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Thermal Comfort Comparison of Different Dwelling Typologies

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Perihan Çulun[1]
ORCID: 0000-0002-1797-9695

Fatma Kürüm Varolgüneş[2]
ORCID: 0000-0002-3214-4274

Gonca Özer Yaman[3]
ORCID: 0000-0002-0156-3994

Cemre Kılınç[4]
ORCID: 0000-0001-8651-6945

Abstract

Thermal comfort in spaces can be defined as the creation of conditions that will provide the users' living standards. Therefore, it is important to investigate the thermal comfort conditions in different types of dwellings and the design parameters that affect these conditions. In this study, thermal comfort conditions in different dwellings were investigated. In this context, thermal comfort conditions were measured between December 2020 and January 2022 in four selected dwellings in Bingöl, located in a cold climate. Measurements were made in the daylight living areas, night living areas and service areas of these dwellings. Temperature and humidity, air velocity, and radiation temperatures in the spaces were measured by TESTO 480 multi-purpose air conditioner, Hot Wire Anemometer DT8880, and infrared non-contact thermometer, respectively. Tables and graphics created using the data obtained from these measurements were evaluated according to the ASHRAE 55 standard. In the analyses made, the thermal comfort conditions of the dwellings with different typologies were compared. As a result of the study, the design parameters that are effective in the differences between the dwellings were evaluated and it was aimed to reveal a methodology that could guide the new designs to be made.

Keywords: *Thermal comfort, dwelling, ASHRAE standards 55, ISO 7730, Bingöl.*

[1] Assist. Prof., Bingöl University, E-mail: pculun@bingol.edu.tr
[2] Assoc. Prof., Bingöl University, E-mail: fkvarolgunes@bingol.edu.tr
[3] Assist. Prof., Bingöl University, E-mail: gozer@bingol.edu.tr
[4] Lecturer. Bingöl University, E-mail: ckilinc@bingol.edu.tr

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Farklı Konut Tipolojilerinin Termal Konfor Koşulları Bağlamında Karşılaştırılması

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Perihan Çulun[5]
ORCID: 0000-0002-1797-9695

Fatma Kürüm Varolgüneş[6]
ORCID: 0000-0002-3214-4274

Gonca Özer Yaman[7]
ORCID: 0000-0002-0156-3994

Cemre Kılınç[8]
ORCID: 0000-0001-8651-6945

Öz

Mekânlarda termal konfor, kullanıcıların yaşam standartlarını sağlayacak koşulların oluşturulması olarak tanımlanabilir. Bundan dolayı farklı tip konutlarda termal konfor koşullarının ve bu koşulları etkileyen tasarım parametrelerinin araştırılması önemli bir konudur. Bu çalışmada farklı tip konutlarda termal konfor koşulları araştırılmıştır. Bu kapsamda soğuk iklim bölgesinde bulunan Bingöl ilinde seçilen dört tip konutta termal konfor koşulları Aralık 2020 ve Ocak 2022 tarihleri arasında ölçülmüştür. Belirlenen bu konutların gündüz yaşama mekânları, gece yaşama mekânları ve servis mekânlarında ölçümler yapılmıştır. Mekânlarda sıcaklık ve nem, hava hızı ve radyasyon sıcaklıkları sırasıyla TESTO 480 çok amaçlı iklimlendirme cihazı, Hot Wire Anemometre DT8880 ve kızılötesi temassız termometre ile ölçülmüştür. Bu ölçümlerden elde edilen veriler kullanılarak oluşturulan tablo ve grafikler ASHRAE 55 standardına göre değerlendirilmiştir. Yapılan analizlerde, birbirinden farklı tipolojilere sahip konutların termal konfor koşulları karşılaştırılmıştır. Çalışmada sonuç olarak, konutlar arasında ortaya çıkan farklılıklarda etkili olan tasarım parametreleri değerlendirilmiş ve yapılacak olan yeni tasarımlar için yol gösterebilecek bir metodoloji ortaya konması amaçlanmıştır.

Anahtar Kelimeler: *Termal konfor, konut, ASHRAE standart 55, ISO 7730, Bingöl.*

[5] Dr. Öğr. Üyesi, Bingöl Üniversitesi, E-mail: pculun@bingol.edu.tr
[6] Doç. Dr., Bingöl Üniversitesi, E-mail: fkvarolgunes@bingol.edu.tr
[7] Dr. Öğr. Üyesi, Bingöl Üniversitesi, E-mail: gozer@bingol.edu.tr
[8] Öğr. Gör., Bingöl Üniversitesi, E-mail: ckilinc@bingol.edu.tr

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Introduction

Buildings are the primary source of energy consumption in urban space. In most countries, energy use in the building sector represents about one third of the total energy consumption (Synnefa et al., 2007). For example, in 2004 the building sector accounted for 40%, 39% and 37% of the total primary energy requirement in USA, the UK and the European Union (Pérez-Lombard et al., 2008; Yang et al., 2014). In Turkey, also, the building sector has a significant share in energy consumption (Koç et al., 2018). The biggest reason for this energy consumption is the neglect of the climate factor in building designs. The lack of consideration of the climatic factor has led to the need for artificial air conditioning fulfilled by mechanical techniques generally, by consuming fossil fuel or electrical energy. In fact, mechanic solutions put entire countries amid energy consumption growth and economic crisis (Santamouris et al., 2001). In buildings with intense mechanical systems, there is an increasing interest in natural ventilation and passive system applications due to problems related to energy, indoor air quality and the environment (Liping & Hien, 2007). Passive systems that use renewable energy sources play an essential role in the energy efficiency of the building (Yilmaz, 2006; Bouden & Ghrab, 2005; Djamila et al., 2013). Buildings that provide indoor comfort with passive methods consume less energy than buildings that use mechanical systems (Nicol & Humphreys, 2002). Likewise, Chen et al. (2016) stated that the layout of the building, its geometry, and envelop thermo-physics and infiltration & air-tightness significantly affect energy efficiency and building performance. Therefore, it is imperative to develop policies for energy saving measures in building construction activities (Yıldız & Arsan, 2011). The fact that 70-90% of the energy consumption in buildings was for providing thermal comfort has led researchers to diversify studies in this field (Yang et al., 2014; Yildiz, 2014). Some were studied under laboratory conditions, while others were in buildings. The laboratory offers stable and consistent conditions that are impossible in field studies. However, laboratory subjects do not engage in familiar surroundings or usual business activities during the test period. This situation led researchers to field studies (Feriadi & Wong, 2004; Bouden & Ghrab, 2005; Wang, 2006; Becker & Paciuk, 2009). The methods of providing comfort conditions in buildings will be revealed more consistently with field studies on different building types in different regions. Many field studies on thermal comfort have conducted worldwide, but they have mostly conducted in tropical and temperate climate regions (Malama & Sharples, 1997; Wang, 2006). This study is of great importance because it is a study conducted in a cold climate region. This study was carried out in the province of Bingöl, located in the east of Turkey. Due to its geographical location, Bingöl Province has continental temperate climate characteristics according to the Köppen-Trewartha climate classification. Winter months are cold and snowy, while summer months are generally hot and relatively short. In the last two decades, the lowest temperature in the region has decreased to -25 °C, while the highest temperature has exceeded 42 °C (Özer Yaman et al., 2021). The most important thing to do to provide suitable comfort conditions in buildings is to reduce heat losses. Within the scope of the study, measurements were made in four types of residences (A type- Single-family dwelling, B type-semi-detached dwelling, C type-Apartment type dwelling, D type-Studio apartment dwelling) in the province of Bingöl. In the study, firstly, the literature was reviewed and the scope of the study was revealed. Then, the dwelling samples in Bingöl were examined and four houses with different features and different users were determined. In the study, thermal comfort conditions such as air temperature, relative humidity, airflow velocity, and radiant temperature of these dwellings were measured between December 2020 and January 2022. The data obtained as a result of the measurements were evaluated using tables and graphics, taking into account the thermal comfort ranges given in ASHRAE Standard 55–2004 and ISO 7730 international standards. While the dwelling sector experienced a rapid change after the 2003 earthquake in Bingöl, it was observed that climate data was not taken into account in this new dwelling production process. This study is aimed to raise awareness in new dwelling areas.

Literature Review

In this study, thermal comfort parameters (air temperature, radiant temperature, relative humidity and air flow velocity) were examined. The most general definition of "thermal comfort" is the environmental values in which we feel mentally comfortable (ASHRAE-Handbook, 1989; Peeters et al., 2009; ASHRAE-Standart-55, 2013). Thermal comfort directly affects situations such as the health of residents, productive and effective working conditions in the working environment and feeling more comfortable psychologically. As a result of their studies, some researchers emphasized that people should no longer be passive receivers of a certain thermal environment, but instead the importance of taking an active role in interacting with the environment. These researchers linked thermal adaptation to three processes: behavioural adaptation, physiological adaptation, and psychological habituation (Choi & Yeom, 2019). One of the most important findings of the field studies is that the thermal comfort responses between the natural heating/cooling system and the mechanical system are different (De Dear & Schiller Brager, 2001; Dhaka et al., 2015). Whether the indoor environment is in thermal comfort conditions for users depends on some subjective and objective parameters. Subjective parameters; are parameters such as age, gender, subcutaneous fat and health status that vary from person to person. Objective parameters are air temperature, radiant temperature, relative humidity and air flow velocity, activity level and clothing insulation level. Objective parameters were taken into account in this study. Various studies have been carried out on thermal comfort parameters. For example, Fountain et al. (1996) conducted a study on the effect of relative humidity on thermal comfort. By creating an experimental environment and changing the relative humidity values at different indoor temperatures, they studied the thermal comfort conditions of the subjects at different clothing insulation levels and different activity levels. Jokl (2002) stated in his study that the heat balance of people is not sufficient for thermal comfort and that radiant comfort is needed. For the heat balance of the body, it is necessary to provide radiant heat from the outside and to release heat to the external environment by convection. This is expressed as a physiological state. Çakır (2006) conducted a study on the effect of design parameters on indoor thermal comfort. In the study, design-related parameters such as thermal mass, direction and size of windows, shading and vegetation, which may affect indoor thermal comfort, are discussed. Measurements related to cooling were made and evaluated statistically. Since the building material is the same, it has been determined that the thermal mass effect is approximately the same in the study areas. Schellen et al. (2010) investigated the effects of deviations in ambient temperature and the width of the temperature range on comfort and performance. As a result of their studies, it is stated that although thermal discomfort cannot be eliminated, fluctuations in ambient temperature have a positive effect on performance and operating speed. Yıldız & Arslan (2011) used uncertainty and sensitivity analysis methods on an existing apartment type to analyse the changes in annual heating and cooling energy loads in apartments in hot humid climates and tested the suitability of the parameters. Ulukavak Harputlugil & Harputlugil (2016) determined the relationship between energy efficiency and user behaviour of a certain type of residence located in four different climatic regions of Turkey. In light of the results obtained from this study, it was stated that there is a need for more detailed studies on user comfort requirements, energy consumption and related behaviour patterns, and the need for quantitative measurements was emphasized. When the studies on thermal comfort are examined, it has been seen that the relationship between housing and thermal comfort has not been examined much. For this reason, it is thought that determining the thermal comfort status by carrying out objective studies in the existing dwellings will be a reference for the new dwellings to be built.

Material and Method

Field of Research

In the study, examinations were conducted in the city of Bingöl, located in a cold climate zone. The city of Bingöl is located in the eastern part of Turkey (Figure 1).

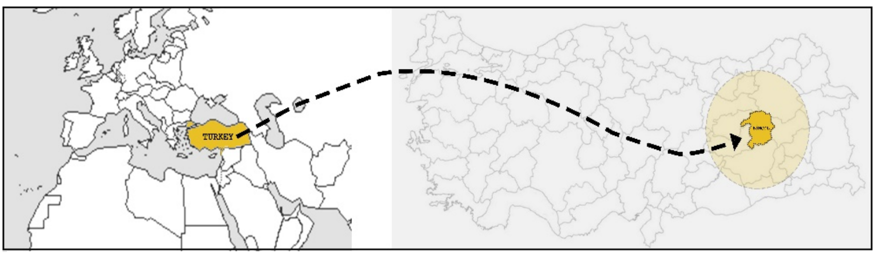


Figure 1. Location of Bingol in Turkey (edited by the authors, 2022)

The study was conducted using two methods: a field study and measurements of thermal comfortable conditions. During the field research, four (4) different dwelling typologies were examined. These are;

a. Single-family dwelling
b. Semi-detached dwelling
c. Apartment type dwelling
d. Studio apartment dwelling

The location of these dwellings in the city of Bingöl is shown in Figure 2.

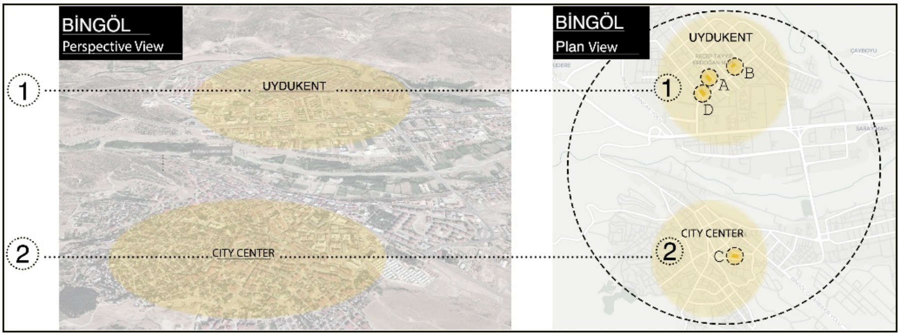


Figure 2. The location of the dwellings in the city (edited by the authors, 2022)

The dwelling typology that we refer to as A-type house is a single-family dwelling with a garden. The schematic plans and pictures of the dwelling typologies are shown in the following Figure 3.

A-Type

Image **Schematic Plan**

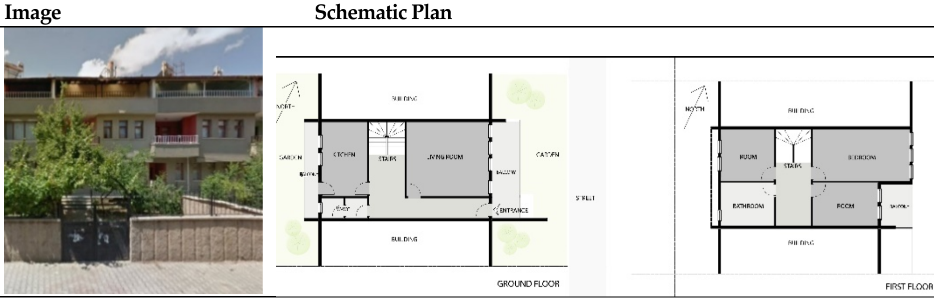


Figure 3. Photo and floor plans of the dwelling A-type (edited by the authors, 2022)

This type of dwelling consists of the ground floor, first floor, and second floor. There are attached buildings on both sides of this building planned as attached. In the area where the entrance of the building is located and the rear facade, there are detached gardens. On the ground floor of the building, there is a living room, kitchen, and toilet, and on the first floor, there are three rooms and bathrooms. On the second floor of the building, there are two rooms and a terrace. The living room and kitchen of the dwelling are oriented to the northeast, and the kitchen and toilet are to the northwest.

The dwelling typology that we refer to as B-type house is a semi-detached dwelling with a garden. The schematic plans and pictures of these dwelling typologies are shown in Figure 4.

B-Type

Image | **Schematic Plan**

Figure 4. Photo and floor plans of the dwelling B-type (edited by the authors, 2022)

This housing type has two floors with an independent apartment on each floor. The apartment examined is located on the second floor. The building in which the residence is located is planned in a separate order. The building has gardens on all four sides. The house has a living room, a kitchen, three rooms, a bathroom, and a toilet. The living room and two bedrooms face northwest, while the kitchen, toilet, bathroom, and one-room apartment face northeast.

The dwelling typology that we refer to as C-type house is an apartment-type dwelling. The schematic plans and pictures of this dwelling type can be found in Figure 5.

C-Type

Image | **Schematic Plan**

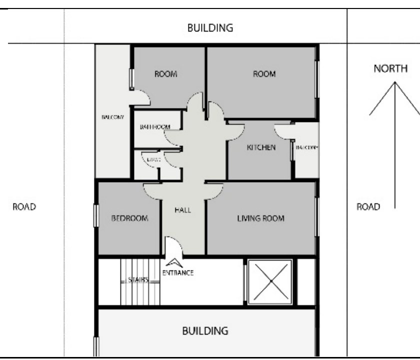


Figure 5. Photo and floor plans of the dwelling C-type (edited by the authors, 2022)

This apartment type is one of three apartments located on the fifth floor of a 6-story apartment block with 21 apartments. Above the living room and kitchen of the apartment C type, there is a roof terrace. The flat in the city centre is planned as an adjacent block and there are neighbouring buildings on the right and left. The front and rear facades face the street. The house has a living room, a kitchen, three rooms, a bathroom, and a toilet. The living room and kitchen face east, while the bedrooms and the toilet face west. The type of house called D-type is a studio apartment dwelling. The schematic plans and pictures of these dwelling typologies are shown in Figure 6.

C-Type

Image | **Schematic Plan**

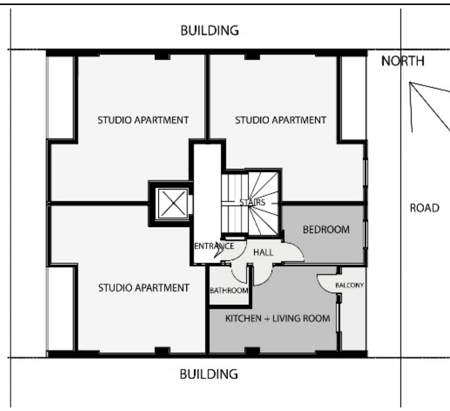
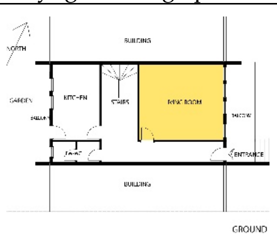
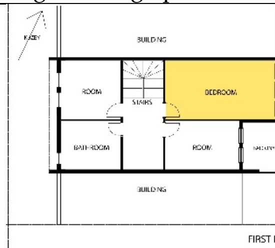
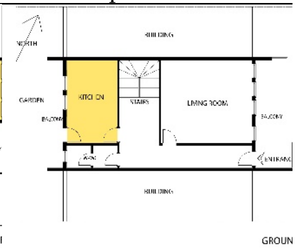
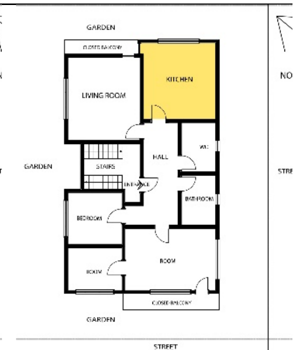
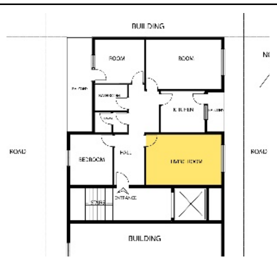
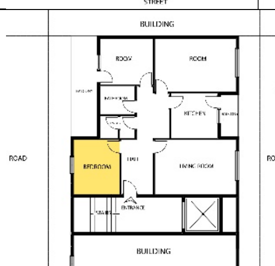
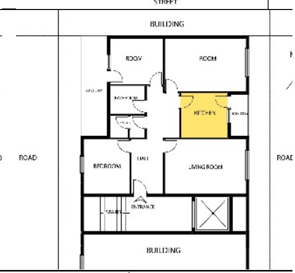
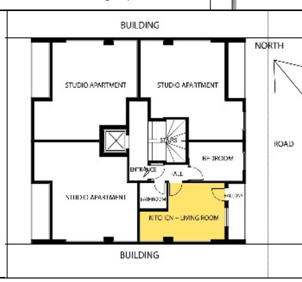
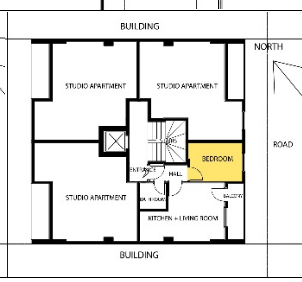


Figure 6. Photo and floor plans of the dwelling type D (edited by the authors, 2022)

This apartment type is one of four apartments located on the third floor of a four-story building with sixteen studio apartments. This apartment, located near the college, is planned as an attached block, and to the right and left of it are adjacent buildings. The front facade faces the street, and the living room and kitchen are planned as a single room. In addition, there is one more room and a bathroom. All rooms of the dwelling are oriented to the southeast.

Measurements were made in the rooms occupied during the day (living room, etc.), rooms occupied at night, and utility rooms (kitchen, etc.) of these dwellings, where measurements were taken. Photographs and schematic diagrams of the premises can be found in the following Table 1.

Table 1. Schematic diagrams of the dwellings (edited by the authors, 2022)

	Daylight Living Space	Night Living Space	Service space
A-Type			
B-Type			
C-Type			
D-Type			

Measurement and Analysis Method

Identified dwellings were examined on-site, and information about the dwellings' environmental factors and spatial organization was compiled. Measurements were taken in spaces occupied during the day (living room, etc.), spaces occupied at night (bedroom, etc.), and the utility spaces (kitchen, etc.) of the dwellings. The characteristics of the measuring devices used are listed in Table 2. As seen from Table 2 indoor temperature and humidity were measured with the TESTO 480. The related device is capable of measuring the temperature range of 0 - 60°C, with ±0.5 accuracy; also it is capable of measuring relative humidity range 0%-100% with 1.0% rH accuracy. Air velocity measured by Hot Wire Anemometer DT8880. Device velocity measurement ranges from 0.1 to 25.0 m/s with ±5% accuracy.

Table 2. Instruments used (TESTO 480, 2020), (CEM DT-8880)(from Özer Yaman et al. 2021)

Parameters	Instrument	Range	Accuracy
Outdoor Temp.	Testo 480 CMI	0 to 60 °C	±0.5
Comfort Temp.	Testo 480 CMI	0 to 60 °C	±0.5
Relative Humidity (Rh)	Testo 480 CMI	0 to 100%	±(1.0% rH + 0.7% Reading)
Air Velocity (V_a)	Hot Wire Anemometer DT8880	0.1 to 25.0 m/s	$\pm 5\% \ \pm 0.1 \ m/s$

The measurements were carried out from December 2020 to January 2022. The parameters of air temperature, humidity, airflow velocity, and radiant temperature values of the locations determined during the measurements were estimated. Calculation of the comfort temperature (T_c) depends on the outdoor temperature (T_o) given by Eq.1 (Nicol & Humphreys, 2004).

$$T_c = 13.5 + 0.54 \ T_o \quad (1)$$

The average radiation temperature found in Eq. 2 developed by Nagano and Mochida (2004) depends on the indoor air temperature (T_i) in this study.

$$T_r = 0.99 \times T_i - 0.01 \quad (2)$$

Measurements were taken from a point in the centre of the determined locations of the dwellings at a height of about 1 m above the ground. Doors and windows were kept closed during the winter and open in the summer. Tables and graphs created with the data obtained from the measurements are compared with the ASHRAE 55 standard, which accepts the comfort temperature range from 20°C to 24°C the relative humidity range from 30% to 65%. Different dwelling typologies were analysed in terms of spatial characteristics.

Measurement Results and Analysis

To provide comfortable conditions in buildings without increasing energy consumption, it is necessary to realize different designs in regions with different climatic and geographical features. In this respect, it is important to investigate interior comfortable conditions in different climate zones and designs. So in this study, the comfortable conditions of 4 (four) different dwelling typologies in the province of Bingöl were investigated. The relevant graphs and tables were obtained by using the averages of the measurements taken a month throughout the year. The results were evaluated based on monthly average temperatures, radiation temperature, relative humidity, and air velocity. Measurements taken from the living room 1, living room 2, kitchen, and wet areas due to the architecture of the first 2 (two) spaces are presented. In the A-type dwelling, the data of the living room, bedroom, and kitchen were obtained, while in the D-type was used for apartment purposes only the living room (kitchen and living room integrated) and bedroom data were obtained.

As it is known, for evaluating whether the indoor air temperature value of a place is comfortable or not, the heating (or winter) season and cooling (or summer) season should be evaluated separately. In this respect, both summer and winter conditions have been evaluated for different types of dwellings discussed in the present study. It is also useful to consider the cooling (or summer) season and heating (or) winter season averages. In this respect, the average of October, November, December, January, February, and March is taken as a basis for the winter season, and the average of April, May, June, July, August, and September for the summer season. As can be seen from Figure 7 and also stated in previous studies, the maximum temperature in Bingöl province goes up to 42°C, and the minimum temperature can go down to -25°C (Kürüm Varolgüneş, 2021). Therefore, it is important to compare the indoor air temperature values with the comfort temperature (T_c) depending on the outdoor temperature.

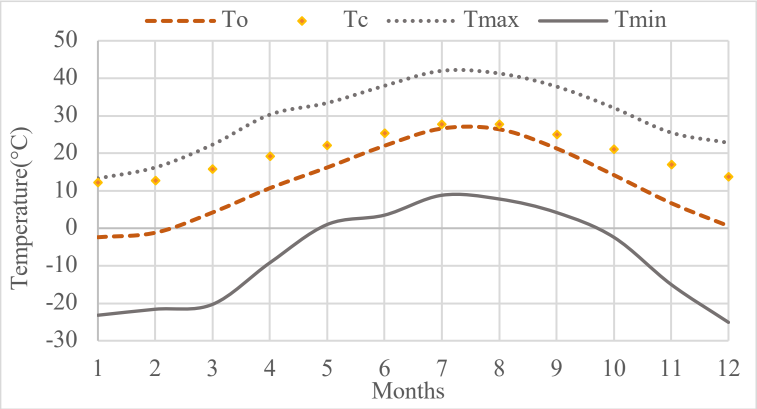


Figure 7. Comfort temperature is based on the outdoor temperature and outdoor temperatures (created by the authors, 2022)

The comfort temperature (T_c) calculated based on the outdoor temperature value (T_o), the monthly average outdoor temperature and the monthly maximum and minimum temperature recorded between 1961-2020 are also seen in Figure 7. In this way, the 12 months of the year are numbered in such a way that January shows the number 1 and December shows the number 12. In the related figure, it is seen that the maximum outdoor temperature value is above 40°C in summer (especially between June-July) and the minimum outdoor temperature value is below -20°C in the first three months of winter (January, February and March).

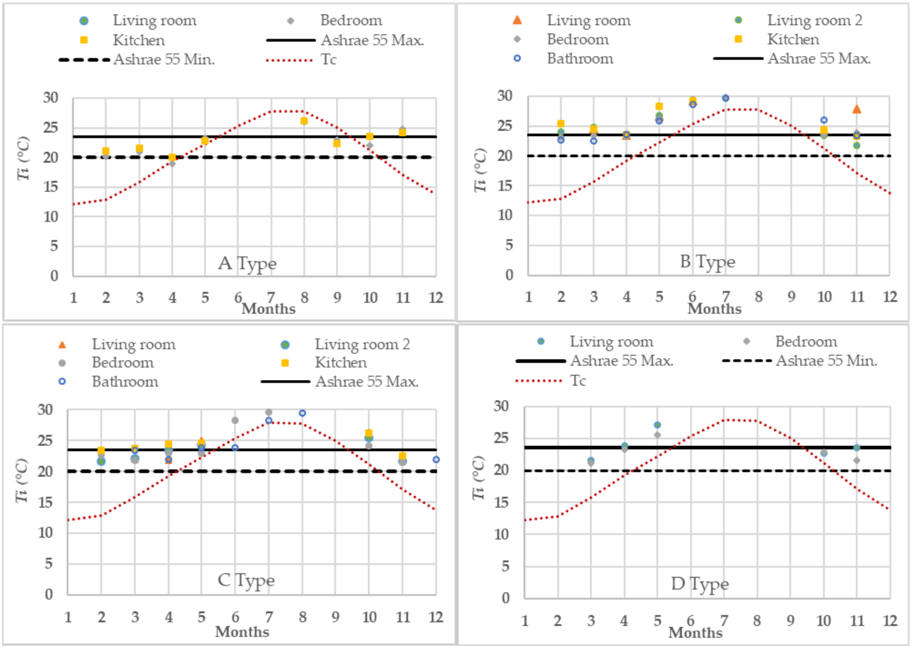


Figure 8. Monthly average indoor air temperatures of places (created by the authors, 2022)

In Figure 8, T_i values of different types of dwellings are shown. For comparison purposes, the lower and upper limit temperature values (20-24°C) of Ashrae 55 and ISO 7730 and the comfort temperature (T_c) value calculated with Eq.1 according to the outdoor temperature value are also given together with the indoor air temperatures in the same figure (Figure 8). If the T_i value falls below the T_c value for the heating season and exceeds the T_c value in the cooling season, the indoor air temperature value should be considered as uncomfortable. In the winter season, the indoor air temperatures in all rooms of all houses are between 20-25°C (see 1., 2., 3., 4. and 10., 11., 12. months in Figure 8). In this respect, it can be said that the indoor temperature values of all places remain between the lower and upper limit temperature values (20-24°C) of Ashrae 55 and ISO 7730 in the winter season. In addition, the indoor temperature values of the winter season remained above T_c. During the winter season, indoor air temperature is not desired to be below the T_c value. At the same time, the T_i values of the winter season are between the standard maximum and standard minimum limit values. In addition, considering the monthly ambient temperature values shown in Table 3, it is understood that the average temperature of the winter season is 22.5, 22.6, 22, 23.9 for A, B, C, and D-type dwellings respectively. In this respect, it can be said that the indoor air temperature in the winter season is comfortable for all dwellings discussed.

Table 3. Indoor air temperature (created by the authors, 2022)

		Indoor air temperature, T_i (°C)			
Months	T_o	**A-Type**	**B-Type**	**C-Type**	**D-Type**
January	-2.4				
February	-1.2	23		22	24.1
March	4.2	21	22	22	24.8
April	10.7	23	24	23	23.4
May	16.2	24	27	24	26.8
June	22.0		32	30	29.4
July	26.6		33	32	30.0
August	26.4	24			
September	21.3	23		26	
October	14.0	22	24	22	23
November	6.7	24	22		24
December	0.6				

Table 4. Indoor air relative humidity (%) (created by the authors, 2022)

Months	**A-Type**	**B-Type**	**C-Type**	**D-Type**
January				
February	34.4		36.9	45
March	39.1	36.4	40.4	49
April	32.2	46.6	26.2	45
May	30.3	30.1	31.2	32
June		24.4	25.7	26
July		28.5	32	28
August	39			
September	39			
October	26	39	33	29
November	32	49	43	28
December				

As seen in the related figure, significant increases occurred in the indoor temperatures of the B, C, and D-type dwellings in the 5th, 6th, 7th, and 8th months. Temperature increases were observed for all rooms where measurements are taken in the relevant figures. The average summer comfort temperatures of the places vary between 25-35 degrees. The T_i values obtained for the summer season were above the standard maximum and also above T_c values. Therefore, it is understood that the indoor temperature in the summer season is not comfortable for the B, D, and C-type dwellings. From Table 3, it is understood that the summer season average indoor temperature value for A, B, C, D-type dwellings is 23.5, 29, 27, 27.4 respectively.

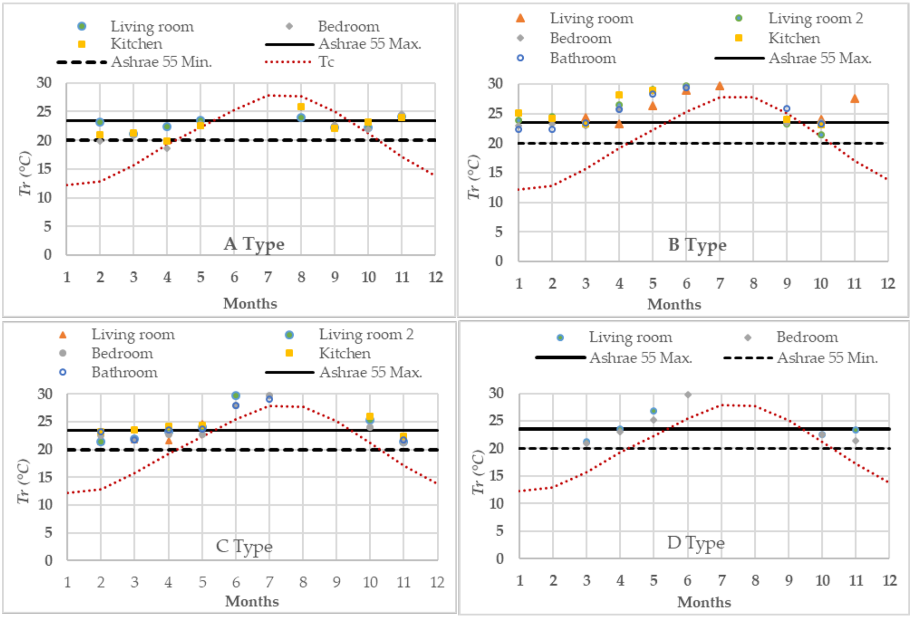


Figure 9. Monthly average radiation temperatures of places (created by the authors, 2022)

Radiation temperatures of houses obtained according to Eq. 2 are shown in Figure 9. In general, it has drawn a similar character to the indoor air temperature value. While the radiation temperature of houses is within the comfort limits for the winter season, it is above the comfortable conditions for the summer season. In general for indoor temperature it can be said that the indoor temperature values of all places almost remain between the lower and upper limit temperature values (20-24°C) of Ashrae 55 and ISO 7730 in the winter season. While the indoor air temperature values of B, D and C type dwellings are generally above the standard maximum in summer, the A type dwelling summer temperature is close to the standard maximum. In this case, it can be said that A type dwelling is comfortable both in summer and winter in terms of indoor temperature and radiation temperature; while indoor and radiation temperature of B, C, D type dwellings are comfortable only in winter season.

The relative humidity of different types of dwellings is shown in Figure 10. According to a related figure, it is understood that the humidity values are relatively high in the winter months. It is understood that the relative humidity value in the A and D-type dwellings are generally between the standard maximum and minimum values of Ashrae 55 limit values (30-65 %). Indoor relative humidity values of the B-type dwelling stay between the limit values excluding the Living room 2. For the C-type, it is understood that the humidity value is between the standards in the winter season, but almost all the values of the summer season are below the minimum value. On the other hand, the humidity values of the C-type dwelling remain within the comfort limits in the winter months, while the summer values fall below the lower limit. When the relative humidity values are examined in generally, it is understood that the A and D type dwelling are within the comfort limits. Indoor relative humidity values of the B type dwellings stay between the limit values excluding the living room 2. The humidity values of the C type dwelling are comfortable in the winter season and below the lower limit in the summer season.

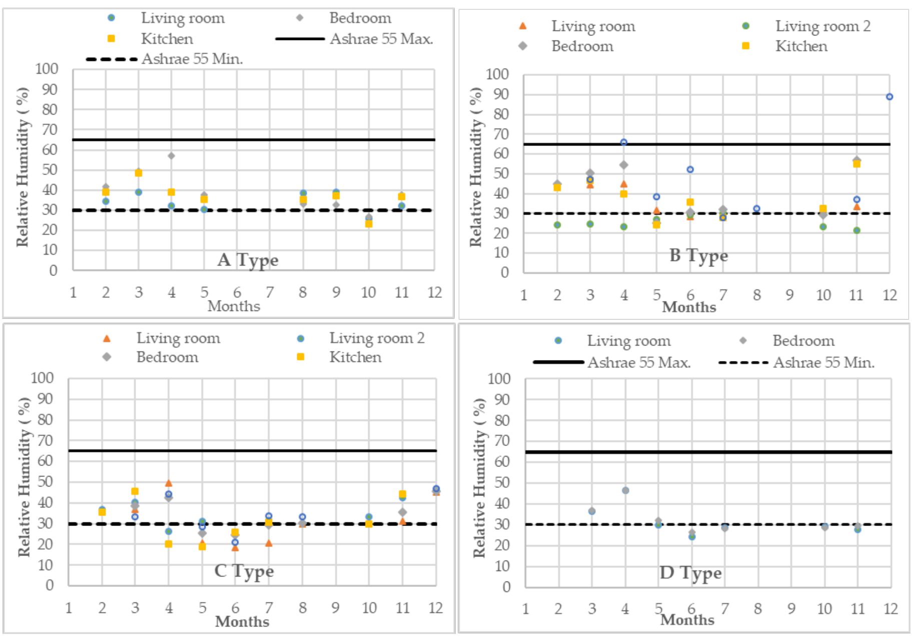


Figure 10. Monthly average comfort relative humidity of places (created by the authors, 2022)

Ashrae 55 winter air velocity comfort limit value is determined as 0.15 m/s, while summer air velocity comfort limit value is determined as 0.25 m/s. Since only the air velocity values for November are presented, the average value of the winter and summer seasons are taken as a basis (equal to 0.175 m/s). Indoor air velocity measurements taken for 20 minutes for four houses are presented in Figure 11.

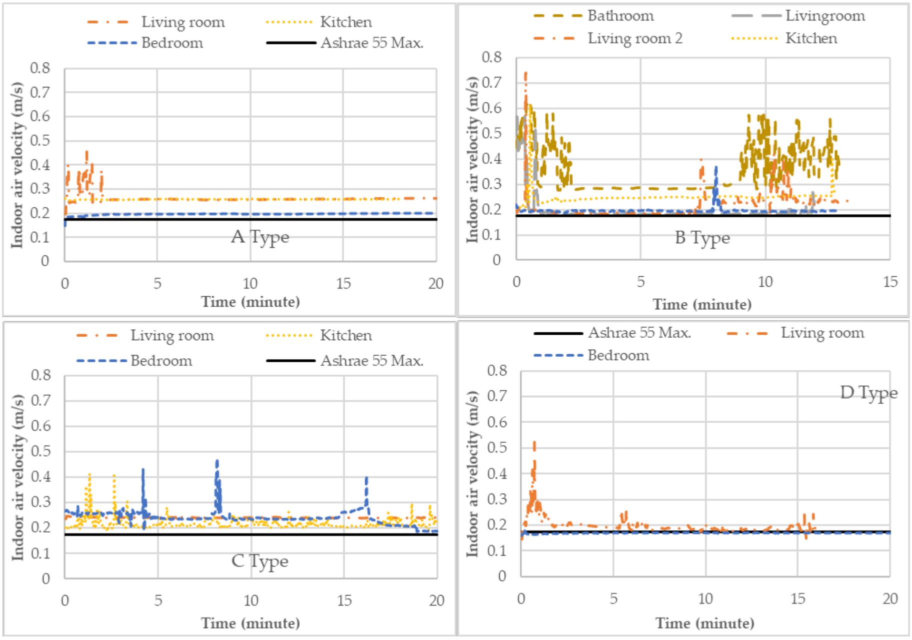


Figure 11. İndoor air velocity (November) (created by the authors, 2022)

According to the related figure, the indoor air velocity of A-type is more stable than D-type; and the D-type value remains more stable than the other houses. The air velocity of the bedroom of A-type dwelling was close to the comfort criterion. On the other hand, it is understood that the air in the living room and kitchen is far from the comfort criterion for the A-type. B-type house air velocities generally fluctuate according to the related figures. It is thought that this situation is due to the fact that the relevant building is an old building, and the windows of the house are single-glazed and air-tight. However, it is understood that the general air velocity is close to the standard limit for the living room, bedroom and salon. Air velocity values of the C-type dwelling are generally above the comfort limit; however, only the values of the kitchen and living room are main close to the limit values. In the bedroom of the relevant house, sudden increases in air velocity have also occurred. It is seen that the indoor air velocity of the D-type dwelling follows the standard values. Therefore, it is understood that among the dwellings considered, only the indoor air velocity of the D-type is at the standard value, and the air velocity of the other dwellings is generally slightly above the standard values. From all velocity figures it is understood that, among the dwellings considered, only the indoor air velocity of the D-type is at the standard value, the velocity of the other dwellings is generally slightly above the standard values.

As a general evaluation, it is concluded that A-type dwelling is comfortable in terms of temperatures and relative humidity. D-type dwelling is comfortable in terms of winter season temperature, relative humidity and indoor air velocity but summer season temperature value is above the limit. B-type dwelling is comfortable in terms of indoor temperature of winter season; however, the summer season temperature values are above the limit. The relative humidity value is close to the comfort limit except the living room 2. However, it is uncomfortable in terms of indoor air velocity. C-type dwelling is comfortable in terms of indoor temperature of winter season; however, the summer season temperature and indoor air velocity values are above the limit. Measures should be taken to bring the summer temperature, relative humidity and air velocity to standard values in the relevant dwellings. Since the relative humidity value depends on the ambient temperature, the relative humidity value of the environment will also improve with the improvement in the temperature value. As the ambient temperature decreases, the saturation pressure will decrease. In this case, the relative humidity will increase. In other words, as the ambient temperature decreases, the relative humidity will increase.

General Evaluation

The general evaluation of the study is summarized in table 5a-b.

Table 5a. General evaluation table (created by the authors, 2022).

Dwelling Type	Urban Settlement Feature	Space	m^2 of Space	m^2 of Window	Direction	Heating Source	Window Type	properties of insulation
A-Type	Single-family dwelling	Living Rooms	30 m^2	5.4 m^2	NE	Gas Boiler	Double Window	Sandwich insulation between double walls
		Bedrooms	25 m^2	4.05 m^2	NE			
		utility rooms (kitchen, etc.)	17 m^2	2.7 m^2	SW			
B-type	Semi-detached dwelling	Living Rooms	23 m^2	1.32 m^2	NE	Combi-Heating-Natural Gas	Double glazed joinery	External wall insulation
		Bedrooms	11 m^2	1.32 m^2	NE			
		utility rooms (kitchen, etc.)	21 m^2	1.32 m^2	SW			
C-Type	Apartment type dwelling	Living Rooms	23 m^2	4.00 m^2	E	Combi-Heating-Natural Gas	Double glazed joinery	External wall insulation
		Bedrooms	13 m^2	1.95 m^2	W			
		utility rooms (kitchen, etc.)	11 m^2	3.42 m^2	E			
D-Type	Studio apartment	Living Room+Kichen	18 m^2	2.1 m^2	SE	Combi-Heating-Natural Gas	Double glazed joinery	External wall insulation
		Bedrooms	10 m^2	2.41 m^2	SE			

Table 5b. General evaluation table (created by the authors, 2022).

Dwelling Type	Temperature		Radiant temperature		Relative humidity		Air velocity
	Summer	Winter	Summer	Winter	Summer	Winter	General
A-Type	Comfortable	Comfortable	Above	Comfortable	Comfortable	Comfortable	Above
	Comfortable	Comfortable	Above	Comfortable	Comfortable	Comfortable	Above
	Comfortable	Comfortable	Above	Comfortable	Comfortable	Comfortable	Above
B-Type	Above	Comfortable	Above	Comfortable	Under	Under	Above
	Above	Comfortable	Above	Comfortable	Comfortable	Comfortable	Above
	Above	Comfortable	Above	Comfortable	Comfortable	Comfortable	Above
C-Type	Above	Comfortable	Above	Comfortable	Under	Comfortable	Above
	Above	Comfortable	Above	Comfortable	Under	Comfortable	Above
	Above	Comfortable	Above	Comfortable	Under	Comfortable	Above
D-Type	Above	Comfortable	Above	Comfortable	Comfortable	Comfortable	Comfortable
	Above	Comfortable	Above	Comfortable	Comfortable	Comfortable	Comfortable

Comfortable (green) Under the comfortable conditions (blue)

Above the comfortable conditions (orange)

According to temperature values, only A-type dwelling provides comfortable conditions in both summer and winter seasons. It is seen that the temperature values for B, C, and D-type dwellings are above the comfortable conditions in summer. Radiant temperature values are above the comfortable conditions in the summer months for all types of dwellings and provide comfortable conditions in the winter months. Relative humidity values are below the comfortable conditions in summer and winter months in B-type dwelling for daytime living spaces. Similarly, the relative humidity of the spaces in the C-type dwelling is below the comfortable conditions in the summer months. Relative humidity values provide comfortable conditions for other housing types. While the air velocity values in D-type dwelling meet the comfortable conditions, they are above the comfortable conditions in other residence types. According to temperature values, only A-type dwelling provides comfortable conditions in both summer and winter seasons. It is seen that the temperature values for B, C, and D-type dwellings are above the comfortable conditions in summer. Radiant temperature values are above the comfortable conditions in the summer months for all types of dwellings and provide comfortable conditions in the winter months. Relative humidity values are below the comfortable conditions in summer and winter months in B-type dwelling for daytime living spaces. Similarly, the relative humidity of the spaces in the According to Table 5 (a, b) dwellings A and B are similar in that they are detached dwellings, while dwelling A is comfortable both in summer and winter, the dwelling B looks comfortable only in winter. The main reason for this difference can be attributed to the fact that A has a semi-detached structure and B has separate order structure.

C-type of dwelling is below the comfortable conditions in the summer months. Relative humidity values provide comfortable conditions for other housing types. While the air velocity values in D-type dwelling meet the comfortable conditions, they are above the comfortable conditions in other residence types.

Conclusion and Recommendations

In this study, indoor temperature, humidity, and air velocities of A, B, C, and D-types of dwelling in Bingöl Province were examined. The measurement results obtained were compared with the Ashrae 55 limit values and evaluated by considering the ISO 7730 standard. Since the indoor relative humidity value is closely related to the indoor temperature value, it can be ensured that the relative humidity values reach the comfort range by bringing the indoor temperature values within the comfort limits. So ambient temperature values can also be reduced a little with appropriate natural ventilation. Therefore, with appropriate and sufficient natural ventilation, the summer comfort temperature can be reduced a little, and also the relative humidity value can be increased.

In general, different types of dwellings in the cold climate zone were examined in this study. Although these dwellings have the same outdoor weather conditions, they show different indoor comfort conditions. It can be said that this situation is related to the urban settlement of the dwellings, their orientation characteristics, the shape and dimensions of the building, and the choice of facade materials. In this context, it is necessary to analyse the comfort conditions in the design process of the dwellings and to carry out the design and implementation process. When the design parameters such as suitable urban settlement, orientation characteristics, building form and dimensions, selection of facade materials are designed correctly, it will provide natural air conditioning. Parameters that provide comfort conditions such as indoor temperature, relative humidity, and air velocity can be brought into the comfort range with less need for artificial air conditioning, with appropriate natural ventilation, appropriate insulation, roof material and double-glazed windows. Optimum solutions can be produced by considering these evaluations in the design, application and use stages of the dwellings.

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Conflict of Interests

The Authors declare no conflict of interest

Nomenclature

Va Indoor air velocity [m/s]
Ti Indoor air temperature [°C]
Tc Comfort temperature basis outdoor temperature [°C]
Tr Indoor radiation temperature [°C]
To Average Outdoor temperature [°C]
Rh Relative humidity [%]

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