Gazi University Journal of Science
GU J Sci
27(3):1005-1013 (2014)

Impact of Energy Efficiency Standard and Climate Change on Summer Thermal Comfort Conditions: A Case Study in Apartment Building

Yusuf YILDIZ[1,♠]

[1]Balikesir University, Faculty of Engineering-Architecture, Department of Architecture, 10145 Balikesir, Turkey

Received: 27/03/2014 Revised: 22/05/2014 Accepted:29/05/2014

ABSTRACT

On account of the global warming, there is an increased concern about the overheating risk in free running buildings. This study investigates the influence of local energy efficiency standard, TS 825and climate change on summer thermal comfort in buildings. It concentrates on a typical apartment building in the context of Istanbul, Turkey by using energy simulation tools EnergyPlus and DesignBuilder. The paper starts with a brief introduction and the concepts of common adaptive thermal comfort models. It is followed by a description of the method. Then the required hourly weather data sets for future are prepared and two thermal models are analyzed with a standard weather data set, as well as the IPCC climate change scenario A2 for the 2020s, 2050s, and 2080s. Lastly, the simulation results which are evaluated based on adaptive thermal comfort approach according to European Standard EN 15251 are shown in detail. The results present an important effect of the climate change on summer thermal comfort and they show small distinctness in the amount of uncomfortable times in summer between apartment buildings applied measures in TS 825 (Model 2) and not applied (Model 1).The average difference between models is 5% according to TMY 2 weather data. It would be only 1.8% in 2080. In addition, TS 825in buildings are the key to vary level of thermal comfort conditions in free running buildings. Therefore it should be updated and extended in view of the effects of climate change.

Keywords: Thermal comfort, Climate change, Energy efficiency standards.

1.INTRODUCTION

Thermal comfort conditions have a relation with the amount of the energy consumed in buildings, because the building cannot provide comfortable conditions every time without using extra energy. Thus an active heating and cooling system can be necessary to reach comfort conditions and it influences energy consumption demand. Buildings should provide a thermal environment which is within the range described in a thermal comfort standard for occupancies. Thermal comfort is defined as *that condition of mind which expresses satisfaction with the thermal environment* by ASHRAE [1].

The total building stock worldwide was 145.1 billion square meters in 2011 and 75% of them was residential buildings [2]. In other words, residential buildings have a relatively significant amount in the building stock of most countries. These buildings are usually heated in winter but they are not fully cooled mechanically in summer. Thus, summer thermal comfort in these kinds of buildings is mostly dependent on features defined in local standards or codes related to energy performance. The standards and codes define minimum level of energy conservation measures for new and existing buildings. Some standards and codes contain various issues or they can be related to only one issue. For instance, TS 825 Thermal Insulation

♠Correspondingauthor, e-mail: yusifyildiz@gmail.com

Regulation in Buildings [3] has only concentrated on reductions of heating energy consumption.

One of the important problems of today is global warming. Global warming can contribute to increase mean outdoor temperatures. In Turkey, climate projections show that 5-6 °C increase in mean outdoor temperatures in the future time period (2071-2100). While winter temperatures will increase 4-6 °C in Eastern regions, increments in summer temperatures will be 6-7 °C in the west part of Turkey [4]. Moreover, according to the actual calculation of heating and cooling-degree days in 2010, heating requirements have decreased in Turkey, but the number of the cooling-degree days has increased in especially Aegean, Mediterranean and Southeastern Anatolia regions of Turkey [5].As a result, thermal comfort conditions and cooling loads of buildings in summer have become increasingly important issues, but local standards and codes under global warming is not clear whether they are sufficient in Turkey. The same situation can be valid for other countries. Therefore, impact of global warming on indoor thermal comfort should be evaluated for especially residential buildings constructed depending or not depending on local energy efficiency standards. A few current studies have investigated about the thermal comfort conditions under climate change. Roetzel and Tsangrassoulis [6] showed that there is a significant effect of the climate change on adaptive thermal comfort. Holmes and Hacker [7] evaluated thermal performance of some buildings under climate change to show principles of climate sensitive low-energy design. De Wilde and Tian [8] analyzed thermal performance of an office building in the UK by using static and adaptive thermal approaches in view of the climate change. Results indicated that adaptive thermal comfort models can be used to understand influences of climate change and to design more resilient buildings for climate change by designers. Although the comfort conditions under climate change has been investigated by several researchers, no enough attempt and emphasis have been made so far in terms of sufficiency of local energy efficient standards and codes together with global warming for residential buildings.

The aim of this study is to investigate how to change level of summer thermal comfort conditions in apartment buildings designed based on local energy efficiency standard TS 825 or not for the current and future climate of the Istanbul, Turkey. Thermal comfort conditions are evaluated based on adaptive thermal comfort approach by using a building simulation engine.

2. ADAPTIVE THERMAL COMFORT APPROACH

Most of the thermal comfort standards are based on a survey conducted in the field where can be a real building or a controlled room. In survey, people are asked to a question which is how you feel. Then people are selected for a reply from a descriptive scale such as the ASHRAE or the Bedford scale [9]. The scale is necessary to decide what temperature or combination of conditions is the most comfortable. According to Nicol and Humphreys [10] the surveys conducted in the field have some disadvantages for the environmental conditions can change in time, thus, making accurate measurements are difficult. In addition, generalization of survey results is hard by using the statistical analysis.

Based on adaptive comfort approach, people can adjust the environment or themselves to adapt different thermal conditions physiologically, psychologically and behaviourally. Physiological adaptation means thermal regulation of the human body. Psychological adaptation is not easily observed because perception of people to the environment can be different. Thus psychological factors can lead to different perception of a space thermally. Behavioral adaptation can be seen virtually and covers conscious or unconscious behaviours in occupied environment such as fitting clothing level, activity type or opening a window and so on [11]. Aim of adaptation is to tolerate discomfort times. Adaptive comfort approach is suitable for naturally ventilated and mixed-mode buildings [12, 13].

There are two common international adaptive thermal comfort standards in literature; one of them is ANSI_ASHRAE Standard 55. The latest version of ANSI_ASHRAE Standard 55 [14] includes the combinations of indoor thermal environmental and personal factors that will provide thermal conditions which are acceptable to a majority of the occupants within the space [15, 16]. Another is European Standard EN 15251 developed by CEN Technical Committee 156 Working Group 12. It shows an adaptive comfort model and provides thermal comfort conditions in buildings which are being neither heated nor cooled mechanically and people can operate windows and are relatively free to select clothing level [17]. Although ANSI_ASHRAE Standard 55 and European Standard EN 15251 are mostly similar, some differences are summarized by Nicol and Humphreys [10];

- The databases used to derivate the models,
- Building types applied to standards. Though ANSI_ASHRAE Standard is applied to naturally ventilated buildings, European Standard EN 15251 can be applied to buildings in free running mode,
- Derivation type of the neutral temperature,
- The outdoor temperature used in standards is different.

In this paper, adaptive thermal comfort conditions are calculated depending on European Standard EN 15251, for the monthly mean temperature used to calculate neutral temperatures in ANSI_ASHRAE Standard can be inadequate because monthly mean temperature can vary within a month and can lead to misconstruction [18].

3. METHODOLOGY

This study analyses summer thermal comfort conditions of an existing apartment building which is accepted that its location is in Istanbul, Turkey. Istanbul is the biggest city of Turkey and the third largest city in the world. Thus it has a big building stock which consists of mostly apartment buildings.

Climate of Istanbul is temperate with hot and humid summers and, cold and wet winters. Different examples have been investigated to select apartment building. The selected building reflects general architectural characteristics of residential buildings including typical design configurations, construction methods and materials for Turkey. It is a seven -storey apartment building with a floor area of 2560 m^2, as shown in Figure 1. Each flat comprises a living room, kitchen, bathroom, wc and three bedrooms.

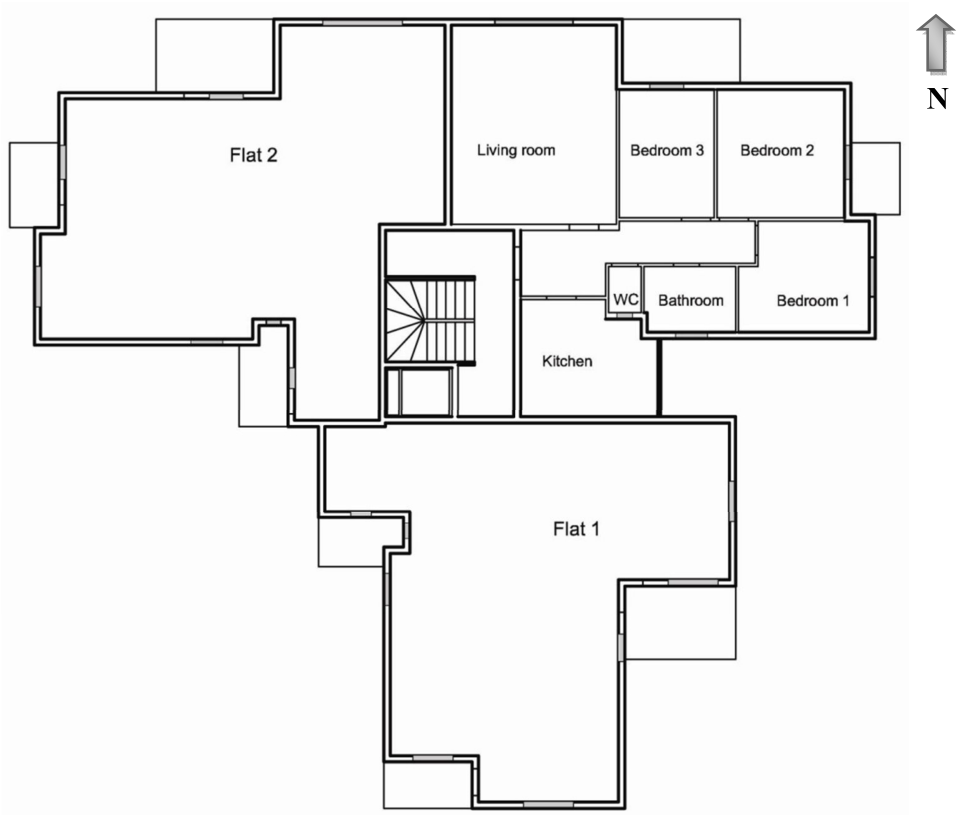

Figure 1. Typical floor plan of selected apartment building

The most common Turkish standard for energy efficiency for buildings entitled Thermal Insulation Regulation in Buildings (TS 825) [3] was published in 1998 but it was applied as compulsory after June in 2000. Thus most of the existing buildings in Turkey have not fulfilled requirements defined in TS 825. Basic objective of TS 825 is to limit heating energy consumption in buildings according to exposed area to volume ratio [19]. In addition, TS 825 defines maximum heat transfer coefficients (U value) for building components such as external wall, ground floor and roof based on defined climate regions in Turkey.

Two thermal models are prepared for this paper. First model represents apartment buildings constructed before 2000. These apartment buildings do not have minimum conditions shown in TS 825. They are being replaced and retrofitted at very low rate. Therefore they do not have enough energy efficient measures such as thermal insulation. Residential buildings constructed after 2000 have usually conditions defined in TS 825. To fulfill requirements shown in TS 825, 3 cm extruded polystyrene (XPS) is applied on external walls and ground floor of selected apartment building. In addition, 8 cm glass wool is applied on the roof. Second thermal model stands apartment buildings constructed depending on local energy efficiency standard of Turkey. Therrmophysical features of building components in current apartment building are summarized in Table 1.

Table 1.Thermophysical properties of building components

Elements	Layers	Existing U values (W/m^2 K)	Maximum U values defined in TS 825 standard for Istanbul
External wall	Plaster (25 mm), brick (190 mm), plaster (15 mm)	1.41	0.6
Internal partition	Plaster (25 mm), brick (190 mm), plaster (15 mm)	1.41	-
Roof	Clay tiles	1.83	0.4
Ground	Covering (10 mm), cast concrete (120 mm), sandy soil	2.1	0.6
Window	Double clear (6 mm) with air gap (13mm)	2.4	2.4

Indoor environmental conditions in summer of first and second models are simulated by using building energy analysis software EnergyPlus (version 5.0). EnergyPlus [20] is selected due to the free availability, high capacity to advanced building simulation and extensive validation. In this study, it is used to estimate indoor operative temperature of living room presented in Figure 1 for potential hottest summer months of Istanbul (June, July and August). Geometric model of apartment building was created by using DesignBuilderv2.04. Then, geometric model was exported into the EnergyPlus for simulation. DesignBuilder is a comprehensive user interface of EnergyPlus. It is accepted that the apartment building is occupied by two adults and one child that the living room is usually occupied between 17:00 and 00:00 on weekdays, and between 08:00 and 00:00 at weekends with summer clothing (0.5 clo). Bedrooms are occupied by one person between 00:00 and 08:00 during all week. For cooling, any mechanical equipment is not used in the selected apartment building. Infiltration of thermal model is assumed as 0.7 air changes per hour (ACH).

One of the significant inputs for building simulation is hourly weather data. Typical Meteorological Year 2 (TMY 2) for Istanbul was used as base weather file in this research because it is a common data for simulation of building energy demand and available freely. In addition, this file consists of historical hourly weather data. Hence, it is not affected by nonsense changes of climate in last decade in Turkey. Hourly weather data representing influence of climate change for future time periods is not available for Istanbul. The Climate Change World Weather File Generator was used to create hourly weather files for the time periods of 2020s, 2050s and 2080s. This tool generates future weather data according to morphing methodology which is based on the UK Handley Center's third generation coupled atmosphere-ocean global climate model (HadCM3). HadCM3 is one of the major models used in the IPCC Third Assessment Report in 2001 [21]. Different climate change scenarios based on the projected future gas emissions is available but the Climate Change World Weather File Generator can only provide future climate data to the A2 scenario defines a very heterogeneous world; continuously increasing global population and regionally oriented economic growth [22]. For that reason, all future climate data was created based on A2 scenario for Istanbul.

3.1. Adaptive thermal comfort calculation: The European Standard EN 15251

The thermal comfort temperature is a function of the outdoor air temperature. For that reason, the monthly mean external air temperature or running mean of the daily mean external air temperature is used in adaptive thermal comfort approaches [23]. The European Standard EN 15251 covers a method to evaluate thermal comfort with allowable minimum and maximum indoor operative temperatures by using the running mean daily external air temperature. Also, the standard includes four categories [24]. Category I (C1) is '*High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons*'. Category II (C2) is '*Normal level of expectation and should be used for new buildings and renovations*'. Category III (C3) is '*An acceptable, moderate level of expectation and may be used for existing buildings*'. Category IV is values outside of the above categories. All categories are shown in Figure 2.

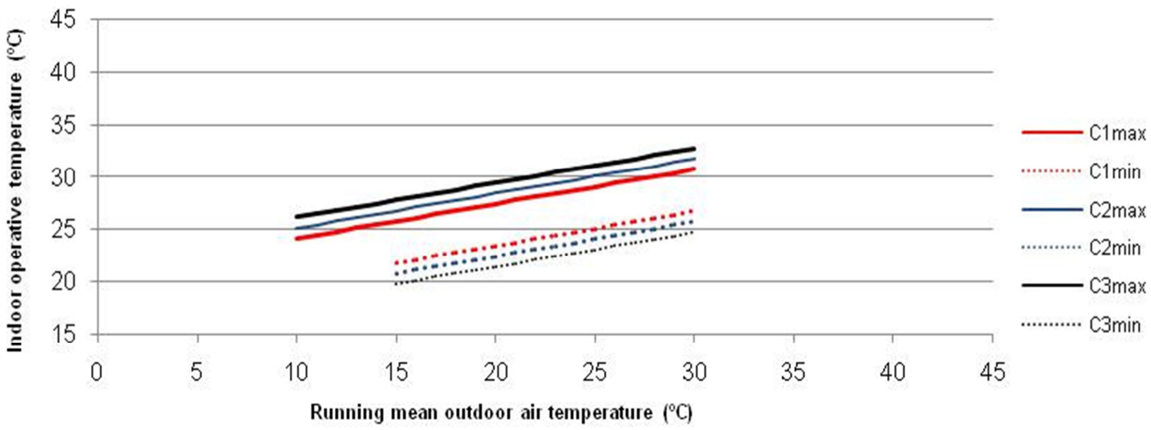

Figure 2. The relationship between the running mean outdoor temperature and the categories shown in The European Standard EN 15251

Minimum and maximum indoor operative temperatures based on the running mean of the outdoor temperature (T_{io-max} and T_{io-min}) for comfort conditions are calculated using below equations:

T_{io-min} = $0.33T_{rm}$ + 18.8 - X ºC for 15 ºC <T_{rm}<30 ºC (1)

T_{io-max} = $0.33T_{rm}$ + 18.8 + X ºC for 10 ºC <T_{rm}<30 ºC (2)

where X takes different values based on categories defined in EN 15251 (±2 K for Category 1, ±3 K for Category 2, ±4 K for Category 3).

The running mean temperature is given by:

$$T_{rm} = (1-\alpha)(T_{ed-1} + \alpha T_{ed-2} + \alpha^2 T_{ed-3} \ldots) \quad (3)$$

which can be simplified to

$$T_{rm} = (1-\alpha)_{Ted-1} + \alpha T_{rm-1} \quad (4)$$

Where T_{rm} is running mean temperature for today, T_{rm-1} is running mean temperature for previous day, T_{ed-1} is the daily mean external temperature for the previous day, T_{ed-2} is the daily mean external temperature for the day before and so on. α is a constant and recommended to use 0.8.

4. RESULTS

To examine the effect of energy efficiency standard, TS 825 and climate change on summer thermal comfort conditions in free running buildings, active cooling is not applied to the selected apartment building. In other words, thermal comfort is only evaluated for the naturally ventilated context according to the European Standard EN 15251 for all time periods. To operate the adaptive thermal comfort with the European Standard EN 15251 method, firstly the daily running mean outdoor air temperature was calculated. Than accepted comfort limits for every category in all time series were determined. They are shown in Table 2. Simulated indoor operative temperatures are plotted against running mean outdoor air temperature calculated based on The European Standard EN 15251. Later, they are compared for each model with an accordingly generated future weather file for the years 2020s, 2050s and 2080s.

Table 2. Calculated comfort limits based on The European Standard EN 15251

Categories	TMY 2	2020	2050	2080
Cat 1	23-29 °C	24-28 °C	24-30 °C	25-30 °C
Cat 2	22-30 °C	23-29 °C	23-30 °C	24-30 °C
Cat 3	21-30 °C	22-30 °C	22-30 °C	23-30 °C

4.1. Analysis of adaptive thermal comfort

Daily operative temperatures obtained from living room vary based on models and each of weather data sets (TMY 2, 2020, 2050, and 2080). Figure 3 illustrates the distribution of operative temperatures for European Standard EN 15251.

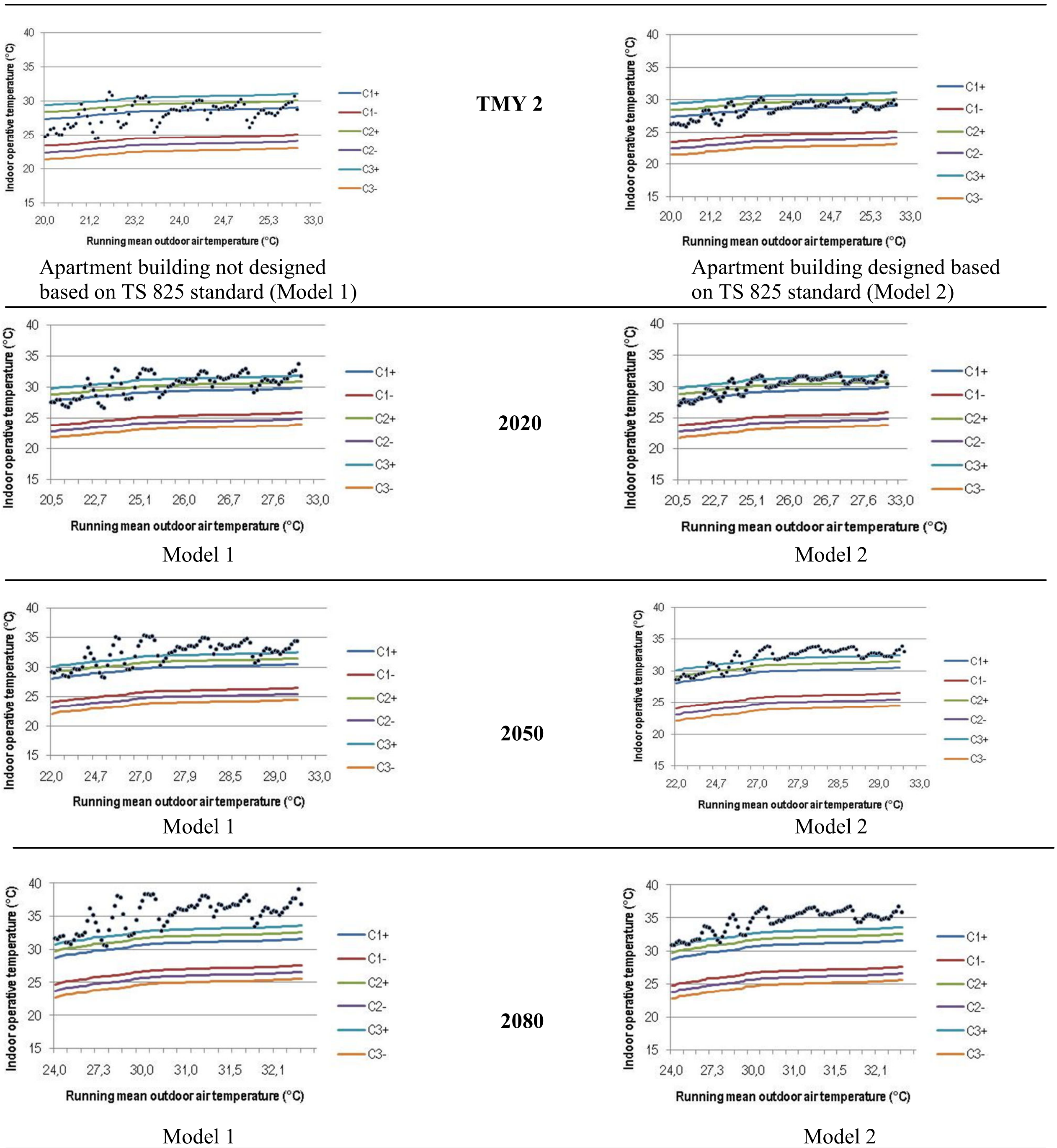

Figure 3. Distribution of indoor operative temperatures based on the European Standard EN 15251 for different building design and time periods of TMY 2, 2020s, 2050s and 2080s

In general, climate change alter the pattern of distribution of daily operative temperatures for the x and y axis for both models. This indicates that climate change has a negative impact on thermal comfort conditions. In addition, it can be observed that whereas fluctuation in daily operative temperatures are different for model 1 and 2, energy efficiency standard, TS 825 leads to a positive change of pattern up or down along y axis.

Percentage time of simulated daily operative temperatures in living room of models based on the European Standard EN 15251 thermal comfort categories are also compared to well understand in Table 3.

Table 3. Percentage time (%) that simulated operative temperatures lie within various thermal comfort categories defined in the European Standard EN 15251

	Apartment building not designed based on TS 825 standard (Model 1)				Apartment building designed based on TS 825 standard (Model 2)			
	TMY 2	2020	2050	2080	TMY 2	2020	2050	2080
Between Cat I min. and Cat I max.	12.2	4.4	-	-	12.2	5.5	1.1	-
Between Cat II min. and Cat II max.	18.8	10	3.3	-	23.3	12.2	3.3	-
Between Cat III min. and Cat III max.	36.6	16.6	6.6	-	34.4	18.8	6.6	2.2
Out of thermal comfort categories	30.4	65	85.3	91.6	28.1	61.5	83	90

Daily operative temperatures are mostly within C1, 2 and 3 limits for TMY 2. However, exceeding hours of thermal comfort categories (C1, 2 and 3) increase for both models until 2080s.It is clear that a large percentage of hours within thermal comfort categories occur for the TMY 2 weather data set in Model 1 and 2. Percentage of hours within thermal comfort Cat 1 limits is 12.2% and 4.4% for TMY 2 and 2020 weather data sets in model 1.For 2050s and 2080s, there are no hours within Cat 1 limits. It is because of the increasing outdoor air temperatures. In model 2 percentages of hours within thermal comfort Cat 1 limits is 12.2%, 5.5% and 1.1% for TMY 2, 2020 and 2050 weather data sets. In 2080s, all hours exceed comfort category limits for model 2. It can be concluded that there is a small difference between percentage of hours within thermal comfort category, Cat 1 for model 1 and 2. In other words, positive influence of TS 825 standard has decreased. In model 1, 18.8% of percentage of hours is between Cat 2 min. and max. limits for TMY 2 and it reduces by up to 0 until 2080s (2020s: 10% and 2050s: 3.3%). 23.3%, 12.2%, 3.3% and 0 of percentage of hours is within Cat 2 limits for TMY 2, 2020s, 2050s, and 2080s in model 2. Lastly, 36.6%, 16.6% and 6.6% of percentage of hours is within Cat 3 limits for TMY 2, 2020s and 2050s in model 1. In 2080s, there are no hours within Cat 3. The amount of percentage of hours in Cat 3 in model 2 is higher than model 1 (TMY 2: 34.4%, 2020s: 18.8%, 2050s: 6.6% and 2080s: 2.2 %). However, difference is very little.

30.4% of indoor operative temperatures are out of thermal comfort categories for TMY 2 in model 1. It is only 28.1% in model 2. The biggest difference occurs in 2020s. Whereas 65% of indoor operative temperatures are out of thermal comfort categories in model 1, it is 61.5% in model 2 in 2020s. The biggest rates for out of thermal comfort categories happen because of climate change in time. In 2080s almost all hours are out of thermal comfort categories for each model. One of the important points is that when the running mean outdoor air temperature is smaller than 10 °C or bigger than 30 °C, the European Standard EN 15251 is not implementable. There are hours (3% - 5%) which are out of applicability range of adaptive comfort model in all weather data sets and its amount increases from TMY 2 to 2080s. Again, climate change has a significant impact on the amount of hours out of applicability range of model compared to other model designed based on TS 825. TS 825 has small effect on the number hours out of applicability range of model and the impact decreases from TMY 2 to 2080s. The main possible reason of this is that TS 825 aims to decrease energy consumption for heating. Thus it does not have specific measures to reduce energy consumption for cooling. The most important measure in TS 825 is only thermal insulation.

5. CONCLUSIONS

This study has investigated the impact of climate change and local energy efficiency standard of Turkey on summer thermal comfort conditions in buildings based on the European Standard EN 15251.Objective of the study is to evaluate that energy efficiency standard TS 825 is adequate or not in capacity to adapt to future climate change in terms of summer thermal comfort conditions in apartment buildings in Turkey. The following conclusions can be drawn: (1) climate change leads to increase the amount of uncomfortable times in apartment buildings which are constructed depending on TS 825 (Model 2) and do not have any measures defined in TS 825 (Model 1) because of the high outdoor temperatures. It should be noted that it can lead to high energy consumption for cooling in that buildings. (2) The number of hours out of comfort categories has increased almost three-fold due to climate change in both models. Energy efficiency measures in TS 825 have reduced the number of hours above comfort categories by maximum 3%. It means that it has relatively a little impact. (3) Energy efficiency standards are a key instrument to determine level of thermal comfort conditions in free running buildings because it is not possible or easy to intervene negative results of climate change with active cooling systems. Standards concerning with energy efficiency should be evaluated and updated in the context of the climate change. In Turkey, TS 825 needs to be developed or a new standard should be prepared, for the amount of summer comfortable hours in apartment building having basic measures in TS 825 is not high compared to other apartment building (no energy efficiency measures). The average difference is 5% according to TMY 2 weather data. It would be only 1.8% in 2080. Moreover, it can be observed that measures in TS 825 such as thermal insulation is not enough to provide thermal comfort conditions in summer in the future.

It is hoped that this study will encourage evaluating appropriateness and adequacy of current energy efficiency standards for future climatic conditions.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] ANSI/ASHRAE Standard 55-2004, 2004, *Thermal Environmental Conditions for Human Occupancy*. Atlanta: American Society of Heating. Refrigerating and Air-Conditioning Engineers.

[2] Internet: http://www.pikeresearch.com/newsroom/worldwide-commercial-and-residential-building-stock-will-grow-to-182-5-billion-square-meters-by-2021 (2013)

[3] TS 825, 2008. *Turkish Standard 825*.Official Gazette Number 27019. Ankara [in Turkish].

[4] Demir, I., Kılıc, G., Coskun, M., 2008, PRECIS Bölgesel İklim Modeli ile Türkiye İçin İklim Öngörüleri: HadAMP3 SRES A2 Senaryosu. IV. *Atmosfer Bilimleri Sempozyumu*, 25-28 Mart, İstanbul. [in Turkish].

[5] Turkish State Meteorological Service, 2012, 2010 Yılı Isıtma ve Soğutma Gün-Derecelerinin Değerlendirilmesi, http://www.dmi.gov.tr/FTPDATA/veri-degerlendirme/sicaklik-gun-derece/yillikmakale/2010-IsitmaVeSogutmaGunDereceleri-Makale.pdf [in Turkish].

[6] Roetzel, A., Tsangrassoulis, A., 2012, Impact of Climate Change on Comfort and Energy Performance in Offices, *Building and Environment*, 57, 349-361.

[7] Holmes, J. M., Hacker, N. J., 2007, Climate Change Thermal Comfort and Energy: Meeting the Design Challenges of the 21st Century, *Energy and Buildings,* 39, 802-814.

[8] Wilde de, P., Tian, W., 2010, The Role of Adaptive Thermal Comfort in the Prediction of the Thermal Performance of a Modern Mixed-Mode Office Building in the UK under Climate Change, *Journal of Building Performance Simulation*, 3, 87-101.

[9] Nicol, F., Pagliano, L., 2007, Allowing for Thermal Comfort in Free-running Buildings in the New European Standard EN15251. *2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century*. 27-29 September Greece.

[10] Nicol, J. F., Humphreys, M. A, 2002, Adaptive Thermal Comfort and Sustainable Thermal Standards for Buildings, *Energy and Buildings*, 34, 563-572.

[11] Singh, K. M., Mahapatra, S., Atreya, K. S, 2011, Adaptive Thermal Comfort Model for Different Climatic Zones of North-East India, *Applied Energy*, 88, 2420-2428.

[12] Pfafferott, J., Herkel, S., Kalz D. E., Zeuschner, A., 2007, Comparison of Low-Energy Office Buildings in Summer using Different Thermal Comfort Criteria, *Energy and Buildings*, 39, 750–757.

[13] Wagner, A., Gossauer, E., Moosmann, C, Gropp, T., Leonhart, R., 2007, Thermal Comfort and Work place Occupant Satisfaction—results of Field Studies

in German low Energy Office Buildings, *Energy and Buildings*, 39, 758–769.

[14] ANSI/ASHRAE Standard 55, 2010, *Thermal Environmental Conditions for Human Occupancy*, ASHRAE Inc. Atlanta.

[15] CEN EN 15251, 2007, Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality. *Thermal Environment. Lighting and Acoustics. European Committee for Standardization*. Brussels, Belgium.

[16] Liang, H. H., Lin, T. P., Hwang R. L., 2012, Linking Occupants' Thermal Perception and Building Thermal Performance in Naturally Ventilated School Buildings, *Applied Energy*, 94, 355-363.

[17] Halawa, E., Hoof van, J., 2012, The Adaptive Approach to Thermal Comfort: A Critical Overview, *Energy and Buildings*, 51, 101-110.

[18] Nicol, J. F., Humphreys, M., 2010, Derivation of the Adaptive equations for Thermal Comfort in Free-running Buildings in European Standard EN 15251, *Building and Environment,* 45, 11–17.

[19] Dikmen, Nese., 2011. Performance Analysis of the External Wall Thermal Insulation Systems Applied in Residences, J. *Of Thermal Science and Technology*, 31, 67-76.

[20] Lawrence Berkeley National Laboratory, 2008, *EnergyPlus manual V3.0,* November 2008. Berkeley.

[21] Intergovernmental Panel on Climate Change, 2001, *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Cambridge: Cambridge University Press.

[22] Nakicenovic N. et al., 2000, *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Cambridge: U.K.

[23] Ferrari, S., Zanotto, V., 2012, Adaptive Comfort: Analysis and Application of the Main Indices, *Building and Environment,* 49, 25-32.

[24] Olesen, W. B., 2007, The Philosophy Behind EN15251: Indoor Environmental Criteria for Design and Calculation of Energy Performance of Buildings, *Building and Environment*, 39, 740-749.