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Impacts of Climate Change on Heating and Cooling Loads in Residential Buildings

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ABSTRACT

In this study, heating and cooling requirements in existing and new built apartment blocks were investigated based on the projected impacts of climate change for three different cities of Turkey, i.e. Ankara, Istanbul and Izmir representing cold, temperate-humid and hot-humid climate conditions. The Hadley Centre Coupled Model Version 3 (HadCM3)-A2a, A2b and A2c experiments was applied to evaluate future climate for the time period 2020s, 2050s, and 2080s. It was found that relatively high effect on heating and cooling loads may occur in residential buildings in Turkey. Although the decrease in the annual energy demand of new built and existing apartment blocks for heating is predicted to vary between approximately 9% and 29%, cooling demand increases between 1.7 and 30-times up to 2080s according to local climate and climate change scenario; HadCM3-A2a, A2b and A2c. Therefore, usage of the passive cooling strategies is essential in residential buildings.

Keywords: *Climate change impact, heating load, cooling load, apartment blocks*

1. INTRODUCTION

Since the beginning of the 1980s, Turkey's energy demand has started to increase owing to a dynamic economic development and rapid population growth [1]. This rapidly increasing energy need of the nation has been met so far by imported oil and gas because of insufficient attempts to promote energy efficiency in all aspects of life [2]. The energy reports of 2001 compiled by The Scientific and Technical Research Council of Turkey (TÜBİTAK) show that the building sector is the second sector demanding the most energy with 19.793 MTOE, and its demand will reach 33.69 MTOE by 2010 [3]. The main reason for the rapid growth may be the noteworthy acceleration in the demand for new buildings. Another reason may be related to the poor quality of the existing residential building stock due to uncontrolled urbanization and building activity. For instance, 88% of the windows in residential buildings nationwide are made of single glass. In addition, there is no roof insulation in 90% of residential buildings and

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96.4% of the buildings have little or no thermal insulation measures [4]. Besides, according to Kayıkçı [5], there are 2.5 million unregistered dwellings in Turkey and no measures whatsoever for energy efficiency are under consideration for these buildings.

According to the study made by Demir, Kılıç, and Coşkun, an increase in mean outside temperature with 4-5 °C was projected throughout Turkey for the time period of 2071-2080 as a result of HaDAMP3's A2 climate scenario compared with corresponding values of 1961-1990. The mean maximum temperature may go up 5-6 °C in the east and 4-5 °C in the rest part of Turkey. The increase in mean minimum temperatures in the western Turkey may be less than eastern parts. Depending on this research, it is a fact that energy demand in buildings may be affected from the climate change in the near future in Turkey [6]. It is the urgent issue when considering the scarcity on number of existing buildings providing appropriate building physics conditions. Increasing in cooling demand may lead to performance related problems in building sector of Turkey. One of them is dependence on exported fuel and electricity supply difficulties because of the excessive and synchronized usage of air-conditioning devices during peak loaded times in summer months. Others can be summarized as follows [7]:

- Use of fossil fuels can cause more poisonous gas release and triggering climate change,
- The possibility of symptoms of flu, muscle pain, asthma, and dry throat, and tuberculosis can increase because of the more usage of air conditioning.

Therefore, this study is important to understand effects of the climate change on the heating and cooling loads of buildings in Turkey. Depend on its results urgent issues such as renewable energy technologies and architectural solutions to reduce energy consumption in buildings can be determined for Turkey.

Several studies have been published until now about impact of climate change on mostly residential buildings and also office buildings. Frank [8] investigated heating and cooling energy demand with transient building simulations for the time period 2050-2100 in the Swiss Central Plateau. Another study for Swiss buildings was made by Christenson et al [9]. In that research, future energy consumption in buildings was calculated by using the degree-days method based on 41 regional climate change scenarios which were generated from 35 simulations with 8 global climate models. At the same time, impact of climate change on building design parameters was investigated. Wang et al. [12] examined heating and cooling energy demand under the climate change impacts on different type of residential buildings such as existing, new built and high efficient which have different energy efficiency rate like 5 star and 7 star from five Australian cities. Collins et al. [13] evaluated how much electricity requirement and carbon emissions from heating and cooling systems would change and when this changing could occur in existing dwelling up to 2080 in United Kingdom depending on UKCIP02 A1F1 climate change scenario. Dolinar et al. [14] examined predicted change in energy requirement for heating and cooling in residential buildings from two typical urban climates in Slovenia. Some of the researcher studied on office buildings. For example, Lam et al. [11] analyzed energy consumption in fully air-conditioned office buildings based on the different emission scenarios in subtropical Hong Kong by making principal component analysis and multi-year dynamic building energy simulation. All researches predict that while future energy for heating demand is decreasing, future energy for cooling demand is increasing in buildings generally. In addition, calculation approach was developed by researchers as well as investigation of climate change impact. Zmeureanu and Renaud [10] developed a method to estimate potential effect of climate change on heating and cooling loads in existing houses. The developed method is based on the house signature, which is generated from historical energy data and it is applicable for individual house and large number houses. Objective of this research is to project how much energy demand for heating and cooling in existing and new build apartment blocks will change based on the impacts of climate change in the most populated cities of Turkey representing hot-humid, temperate humid and cold climate regions.

2. METHODOLOGY

2.1. Climate Change Weather Data

The consistent climate change scenario have been taken form SRES-driven experiments made by using the UK Handley Center's third generation coupled atmosphere-ocean global climate model (HadCM3). Usage of this model allows investigating magnitude of climate change and its impacts [15]. The model includes different assumptions based on the predicted future gas emissions. A2 storyline is selected for this study, which assumes heterogeneous world with continuously increasing global population and regionally oriented economic growth which is more fragmented and slower than in other storylines [16]. The projections based on the averaged results of A2a, A2b and A2c experiments for four grid points closest to the selected cities-Ankara, Istanbul and Izmir were made to see impact of the climate change on energy demand in existing and new built apartment blocks. Three ensemble members of A2 were produced as A2a, A2b and A2c by The Hadley Centre because a form of natural climate variability is accounted for in the models [17]. Reason for selection of these cities is that the number of the apartment blocks in selected cities constitutes 45% of apartment blocks in Turkey [18]. Typical Meteorological Year 2 (TMY 2) data for selected three cities were used as reference weather file because it is a common data for simulation of building energy demand [19]. These files consist of weather data from 1982 to 1997 and they were accessed from U.S. Department of Energy [20]. Future TMY weather data files were generated by using so-called 'morphing' approach by using CCWorldWeatherGen V1.4 tool [21].

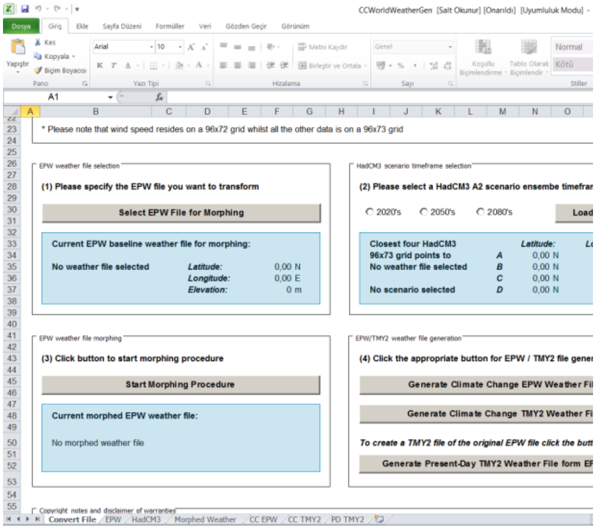

Fig. 1. Data screen of CCWorldWeatherGen V1.4 tool

The morphing approach is combination of present-day weather information data and results of climate change models. It also has three advantages. Firstly, weather series used as baseline climate is reliable. Another advantage is that ended weather sequence is probably meteorologically consistent. Lastly, spatial downscaling is achieved because of the present day weather information which is generated from at a real location [19]. Figure 2 shows the evaluation of monthly mean temperatures, relative humidity and direct solar radiation for Ankara, Istanbul and Izmir considered in this research for the time period 2020s, 2050s, and 2080s. It is clear that while mean temperature and daily solar radiation increases, relative humidity decreases in the selected cities. It was also found that the increase of air temperature in temperate-humid climate is higher than in cold and hot-humid climate.

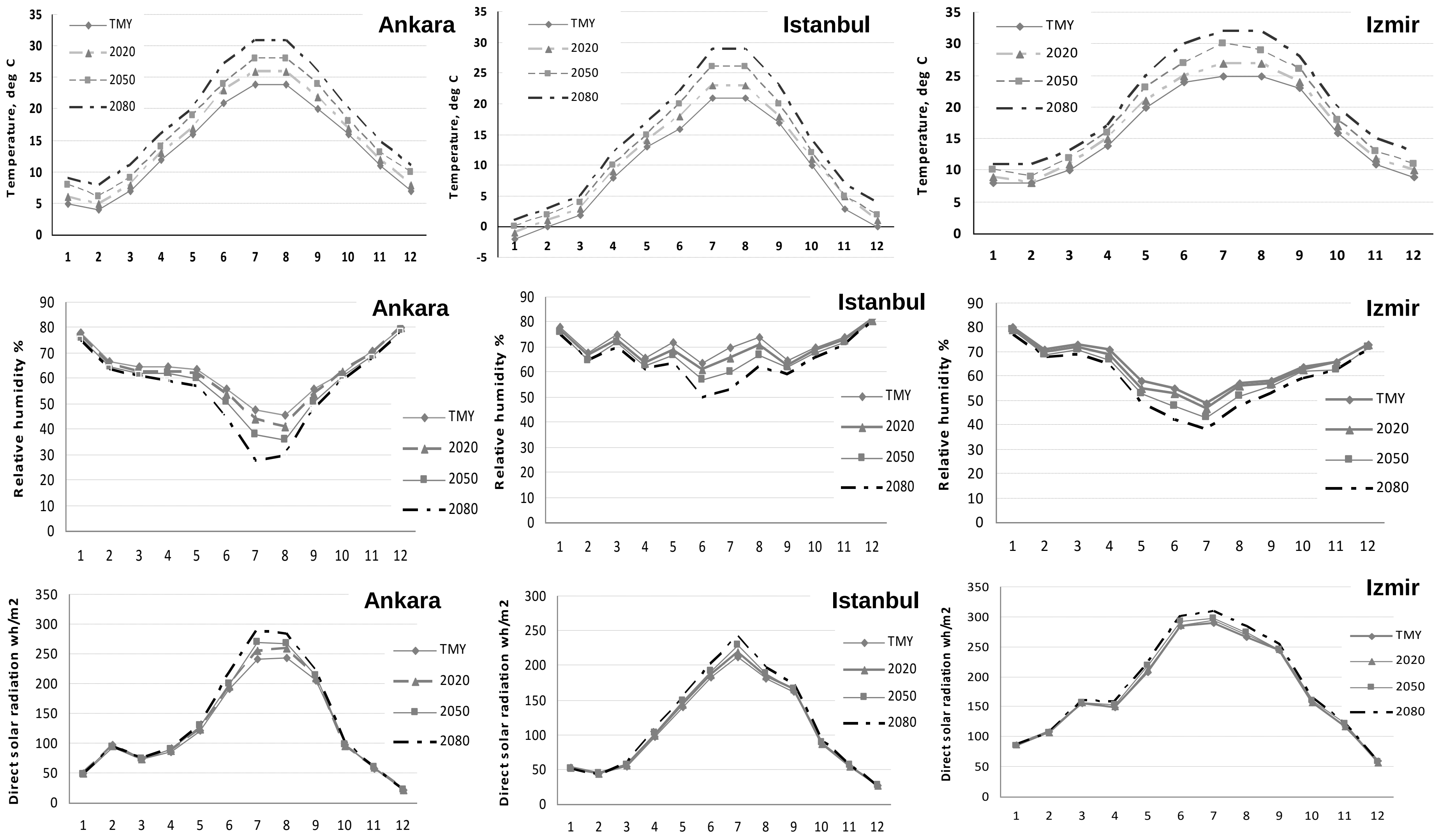

Fig. 2. Projections of monthly mean temperatures, relative humidity, and direct solar radiation for selected cities

2.2. Building Description and Simulation Programme

In Turkey, regional differences in climatic conditions do exist because of the complex topography and its location. For brevity, research was limited with three the most populated cities of Turkey (see Table 1). The biggest city is Istanbul which represents temperate-humid climate. Ankara is the second biggest city representing cold climate and Izmir is another biggest city representing hot-humid climate region.

Table 1. Location of selected cities

City	Latitude	Longitude	Altitude
Istanbul	40°97´N	28°82´E	37 m
Ankara	39°57´N	32°54´E	891 m
Izmir	38°25´N	27°08´E	29 m

To predict the influence of climate change on the energy demand of apartment blocks in various locations and climates, an existing apartment block shown in Fig. 3. was modeled in this study.

Fig. 3. The floor plan of apartment block

The apartment block which consists of three flats in each floor is eight story and the flat has three bedrooms, a living space, kitchen, bathroom and toilet. Three flats have floor area of 320 m^2. General features of apartment block are summarized in Table 2.

The apartment block was built in 1990 and Turkish Standard 825 (TS 825) "thermal insulation in buildings" was not mandatory [22]. It made obligatory in 2000. This standard was indicating limits of building's energy requirement depending on exposed area to volume ratio in Turkey and it was incorporated with Regulation for Energy Performance of Building (EPB) in 2009. Therefore, the existing apartment block does not have enough thermal insulation except for the roof. In other words, it does not provide minimum requirements of TS 825. The existing building components such as external walls, ground floor and roof was modified with application of minimum thermal insulation to achieve conditions defined in TS 825 based on the different climate regions as detailed in Table 3. Improved building components represent features of new built apartment blocks in Turkey.

Table 2. Basic features of modeled building

Total height (m)	23.2			
Glazing ratio (%)	31			
U values (W/m^2 K)	**Existing**	**Values for new buildings in Izmir***	**Values for new buildings in Istanbul***	**Values for new buildings in Ankara***
External wall construction	1.4	0.7	0.6	0.5
Ground floor construction	2.1	0.7	0.6	0.45
Roof construction	0.83	0.45	0.4	0.3
Window	2.47	2.4	2.4	2.4
Infiltration rate (ac/h)	1			

*Proposed values in TS 825

Table 3. Modifications to the base apartment block to achieve minimum conditions defined in TS 825 for new buildings.

Location	Modifications
Izmir (1. climate region)	External wall: 3cm XPS Ground floor: 3cm XPS Roof: 8cm glass wool Window: Double low-e glazing
Istanbul (2. climate region)	External wall: 4cm XPS Ground floor: 4cm XPS Roof: 9cm glass wool Window: Double low-e glazing
Ankara (3. climate region)	External wall: 5cm XPS Ground floor: 6cm XPS Roof: 10cm glass wool Window: Double low-e glazing

Thermal simulation programme, EnergyPlus V3.1 was used to theoretically calculate energy consumption for heating and cooling of existing and new built apartment blocks under selected climate change scenario for the time period 2020s, 2050s, and 2080s. A heating thermostat setting of 20°C is used and the cooling thermostat setting is determined as 26°C. Two performance criteria-heating and cooling loads were evaluated and compared.

3. RESULTS

The projected annual energy requirements for heating and cooling are shown as kWh per floor area, ie., kWh/m^2.

3.1. Impacts of Climate Change on Heating Energy

The calculated heating energy demands for the existing and new built apartment blocks subject to the different cities and time periods are given in Figure 4. According to results of the simulation based on the reference year by TMY, there is relatively high difference between the energy demand of existing and new built apartment blocks. In other words, heating demand in existing apartment block is approximately more than 24% in new built apartment blocks in Ankara. It is more than 22% in Istanbul and more than 18.7% in Izmir. In addition to this, rate of difference is approximately the same depending on effect of climate change in all cities for each time period. This shows that buildings constructed according to the TS 825 have better thermal performance in winter than buildings not constructed based on TS 825. In addition, there is difference in heating demand between the cities because of the regional climatic features. Though the highest energy for heating is necessary in Ankara, lowest energy for heating is necessary in Izmir. The difference is 50% in existing and new built apartment blocks between the cities. General trend in heating demand for the time period 2002s, 2050s, and 2080s was determined as reduction for existing and new built apartment blocks in all cities depending on the selected climate change scenario. This reduction varies based on regional climate. The drop in heating energy changes between 10% and 28% in Ankara (cold climate). In Istanbul (temperate-humid climate) this change is between 13% and 40% and the maximum percentage reduction in heating loads was found as 15%-44% in Izmir (hot-humid climate). It is clear that heating requirements in new built and existing apartment blocks may be less than today in the near future.

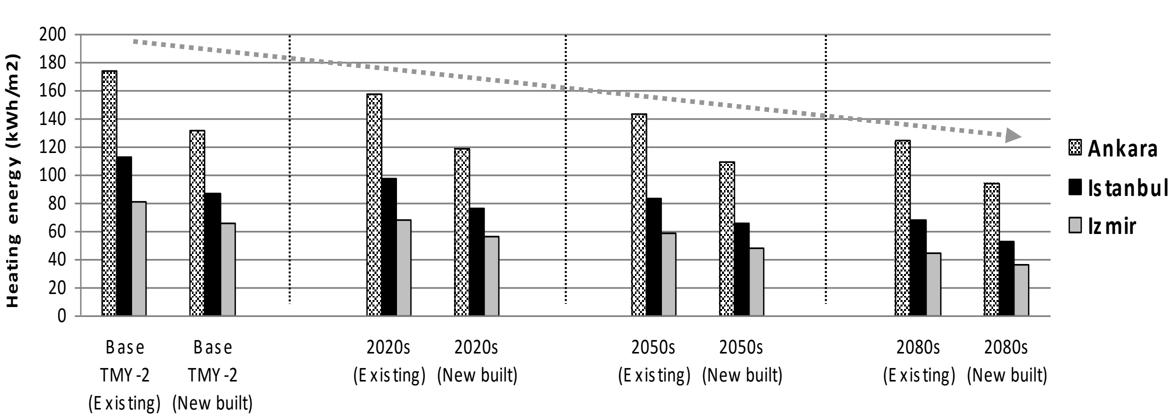

Figure 4. Impacts of climate change on heating energy

3.2. Impacts of Climate Change on Cooling Energy

As similarly with heating requirements, cooling demands in existing apartment block is more than new built apartment block with 56.5% in Ankara, 37.6% in Istanbul, and 30.6% in Izmir based on TMY data. However this difference between existing and new built apartment blocks in all cities decreases in every future time period. Namely, it may reduce up to 31% in Ankara, 29% in Istanbul, and 28.6% in Izmir by 2080s. By considering extend energy performance regulations in use in Turkey, this indicate that the energy performance in terms of cooling gets worse in buildings. In other words, residential buildings built according to TS 825 may not lead to enough energy saving for cooling in the future. This is mostly because of the scope of the TS 825. TS 825 only regulate energy consumption limits for heating in buildings depending on climatic regions of Turkey. Thus it does not cover specific measures to reduce cooling requirements. However there is no any code regulating cooling demand in buildings of Turkey.

The energy requirement for cooling in existing and new built apartment blocks is considerably increasing compared to the reduction in heating demand in three cities due to the global warming (see Figure 5). Rate of the cooling demand also varies according to regional climatic features. For example, cooling energy demand in hot-humid climate (Izmir) is more than other climatic regions but this increase is determined as minimum compared to another cities. That is to say, in 2080s though 4 -times more energy for cooling may be needed in hot-humid climate, in temperate-humid climate, the increase in energy for space cooling may be 10-times more. Moreover, maximum rise in energy requirement for cooling is projected to be more than 30-times by 2080 in new built apartment block, while in existing apartment block this increase is only more than 20-times in cold climate. It is mainly related to the level of thermal insulation. In other words heat loss may be less in new built apartment block especially in night when indoor temperature is higher than outdoor temperature.

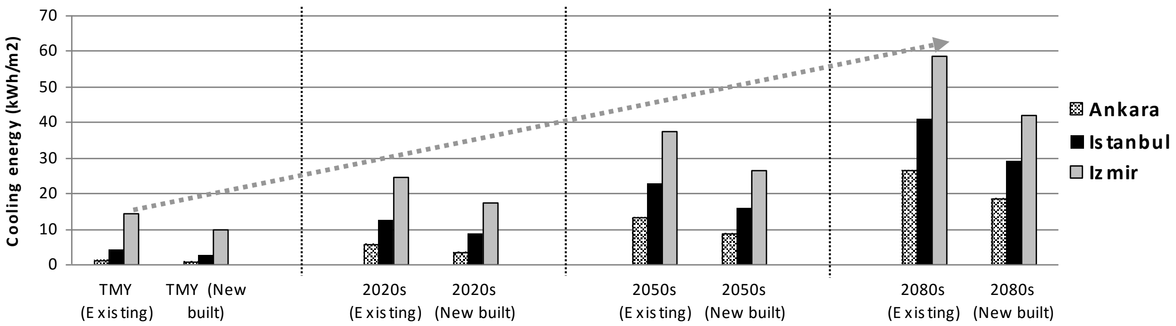

Figure 5. Impacts of climate change on cooling energy

4. CONCLUSION

In this study predicted energy requirement of existing and new built apartment blocks in Ankara, Istanbul, and Izmir is presented for the time period 2020s, 2050s and 2080s based on level of selected climate change scenario (HadCM3- A2a, A2b, A2c experiments). To our knowledge, this is one of the first studies related to evaluation of impact of climate change on heating and cooling loads of residential buildings in Turkey. The results of the study can be summarized as follows:

- Though the climate in Turkey is expected to warm up, heating requirement in buildings is still higher than cooling demand in selected cities.
- According to TMY and future projection heating and cooling energy demand in existing apartment blocks based on thermal insulation level and glazing types is more than new built apartment blocks in Turkey.
- The increase in cooling energy demand is much more than decrease in heating energy requirement. In other words, the changes of total energy (heating and cooling) in selected cities are dominated by the increase in energy demand for cooling.
- Buildings constructed according to TS 825 provide better energy performance in winter season but not are in summer in the projected time periods. This indicates necessity of passive cooling strategies such as natural ventilation and shading as well as thermal insulation in such buildings.

This paper conveys that there is an insufficiency in buildings. Buildings in Turkey have a long life period varying between 50-70 years. The architects and engineers usually designs buildings based on statistical past climatic values. However the outdoor climatic conditions are changing. Therefore the buildings designers should re-examine design criteria related to climate especially for summer months and related authorities should prepare codes to regulate cooling consumption in buildings in Turkey.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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