and the decision has been made between available products for the window panes in Turkey. Five types of windows are determined, and specific characteristics and thermal properties of the windows are explained in Table 5.

Window type differentiations are conducted by changes in the glass type, number and thickness of the layers. Therefore, three types of double and two types of triple glasses are used for the proposals. The standard glass, namely the base case, includes two clear float layers with the 12-mm air gap. The other double glass windows differentiate with one layer of low-e coated clear float (Ecotherm), and clear float with a solar low-e coating (Ecosol). In addition, the triple glasses vary according to the coating properties of outer layer, which are covered

Table 3
The ratio of changes in annual performance characteristics of the building, compared to the recent values.

The Ratio of Annual Changes in Uncertainties (%)	Intermediate Floor			Top Floor		
	2020s	2050s	2080s	2020s	2050s	2080s
Annual Heating Consumption	−13.6	−26.7	−44.2	−13.1	−26.7	−44.2
Annual Cooling Consumption	23.2	49.5	93.1	28.3	59.3	110.7
Annual Operational CO_2 Emissions	15.9	34.3	65.2	18.1	37.8	72.0
Annual Total Energy Consumption	6.1	14.0	29.2	6.0	13.1	27.4

Table 4
The most sensitive parameters for annual total energy consumption.

	Ranking	Recent	2020s	2050s	2080s
Intermediate Floor	1	SHGC Window S-W	SHGC Window S-W	SHGC Window S-W	SHGC Window S-W
	2	SHGC Window N-E	SHGC Window N-E	SHGC Window N-E	SHGC Window N-E
	3	SHGC Window S-E	SHGC Window S-E	SHGC Window S-E	SHGC Window S-E
	4	U Window N-E	SHGC Window N-W	SHGC Window N-W	SHGC Window N-W
Top Floor	1	SHGC Window N-E	SHGC Window N-E	SHGC Window N-E	SHGC Window S-W
	2	SHGC Window S-W	SHGC Window S-W	SHGC Window S-W	SHGC Window N-E
	3	U Window N-E	SHGC Window S-E	SHGC Window S-E	SHGC Window S-E
	4	Ins Mat Cond R	Ins Mat Cond R	Ins Mat Cond R	Ins Mat Cond R

with low-e or solar low-e filters. The thermal properties of the glasses belong to the specified values of national product company i.e. Trakya Glass in Turkey (Trakya Cam, 2017).

The sensitivity analysis results indicate that; thermal effects of the windows have shown variations along with different facades of the building, as well. In fact, S-W and N-E window SHGC values have turned out to be the most important parameters for energy and environmental performance of the building (Table 4). Hence, three proposals are created for design decision support, by focusing on transparent surface variations of different orientations.

Then, annual total energy consumption calculations with respect to different glass types for each climate scenario are investigated through building performance simulations. Only the glass types are changed for each model, while the other parameters are kept constant during simulations. The standard double glass (Table 5) is assigned as the base case of the simulations. The comparison of suggested glass types with the base case is used for energy saving estimations.

4.2.2. Proposal 1

The first proposal includes the variations in transparent surfaces of S-W facade for the intermediate and top floors. The results of the annual total energy saving of the building regarding the performance simulations for S-W window variations of the intermediate and top floors are investigated (Table S 2). Furthermore, possible total energy saving ratios, depending on the changes in glass types with reference to the future energy characteristics of the building are calculated (Table S 3). The simulation results convey that, significant amounts of decrease in energy are obtained by changing only the type of S-W window pane. For instance, selecting double glass with one clear float layer and one layer of coated glass with low-e filter (Ecosol) (number 2 in Table 5) on the intermediate floor, creates around 9% of annual total energy saving, when compared to the standard double glass (Table S 2).

4.2.3. Proposal 2

The second proposal contains the modifications in N-E facade openings of both floors. The outcomes of building performance simulations according to the application of different glasses are analyzed for the recent period and for future climate scenarios (Table S 4 and Table S 5). The highest amount of annual total energy saving ratio is provided by the triple glass with solar low-e layer (number 4) as 11% for the intermediate, and 10% for the top floor. At the same time, double glass with solar low-e coating (number 2) has a 9% annual total energy saving ratio, which is like the triple glasses. The energy performance of the intermediate floor is not excessively affected by the applications of the proposal for future climate conditions, and similar outcomes are acquired from the simulations. However, energy performance characteristics of the top floor are more dependent on climate change (Table S 5).

4.2.4. Proposal 3

The third proposal focuses on the alteration of entire openings on both floors, so that five different glasses are designated to each facade, and the building performance is investigated according to these variations (Table S 6 and Table S 7). The most efficient energy performance is provided by the triple glass with a solar low-e coating (number 4), with 29% total energy saving ratio, when compared to the standard double glass. It is followed by the triple glass with low-e layer (number 3) with 25% lower energy consumption ratio on the intermediate floor, whereas double glass (number 2) provides 23% energy gain. In addition, the effects of future climate scenarios on energy conservation properties of different glasses are examined, and increases in total energy saving ratios are observed, which point out the importance of design decisions for long term performance characteristics of the building. For instance, usage of the double glass with a solar low-e layer (number 2) on the intermediate facade windows, provides 24%, 26% and 27% energy savings during the 2020s, 2050s and 2080s (Table S 6 and Table S 7).

4.3. Discussion

The study focused on the calculation of the future heating and cooling energy demand as well as operational CO_2 emissions of a typical residential block by means of different sample variations concerning design and thermophysical decisions in early stages of design and the effects of global warming. The findings make a contribution to the literature in terms of containing an integrated approach to analyze the impact of these factors on the future energy demand and emissions of residential buildings in Turkey. At the same time, the results of this study agree with several studies showing a reduction of future heating energy demand and an increase in future cooling energy demand. For instance, this study revealed the reduction of heating energy demand around 30% when comparing the current situation with the 2050s, while Andrić et al. (2016) indicate a decline in the future heating energy consumption of residential buildings of 22–52% when comparing 2010 with 2050s.

In addition, even though Andric et al. (2015) claim that just due to

Table 5
Technical information about the selected glass types.

No	Glass Types	Glass /air gap / glass thickness (mm)	SHGC Values	U Values (W/m²K)
	Standard glass (Clear float + Air gap + Clear float) (Base case)	4 + 12 + 4	0.75	2.9
1	Clear float + Air gap + TRC Ecotherm	4 + 12 + 4	0.55	1.6
2	Clear float + Air gap + Ecosol	4 + 12 + 4	0.44	1.6
3	LowE + Air gap + Clear float + Air gap + LowE	4 + 12 + 4 + 12 + 4	0.48	0.9
4	Solar LowE + Air gap + Clear float + Air gap + LowE	4 + 12 + 4 + 12 + 4	0.39	0.9

the changed weather variables, heating related annual CO_2 emissions could decrease from 8% up to 34% in 2050 (compared to 2010, depending on the weather scenario and heating system considered), the simulation results of the current study indicated the rise of total energy consumption related annual CO_2 emissions of 37% when comparing recent period with 2050s.

It is significant to consider the future energy performance properties in addition to the recent design qualifications of the building. The study showed that, consideration of the effects of specific design parameters in future would be beneficial for providing guidance for early design decisions. For instance, specified triple glasses have 0.9 W/ m^2K, and double glasses have 1.6 W/ m^2K U values, while SHGC values are around 0.4 and 0.55 for the selected glass types. Transparent surface limitations of TS 825 regulations in Turkey are only related to U values of the window panes in terms of the energy performance of the buildings (Turkish Standards Institute, 2008). However, the amount of annual total energy saving changes slightly, despite huge differences between U values of the windows.

Accordingly, the third design decision support proposal shows the best results in terms of decreasing energy and environmental consumption characteristics of the building. In other words, even though S-W facade has the highest impact on the performance of the building, application of triple glasses on transparent surfaces of all facades would help to minimize the amount of energy consumption of the building annually.

Huang and Hwang (2016) imply that, exterior wall's U-value, roof's U-value, glazing's U-value, SHGC, exterior shading devices of the fenestration, and WWR are the most important parameters for a designer to consider. Similarly, the sensitivity analysis results of the study also emphasized the importance of window U values and SHGC as well as the effects of applications of different glass types on different facades for the building energy performance characteristics. It is possible to find many examples from various countries or organizations, explaining the significance of SHGC values as much as U values of windows in building energy performance regulations. For instance, Passive House Institute US (PHIUS) is the organization, focusing on high-performance passive building principles, and the mainstream market energy performance standards. The criteria specified for different climatic zones of the organization focus on overall window U values, south, north, east and west SHGC values separately (PHIUS, 2017). Therefore, reconsidering the regulations in Turkey, and focusing on SHGC of windows as much as U values would be an option for improving the energy performance of residential buildings, as well.

5. Conclusion and future work

5.1. Conclusion

In this study, annual energy consumption and operational CO_2 emission characteristics of a residential block in early design stages are evaluated according to recent and projected weather conditions. Simulations have clarified the impacts of global warming on annual energy consumption and CO_2 emissions of different floors.

The results show that, intermediate and top floors follow similar performance patterns throughout the years. Annual heating and cooling consumptions balance between the 2020s and 2050s, although equalization of the top floor performance values is later than the intermediate floor. After the 2050s, accelerated increase in annual cooling consumption with respect to the effects of global warming is observed, as well.

It is also investigated that; the most important parameters are related to the transparent surfaces of the building envelope. Namely, SHGC values of S-W and N-E facade windows are found to be the most significant variables, followed by S-E and N-W facade windows in terms of energy and environmental performance of the building according to present and future weather conditions. These results also clarify the deficiencies of thermal insulation regulations in Turkey, since they consist of limitations only for the U values of windows in terms of building energy characteristics. Reassessment of the regulations and providing additional criteria about SHGC values of transparent surfaces would be beneficial for decreasing building energy demands.

The specification of the most sensitive parameters on building performance provided data for creating different design support proposals, as well. According to the results, significant amounts of decrease in energy use is obtained by changing only S-W windows. The outcomes of the building performance simulations along with the modifications in N-E openings of the intermediate and top floors showed that, the highest amount of annual total energy saving is provided by the solar low-e layered triple glass. Moreover, improvements in the energy properties of the intermediate floor are not affected significantly by future climate scenarios, and similar simulation outcomes are observed for future periods.

Giving priorities to the intermediate floor for material selections during design stages is more influential than the top floor variations in terms of energy and environmental perspectives. Besides, developments in openings may improve the performance effectiveness of the building for future, since the increase in annual total energy saving is observed during following years. To understand the effects of specific design parameters in future is critical for providing guidance for early design decisions because it is significant to consider the future energy performance properties additionally to the recent characteristics of the building.

One of the main contributions of this paper to the extant literature is to evaluate energy and environmental performance, simultaneously, and visualize different performance improvement options for design decision support. Consideration of changes in performance characteristics of the building according to climate change is also another important contribution to the studies focusing on long-term building performance characteristics. In conclusion, the results of this study can provide more consciousness for building professionals about the significance of systematic design decision approach in the early design process of residential buildings in hot-humid climates.

5.2. Limitations and future challenges

During this study, there have been some limitations and assumptions arising from several sections of the overall methodology of the paper. Namely, the limitations are caused by the determination of design parameters and dynamic building performance software. Moreover, some assumptions are required in terms of detailing the process of digital building model, since the case residential building is in early design stage and not built, yet.

Determination of input parameters is specified according to the current design phase of the building. In fact, it was not possible to make direct modifications for every parameter in dynamic building performance software. Difficulties in the simulation program DesignBuilder, for example, caused integration of overhangs in EnergyPlus, as well. DesignBuilder is not capable of conducting multiple simulations simultaneously, so that EnergyPlus software is also included. Calculation of operational CO_2 emission properties of the building is handled manually in order to collect more proper results, since DesignBuilder software does not provide the emission factors of Turkey.

Simulation phase of the design decision support process includes some limitations and assumptions. Initially, simplifications in floor plans of the building were required because of increasing simulation duration in EnergyPlus. The building is assumed to be unoccupied for the digital model. Moreover, the thermal properties of the selected floors are arranged by specifying heat exchange as adiabatic to prevent unpredicted energy consumption values.

For the future of the current study, integrating uncertainty and sensitivity analyses with different optimization tools would be beneficial to provide optimal solutions during design process. For instance, if the client is more focused on financial issues, or future characteristics of the building, researches may be narrowed down to specific subjects. This can provide more detailed information for building professionals.

Window to wall ratio is an essential design parameter for the performance characteristics of the building, especially for the case building, since it has significant number of transparent surfaces. This variable can be included as another input for the simulations. Then, if it comes out to be a significant factor in building performance characteristics, additional design proposals may be offered for a better performing building.

The use of double skin facade with natural ventilation would be another physical input parameter which may be integrated into the sensitivity analysis. Combining different orientations with the investigation of occupant controlled operational costs would also be investigated to provide additional design options and decision support to the architect for the case building.

The operational CO_2 emission characteristics of the building are the only environmental factor observed during simulations. Embodied carbon footprints of materials may also be specified as another performance indicator, while examining input parameters. Hence, more comprehensive outcomes may be revealed, in terms of environmental impact of the building.

The uncertainties of input parameters on annual energy consumptions and operational CO_2 emissions are observed during the analysis process. Uncertainty analyses are acquired depending on the physical, and design variables together. However, they might be handled separately, since uncertainties due to physical, design or scenario input parameters have different impacts on the outcome. Therefore, more comprehensive and detailed results may be acquired in case of decomposition in input parameters.

Life cycle assessment of the residential building would also bring the study a step further by utilizing environmental impacts associated with entire lifespan of the block, from cradle to grave, and help to create broader outlook on environmental concerns.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2019.101580.

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