INVESTIGATION OF THE INDOOR MICROCLIMATE OF HISTORIC AGIOS VOUKOLOS (*AZİZ VUKOLOS*) CHURCH IN İZMİR TO DETERMINE AND IMPROVE THERMAL COMFORT CONDITIONS

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ABSTRACT

INVESTIGATION OF THE INDOOR MICROCLIMATE OF HISTORIC AGIOS VOUKOLOS (*AZİZ VUKOLOS*) CHURCH IN İZMİR TO DETERMINE AND IMPROVE THERMAL COMFORT CONDITIONS

The conservation of the historical building by improving the thermal comfort conditions contributes to the reuse of the buildings. Besides thermal improvement, the authentic values of the historical building should be taken into consideration. The aim of this thesis is to examine the effects of indoor microclimate characteristics of historic Agios Voukolos Church on the occupants and the wall paintings of the building, and to bring improvement suggestions that consider the values of the historical church by evaluating the thermal comfort conditions. The method of the study consists of on-site examination, on-site measurements of microclimate parameters, calculations and surveys. Air temperature, relative humidity, air velocity and mean radiant temperature measurements were conducted. In order to determine thermal comfort level, Predicted Mean Vote (PMV)–Predicted Percentage Dissatisfied (PPD) method developed by Fanger (1967, 1970) was used and survey studies were carried out during activities in winter. The threshold values specified in the ISO 7730:2005 and EN 16798-1:2019 standards were taken into account. According to the calculations, it was understood that the occupants felt warm in July and August, and cold in November through March. Survey study conducted in winter also confirmed that occupants are not satisfied with thermal comfort conditions. Additionally, respective UNI 10829:1999 standard and the decree published by the Italian Ministry of Culture in 2001 were used to determine the effect of indoor microclimate on wall paintings and ornaments. As a result, secondary glazing system, nighttime ventilation and radiant heaters were suggested for thermal improvement.

ÖZET

İZMİR'DE TARİHİ AZİZ VUKOLOS KİLİSESİ'NİN İÇ MEKAN MİKROKLİMASININ TERMAL KONFOR KOŞULLARININ BELİRLENMESİ VE İYİLEŞTİRİLMESİ İÇİN İNCELENMESİ

Tarihi yapıların korunmasında, termal konfor şartlarının iyileştirilmesi, yapıların yeniden kullanılmasına katkı sağlar. Isıl iyileştirmelerde, tarihi yapının korunması gereken özgün değerleri göz önünde bulundurulmalıdır. Bu tezin amacı, İzmir'de tarihi Aziz Vukolos Kilisesi'nin iç mekan iklim özelliklerinin kullanıcılar ve yapı içindeki duvar resimleri üzerindeki etkisini incelemek ve termal konfor koşullarını değerlendirerek tarihi kilisenin değerlerini gözeten iyileştirme önerileri getirmektir. Çalışmanın yöntemi, yerinde inceleme, ölçüm ve anket çalışmasına dayanmaktadır. Yapıda bir yıl süresince hava sıcaklığı, bağıl nem, hava hızı ve ortalama radyant sıcaklık ölçümleri yapılmıştır. Termal konforun belirlenmesi için Fanger'in (1967, 1970) Tahmin edilen Ortalama Değerlendirme (PMV) – Tahmin edilen Memnuniyetsizlik Oranı (PPD) metodu kullanılmış ve kış mevsiminde etkinlikler sırasında anket çalışmaları yapılmıştır. Sonuçların değerlendirilmesinde ISO 7730:2005 ve EN 16798-1:2019 standartlarında belirtilen eşik değerleri göz önüne alınmıştır. Hesaplama sonuçlarına göre, kilisede Temmuz ve Ağustos aylarında sıcak, Kasım'dan Mart ayına kadar soğuk hissedildiği görülmüştür. Kışın yapılan anket çalışması da, bireylerin mekanı soğuk hissettiğini ve termal konfor koşullarından memnun olmadığını doğrulamıştır. Ayrıca iç mekan ikliminin duvar resimleri ve süslemelere etkisinin tespit edilebilmesi için UNI 10829:1999 Standartında ve İtalya Kültür Bakanlığı'nın 2001'de yayınladığı kararnamede belirtilen eşik değerlerden faydalanılmıştır. Yapılan değerlendirmeler sonucunda, termal iyileştirme için ikinci pencere sistemi, gece havalandırması ve radyant ısıtıcı kullanımı önerilmiştir.

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CHAPTER 1

INTRODUCTION

In terms of reuse of historical buildings, the new function should be compatible with the environmental and spatial characteristics of the building for a sustainable conservation approach, and this function is determined by the information obtained from the historical building (ICOMOS, 1964, Article 5; ICOMOS, 1999, Article 7). For this reason, indoor microclimate researches are essential to making decisions about reuse of the building and structural interventions. Indoor microclimate is defined as all of the physical variables that describe the weather characteristics in the space. Physical variables can be listed as air temperature, mean radiant temperature, absolute humidity, specific humidity, relative humidity, air velocity, indoor pollution variables and light intensity (Camuffo, 1998/2014; Cardinale, Rospi and Cardinale, 2014; Pretelli and Fabbri, 2018).

Conducting indoor microclimate analysis studies provide thermal comfort improvement in historical buildings, as well as contribute to conservation of the building and building elements. However, if the comfort criteria conflicts with the conservation criteria, preserving the values of the building should be a priority (CEN, 2012). Thermal comfort is defined as the response of a person in a particular clothing to the thermal environment depending on subjective feelings, within the ambient temperature associated with particular mean radiant temperature, humidity and air movement (IUPS Thermal Comission, 1973/2001). Thermal comfort conditions depend on environmental variables such as air temperature, mean radiant temperature, air velocity and relative humidity, and personal variables such as metabolic rate and clothing insulation, in terms of occupants' satisfaction or dissatisfaction (Fanger, 1967; ISO, 2005; ASHRAE, 2017). In addition, changes and deteriorations in historical buildings should be evaluated together with indoor microclimate studies (Camuffo, 1998/2014). Indoor microclimate studies in historical buildings can also provide information about habits and lifestyles of past periods. These can be listed as heating-cooling the place, the type of clothing of the people, and the use of the place.

The conservation of the historical building by improving the thermal comfort conditions contributes to the reuse of the buildings. In this study, the effects of indoor microclimate characteristics on the occupants and wall paintings during the use of the Agios Voukolos Church were examined and thermal comfort conditions were evaluated.

Agios Voukolos Church is one of the three Greek Orthodox churches in Izmir that has survived from the 19th century. The church construction began in 1866 and was completed in 1887. The church, which has 19th century Neoclassical architectural features, has historical and architectural values with its authentic plan and spatial characteristics, architectural and ornamental elements, construction technique and materials. The church is a cross plan and semicircular apse protrudes on the east wall of the bema. On the narthex, there is the gallery floor, which is reached from the outside by a staircase adjacent to the north wall of the west cross arm. The main entrance is from the narthex in the west, with a double door with marble jamb, and secondary entrances are provided by other doors on the north and south sides. In the center of the cross plan, there is a glass skylight on the drum. The building has a plain appearance with its rubble stone, rough cut stone and brick facades (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014). The church has richly ornamented walls and ceiling. Five secco paintings are partially visible on the half dome of the apse, in the niche to the north of the apse, on the east wall of the south cross arm, and on both sides of the entrance on the west wall. There is a figure of Jesus in the apse, a figure of Ioannes Khrysostomos (St. John of the Golden Mouth) on the east wall of the south cross arm, a figure of Archangel Michael on the south of the west wall, and a figure of Archangel Gabriel in the north of the west wall (Mercangöz, 2010). The restoration of the church was carried out between 2009-2010 and it was refunctioned as a "Culture and Art Center". During the restoration, the paintings were left as reached today and the damaged paints were repaired in a lighter shade than their original color (İpekoğlu et al., 2013; İpekoğlu et al., 2014).

Within the scope of this study, indoor air temperature, relative humidity, mean radiant temperature and air velocity variables were monitored for a year in the Agios Voukolos Church, and the thermal comfort conditions for the occupants was evaluated with the data obtained. In addition, the effects of the obtained air temperature and relative humidity values on the wall paintings was investigated. This study has importance in terms of creating data for the evaluation of the indoor microclimate of the building.

1.1. Problem Definition

Determining the indoor microclimate characteristics during the preparation of restoration projects of historical buildings is important for the development of decisions regarding the comfort conditions in relation to the use of the building. In Turkey, studies on the determination of the thermal characteristics of the building are not carried out for the restoration projects of historical buildings. However, these studies should be carried out before, during and after restoration according to the characteristics and function of the historical building (Cardinale et al., 2014). The systems to be proposed for heating and cooling before restoration of historical buildings can be realized by analyzing the current climate situation. For this reason, in this study, it was deemed necessary to evaluate the thermal characteristics by monitoring the indoor microclimate data in order to improve the thermal performance of the Agios Voukolos Church, which has been restored and is used as a Culture and Art Center, and to conserve the historical building with a sustainable understanding.

1.2. Aim and Scope of the Study

Evaluation of thermal comfort conditions in the conservation of historical buildings has importance for intervention decisions. However, the authentic values of the historical building that should be preserved should be taken into consideration before thermal improvement. The aim of this thesis is to examine the effects of indoor microclimate characteristics of the Agios Voukolos Church on the occupants and the wall paintings of the building, and to bring improvement suggestions that consider the values of the historical church by evaluating the thermal comfort conditions. For this purpose, the study will seek answers to the following questions:

- How do the indoor temperature and relative humidity values of the Agios Voukolos Church change in a year and in four seasons indoors and outdoors, on the ground floor and on the gallery floor?

- How do indoor air temperature, relative humidity, air velocity, mean radiant temperature, metabolic rate and clothing insulation affect the thermal comfort conditions? How does the thermal comfort in the church differ during the twelve months?
- What is the relationship between the Actual Mean Vote (AMV) based on surveys and the Predicted Mean Vote (PMV) based on the measurements, which determine the occupants’ thermal comfort perception?
- How do the indoor air temperature and relative humidity values of the church affect the wall paintings?
- What should be the necessary interventions to provide acceptable thermal comfort conditions in the church?

The hypothesis of this thesis is that the thermal comfort, which is effective in the use of historical buildings, is determined by the intervention decisions to provide conservation of the building with its values, as a result of examining the indoor microclimate characteristics.

Within the scope of the study, indoor air temperature, relative humidity, mean radiant temperature and air velocity were measured throughout the year, survey studies were conducted to determine the thermal perception of occupants and the data obtained were evaluated. In the thermal comfort calculation and evaluation process, the concept of adaptive thermal comfort, which deepens on the physiological bases of comfort, the human body and its dynamics, is excluded from the scope of the study.

1.3. Method of the Study

The method of the study consists of on-site examination, on-site measurements of microclimate parameters, thermal comfort calculations and surveys. The planning and spatial characteristics, the construction technique and the use of materials, as well as the information on restoration interventions of the Agios Voukolos Church have been determined from published sources (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014). The plan, view and section drawings showing the current state of the building were obtained from the archive of İzmir Institute of Technology, Faculty of Architecture, Department of Conservation and Restoration of Cultural Heritage (Yardım et al., 2004-2007).

Suitable places for on-site measurement devices were determined inside and outside the church, and air temperature, relative humidity, mean radiant temperature and air velocity data were collected between July 2019–May 2020. These data were recorded with data logger devices and care was taken not to damage the building while the devices were placed. Attention was paid to place the devices that measure air temperature and humidity in a position that can reflect the thermal characteristics correctly, and that the device used outside is not exposed to wind, precipitation and direct sunlight. In addition, in order to increase the success of the measurements, high sensitivity and calibrated devices were used. While obtaining indoor measurements, open or closed doors and windows, the number and density of occupants in the space that affect the energy exchange of the space were recorded.

In order to determine the thermal comfort of the building, the Predicted Mean Vote – Predicted Percentage Dissatisfied (PMV-PPD) method developed by Fanger was used and the threshold values specified in ISO 7730 were taken into account in the evaluation of the results (Fanger, 1967; Fanger, 1970; ISO, 2005).

During the events in the church, a survey study was conducted to determine the thermal perception of the occupants of the place, based on Fanger's 7-grade thermal evaluation table, including information on clothing insulation.

In the study, computer modeling technology was not used for determining thermal characteristics of the building, on-site measurements were carried out. On-site measurements provide the actual values of the air temperature, relative humidity, mean radiant temperature and air velocity parameters to reach reliable results in the evaluation of the current situation. The method of the study is explained systematically in Chapter 3.

1.4. Literature Survey

Studies on indoor microclimate and thermal comfort properties of buildings can be listed as,

- Pioneering studies on thermal comfort parameters and calculations (Houghten and Yagloglou, 1923; Vernon and Warner, 1932; Bedford, 1936; Winslow et al., 1937; Olgyay, 1963; Fanger, 1967; Fanger, 1970)
- Review studies on thermal comfort (Auliciems and Szokolay, 1997/2007; Brager and De Dear, 1998; Djongyang et al., 2010; Mishra and Ramgopal, 2013; Alwetaishi, 2016; Martinez-Molina et al., 2016)
- Studies on indoor microclimate, energy efficiency and thermal comfort in historical buildings.

  Studies on historical buildings:
- **Studies that provide general information on thermal properties and their effects on the deterioration of objects** (Camuffo, 1998/2014; Larsen and Broström, 2015; Timur et al., 2017; Pretelli and Fabbri, 2018)
- **Indoor microclimate, energy efficiency and thermal comfort studies in historical houses:** Jankovich and Puccetti (1983) suggested three different passive solar systems for heating and cooling, and wind, water and solar energy systems for electricity generation, as passive and low-energy systems for thermal improvement as a result of measurements of a rural house in Tuscany, Italy. Tassiopoulou et al. (1996) emphasized necessity of evaluating the summer and winter thermal behavior of an Athens house in Plaka region near the Acropolis by examining the spatial characteristics, climatic characteristics, user profile and use of the building, and modeling the building digitally with the TAS thermal analysis program, while making energy efficiency decisions for conservation interventions. Ealiwa et al. (2001) stated that thermal comfort satisfaction is 54% in traditional houses and 15% in modern houses, as a result of the thermal comfort comparison made by calculating after measurements in summer season PMV (predicted mean vote) and AMV (actual mean vote) by survey method in 24 traditional and naturally ventilated houses and 27 modern houses in the oasis of Ghadames in Libya. Cantin et al. (2010) examined the environment, traditional construction methods, building envelope, indoor microclimate conditions and occupants of 11 historic houses in Paris, Strasbourg, Toulouse, Vouvray, Marne, Nice, Bretagne, Corrèze, Normandie and Alsace in France. According to the obtained information, they have shown that the energy consumption of selected historic houses is less than modern houses. Nguyen et al. (2011) showed that the

traditional houses in Vietnam were designed using creative strategies according to the climatic characteristics of the region and adapt to climatic conditions except harsh climatic conditions by measuring indoor microclimate parameters and creating CFD (Computational Fluid Dynamics) simulation. Omar and Syed-Fadzil (2011) conducted on-site measurements in a historic house in Penang, Malaysia, using passive cooling, to examine its thermal performance and make recommendations for energy efficiency. Li et al. (2012) analyzed the energy consumption and indoor environmental quality of Nanjing Tulou houses in China, which were built using rammed earth and wood, and found that the primary energy consumption was lower and the thermal comfort level was higher than other rural houses. Morelli et al. (2012) carried out indoor microclimate measurements and calculations on the conversion of a historical house to a nearly zero energy building in Copenhagen, Denmark, and achieved a 68% reduction in energy use with the retrofitting suggestions. Kacher (2013) developed passive improvement methods for energy efficiency by using CFD and energy simulation method in traditional houses in the south of Algeria and showed that the energy performance of buildings is high without active retrofitting methods. Li et al. (2013), by conducting indoor environmental quality measurements and surveys in Tulou houses built with rammed earth and wood in China, determined that individuals living in these buildings were more satisfied with the indoor thermal environment and indoor environmental quality than those living in other rural buildings. Moschella et al. (2013) studied the conflicts between the application of photovoltaic panels using solar energy to reduce energy use and to use renewable energy sources and conservation of the building in a historic house in Catania, Italy. Pérez Gálvez et al. (2013) examined two proposals for the restoration of a historic house in Seville, Spain, in terms of energy efficiency and sustainability, and evaluated them in terms of energy efficiency and CO_2 emission. Alev et al. (2014) tried different scenarios in the Baltic Sea region in Estonia, Finland and Sweden with the aim of energy saving. Arumägi and Kalamees (2014) analyzed energy consumption of wooden houses in Estonia by carrying out measurements, digital simulations and economic calculations and developed recommendations and found that a 20% - 65% reduction was achieved in primary energy consumption. Ben and Steemers (2014) have shown that changing the behavior of individuals living in historical houses at the Brunswick Center in England will result in an energy saving increase of 62% - 86%. Fabbri et al. (2014) assumed that a historical house was built at different times (1950, 1970, 1985 and 1995) in Cesena, Italy. They performed energy efficiency analyzes on four different digital models and showed that the relationship between technological developments in construction and energy savings is not linear. Khalili and Amindeldar (2014) developed passive retrofitting methods for energy efficiency using CFD and energy simulations for traditional houses in Yazd, Kashan, Zavare and Isfahan in Iran. Moran et al. (2014), determined that CO_2 emissions were reduced by 83% and energy savings increased by 55% by using the 'Passive House Planning Package' in three houses in England. Polo López and Frontini (2014) studied the difficulties that can be experienced in the use of photovoltaic panels and the conservation of the historical building while improving the energy performance. Şahin et al. (2014, 2015) conducted an energy efficiency improvement study by using building energy simulation (BES) method in *İzmir Semt Merkezi*, which is a historical house in İzmir, Turkey, and made suggestions considering the values of the building. Giombini and Pinchi (2015) studied energy performance improvement in historical houses in Perugia, Italy, using historical documents, on-site measurements, survey and infrared thermography. Ulu and Durmuş Arsan (2017) have reviewed and compiled research and projects on energy efficiency improvement by preserving historical houses in European Union countries and Turkey. Mukhopadhyay et al. (2019) analyzed historic houses in Havre, Montana, in the USA by using the 2012 version of the International Energy Conservation Code (IECC), and stated that 81% energy savings were achieved after all recommendations. Timur (2019), examined the retrofitting potential of thermal interventions that will not cause loss of heritage value of the traditional houses with exterior hall (*sofa*) in Muğla, Turkey, as a result of recording the climatic data in the historic houses and analyzing the thermal properties with the DesignBuilder building simulation software. Caro and Sendra (2020, 2021) examined occupant behaviors and passive methods to improve thermal performance for houses located in the historic center of Seville, Spain, in the Mediterranean climate zone, and also analyzed the factors on which the improvement of indoor environmental quality and thermal comfort depends. Ulu and Durmuş Arsan (2020) created building performance simulations (BPS) for the historical urban texture consisting of 22 historic houses in İzmir, Turkey, located in the Mediterranean climate zone, and studied on energy performance improvement based on annual energy consumption by using the EN 16883 Standard. Rieser et al. (2021) studied on providing the ventilation need in order to increase the indoor air quality of historical houses with preserving the values of historical buildings and considering energy efficiency.

- **Indoor microclimate, energy efficiency and thermal comfort studies in historical museums, libraries and theaters:** Camuffo et al. (1999) measured and analyzed indoor microclimate and pollution in summer and winter seasons in Venice Correr Museum in Italy and observed that pollutants increased with frequent opening of doors and windows in summer. Saïd et al. (1999) observed temperature, relative humidity, and surface wetting-drying cycles in the historic house serving as a museum in Ottawa, Canada, and found that leaks in the building envelope caused condensation and ice formation on the interior of the walls and ceiling. Camuffo et al. (2001), analyzed indoor microclimate, air pollution and biological contamination levels in Venice Correr Museum, Italy, in Art History Museum Wien, Austria, in Royal Museum of Fine Arts Antwerp, Belgium, in Sainsbury Centre Visual Arts, England in order to suggest improvement methods. Pavlogeorgatos (2003) explained that humidity, temperature and pollution in museums are the most important factors that cause the deterioration of artworks in exhibition halls and storage areas, and examined the situations that may cause the deterioration of artworks in the museum. Gysels et al. (2004) examined the indoor and outdoor conditions of the Royal Museum of Fine Arts Antwerp, Belgium, the factors affecting air quality and pollution inside the museum, and found that the museum was affected by the unbalanced heating and air conditioning systems, humidifiers, ventilation and lighting systems, daily use of the exhibition and flow of visitors. Yau et al. (2011) measured the thermal perception of occupants for three galleries at the Malaysian National Museum in Kuala Lumpur by survey method and calculated the Actual Mean Vote (AMV) value and determined that the place was thermally uncomfortable according to ASHRAE Standard 55. As a result of this situation, Predicted Mean Vote (PMV) was calculated for thermal comfort determination and it was seen that HVAC systems may be needed in the museum. Farreny et al. (2012) analyzed the energy profile by examining bills in order to determine and reduce energy consumption in 28 museums in Barcelona, Spain, and explained that water and energy consumption is related to building size, activity rate, number of visits and working hours. Fabbri and Pretelli (2014) emphasized that the Maltestiana Library in Cesena, Italy, which was built as a library in 1454 and continues to function, can preserve the artworks with its authentic indoor microclimate characteristics without an HVAC system, and the indoor microclimate changes even if the windows are left open for a long time. Wang et al. (2014) analyzed the indoor microclimate in a national gallery, using both measured and modeling data, and showed that 60% energy savings could be achieved with energy improvement methods tested by simulations. Sciurpi et al. (2015) calculated the performance index of temperature and relative humidity according to the UNI 10829 standard after measuring indoor microclimate parameters at the La Specola Museum in Florence, Italy, and developed strategies to reduce solar heat gain by using digital simulations to reduce the temperature that could damage the artifacts. Andretta et al. (2016) carried out indoor and outdoor climate values and pollution measurements in summer and winter in the Classense Library in Ravenna, Italy, and examined the accumulation rates and concentration of pollutants by examining indoor and outdoor air changes in this process. Ricciardi et al. (2016) preferred the survey method to examine the thermal perceptions of the occupants at the Fraschini Theater in Pavia, Italy, and showed that this method quickly yielded results for the thermal comfort analysis. Tort-Ausina et al. (2016) preferred the survey method in order to determine the thermal comfort by considering the gender and age differences of the occupants in the Valencia History Museum in Spain and created data for thermal comfort improvement. Schito and Testi (2017) explained the risk assessment models for the preservation of artifacts in museums and applied these evaluation models to determine the acceptableness of hygrothermal values for paper, panel paintings and wooden sculptures in a museum in Pisa, Italy, and prepared the performance index for temperature and relative humidity. Şahin et al. (2017) measured thermo-hygrometric parameters during a year in the Necip Paşa Library in İzmir, Turkey, applied a risk assessment based on the control classes of ASHRAE Chapter 21 in order to evaluate the risks of mechanical, chemical and biological deterioration for the artifacts, and made recommendations to preserve them. Martinez-Molina et al. (2018) carried out measurements and surveys during a year to determine the thermal comfort conditions at the Valencia History Museum in Spain, compared the Predicted Mean Vote (PMV) that calculated after measurements and Thermal Sensation Vote (TSV) calculated after surveys. Although different results were obtained, it has been determined that the museum is thermally uncomfortable. Schito et al. (2018) changed temperature and relative humidity values by digital simulation method in order to preserve artworks, ensure energy efficiency and provide thermal comfort in a museum in Pisa, Italy, and examined the effects of changing conditions on artworks, thermal comfort and energy efficiency. Balocco et al. (2020) evaluated the results obtained from experimental measurements at the San Marco Museum in Florence, Italy, and examined the damage and deterioration in artworks.

- **Indoor microclimate, energy efficiency and thermal comfort studies in historical education buildings:** Butera et al. (1985) analyzed the climatic characteristics, spatial characteristics and usage situation of 29 historical schools in Palermo, Italy, by digital simulation method, conducted energy saving studies and made heating system decisions. Hanna (2002) compared the daylight, acoustic performance and thermal comfort results calculated by measurements and survey method at Glasgow School of Art in Scotland and analyzed them as statistical data. Lagüela et al. (2011) analyzed heat loss in a historical school in Galicia, Spain, using laser scanners and thermographic cameras. Mørck and Paulsen (2014), Zinzi et al. (2014), Erhorn-Kluttig and Erhorn (2014) and Buvik et al. (2014) conducted measurements in historical schools in Germany, Italy, Denmark and Norway within the scope of the “School of the Future” project within the 7th Framework Program of the European Union and studied on energy efficiency, reducing heat losses from the building envelope, solar heat gains, heating/cooling, optimal use of ventilation, lighting systems and energy supply/generating systems. Sauchelli et al. (2014), after measurements in a historical high school building in Varese, Italy, showed that a 70% reduction in energy demand with passive retrofitting methods and nearly zero energy building can be obtained with active retrofitting methods in order to increase energy efficiency. Martinez-Molina et al. (2017) conducted indoor microclimate measurements at a historic school in Villar del Arzobispo, Spain, and studied on comparisons of thermal comfort and indoor environmental quality after surveying students and teachers.
- **Indoor microclimate, energy efficiency and thermal comfort studies in historical palace buildings:** Costanzo et al. (2006) monitored the indoor

microclimatic conditions of Palazzo Steri in Palermo, Italy, in order to preserve the artwork it contains, and concluded that an air-conditioning system should be installed for summer and winter seasons. Balocco (2007) prepared a 3D CFD digital simulation that analyzes the temperature and vapor concentration distributions caused by natural convection, fan coil systems and humans after microclimatic parameters and air velocity measurements in the Two Hundred Hall of Palazzo Vecchio in Florence, Italy. Balocco and Grazzini (2007) proposed to install a mobile platform on existing floor with a heating system, and conducted indoor microclimate measurements in the Five Hundred Hall of Palazzo Vecchio in Florence, Italy, examined its effects with the CFD digital model and determined that the platform was compatible with the historical building. Ascione et al. (2011) prepared a digital simulation to make the restoration intervention decisions for Palazzo dell'Aquila Bosco Lucarelli in Benevento, Italy, examined the energy performance of the building and determined that 22% primary energy savings could be achieved with retrofitting methods. Corgnati and Perino (2013) created a CFD simulation to evaluate the indoor microclimate conditions and ventilation strategy of the Senate Chamber at Palazzo Madama in Turin, Italy, and showed that the place can be suitable for exhibitions by installing an HVAC system.

- **Indoor microclimate, energy efficiency and thermal comfort studies in historical churches and other religious buildings:** Camuffo and Bernardi (1995) conducted indoor microclimate measurements in the Sistine Chapel in Vatican and examined the effects of artificial lighting, heating, pollutants, and heat and humidity released by visitors to the building. In order to analyze the effects of the direct sunlight on the wall paintings, they determined orbits on the paintings according to time and developed suggestions. Bernardi et al. (2000) they analyzed the indoor microclimate with measurements and analyzed the porosity of stone as building material in St. Stephen's Church in Nassebar, Bulgaria to preserve the wall paintings deteriorated as a result of previous interventions. Limpens-Neilen (2006) worked on the pew heating method, which is a local heating option, in order to provide thermal comfort and heat without damaging the building and artifacts, by on-site measurements and CFD simulations in the church in Rocca Pietore, Italy. Bencs et al. (2007) investigated the effects of the warm-air heating system on the heating of pews and the distribution of pollutants in the church in Rocca Pietore, Italy, by on-site measurements. Samek et al. (2007)

studied the effects of electric radiant heaters on microclimate, airflow, and deposition of particulate matter in the Saint Michael Archangel Church in Szalowa and the Saint Catherine Church in Kraków, Poland. As a result, they observed that radiant heaters change the indoor microclimate only in the region where they are located and there is no particulate matter accumulation due to low airflow. Nilsson and Broström (2008) determined the thermal comfort conditions by PMV-PPD analysis of local heating by placing radiant heaters on chandeliers and heating pads on pews in two churches at Gotland University in Sweden. Vuerich et al. (2008) measured air temperature, relative humidity and tropospheric ozone content during the summer season in San Vincenzo Church in Modena, Italy, and examined their effects on historical artifacts. Camuffo et al. (2010b) collected data for three years at the Santa Maria Maddalena Church in Rocca Pietore, Italy, and analyzed previously used warm-air heating system and pew heating system comparatively by using CFD simulations. Bolorforoush (2014) stated that in order to reduce energy consumption in Lichfield Cathedral in England, it is necessity to change usage and energy management. Also the pew heating, which is the local heating system, improvement of windows and insulation of the roof were proposed. Cardinale et al. (2014) examined the performance of the low-temperature floor heating system and its effects by measurements at the Matera Cathedral in Sassi, Italy, and did not observe any negative effects on historical building. D'Agostino and Congedo (2014) created a three-dimensional CFD model in order to find a solution that could provide a suitable microclimate for the conservation of the Lecce Cathedral in Italy, and developed the model with different climate scenarios to analyze the climatic conditions inside the building. Silva and Henriques (2014) analyzed indoor microclimate parameters of St. Christopher Church in Lisbon, Portugal by using EN 15757, proposed a new analysis method for temperate climates based on EN 15757, influenced by UNI 10829 and the ASHRAE Handbook. Bonacina et al. (2015) reported the results of 20 years of indoor microclimate monitoring at the Scrovegni Chapel in Padova, Italy. Aste et al. (2016, 2017) analyzed different heating systems by using digital simulation for The Basilica di S. Maria di Collemaggio in L'Aquila, Italy, and studied on developing a prototype of pew heating system to provide thermal comfort. Turcanu et al. (2016) compared the performance and financial calculation results of the static heaters and underfloor heating system created by CFD simulation. Diler et al. (2017) recorded indoor microclimate data during a year in the Ulu Mosque in Manisa, Turkey, modeled the building using the DesignBuilder v4.2 software, and evaluated the indoor microclimate conditions. Based on the data obtained, thermal comfort was analyzed by using the PMV-PPD method. Cannistraro and Restivo (2018) analyzed conservation status of historical artifacts in SS. Crufix Church in Milazzo, Italy, according to relative humidity and temperature values determined by the UNI 10829 standard and the decree published by the Italian Ministry of Culture on May 10, 2001. Pałupska and Kanaś (2018), after analyzing indoor relative humidity and temperature values at University Church in Wrocław, Poland, examined the effects of the existing warm-air heating system and the proposed low temperature radiant heating system on the historical building and thermal performances. As a result, they determined that the warm-air heating system will damage the historical artifacts and will negatively affect the thermal comfort conditions due to low relative humidity level. However, the radiant heaters to be placed in the pews will provide thermal comfort without changing the climate of the church. Varas-Muriel and Fort (2018), investigated the effect of the underfloor heating system by making indoor microclimate measurements in the Our Lady of the Assumption Church in Algete, Spain. They observed that as a result of heating for more than one hour, the historical building may be damaged. However, the thermal comfort level will be low in a shorter heating period. Aste et al. (2019) analyzed the indoor relative humidity and temperature values in Duomo di Milano, Italy, and examined the risk of physical, chemical and biological deterioration of the artifacts (wood, stone and metal). De Rubeis et al. (2020) examined the thermo-hygrometric data by using digital simulation by using UNI 10829 and testing different scenarios for Santa Maria Annunziata of Roio Church in L'aquila, Italy, and emphasized that the HVAC system is necessary for preservation of artworks and thermal comfort of occupants.

Standards and documents on indoor microclimate and thermal comfort can be specified as ISO 7726, UNI 10829, ISO 7730, EN15757, EN15758, EN 15759-1, ASHRAE Standard 55, ASHRAE Handbook ve EN 16798-1. The documents are described in Table 1.1.

Table 1.1. Standards on indoor microclimate and thermal comfort of historical buildings

ISO 7726 (1998)	Ergonomics of the Thermal Environment – Instruments for Measuring Physical Quantities	It is an ISO document that specifies the properties of instruments for measuring the physical parameters characterizing a thermal environment and methods for measuring the physical variables of that environment.
UNI 10829 (1999)	Works of Art of Historical Importance – Ambient Condition for the Conservation – Measurement and Analysis	It is a document that proposes a methodology for environmental thermo-hygrometric and lighting quantity measurement for the preservation of historical and artistic assets, and contains information on the examination and analysis of data collected for evaluation purposes.
ISO 7730 (2005)	Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria	This standard was developed in parallel with the revised ASHRAE Standard 55 and is one of the ISO documents that determines the methods for the measurement and evaluation of thermal environments in which people are affected.
EN 15757 (2010)	Conservation of Cultural Property – Specifications for Temperature and Relative Humidity to Limit Climate – Induces Mechanical Damage in Organic Hygroscopic Materials	It is the European standard that includes indoor temperature and relative humidity properties to conserve museums, galleries, archives, libraries, churches and historical buildings by restricting mechanical deterioration and reducing stress on organic materials.
EN 15758 (2010)	Conservation of Cultural Property – Procedures and Instruments for Measuring Temperatures of the Air and of the Surfaces of Objects	It is the European standard that includes the procedures for measuring devices and measurements for indoor and outdoor air temperature and surface temperature in historical buildings.
EN 15759-1 (2012)	Conservation of Cultural Property – Indoor Climate – Part 1: Guidelines for Heating Churches, Chapels and Other Places of Worship	It is the European standard that explains the indoor climate and heating of places of worship (churches, chapels, mosques and synagogues), which are an important part of cultural heritage, through the concept of conservation.
EN 16883 (2017)	Conservation of Cultural Heritage – Guidelines for Improving the Energy Performance of Historic Buildings	It presents a normative working procedure for selecting measures to improve energy performance, based on an investigation, analysis and documentation of the building including its heritage significance.
ASHRAE Standard 55 (2017)	Thermal Environmental Conditions for Human Occupancy	This standard enables the determination of personal variables and combinations of indoor climate variables that will produce thermal environmental conditions acceptable to the majority of people in the space.
ASHRAE Handbook (2019)	HVAC Applications	It includes 61 chapters that help design and use equipment and systems that ASHRAE engineers described.
EN 16798-1 (2019)	Energy Performance of Buildings – Ventilation for Buildings – Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics – Module M1-6 (Revision of EN 15251:2007)	It is the document used for energy calculations in buildings, year-round evaluation of indoor thermal environment and design of systems.

1.4.1. Studies on Examining the Indoor Microclimate of Historical Churches in terms of Thermal Comfort and Conservation of Historical Artifacts

Studies on thermal comfort in historical churches vary in terms of deteriorations, heating, ventilation and air conditioning (HVAC) systems, energy efficiency and economic impact. Analyzed studies are listed in Table 1.2.

Table 1.2. Studies in historical churches according to research topics and methods

References	**Date**	**Location**	**Research Topics**					**Research Methods**	
			TC	**D**	**HS**	**EE**	**EI**	**MM**	**DS**
Nilsson and Broström	2008	Sweden	●	●	●			●	
Camuffo et al.	2010	Italy	●	●	●	●		●	●
Cardinale et al.	2014	Italy	●	●	●			●	
Turcanu et al.	2016	Romania	●	●	●	●	●	●	●
Aste et al.	2016	Italy	●	●	●	●		●	●
Aste et al.	2017	Italy	●	●	●	●		●	●
Varas-Muriel and Fort	2018	Spain	●	●	●			●	●
Cannistraro and Restivo	2018	Italy		●				●	
Pałupska ve Kanaś	2018	Poland	●	●	●			●	
Aste et al.	2019	Italy		●				●	
De Rubeis et al.	2020	Italy	●	●	●	●		●	●

Abbreviations: TC, thermal comfort; D, deteriorations; HS, heating, ventilation and air conditioning (HVAC) systems; EE, energy efficiency; EI, economical impact; MM, microclimatic measurements; DS; digital simulation

Nilsson and Broström (2008), in their study by Gotland University, in Sweden, placed new radiant heating systems on chandiliers and heating pads on pews in two churches that aimed to provide thermal comfort to occupants by local heating system, without completely heating the buildings, without changing the natural climate. Measurements were conducted during January 2008 and PMV - PPD calculations were made to examine the thermal comfort conditions. It has been observed that occupants feel the place thermally uncomfortable when the heating systems are turned off. In addition, heating only pews with heating pads was not sufficient for comfort. It was possible to provide thermal comfort (PMV = -0.3, PPD = 7%) when the occupants were dressed according to 2 clo clothing insulation, when both the radiant heaters and the heating pads on pews were turned on.

Camuffo et al. (2010b) collected data for three years between 2002-2005 in the Santa Maria Maddalena Church, built in the 15th century in Rocca Pietore, Italy, and analyzed comparatively the warm-air heating that was previously used and pew heating in the church. Purpose of the study was providing thermal comfort for users in historical churches by preventing damage to historical building and artifacts. After measurements, it was seen that the warm-air heating systems placed in the church during restoration caused a sharp vertical thermal gradient. This situation affected the thermal comfort negatively (15 ^{o}C at head level, 0 ^{o}C at foot level) and also damaged the artworks and may cause cracks on them. According to CFD (Computational Fluid Dynamics) simulations, pew heating with radiant heaters provided thermal comfort by warming the body of the occupants in a balanced way (6-8 ^{o}C at head level, 10-15 ^{o}C at leg level, 18-25 ^{o}C at foot level), and reduced spreading unwanted amount of heat indoors.

Cardinale et al. (2014) investigated the performance of the low-temperature radiant floor heating system and its effects on the Matera Cathedral, built in the 13th century in Sassi, Italy. After this system was applied to the renewed floor of the church, the heat stayed in the area where thermal comfort was desired, and only a small part of the heat was dispersed to the building via convection, and the artworks were not exposed to harmful sharp fluctuations in temperature and humidity. According to April measurements while the system was operating, the church was found to be thermally comfortable (PMV = 0.25, PPD = 5.3%). In addition, it was determined that the air temperature and relative humidity values are in acceptable range to conserve the artworks (16 ^{o}C < T=18 ^{o}C < 22 ^{o}C, 45% < RH=54% < 55%).

Turcanu et al. (2016), examined the heating systems by using CFD (Computational Fluid Dynamics) simulations and made financial calculations for The Mother of God Church, which was built in 1782 in Jassy, Romania. For January measurements, data logger devices measuring air temperature and relative humidity were placed. Existing static heaters made of cast iron and proposed underfloor heating system were evaluated by simulations. According to the analysis, all the air is heated by static heaters and the heated air tends to rise towards the upper levels of the church, which contains the artworks, and the heat is stratified. However, underfloor heating system spreads the heat more homogeneously in the space. Static heaters damage the artworks due to air movement, and accumulate dust and dirt on them. Underfloor heating system can be fixed at the conservation temperature and thermal comfort can be achieved much faster. In addition, the underfloor heating system increases energy efficiency. As a result, it has been seen that the underfloor heating system is more compatible with the historical church.

Aste et al. (2016) analyzed different heating systems by digital simulations for The Basilica di S. Maria di Collemaggio, built in 1288 in L'Aquila, Italy, and studied on creating a prototype for thermal comfort by pew heating system. Among the various heating system solutions examined, pew heating was considered, both for thermal comfort and for the preservation of artworks. In this study, instead of electric radiant systems, which are generally preferred in terms of energy efficiency, hydronic systems that work with 70% more efficient generation systems such as heat pumps were preferred. After CFD (Computational Fluid Dynamics) analysis, the study confirms that pew heating is an effective solution; because the system provides local thermal comfort, significant energy savings, and preserves the historical building.

Aste et al. (2017) examined the high-efficiency hydronic pew-based heating system designed for The Basilica di S. Maria di Collemaggio in L'Aquila, Italy, in terms of thermal comfort by making PMV calculations, digital model and CFD analyzes. The analysis results showed that the vertical temperature increase in the church was about 2.7°C and therefore did not cause climate changes that could damage the building. After heating, according to PMV calculations, thermal comfort level was acceptable ($-0.3 < PMV < -0.1$).

Varas-Muriel and Fort (2018) examined the heating system and the impact of visitors in the Our Lady of the Assumption Church, whose construction began in the 16th century and was completed in the 18th century, in Algete, Spain. During its restoration in 2006, a natural gas-fuelled, centralised, intermittently operated heating system with network of underfloor hot water (70-80 ºC) pipes was installed. Temperature, relative humidity, dew point, absolute humidity, humidity mixing ratio, air velocity and CO_2 level measurements were conducted in the church. After the measurements, PMV calculations and thermal comfort evaluations, in order to provide thermal comfort and to prevent mechanical deterioration for historical artifacts, only 30 minutes of heating on the weekend was deemed appropriate in the church.

Cannistraro and Restivo (2018) determined the appropriate relative humidity and temperature values for the objects inside the SS. Crucifix Church built in the 17th century in Milazzo, Italy, and made evaluations based on the preservation of historical artifacts.

Measurements were carried out in the summer season, in July and August. The temperature and relative humidity values for preserving organic artifacts should be 21 ºC < T < 23 ºC, 20% < RH < 35%, for religious clothing should be 19 ºC < T < 24 ºC, 30% < RH < 50%. However, the temperature and relative humidity levels were determined to be much higher than these values.

Pałupska and Kanaś (2018), after analyzing the indoor relative humidity and temperature values of the University Church built in Wroclaw in Poland in the 17th century, examined the effects of the existing unused warm-air heating system and the proposed low-temperature radiant heaters. The hot air supplied by the warm-air heating system tends to rise and there is a risk of damaging the wall paintings on the ceiling. Warm-air heating system can cause shrinkage, swelling and cracks on hygroscopic objects. In addition, the decreasing relative humidity for providing thermal comfort in the church makes it difficult to preserve the artifacts. It is thought that the artworks can be preserved in natural climatic conditions, so placing low-temperature radiant heaters, which do not completely change the indoor microclimate in pews, were proposed to provide thermal comfort.

Aste et al. (2019) analyzed the indoor relative humidity and temperature values of the Duomo di Milano (Milan Cathedral), built in Italy in the 14th century, and examined the risk of physical, chemical and biological deterioration of the artifacts (such as wood, stone and metal). In the building, measurements were carried out in two steps. Temperature, relative humidity and air velocity measurements were conducted with portable instruments between February and July 2016 as preliminary measurements. After that, data logger devices installed in the building for long-term measurements, and these measurements were carried out between July 2016 and June 2017. As a result of the analyses, it was found that summer temperatures were above the recommended values (19 ºC < T < 24 ºC, $\Delta T_{max} < 1.5$ ºC) and relative humidity values were close to the upper recommended values (50% < RH < 60%, $\Delta RH_{max} < 4\%$) for preservation of wooden artifacts. It is understood that under these conditions, biodegradation can occur and microorganisms can multiply on wooden artifacts. The daily fluctuation of relative humidity was up to 6% in the building, so this situation causes cracks on objects. Relative humidity values above 60% during February, December, March and May were above the recommended values for the preservation of stone artifacts (15 ºC < T < 25 ºC, 20% < RH < 60%, $\Delta RH_{max} < 10\%$) that can cause the formation of microorganisms. It has been stated that there is a risk of corrosion as the relative humidity values were higher than the recommended value for metal objects (RH < 50%) most of the year.

De Rubeis et al. (2020) analyzed thermo-hygrometric data by using digital simulations for the Santa Maria Annunziata of Roio Church, which was built in the 12th century, which was restored after the earthquake in 2009 in Italy. Afterwards, the necessity of the HVAC system was considered in terms of the preservation of artworks and thermal comfort of the occupants. After the measurements of air temperature, air velocity, relative humidity and solar radiation, it was determined that the temperature and relative humidity levels were below the values required for the preservation of artworks and thermal comfort conditions could not be provided. It has been determined that it is not possible to preserve historical artifacts and provide thermal comfort without the HVAC system, so different scenarios have been tested with DesignBuilder and EnergyPlus software.

1.4.2. Studies on Examining Thermal Comfort by Survey Method in Historical Buildings

Studies on thermal comfort in historical buildings vary in terms of heating, ventilation and air conditioning (HVAC) systems, energy efficiency and economic impact. For thermal comfort analysis, besides the measurements of indoor microclimate variables and digital simulation method, survey method can be applied to the occupants. The studies performed are listed in Table 1.3. By comparing the results of the survey studies with the calculated results, productive results can be obtained.

Yau et al. (2011) compared the PMV-PPD values calculated after air temperature, mean radiant temperature, relative humidity and air velocity measurements and actual mean vote (AMV) values obtained by survey study for thermal comfort analysis for the Muzium Negara (National Museum of Malaysia). They examined thermo-hygrometric conditions and studied on a compatible HVAC system, taking into account the temperature of 15-25 ^{o}C and the relative humidity that should be lower than 60%, according to the ASHRAE Handbook, in order to preserve the artifacts exhibited in the museum. In the survey study, occupants were asked to answer how they felt the temperature of the museum according to the thermal sensation scale with 7 options (3, 2, 1, 0, -1, -2, -3). According to the survey results, the percentage of dissatisfaction was found to be higher than the PPD calculation results and was determined as 22%. This value indicates that the thermal comfort conditions are unacceptable.

Table 1.3. Thermal comfort studies in historical buildings by survey method

References	**Date**	**Location**	**Building**	**Research Topics**				**Research Methods**	
				TC	**D**	**HS**	**EE**	**Q**	**MM**
Yau et al.	2011	Malaysia	National Museum of Malaysia	●	●	●	●	●	●
Tort-Ausina et al.	2016	Spain	Valencia History Museum	●				●	
Martinez-Molina et al.	2018			●				●	●
Ricciardi et al.	2016	Italy	Fraschini Theatre	●		●		●	●

Abbreviations: TC, thermal comfort; D, deteriorations; HS, heating, ventilation and air conditioning (HVAC) systems; EE, energy efficiency; Q, questionnaire survey; MM, microclimatic measurements

Tort-Ausina et al. (2016) conducted a thermal comfort analysis through a survey study at the Valencia History Museum, which was built as an underground water reservoir in 1850 and functioned as a museum after restoration in 1998. The occupants were asked questions about the perceived air temperature, air quality satisfaction, and perceived humidity. According to the results of the study, 65% of the occupants felt the air temperature, 94% the air quality and 81% the humidity sufficient.

Martinez-Molina et al. (2018) studied on thermal comfort analysis of the Valencia History Museum by air temperature, relative humidity, air velocity measurements taken hourly for a year and survey method. Thermal comfort calculations according to Fanger's PMV method and Thermal Sensation Vote (TSV) values according to the thermal sensation scale with 7 options (3, 2, 1, 0, -1, -2, -3) obtained from the survey study have been compared considering the temperature and relative humidity values at which the historical building and artifacts can be preserved. As a result, TSV values were between -1 and +1 (slightly cool - slightly warm), while PMV values were between 0 and -2 (neutral – cool) during the year. According to PMV calculations, the museum was felt colder.

Ricciardi et al. (2016) carried out air temperature, relative humidity, mean radiant temperature, air velocity and floor temperature measurements and survey studies in the case of the heating system on and off for thermal comfort analysis at the Fraschini Theatre, which was built in 1773, restored in 1985, and wooden materials were renewed in 2010. The PMVq (obtained by the survey studies) and PMV (calculated after the measurements) values were compared and the appropriate air temperature values were determined for thermal comfort. The appropriate air temperature was calculated as 24 ^{o}C when the heating system is on and 25 ^{o}C when the heating system is off and determined 23 ^{o}C according to survey studies.

1.5. Structure of the Thesis

The thesis titled "Investigation of the Indoor Microclimate of Historic Agios Voukolos (*Aziz Vukolos*) Church in İzmir to Determine and Improve Thermal Comfort Conditions" consists of six chapters. The first chapter covers problem definition, aim and scope of the study, method of the study and the literature survey.

In the second chapter, general information is given about the definition of thermal comfort, varibles and the effects on historical building elements and artifacts, by use of previous studies and research.

In the third chapter, the study method is explained. Information on the air temperature, relative humidity, air velocity and mean radiant temperature measurements and measurement devices, the formulas to be applied for thermal comfort calculation, and the survey study conducted for the determination of thermal comfort during activities is given.

In the fourth chapter, information about the location, plan and interior characteristics, facade characteristics, construction technique and material use and restoration process of the Agios Voukolos Church is given. In addition, the climatic characteristics of the city of Izmir, where the church is located, are also explained in this section.

In the fifth chapter, the air temperature and relative humidity data measured in the church are analyzed as diagrams and tables. Thermal comfort calculations were made based on the PMV-PPD (Predicted Mean Vote – Predicted Percentage Dissatisfied) method by using hourly and monthly average data of air temperature, relative humidity, air velocity and mean radiant temperature values measured during the year. The AMV (Actual Mean Vote) values were obtained by the survey studies that were applied for the determination of thermal comfort during activities in winter season. The PMV-PPD values were examined and PMV values were compared with AMV values. The effects of the measured air temperature and relative humidity values on the wall paintings were investigated. The results obtained were compared with the results found in similar studies conducted in historical churches. As a result of the determinations, passive and active improvement suggestions were developed in order to improve the thermal comfort in the church.

In the conclusion, which is the sixth chapter, the findings obtained from the study are discussed and evaluated. Suggestions developed as a result of the findings are stated and the importance and contribution of the study are emphasized.

CHAPTER 2

DEFINITION OF THERMAL COMFORT IN HISTORICAL BUILDINGS, VARIABLES AND EFFECTS ON BUILDING ELEMENTS AND HISTORICAL ARTIFACTS

The indoor microclimate is a system that exchanges heat and air with the outdoors and involves all of the physical variables that define the properties of the air in a place. These can be defined as air temperature, mean radiant temperature, humidity, air velocity, indoor pollution variables, light intensity and ultraviolet radiation. Thermal comfort varies according to people's nutrition type, clothing and activities and is related to how individuals feel the warmth in the place. Whereas the indoor microclimate is related to the physical condition of the interior and it is not certain that thermal comfort will be provided (Camuffo, 1998/2014; Cardinale et al., 2014; Pretelli and Fabbri, 2018).

The origin of indoor microclimate can be thought of as people heating natural habitats such as caves with fire. Later, these living spaces were transformed into barracks, wooden, stone and brick structures over time. This transformation enabled energy exchange between indoor and outdoor in winter and reduced solar radiation in summer. Fire and brazier were used until the Middle Ages, then hearth during the Middle Ages, and stoves after the 14th and 15th centuries. This development has played a major role in controlling the indoor microclimate. After the industrial revolution in the 18th century, the concept of indoor air conditioning completely changed and the first steam-powered heating systems using fossil resources or wood emerged. As a result, the indoor microclimate has become artificial and the amount of energy required for thermal comfort conditions can be regulated. In the 20th century, artificial climate control gained momentum with the development of devices that regulate the air conditions. Today, the indoor microclimate can be changed easily by using thermostats (Pretelli and Fabbri, 2018).

2.1. Definition of Indoor Microclimate and Variables

The indoor microclimate is defined as all of the physical variables that describe the weather characteristics in a place. If this situation is evaluated physically, it can be explained as an open system that exchanges mass and energy. Mass exchange is occured by air leakage from doors and windows, which gives movement to substances such as dust and CO_2. Energy exchange is occured by the sun, the presence of people, or the temperature difference between indoor and outdoor spaces caused by changes in absolute and relative humidity (Vuerich et al., 2008; Camuffo et al., 2010a; Cardinale et al., 2014; Pretelli and Fabbri, 2018).

Physical variables can be listed as air temperature (^oC or ^oF), mean radiant temperature (^oC or ^oF), absolute humidity (g_v/m^3), specific humidity (g_v/kg_a), relative humidity (%), air velocity (m/s), CO_2, CO, volatile organic compound (VOC), dust, illuminance (lx) and ultraviolet radiation ($\mu W1m^{-1}$) (Camuffo, 1998/2014; Cardinale et al., 2014; Pretelli and Fabbri, 2018).

2.2. Indoor Microclimate and Alteration in Historical Buildings

According to UNESCO's definition of "cultural heritage", it includes not only monuments and objects, but also traditions and life styles from the past (UNESCO, n.d.). If indoor microclimate studies in historical buildings are also evaluated in this context, it contributes to expanding the knowledge about habits and life styles different from today (Pretelli and Fabbri, 2018). In addition, studies on the indoor microclimate in historical buildings play an important role in the decision to reuse the building and in structural interventions. Studies on indoor microclimate provides thermal comfort improvements in historical buildings, as well as contributes to the conservation of the building and its elements (CEN, 2012; Cardinale et al., 2014; Timur et al., 2017).

The steps required to determine the appropriate indoor microclimate can be specified as follows (CEN, 2012):

- Determination of historic indoor microclimate

- Determination of indoor microclimate for conservation
- Determination of indoor microclimate for thermal comfort
- Determination of the appropriate climate, taking into account the conservation and thermal comfort conditions

The effects that change the indoor microclimate and the feeling of this climate in historical buildings can be listed as follows (Pretelli ve Fabbri, 2018; Fabbri, Pretelli ve Bonora, 2019):

- Physical features such as the geometry and form of the building, changes to the roof, walls, doors or windows, stove, fireplace or modern HVAC systems installed later
- Cultural features such as the clothes of the people, nutritional intake, their habits and rituals

Original indoor microclimate refers to the indoor climate at the time the building was built. Construction technique, openings such as doors and windows, air conditioning methods of the period, positioning according to the sun, seasonal climate changes affect the indoor microclimate. The original indoor microclimate can provide the most suitable indoor microclimate conditions to conserve the building and its elements and it can be created by computer simulation based on historic, climatic and architectural data (Pretelli and Fabbri, 2016; Pretelli and Fabbri, 2018; Fabbri et al., 2019).

Subsequent indoor microclimate refers to the indoor microclimate of the building's historical times, which is formed by changes in the structure. It arises as a result of additions such as roofs, masses, finishing materials, demolished parts and changed air conditioning systems (Pretelli and Fabbri, 2016; Pretelli and Fabbri, 2018; Fabbri et al., 2019).

Actual indoor microclimate is the current microclimate of the building. This climate can be recorded with measurement instruments placed in the building and is determined based on the data obtained. Simulations by using data can also be prepared and used for compatible intervention decisions for thermal comfort improvement (Pretelli and Fabbri, 2016; Pretelli and Fabbri, 2018; Fabbri et al., 2019).

2.3. Definition of Thermal Comfort and Variables

Building performance is a concept that refers to the fact that buildings meet the requirements and purposes for which they were built (De Wilde, 2018). The properties of building components affect the performance of the building. Building performance includes various systems such as energy efficiency, lighting, sewage, drainage, electricity supply, acoustic comfort, visual comfort, indoor air quality and thermal comfort (De Wilde, 2019).

Each building has its own characteristics according to the differences in the internal and external environments of the building (Douglas, 1996). Building performance has a strong relationship with building design and occupants (McDougall et al., 2002) and affects the comfort of occupants (Preiser and Schramm, 2002).

Within building performance systems, thermal comfort refers to the response of a person in particular clothing to the thermal environment at the air temperature associated with particular mean radiant temperature, relative humidity, and air movement (IUPS Thermal Comission, 1973/2001; Kraliková and Sokolová, 2015).

Thermal comfort is defined by the opinions of the people in a space, depending on the subjective feelings about the temperature. In general terms, thermal comfort should be defined as a neutral state, not too cold or too hot. In historical buildings and museums, required thermal environmental conditions for thermal comfort and the preservation of the artifacts and the building may not be the same (ISO, 2005; ASHRAE, 2017).

The idea of building design based on thermal comfort was first put forward by Socrates in 400 BC and he stated how the building should be constructed in order to provide thermal comfort (Auliciems and Szokolay, 1997/2007). Vitruvius also emphasized the need to pay attention to climatic data for building design (Pollio, ca. 80-15 B.C.E./1960). Until the industrial revolution, thermal comfort was not an issue; because the possibilities were limited to provide comfort. Heating technology began to develop from the end of the 18th century, and mechanical cooling from the beginning of the 20th century (Auliciems and Szokolay, 1997/2007). The first serious study on thermal comfort, especially in high temperatures, was conducted by Haldane (Haldane and Priestley, 1905). Later, in the laboratory of the American Society of Heating and Ventilating Engineers (ASHVE), Houghten and Yagloglou tried to define the "comfort zone" (Houghten and Yagloglou, 1923). Vernon, Warner and Bedford conducted experimental studies for factory workers (Vernon and Warner, 1932; Bedford, 1936). Then, analytical studies were continued in the USA by Winslow, Herrington and Gagge (Winslow, Herrington and Gagge, 1937). During and after World War II, research activities increased and many disciplines besides engineering took part in thermal comfort studies (Fabbri, 2015). Victor Olgyay is the first person to compile interdisciplinary studies and explain them for architectural purposes (Olgyay, 1963). Fanger developed the PMV model for describing the thermal comfort by focusing on the physical variables of an environment, the physiological variables of people, and the sense of well-being expressed by people (Fanger, 1967; Fanger, 1970). After the studies developed by Fanger, scientific researches deepened on the physiological basis of comfort, the human body and its dynamics. Today, studies on this subject are still ongoing (Brager and De Dear, 1998; Olesen and Parsons, 2002; Humphreys and Hancock, 2007; Yao et al., 2009; Djongyang et al., 2010; Frontczak and Wargocki, 2011; Mishra and Ramgopal, 2013; Carlucci et al., 2018; Humphreys and Fergus Nicole, 2018; Xu et al., 2018; De Dear et al., 2020; Parkinson et al., 2020).

It is important to improve energy efficiency and thermal comfort conditions of historical buildings to conserve by using them. There may be conflicts between comfort criteria and conservation criteria. In this case, the preservation of the historical building and its values should be a priority (Camuffo et al., 2010b; Frontczak and Wargocki, 2011; CEN, 2012; Cardinale et al., 2014; D'Agostino and Congedo, 2014; Fabbri and Pretelli, 2014; Silva and Henriques, 2014; Martinez-Molina et al., 2016; Litti et al., 2017; Pretlove, 2017; Martinez-Molina et al., 2018; Pałupska and Kanaś, 2018).

The conflicts between thermal comfort and conservation criteria can be solved by following determined steps (CEN, 2012):

- Critical situations related to thermal comfort and conservation are determined.
- Possible solutions are defined.
- Suggestions are evaluated in terms of conservation and thermal comfort.

Thermal comfort analyzes and recommendation for historical buildings are carried out in accordance with the standards (Table 1.1).

2.3.1. Thermal Comfort Estimation Approaches

Generally, Predicted Mean Vote (PMV) model developed by Fanger is used for thermal comfort calculations in buildings. According to this model, thermal comfort is expressed by the people's satisfaction with the thermal environment. The model was created through laboratory studies in the second half of the 1960s. Fanger's work is aimed at determining the thermal condition, which is comfortable for any activity and type of clothing, for the largest percentage of a particular group in the environment (Fanger, 1967). The concepts of Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) are all about people's feelings and opinions (Fanger, 1970).

Actual Mean Vote (AMV) value is obtained by survey method and shows the thermal comfort conditions. The thermal comfort level can be determined by Fanger's 7-point thermal sensation scale and temperature-humidity satisfaction responses in the survey study (Yau et al., 2011; Ricciardi et al., 2016; Tort-Ausina et al., 2016; Martinez-Molina et al., 2018; Pretelli and Fabbri, 2018).

Today, ISO 7730 and ASHRAE Standard 55 documents are used in thermal comfort research.

2.3.1.1. Predicted Mean Vote (PMV)

Predicted Mean Vote (PMV) is an index that estimates the vote value of occupants on a 7-point thermal sensation scale (Table 2.1), from +3 to -3, based on the heat balance of the human body.

Table 2.1. 7-point thermal sensation scale (Source: ISO, 2005)

PMV vote	+3	+2	+1	0	-1	-2	-3
Sensation	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold

2.3.1.2. Predicted Percentage Dissatisfied (PPD)

The Predicted Percentage Dissatisfied (PPD) is an index that estimates the percentage of thermally dissatisfied occupants who feel extremely hot or extremely cold. Thermally dissatisfied people are those who voted hot, warm, cool or cold on the 7-point thermal sensation scale given in Table 2.1 (ISO, 2005). The relation between PMV and PPD is shown in Figure 2.1.

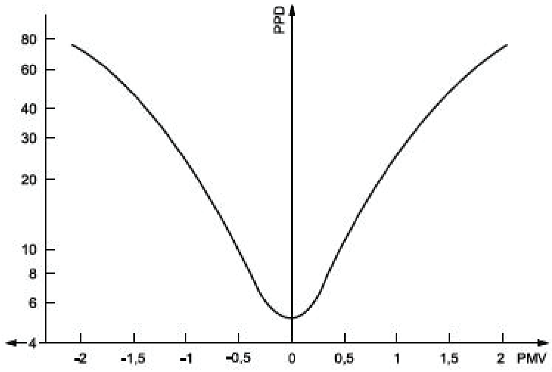


Figure 2.1. Relation between PMV and PPD (Source: ISO, 2005)

Expected indoor air quality conditions for the buildings defined in EN 16798-1 standard as four categories (Table 2.2). Historical buildings must be conserved with their original characteristics, so the requirements for thermal comfort should be evaluated differently from modern buildings. In this direction, thermal comfort requirements of historical buildings have been proposed as Category III according to EN 15251, that is, the old version of EN 16798-1 (Timur, 2019). As seen in Table 2.3, the appropriate PMV values should be between -0.7 and +0.7, and the PPD value should be less than 15%.

Table 2.2. Thermal comfort categories according to building types in EN 16798-1 (Source: CEN, 2019)

Category	**Explanation**
I	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.*
II	Medium level of expectation *and should be used for new buildings and renovations.*
III	Moderate level of expectation *and may be used for existing buildings.*
IV	Low level of expectation. *This category should only be accepted for a limited part of the year.*
The parts in italics have been eliminated in the EN 16798-1 (revision of EN 15251).	

Table 2.3. Acceptable PMV and PPD values according to categories (Source: CEN, 2019)

Category	**Range of Acceptability**	
I	-0.2 < PMV < 0.2	PPD < 6%
II	-0.5 < PMV < 0.5	PPD < 10%
III	-0.7 < PMV < 0.7	PPD < 15%
IV	PMV < -0.7; or 0.7 < PMV	PPD > 15%

2.3.1.3. Actual Mean Vote (AMV)

Thermal comfort can be analyzed by survey method and evaluated with standards. By these surveys thermal comfort as thermal sensation they feel, occupants' activities and clothing can be determined (Yau et al., 2011; Ricciardi et al., 2016; Tort-Ausina et al., 2016; Martinez-Molina et al., 2018; Pretelli and Fabbri, 2018).

Actual Mean Vote (AMV) is obtained by weighted average method of the responses given according to Fanger's 7-point thermal sensation scale. This value indicates the thermal comfort level.

Comparing PMV and AMV values for thermal comfort analysis is important to obtain clear results.

2.3.2. Thermal Comfort Variables

Even if thermal comfort conditions depend on many parameters such as the characteristics of the building, human dimensions, age and gender in terms of people's satisfaction or dissatisfaction, they are grouped as environmental and personal variables. Environmental variables are air temperature, relative humidity, air velocity and mean radiant temperature, and personal variables are metabolic rate and clothing insulation (Fanger, 1967; Parsons, 2002; ISO, 2005; CEN, 2012; ASHRAE, 2017).

2.3.2.1. Environmental Variables

The most effective factors for thermal comfort are environmental factors (Alwetaishi, 2016). When considering thermal comfort, air temperature, relative humidity, air velocity and mean radiant temperature, which are considered as environmental variables, are the primary factors (Parsons, 2002; ASHRAE, 2017).

2.3.2.1.1. Air Temperature

Air temperature (^{o}C, ^{o}F) is the temperature read on a thermometer in a location exposed to air but protected from direct sunlight or other energy sources (Camuffo, 1998/2014; CEN, 2010b; Camuffo et al., 2010a; Larsen and Broström; 2015). Air temperature values depend on external climatic conditions, especially outside air temperature and solar radiation, internal heat load (presence of people, devices and machines), natural ventilation and heating systems (Larsen and Broström, 2015; Pretelli and Fabbri, 2018). In addition, air temperature values are related to relative humidity depending on the change of water vapor in the air (humidification - dehumidification) (Camuffo, 1998/2014; Pretelli and Fabbri, 2018).

Humans are very sensitive to temperature and therefore air temperature is the most important environmental variable for thermal comfort (Hanqing et al., 2006; Van Hoof and Hensen, 2007; Metje et al, 2008; Bratasz, 2013). In addition to using thermometers for air temperature measurement, data logger devices are used to monitor and record temperature changes (CEN, 2010b; Larsen and Broström, 2015). There should be at least 3 minute cycles during air temperature measurement, these cycles can be extended up to 15 minutes (ASHRAE, 2017).

2.3.2.1.2. Relative Humidity

Relative humidity (% RH) is the ratio of actual vapor pressure to saturation vapor pressure (CEN, 2010a). It is affected by temperature, and if the temperature increases, the relative humidity decreases (Camuffo, 1998/2014; Pretelli and Fabbri, 2018). Relative humidity can be calculated using Formula 2.1.

$$RH = (\text{Actual vapor pressure} / \text{Saturation vapor pressure}) \times 100 \qquad (2.1)$$

Humidity level can be changed in the air by ventilation, weather conditions (rain, fog, sun), presence of people (breathing, perspiration), heating systems, humidification systems and wet spaces (Larsen and Broström, 2015; Pretelli and Fabbri, 2018).

For the measurement of relative humidity, the use of wet bulb thermometer, dry bulb thermometer and psychometric diagram is common. Data logger devices are widely used in studies (Camuffo et al., 2010a; Larsen and Broström, 2015; Pretelli and Fabbri, 2018). The average of relative humidity is used for calculations as well as air temperature (ASHRAE, 2017).

The effect of humidity in terms of thermal comfort depends on air temperature and air velocity. High humidity in hot regions is an important problem as it will prevent sweating required to cool the skin (Parsons, 2002). Values of relative humidity between 40-70% do not have significant effects on thermal comfort (Yang et al., 2014). According to the EN 15759-1 standard, considering thermal comfort, the relative humidity should be kept in the range of 30-80% (CEN, 2012).

2.3.2.1.3. Air Velocity

Air velocity (m/s) is the total airflow in a space. It can occur as a result of the following factors (Larsen and Broström, 2015; Pretelli and Fabbri, 2018):

- Convection movements associated with temperature and pressure difference and vertical stratification of air at the upper level of the building,
- Convection movements close to surfaces with different temperature than air, such as cold walls, windows, roofs and heaters,
- Air leakage caused by the pressure difference between air volumes (It is a common situation caused by openings in windows and doors in historical buildings),
- Large volume air movements as a result of temperature and pressure difference through natural ventilation,
- The movement of the air volume with the instrument used, through mechanical ventilation.

Air velocity is measured by an anemometer. There are also electronic measuring devices developed for indoor air velocity measurement. Measurements should be conducted with a maximum cycle of 3 minutes, increasing the cycle time may result in different air velocity averages (ASHRAE, 2017). The air velocity value generally varies between 0 m/s (still air) and 1.5-2 m/s (natural or mechanical ventilation) (Pretelli and Fabbri, 2018).

It is an important factor as people are sensitive to air velocity and can create a cooling effect by evaporating moisture from the skin (Auliciems and Szokolay, 1997/2007; Yang et al., 2014) and the air velocity affects the convective heat exchange between the person and the environment (ISO, 2005). It can provide heating or cooling of the place together with indoor conditions such as indoor air temperature and relative humidity (Hall, 2010). Passive or active systems that provide inhomogeneous air velocity can cause excessive heat losses (ASHRAE, 2017).

According to ASHRAE Standard 55, it is stated that the maximum air velocity of 0.2 m/s is appropriate. Even if the air temperature is high, excessive air velocity has disturbing effect (ASHRAE, 2017). Also, if the weather is cool or cold, air movement can have a negative effect on thermal comfort, so air movement should be minimal (CEN, 2005; CEN, 2012).

2.3.2.1.4. Mean Radiant Temperature

According to ISO 7726 (1998), the mean radiant temperature is explained as “the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure” (p. 2). Mean radiant temperature is also defined as the average temperature emitted from objects in the environment (HSE, 2012). In some cases, this factor may be more effective than the air temperature. While the most important factor to consider may be the sun, stoves, dryers, ovens and hot surfaces may also be important factors affecting radiant temperature (HSE, 2012).

Mean radiant temperature cannot be measured directly; however, it can be approximated by globe thermometer measurements. The globe thermometer is a matte black copper sphere, usually 150 mm in diameter, with a thermometer in its center (Auliciems and Szokolay, 1997/2007).

The comfort zone can also be calculated with the operative temperature (combination of air temperature and mean radiant temperature), which provides acceptable thermal conditions. It can be calculated using Formula 2.2 for occupants who are not exposed to direct sunlight and air velocity higher than 0.20 m/s and have physical activity that can be considered sedentary (1.0 – 1.3 met) (ASHRAE, 2017).

$$t_o = (t_a + t_r) / 2 \tag{2.2}$$

t_o = operative temperature, t_a = air temperature, t_r = mean radiant temperature

2.3.2.2. Personal Variables

When calculating thermal comfort, the activity status and clothing of the occupants should be taken into account. Significant differences should be considered in physical activity, which affects occupants' metabolic rate, and clothing that affects clothing insulation (Alwetaishi, 2016; ASHRAE, 2017).

2.3.2.2.1. Metabolic Rate

Metabolic rate (met) is a measure of metabolism that describes the power (W/watt) per square meter (m^2) of an individual's skin. Therefore, this value is a measure of energy per surface unit and time unit (Pretelli and Fabbri, 2018).

The "met" is a defined unit of measurement for determining the "sitting-resting" metabolic rate of human (1 met = 58.15 W/m^2). In other words, it is a unit of measurement used to express the metabolic rate of a person with an insulating value of 1 clo while sitting (IUPS Thermal Comission, 1973/2001). Table 2.4 shows metabolic rate values according to different activities.

A difference of 0.1 met in metabolic rate can cause a thermal change equal to 1 ^oC. Likewise, a difference of 0.4 met can cause a temperature difference of 2.5-3 ^oC. This indicates that different activities produce different thermal change (ISO, 2005).

Table 2.4. Metabolic rate values according to different activities (Source: ISO, 2005)

Activity	**Metabolic Rate**	
	W/m^2	**met**
Reclining	46	0.8
Seated, relaxed	58	1.0
Sedentary activity (office, dwelling, school, laboratory)	70	1.2
Standing, light activity (shopping, laboratory, light industry)	93	1.6
Standing, medium activity (shop assistant, domestic work, machine work)	116	2.0
Walking on level ground:		
2 km/h	110	1.9
3 km/h	140	2.4
4 km/h	165	2.8
5 km/h	200	3.4

2.3.2.2.2. Clothing Insulation

In prehistoric times, people used animal fur to protect themselves from the cold. Both clothes and skin can be thought of as insulation that protects people from the environment (De Carli et al., 2007).

It is important to know the thermal resistance of clothing when calculating thermal comfort. Its unit is “clo” (1 clo = 0.155 m^2K/W) (ASHRAE, 2017). The “clo”, a unit developed to express thermal insulation, represents the isolation on the person (IUPS Thermal Comission, 1973/2001).

Clothing keeps the body in an acceptable thermal condition for different climates (Oliveira et al., 2011). In cold weather, warm clothing reduces the cooling of the body and therefore less heating is needed. It can be uncomfortable if a person's body is partly warm and partly cold (CEN, 2012). Thermal insulation values of some clothing combinations are shown in Table 2.5.

Table 2.5. Thermal insulation values of some clothing combinations
(Source: ISO, 2005)

Daily Wear Clothing	I_{cl}	
	clo	**m^2K/W**
Panties, T-shirt, shorts, light socks, sandals	0.30	0.050
Underpants, shirt with short sleeves, light trousers, light socks, shoes	0.50	0.080
Panties, petticoat, stockings, dress, shoes	0.70	0.105
Underwear, shirt, trousers, socks, shoes	0.70	0.110
Panties, shirt, trousers, jacket, socks, shoes	1.00	0.155
Panties, stockings, blouse, long skirt, jacket, shoes	1.10	0.170
Underwear with long sleeves and legs, shirt, trousers, V-neck sweater, jacket, socks, shoes	1.30	0.200
Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	1.50	0.230

2.4. Effects of Indoor Microclimate in Historic Buildings on the Building Elements and Historical Artifacts

“Historical climate” is the climatic conditions in a microenvironment where the cultural heritage object is protected and acclimatized all the time or for a long time (at least one year) (CEN, 2010a). However, in today's conditions, it is not possible to determine the indoor climatic conditions that protected the historical artifacts centuries ago.

All disciplines working on historical buildings share the aim of conserving the building and its elements. To achieve this goal, they examine the causes of deteriorations and develop the best strategies to slow or prevent them. Changes and deteriorations in the building and material component of the building cannot be studied by ignoring the indoor microclimate conditions. Without this information, understanding of deterioration phenomenon is insufficient or incomplete (Camuffo, 1998/2014; Camuffo et al., 2010a; Silva and Henriques, 2014; Şahin et al., 2017; Muñoz-Gonzáles et al., 2018; Pretelli and Fabbri, 2018).

Today, indoor microclimate conditions in modern buildings can be controlled simply by using Heating, Ventilation, and Air Conditioning (HVAC) systems; but it is not possible to do this in historical buildings. Some historical buildings have unique architectural features and hygrothermal (thermal and humid) behaviors. HVAC systems can change indoor microclimate conditions in a way that stresses the building and the objects it contains (Padfield et al., 2007; Fabbri, 2013; Pretelli et al, 2013; Litti and Audenaert, 2014; Schito and Testi, 2017; Şahin et al., 2017). The building and the artifacts bear traces of the previous climate that damaged them. Even if the indoor microclimate of the building is changed later, the effect of unsuccessful weather conditioning cannot be reversed (Larsen and Broström, 2015; Pałupska and Kanaś, 2018).

Determination of indoor microclimate variables is important to identify deterioration risks for buildings and artworks. Deterioration occurs as a result of indoor microclimate variables such as relative humidity, air temperature and air pollution which are unsuitable for the building and its elements (La Gennusa et al., 2005; Vuerich et al., 2008; Fabbri and Pretelli, 2014; Cardinale et al., 2014; Cannistraro and Restivo, 2018; Pretelli and Fabbri, 2018; Aste et al., 2019).

2.4.1. Effects of Relative Humidity and Temperature on Deterioration

In particular, by providing suitable values for air temperature and relative humidity, deterioration can be prevented so that objects can be preserved. The appropriate value ranges for relative humidity and temperature may vary depending on the material and the condition of the object. Some objects may be made with a combination of different materials. The preservation situation can become more complicated as the range of values for each material to be preserved in terms of relative humidity and air temperature is different (UNI, 1999; Larsen and Broström, 2015; Cannistraro and Restivo, 2018).

2.4.1.1. Relative Humidity

For historical buildings and artifacts, relative humidity is the most common cause of deterioration due to the hygroscopicity of materials. Hygroscopic material is a substance that absorbs moisture when the relative humidity increases and gives moisture when the relative humidity decreases (CEN, 2010a). Cyclic changes in relative humidity can cause physical damage to organic hygroscopic materials such as wood, fabric, paintings and books (Pałupska and Kanaś, 2018; Pretelli and Fabbri, 2018).

Relative humidity is the most critical variable in terms of conservation and should be kept as constant as possible at the required level. Relative humidity depends on moisture content and air temperature (CEN, 2012).

Mechanical deterioration occurs as a result of short-term relative humidity fluctuations hourly, daily and weekly. The main reason for this deterioration is the expansion and shrinkage of the material (Bülow, 2002; CEN, 2012; Martens, 2012; Larsen and Broström, 2015; Cannistraro and Restivo, 2018; ASHRAE, 2019). Thus, it may cause irreversible physical damage (Bülow, 2002). Fluctuation of +/- 10% in the relative humidity value is acceptable for many materials (Larsen and Broström, 2015).

An upper limit for the relative humidity level should be determined to prevent biological deterioration such as mold, rot, infestation and corrosion of some metals, and a lower limit should be determined to prevent the materials from becoming brittle (Camuffo, 1998/2014; Huijbregts et al., 2010; CEN, 2012; Silva and Henriques, 2015; Pałupska and Kanaś, 2018; ASHRAE, 2019). The risk of biological deterioration is very high at a relative humidity of more than 65% and air temperature higher than 20 ºC (Aghemo et al., 1996; Larsen and Broström, 2015; Cannistraro and Restivo, 2018).

Equilibrium Moisture Content (EMC) is the moisture content of a hygroscopic material at particular relative humidity and air temperature level, when it does not absorb or release moisture (CEN, 2010a). The EMC value of each material is at a certain level in order to prevent chemical, physical or biological deterioration. When EMC is too low or too high, relative humidity becomes a risk factor (Camuffo, 1998/2014; CEN, 2010a; ASHRAE, 2019).

2.4.1.2. Air Temperature

The air temperature must be controlled to preserve the materials. Air temperature may be a variable that affects deterioration, or it may also have an indirect effect with relative humidity (Camuffo, 1998/2014; CEN, 2012). In order to prevent condensation on sensitive surfaces, the temperature should be kept above the dew point (Camuffo, 1998/2014; CEN, 2012).

It can cause changes in the size of objects with temperature change or objects can become brittle at low temperatures. Also, low values can cause mold growth on objects or decay of organic objects (Camuffo, 1998/2014; Larsen and Broström, 2015; Cannistraro and Restivo, 2018; ASHRAE, 2019).

At high temperature, harmful chemical processes are accelerated and together with absorbed moisture cause rapid chemical deterioration of objects, especially paper-based ones. Low temperature and relative humidity conditions are required to prevent chemical deterioration of artifacts. Generally, temperature of 20 ºC and relative humidity of 50% is recommended (CEN, 2012; Martens, 2012; Larsen and Broström, 2015; ASHRAE, 2019). It can also cause excessive dryness and dust formation with high temperature and low relative humidity levels. Both air temperature and relative humidity values should be controlled (ASHRAE, 2019).

The temperature tends to increase stratification in the upper part of the place. This temperature difference can occur at different times of the day or at different times of the year. This situation, called thermal gradient, can cause deterioration of the building and artifacts (Pretelli and Fabbri, 2018).

The air temperature and relative humidity values required for the preservation of historical artifacts are specified in the standards according to different materials and deterioration (Table 2.6, 2.7, 2.8, 2.9 and 2.10).

Table 2.6. Recommended air temperature and relative humidity values to prevent physical and chemical deterioration of materials (Source: MiBAC, 2001)

	Air temperature (ºC)	Relative humidity (%)
Iron armors, weapons		< 40
Ivory, bones	19-24	45-65
Bronze		< 55
Paper, papier-mâché	19-24	50-60
Anatomical collections	19-24	40-60
Mineralogical collections, marbles, stones	< 30	45-60
Leather, hides, parchment		50-60
Discs, magnetic tapes	10-21	40-60
Herbaria and botanical collections	-5-15	40-60
Film	2-20	30-50
Pictures	19-24	20-30
Insects and entomological collections	19-24	40-60
Oriental lacquers	19-24	50-60
Wood	19-24	40-65
Painted wood, polychrome sculptures	19-24	45-65
Manuscripts	19-24	50-60
Ethnographic material	19-24	40-60
Generic organic material	19-24	50-65
Plastic material		30-50
Metals and polished alloys, brass, silver, pewter, lead, copper		< 45
Inlaid and lacquered furniture	19-24	50-60
Mosaics, frescoes, and wall paintings	Min 6ºC (winter) Max 25ºC (summer)	45-65
Gold		< 45
Papyri	19-24	35-50
Pastel, watercolor paintings, drawings, prints	19-24	50-60
Fur, feathers	15-21	45-60
Paintings on canvas	19-24	35-50
Porcelain, pottery, terracotta		20-60
Silk		50-60
Fabrics, carpets, tapestry		40-60
Glass and stable glass windows		25-60

Table 2.7. Recommended air temperature and relative humidity values to prevent biological deterioration of materials (Source: MiBAC, 2001)

Organic artifacts		Air temperature (°C)	Max daily variation	Relative humidity (%)	Max daily variation
Paintings	On canvas	19-24	1.5	40-55	6
	On panel	19-24	1.5	50-60	2
Wood		19-24	1.5	50-60	2
	Archeological	19-24	1.5	50-60	2
	Wet	< 4		-	
Paper		18-22	1.5	40-55	6
	Pastel, watercolor paintings	< 10		< 65	
	Books and manuscripts	< 21	3	45-55	5
	Graphic material	< 21	3	45-55	5
Leather, hide, parchment		4-10	1.5	40-55	5
	Cellulosic	19-24	1.5	30-50	6
	Protein based	19-24	1.5	>50-55	
Ethnographic collections		15-23	2	20-35	5
Stable materials		-30		35-65	

Table 2.8. Air temperature and relative humidity values required for the preservation of organic objects (Source: UNI, 1999)

	Air temperature (°C)	Max excursion air temperature (Δ°C)	Relative humidity (%)	Max excursion relative humidity (Δ%)
Artistic artifacts in paper, tissue paper, papier-mâché, tapestry	18-22	1.5	40-55	6
Fabrics, curtains, carpets, fabric tapestry, silk, costumes, clothes, religious vestments, objects in natural fibers, sisal, jute	19-24	1.5	30-50	6
Wax, anatomic waxes	< 18	Not relevant	Not relevant	Not relevant
Herbaria and collections	21-23	1.5	45-55	2
Entomological collections	19-24	1.5	40-60	6
Animals and anatomical organs in formalin	15-25	-	Not relevant	Not relevant
Dried animals and anatomical organs, mummies	21-23	1.5	20-35	-
Fur, feathers, stuffed animals	4-10	1.5	40-50	5
Drawings, watercolor paintings and others on paper support	19-24	1.5	45-60	6
Ethnographic collections, masks, leather, leather clothes	19-24	1.5	45-60	6
Paintings on canvas, oil on canvas, gouache	19-24	1.5	45-55	6

(cont. on next page)

Table 2.8. (cont.)

	Air temperature (°C)	Max excursion air temperature (Δ°C)	Relative humidity (%)	Max excursion relative humidity (Δ%)
Paintings on canvas, oil on canvas, gouache	19-24	1.5	45-55	6
Documents from archieves on paper or parchment, papyri, manuscripts, printed volumes, philatelic collections	13-18	-	50-60	5
Book ligatures in leather or parchment	19-24	1.5	45-55	6
Lacquers, inlaid, lacquered and decorated furniture	19-24	1.5	50-60	4
Wooden polychrome sculptures, painted wood, paintings on wood, icons, wooden musical instruments, wooden pendulum clocks	19-24	1.5	50-60	4
Wooden non-painted sculptures, wicker objects, wooden or bark panels	19-24	1.5	45-60	4

Table 2.9. Air temperature and relative humidity values required for the preservation of inorganic and compound objects (Source: UNI, 1999)

	Air temperature (°C)	Max excursion air temperature (Δ°C)	Relative humidity (%)	Max excursion relative humidity (Δ%)
Porcelain, pottery, terracotta, shingle not from excavations or deprived of minerals from excavations	Not relevant	-	Not relevant	10
Porous stones, rocks, minerals and meteorites	19-24	-	40-60	6
Stone mosaics, nonporous stones, rocks, minerals and meteorites, fossils, stone collections	15-25	-	20-60	10
Metals, polished metals, metallic alloys, silvers, armors, bronzes, coins, copper, iron, steel, lead, pewter and tin objects	Not relevant	-	< 50	-
Metals with active corrosion sites	Not relevant	-	< 40	-
Gold	Not relevant	-	Not relevant	-
Chalk	21-23	1.5	45-55	2
Instable, iridescent, sensitive glasses or glass mosaics	20-24	1.5	40-45	-
Mixed Objects				
Wall paintings, frescoes, sinopias	10-24	-	55-65	-
Wall dry paintings	10-24	-	50-65	-
Ivories, horns, malacological collections, eggs, nests, corals	19-24	1.5	40-60	-
Phonographic disks	10-21	-	40-55	2

(cont. on next page)

Table 2.9. (cont.)

	Air temperature (°C)	Max excursion air temperature (Δ°C)	Relative humidity (%)	Max excursion relative humidity (Δ%)
Synthetic fibers	19-24	-	40-60	-
Film, colored pictures	0-15	-	30-45	-
Film, b/w pictures	0-15	-	40-60	-
Magnetic tapes (excluded tapes for computer and videotape)	5-15	-	40-60	-
Organic objects coming from wet excavation sites (before treatments)	< 4	-	Saturated air	-
Plastic materials	19-24	-	30-50	-

Table 2.10. Required indoor microclimate conditions for preservation of collections (Source: ASHRAE, 2011)

Type	**Set Point or Annual Average**	**Maximum Fluctuations and Gradients in Controlled Spaces**		
		Class of Control	**Short Fluctuations plus Space Gradients**	**Seasonal Adjustments in System Set Point**
General Museums, Art Galleries, Libraries, and Archives All reading and retrieval rooms, rooms for storing chemically stable collections, especially if mechanically medium to high vulnerability	50% RH (or historic annual average for permanent collections) Temperature set between 15 and 25 °C *Note*: Rooms intended for loan exhibitions must handle set point specified in loan agreement, typically 50% RH, 21 °C, but sometimes 55% or 60% RH.	**AA** Precision control, no seasonal changes, with system failure fallback	±5% RH, ±2 K	RH no change; Up 5 K, down 5 K
		A Precision control, some gradients or seasonal changes, not both, with system failure fallback	±5% RH, ±2 K	Up 10% RH, down 10% RH; Up 5 K, down 5 K
			±10% RH, ±2 K	RH no change; Up 5 K, down 10 K
		B Precision control, some gradients plus winter temperature setback	±10% RH, ±5 K	Up 10% RH, down 10% RH; Up 10 K but not above 30 °C
		C Prevent all high-risk extremes	Within 25 to 75% RH year-round Temperature rarely over 30 °C, usually below 25 °C	
		D Prevent dampness	Reliably below 75% RH	

2.5. Heating of Historic Churches with Compatible Methods

Historical churches do not have an original heating system (Samek et al., 2007). The indoor microclimate of buildings without a heating system is only affected by the outdoor climate, building envelope, air exchange and activities in the building (Nilsson and Broström, 2008; CEN, 2012). In the 19th century, churches started to be heated with wood and coal-burning stoves, but the place was felt very hot by those sitting next to the stove and very cold by those sitting far from the stove. Then, a local heating system was implemented, which heats the pews with hot water or steam created by an oil or coal-burning boiler. With the increasing demand for thermal comfort after World War II, central heating systems were used in churches with methods such as warm-air heating and floor heating (Limpens-Neilen, 2006; Bolorforoush, 2014).

Before choosing a heating system for thermal comfort in historical buildings, outdoor climate, indoor climate and its effects on historical buildings and artifacts, conservation requirements, technical features of the system, and installation-maintenance cost of the system should be examined (Pałupska and Kanaś, 2018). It is recommended to pay attention to the following for heating system changes in historical buildings (CEN, 2012):

- The priority should be that the system to be applied is not long-lasting, but that it does not damage the building.
- The selected heating system should not attract attention visually.
- The light and sound produced by the system should be considered.
- Systems that will cause intervention on walls or floors should not be applied without expert opinion.
- Structural changes should not be made for elements such as ducts, cables and pipes unless necessary.

Heating systems are divided into two as general heating and local heating according to the distribution of heat to the space. General heating refers to heating the building as a whole, with historical objects and occupants (Camuffo et al., 2010b; CEN, 2012; Pałupska and Kanaś, 2018). Local heating refers to heating some parts of the building. The temperature increase throughout the building is considerably less compared to the heated area. Undesirable climatic changes throughout the building can be prevented by this method (Nilsson and Broström, 2008; Camuffo et al., 2010b; CEN, 2012; Larsen and Broström, 2015; Aste et al., 2016; Aste et al., 2017).

Heating systems are divided into two as continuous heating and intermittent heating according to timing. Continuous heating refers to the heating of the building during the cold period (CEN, 2012; Pałupska and Kanaś, 2018). The negative side of this type of heating is that it creates a risk of particle deposition and thermal stratification (Camuffo et al., 2010b; CEN, 2012; Turcanu et al., 2016). Intermittent heating is a form of heating space within a limited time. With this method, climatic change can occur in the building for a while; but it can be properly designed and managed (CEN, 2012; Munõz-González et al., 2018). Intermittent heating systems consume less energy than continuous heating (Pałupska and Kanaś, 2018). However, this method can cause particle deposition, cold draughts and condensation (CEN, 2012).

While providing thermal comfort, the heating system to be preferred should be compatible with the historical building and not to damage it. The EN 15759-1 standard can be used in selecting the appropriate heating system for historical churches. In its content, information is given about the positive and negative aspects of some heating systems in the heating of historical churches. These heating systems are warm-air heating, infrared heating (IR), radiator heaters, heating with pipes placed in the wall, underfloor heating and pew heating (CEN, 2012).

CHAPTER 3

METHOD OF THE STUDY

The method of the study consists of on-site examination, on-site measurements of microclimate parameters, thermal comfort calculations and surveys. In the study, computer modeling technology was not used, only on-site measurements were conducted. It is thought that by on-site measurements of air temperature, humidity, mean radiant temperature and air velocity parameters, it will provide reliable data for the evaluation of the current situation.

Information about plan and spatial characteristics, construction technique and material use and restoration interventions of the Agios Voukolos Church were determined from published sources (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014). The plan, elevation and section drawings showing the current state of the building were obtained from the archives of İzmir Institute of Technology, Faculty of Architecture, Department of Conservation and Restoration of Cultural Heritage (Yardım et al., 2004-2007).

3.1. On-Site Measurements

Air temperature, relative humidity, mean radiant temperature and air velocity measurements were conducted after selecting suitable places for measurement devices in the church. Measurements were made between 9 July 2019 – 22 May 2020, but June 2020 measurements could not be obtained due to COVID-19 epidemic.

3.1.1. Air Temperature and Relative Humidity Measurements

The measurements were carried out with data logger devices that measure air temperature and relative humidity, which are shown in Figure 3.1 and whose properties are given in Table 3.1.

Figure 3.1. HOBO U12-012 data logger device (Source: Onset, 2019)

Table 3.1. Properties of HOBO U12-012 data logger device (Source: Onset, 2019)

Measuring Range	
Air Temperature:	-20 ºC – 70 ºC
Relative Humidity:	5% - 95%
Accuracy	
Air Temperature:	Between 0ºC – 50ºC, ± 0.35ºC
Relative Humidity:	Between 10% - 90%, ± %2.5

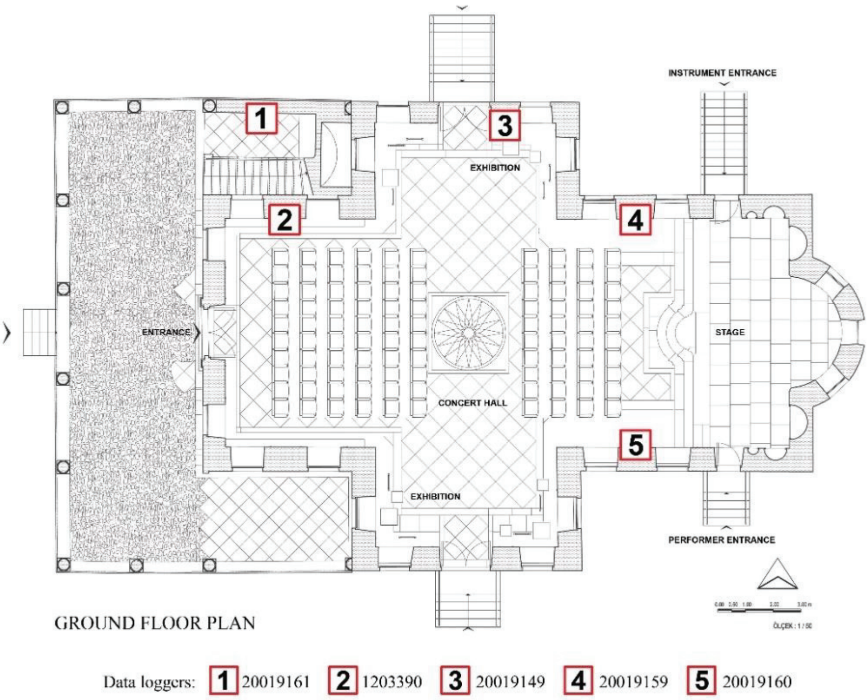


Figure 3.2. Air temperature and relative humidity data logger device locations on the ground floor (Drawing source: Yardım et al., 2004-2007)

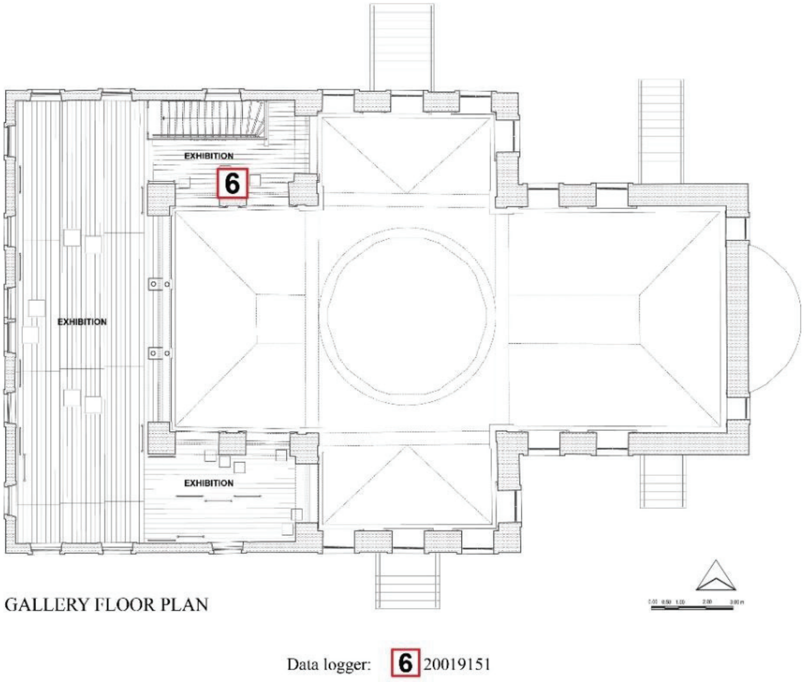


Figure 3.3. Air temperature and relative humidity data logger device locations on the gallery floor (Drawing source: Yardım et al., 2004-2007)

While placing the data logger devices, the locations of the seating units were taken into account in order to examine the thermal comfort conditions for occupants. Therefore, no data logger device was placed in the apse. In addition, it was not desired to damage the wall paintings as a result of placing the devices in the niches. Considering the south wall, which is heated by the sun, may cause a misleading effect on the measurements, most of the data logger devices were placed in the north and care was taken to ensure that the devices were not exposed to direct sunlight. The device No. 6 on the gallery floor was placed approximately at the same level in the vertical direction in order to compare the data collected with the device No. 2 on the ground floor. Considering the height of the church, the devices were placed at a height of approximately half the walls for the ground floor and gallery floor, at a height of 3.00 m on the ground floor and 2.50 m on the gallery floor. The locations of the devices are indicated in Figure 3.2 and 3.3.

The device No. 1 with serial number 20019161 was placed on the upper part of the window on the north exterior wall of the stairwell, on the ground floor, and care was taken not to expose it to wind, precipitation and direct sunlight. Considering the size of the space, the device No. 2 with serial number 1203390 between the windows on the north wall at the entrance, the device No. 3 with serial number 20019149 on the north wall of the cross arm in the north-south direction, on the surface between the window and the door, the device No. 4 with serial number 20019159 between the windows on the north wall of the apse, the device No. 5 with serial number 20019160 between the windows on the south wall of the apse, the device No. 6 with serial number 20019151 on the north wall facing the gallery space on the gallery floor were placed for the collection of air temperature and relative humidity data of the church. While placing the devices on the walls, care was taken not to damage the building. After the devices were removed, the places where the devices were mounted were repaired using the same wall paint.

Measurements were made between 9 July 2019 – 22 May 2020, covering all seasons, and the measurement values were recorded with a 10-minute cycle. The data were transferred from the devices to the electronic environment with the HOBOware software using the connection cable.

(a) (b) (c)

Figure 3.4. Data transfer from data logger No. 2 to digital environment (07.08.2019), a) Data logger No. 2, b) Attaching a connecting cable to the device, c) Data transfer

3.1.2. Mean Radiant Temperature Measurements

Mean radiant temperature and air velocity measurements were conducted by attaching the required probe (Figure 3.5) to the Testo 400 - The multi-function meter/logger device (Figure 3.6). The Testo 400 dual-channel instrument is a multi-parameter handpiece for carrying out indoor air quality measurements, including air temperature, relative humidity, air velocity, pressure, carbon dioxide and carbon monoxide. The instrument can be used as a complete recording system and can be connected directly to a computer (Testo, 2004).

The globe thermometer probe was placed in the middle of the cross plan, taking into account the positions of the seating units, and at a height of 90 cm relative to the seated individual, as seen in Figure 3.7. Also care was taken not to be exposed to direct sunlight. Measurements were conducted every fifteen days and at event times, covering all seasons, and the measurement values were recorded with a 2-minute cycle. During the events, continuous measurements could not be conducted in terms of the safety of the devices.

Figure 3.5. Globe thermometer probe measuring mean radiant temperature (Source: Testo, 2004)

Figure 3.6. Testo 400 – The multi-function meter/logger (Source: Testo, 2004)

Table 3.2. Properties of globe thermometer probe (Source: Testo, 2004)

Mean Radiant Temperature	
Measuring Range	0 ºC – 120 ºC
Accuracy	Between 0 ºC – 49.9 ºC, ± 0.5ºC Between 50ºC – 120ºC, ± 1ºC

(a) (b) (c)

Figure 3.7. Mean radiant temperature measurement with a globe thermometer (15.11.2019), a) Placement of the globe thermometer in the space, b) Mean radiant temperature measurement setting, c) Testo 400, which records and displays the values

3.1.3. Air Velocity Measurements

Testo 400 - The multi-function meter/logger instrument (Figure 3.6) and a three-function probe (Figure 3.8) measuring air temperature, relative humidity and air velocity were used for air velocity measurement.

Three-function probe was placed in the middle of the cross plan, taking into account the positions of the seating units, and at a height of 90 cm relative to the seated individual, as seen in Figure 3.9. Measurements were conducted every fifteen days and at event times, covering all seasons, and the measurement values were recorded with a 2-minute cycle. During the events, continuous measurements could not be conducted in terms of the safety of the devices.

Figure 3.8. Three-function probe used for air velocity measurement (Source: Testo, 2004)

Table 3.3. Properties of three-function probe (Source: Testo, 2004)

Air Velocity	
Measuring Range	0 m/s – 10 m/s
Accuracy	Between 0 m/s – 10 m/s, ± (0.03 m/s ± %0.5 of mv)

```
NONAME
15.11.19    12:02:00
Val:           1
  %        °C     m/sn
 53.6     22.3    0.00
 53.5     22.3    0.00
 53.5     22.4    0.00
 53.3     22.5    0.00
 53.1     22.6    0.00
```

(a) (b)

Figure 3.9. Air velocity measurement with three-function probe (15.11.2019), a) Placement of the three-function probe in the space, b) Recording of air velocity measurement data

3.2. Thermal Comfort Calculations

As a result of the measurements, Fanger's PMV-PPD (Predicted Mean Vote - Predicted Percentage Dissatisfied) method was used to determine the thermal comfort of the church, and the threshold values specified in ISO 7730 were taken into account in the evaluation of the results.

PMV value can be calculated using Formulas 3.1, 3.2, 3.3 and 3.4 (ISO, 2005):

$$PMV = [0{,}303 \,.\, \exp(-0{,}036 \,.\, M) + 0{,}028] \,.$$
$$\{(M - W) - 3{,}05 \,.\, 10^{-3} \,.\, [5733 - 6{,}99 \,.\, (M - W) - p_a] - 0{,}42 \,.\, [(M - W) - 58{,}15]$$
$$- 1{,}7 \,.\, 10^{-5} \,.\, M \,.\, (5867 - p_a) - 0{,}0014 \,.\, M \,.\, (34 - t_a)$$
$$- 3{,}96 \,.\, 10^{-8} \,.\, f_{cl} \,.\, [(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl} \,.\, h_c \,.\, (t_{cl} - t_a)\} \qquad (3.1)$$

$$t_{cl} = 35{,}7 - 0{,}028 \,.\, (M - W) - I_{cl} \,.\, \{3{,}96 \,.\, 10^{-8} \,.\, f_{cl} \,.\, [(t_{cl} + 273)^4 - (t_r + 273)^4]$$
$$+ f_{cl} \,.\, h_c \,.\, (t_{cl} - t_a)\} \qquad (3.2)$$

$$h_c = 2{,}38 \,.\, |t_{cl} - t_a|^{0{,}25} > 12{,}1 \,.\, \sqrt{v_{ar}} \quad \text{ise} \quad 2{,}38 \,.\, |t_{cl} - t_a|^{0{,}25}$$
$$2{,}38 \,.\, |t_{cl} - t_a|^{0{,}25} < 12{,}1 \,.\, \sqrt{v_{ar}} \quad \text{ise} \quad 12{,}1 \,.\, \sqrt{v_{ar}} \qquad (3.3)$$

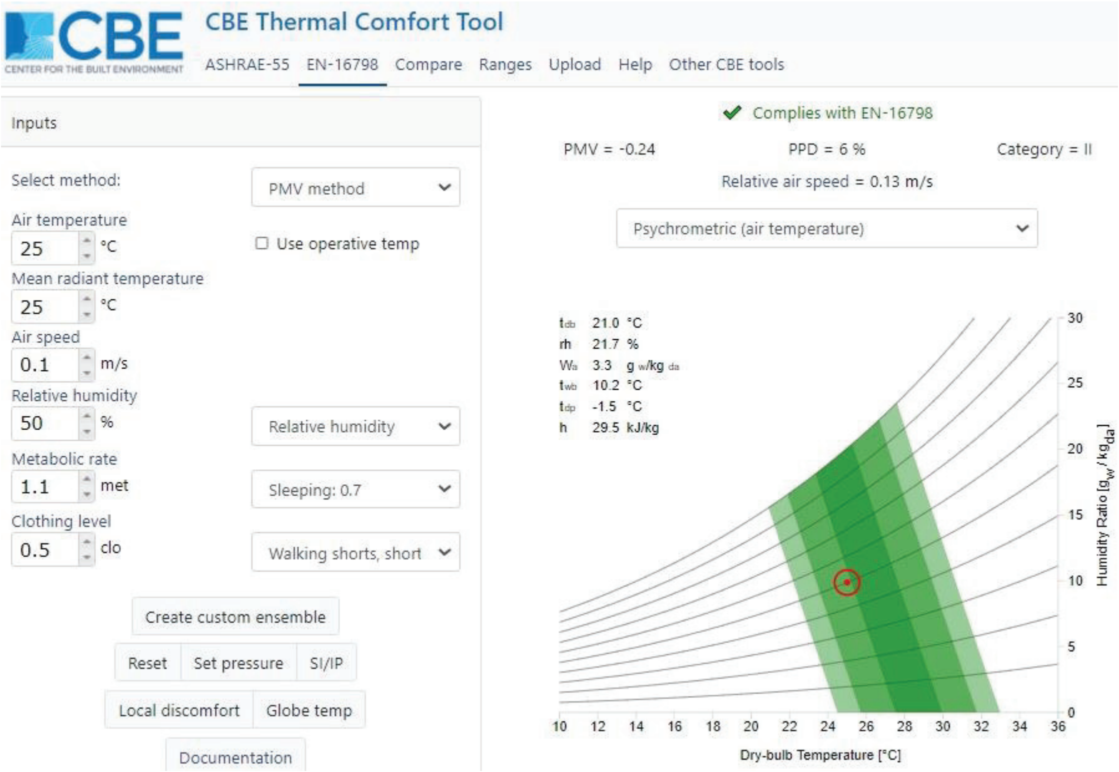
$$f_{cl} = I_{cl} \leq 0{,}078\ m^2K/W \quad \text{ise} \quad 1{,}00 + 1{,}290 \,.\, I_{cl}$$
$$I_{cl} > 0{,}078\ m^2K/W \quad \text{ise} \quad 1{,}05 + 0{,}645 \,.\, I_{cl} \qquad (3.4)$$

M: metabolic rate (W/m^2), W: effective mechanical power (W/m^2), I_{cl}: clothing insulation (m^2. K/W), f_{cl}: clothing surface area factor, t_a: air temperature (^{o}C), t_r: mean radiant temperature (^{o}C), v_{ar}: relative air velocity (m/s), p_a: water vapour partial pressure (Pa), h_c: convective heat transfer coefficient [W/(m^2.K)], t_{cl}: clothing surface temperature (^{o}C)

After the calculations, the PMV value was evaluated according to Fanger's 7-point thermal sensation scale (-3, -2, -1, 0, +1, +2, +3) (Table 2.1). According to the PMV value, the PPD value can be calculated with the Formula 3.5 (ISO, 2005):

$$PPD = 100 - 95 \,.\, \exp(-0{,}03353 \,.\, PMV^4 - 0{,}2179 \,.\, PMV^2) \qquad (3.5)$$

Predicted Mean Vote (PMV) – Predicted Percentage Dissatisfied (PPD) calculations for thermal comfort analysis were made by using CBE Thermal Comfort Tool according to the EN 16798-1. This tool was created by University of California, Berkeley (Figure 3.10).


CBE Thermal Comfort Tool

Inputs

Select method: PMV method

Air temperature 25 °C

☐ Use operative temp

Mean radiant temperature 25 °C

Air speed 0.1 m/s

Relative humidity 50 %

Metabolic rate 1.1 met — Sleeping: 0.7

Clothing level 0.5 clo — Walking shorts, short

✓ Complies with EN-16798

PMV = -0.24

PPD = 6 %

Category = II

Relative air speed = 0.13 m/s

Psychrometric (air temperature)

Figure 3.10. Model making PMV-PPD calculations based on EN 16798-1
(Source: Tartarini et al., 2020)

As seen in Table 2.2, historical buildings should be evaluated in Category III in terms of thermal comfort. The required PMV and PPD values for Category III are shown in Table 2.3. Values of -0.7 / +0.7 for PMV, and values less than 15% for PPD are recommended. Thermal comfort evaluation of the Agios Voukolos Church was made according to these threshold values.

3.3. Survey Study

In the church, which is used as a Culture and Art Center at present (Figure 3.11, 3.12 and 3.13), survey studies were conducted with the occupants during the events in order to calculate the Actual Mean Vote (AMV) value and compare it with the PMV value and also to get information about the clothing combinations (Figure 3.14). During the data collection process, events at the church were canceled after March 2020 due to the COVID-19 epidemic. Survey studies could only be carried out in the winter season because there were no events in the summer. In Table 3.4, the date of the 5 surveys conducted, the type of events, and the number of occupants are indicated.

Figure 3.11. Concert event on 23 November 2019 at the Agios Voukolos Church

Figure 3.12. Concert event on 14 December 2019

Figure 3.13. Concert event on 16 December 2019

Table 3.4. The dates, types of events and the number of occupants of survey studies

Date	Type of Events	Number of Occupants
23.11.2019 19:30-20:00	Concert	20
14.12.2019 19:30-20:00	Concert	24
16.12.2019 19:30-20:00	Concert	25
28.12.2019 19:30-20:00	Concert	21
14.02.2020 13:30-14:00	Conversation	20

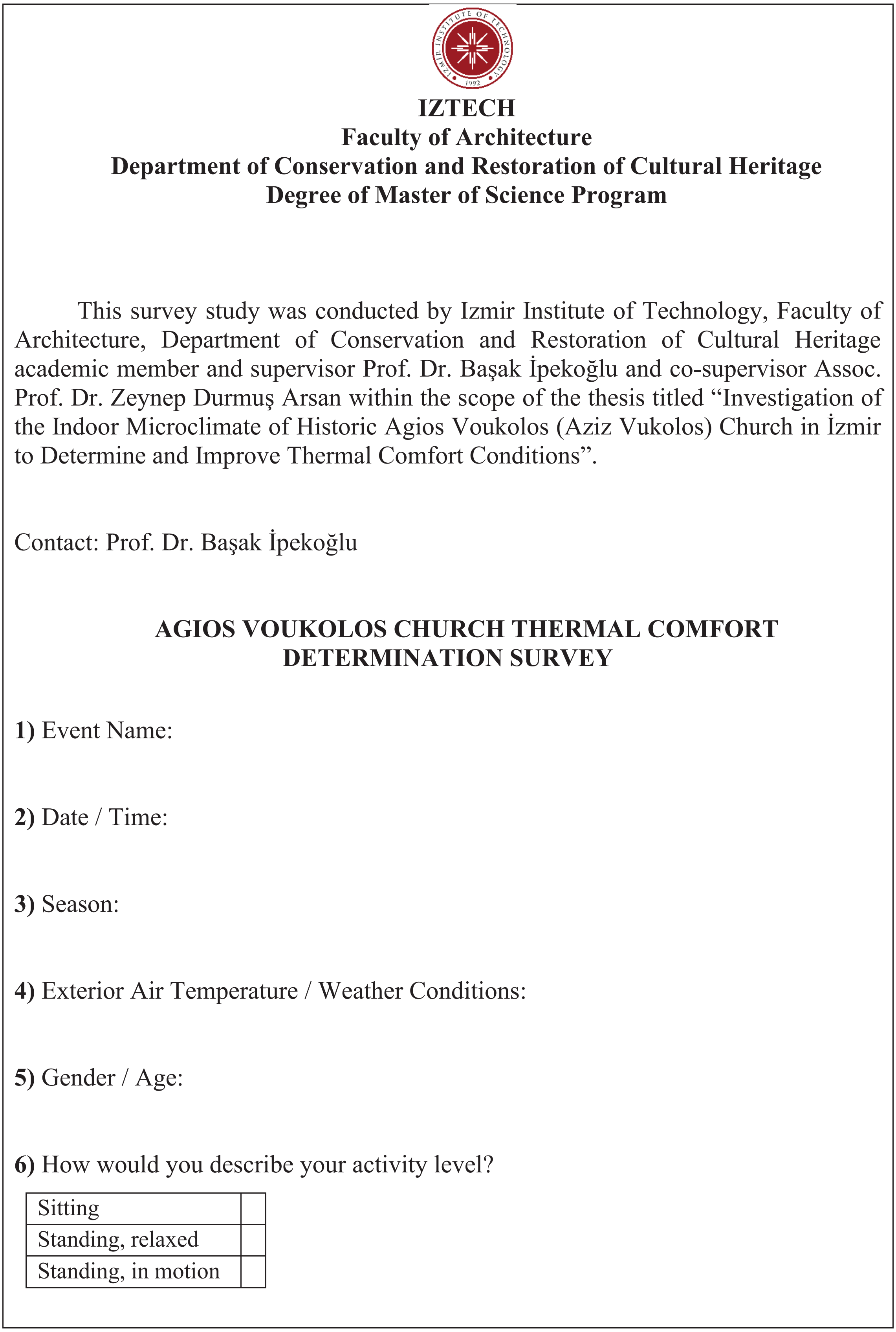
The questions in the survey were prepared based on information obtained from published studies (Yau et al., 2011; Ricciardi et al., 2016; Tort-Ausina et al., 2016; Martinez-Molina et al., 2018; Pretelli and Fabbri, 2018). The survey sheet given to the users of the space in the study is shown in Figure 3.14. The survey contains information about event type, date, season, weather conditions, gender, age, activity level, thermal perception according to 7-point thermal sensation scale and clothing combinations. The AMV value was obtained by the weighted average of the responses given according to Fanger's 7-point thermal sensation scale in the survey content.

3.4. Analysis of the Effects of Indoor Air Temperature and Relative Humidity on the Wall Paintings

The UNI 10829 Standard (UNI, 1999) and the decree announced by the Italian Ministry of Culture (MiBAC, 2001) were used to determine the appropriate thermo-hygrometric values for the wall paintings (Canistraro and Restivo, 2018; Aste et al., 2019; De Rubeis et al., 2020). The appropriate thermo-hygrometric values determined for the preservation of wall paintings are given in Table 3.5.

Table 3.5. Recommended thermo-hygrometric values for preservation of the wall paintings

	Air temperature	Relative humidity
UNI 10829 (UNI, 1999)	10-24 ºC	55-65 %
MiBAC D.M. (MiBAC, 2001)	min 6 ºC (winter) max 25 ºC (summer)	45-65 %



IZTECH
Faculty of Architecture
Department of Conservation and Restoration of Cultural Heritage
Degree of Master of Science Program

This survey study was conducted by Izmir Institute of Technology, Faculty of Architecture, Department of Conservation and Restoration of Cultural Heritage academic member and supervisor Prof. Dr. Başak İpekoğlu and co-supervisor Assoc. Prof. Dr. Zeynep Durmuş Arsan within the scope of the thesis titled "Investigation of the Indoor Microclimate of Historic Agios Voukolos (Aziz Vukolos) Church in İzmir to Determine and Improve Thermal Comfort Conditions".

Contact: Prof. Dr. Başak İpekoğlu

AGIOS VOUKOLOS CHURCH THERMAL COMFORT DETERMINATION SURVEY

1) Event Name:

2) Date / Time:

3) Season:

4) Exterior Air Temperature / Weather Conditions:

5) Gender / Age:

6) How would you describe your activity level?

Sitting	
Standing, relaxed	
Standing, in motion	

Figure 3.14. Survey applied during events in the church

(cont. on next page)

7) How do you feel the warmth in the space?

(-3) Cold	
(-2) Cool	
(-1) Slightly Cool	
(0) Neutral	
(+1) Slightly Warm	
(+2) Warm	
(+3) Hot	

8) Clothing: (You can mark more than one option according to the clothing situation.)

Tops		Bottoms		One-Piece Clothing		Outdoor Clothing		Shoes	
Underwear		Underwear		Short Dress		Raincoat		Socks	
T-shirt		Shorts		Long Dress		Topcoat		Sandals	
Shirt		Trousers				Denim Jacket		Summer Shoes	
Blouse		Short Skirt				Leather Jacket		Winter Shoes	
Blouse or Shirt with Vest		Long Skirt				Winter coat		Sneakers	
Blouse or Shirt with Sweater						Cloak		Boot	
Thin Sweater						Greatcoat		Long boot	
Thick Sweater									

Thank you for your participation and interest.

Contact Information of the Surveyor:

Damla Akın Yalçin

Figure 3.14 (cont.)

In order to preserve the wall paintings, the air temperature and relative humidity values were turned into performance index tables with their hourly averages. The performance index (PI) shows the percentage of time in the recommended range of air temperature and relative humidity (Schito and Testi, 2017; Balocco et al., 2020). The measured data were evaluated firstly according to the UNI 10829, then to the MiBAC D.M., and finally to both UNI 10829 and MiBAC D.M. Performance indexes were calculated firstly for air temperature, then for relative humidity, and finally for both air temperature and relative humidity. The final performance indexes in the tables shows the percentage of time of air temperature and relative humidity in the recommended range (10-24 ^{o}C for air temperature and 55-65% for relative humidity) according to UNI 10829 and MiBAC D.M.

CHAPTER 4

ARCHITECTURAL CHARACTERISTICS OF AGIOS VOUKOLOS CHURCH AND CLIMATIC CHARACTERISTICS OF İZMİR

Agios Voukolos Church is one of the three Greek Orthodox churches in İzmir that have survived from the 19th century. The church, which was started to be built in 1866, was completed in 1887 according to the inscription at the north entrance. The building has architectural and historical value as it is one of the rare buildings in İzmir, which has 19th century Neoclassical architectural features. Also it has spatial value because it has a cross plan type and a different design from other Greek Orthodox churches in Western Anatolia (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014).

After the proclamation of the Republic in 1923, the church was used as an Archeology Museum. The building, which served as a museum until 1984, was later used as a study hall and storage by the Ministry of Culture, Directorate of State Opera and Ballet. During this period, it suffered from a fire and was left abandoned. In July 2003, the survey, restitution studies and restoration projects of the Church and its annexes were prepared and application consultancy was provided by the Izmir Institute of Technology, Faculty of Architecture, Department of Conservation and Restoration of Cultural Heritage upon the request of the İzmir Metropolitan Municipality. The building, which was restored in 2009-2010, is used as a Culture and Art Center today.

Agios Voukolos Church is located in the Kapılar, Basmane District, in a 2665 m^2 courtyard, in the east-west direction. The main entrance of the courtyard is provided by a monumental entrance gate from the north, and the secondary entrance is from a large garden gate from the west (Figure 4.3).

4.1. Location

İzmir is geographically located in the west of Turkey. It is surrounded by Balıkesir in the north, Manisa in the east, Aydın in the south and the Aegean Sea in the west (Figure 4.1).

Agios Voukolos Church is located in the Kapılar, Basmane, Konak District of İzmir (Figure 4.2).

Figure 4.1. Location of İzmir in Turkey[1]

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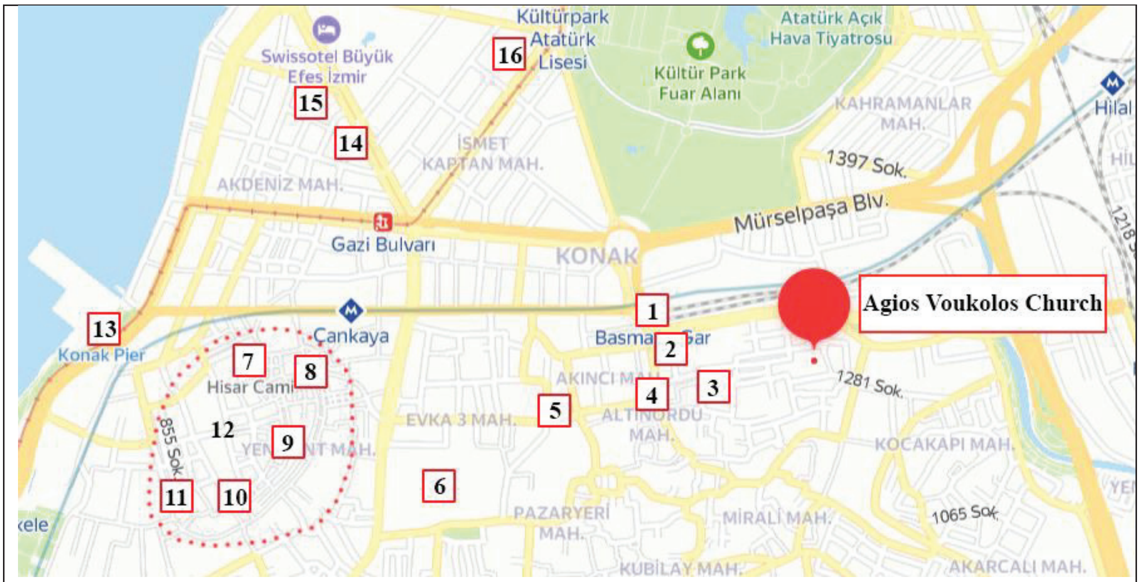
[1] http://cografyaharita.com/haritalarim/4lturkiye-haritasi2.png, access date: 24.03.2021



1. Basmane Train Station, **2.** Çorakkapı Mosque, **3.** Abdullah Efendi Mosque, **4.** Basmane Police Station, **5.** Hatuniye Mosque, **6.** Agora Archaeological Site, **7.** Hisar Mosque, **8.** Şadırvanaltı Mosque, **9.** Kestane Pazarı Mosque, **10.** Başdurak Mosque, **11.** Kemeraltı Mosque, **12.** The Khans in Konak town center: Abacıoğlu Khan, Arap Khan, Büyük Kardıçalı Khan, Büyük Osmanoğlu Khan, Çakaloğlu Khan, Demir Khan, Fazlıoğlu Khan, Kadıoğlu Khan, Kavaflar Khan, Kemahlıoğlu Khan, Kızlarağası Khan, Leblebici Khan, Manisalıoğlu Khan, Mirkelamoğlu Khan, Piyaleoğlu Khan, Selvili Khan, Sulu Khan, Yeni Khan, **13.** Konak Pier, **14.** Saint Polycarpe Church, **15.** Saint Mary's Church, **16.** Agia Fotini Church

Figure 4.2. The location of the Agios Voukolos Church and the historical buildings around it[2]

4.2. Plan and Interior Characteristics

The church is a cross plan and semicircular apse protrudes on the east wall of the bema. The narthex is located in the west and there is a gallery floor above it. This gallery floor is accessed from the outside by a staircase adjacent to the north wall of the west cross arm (Figure 4.4). The main entrance is provided from the narthex in the west by a double-winged door with a marble jamb, and secondary entrances are provided by other doors on the north and south sides. In the center of the cross plan, there is a dome drum

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[2] https://yandex.com.tr/harita/org/aziz_vukolos_kilisesi_/217902832887/?ll=27.147615%2C38.421467&z=18.37, access date: 26.03.2021

consisting of gold leaf meander, floral motifs and egg friezes and a glass skylight that was constructed after the original dome above it (Figures 4.7, 4.8). The windows are surrounded by plaster moldings. The arms of the cross are supported by arches and covered with gilded and ornamented vaults deteriorated after the church became a museum in the early Republic period (1930's) (Figure 4.9). The floor consists of black and white checkered marble with a sixteen armed sunburst figure under the dome (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014).

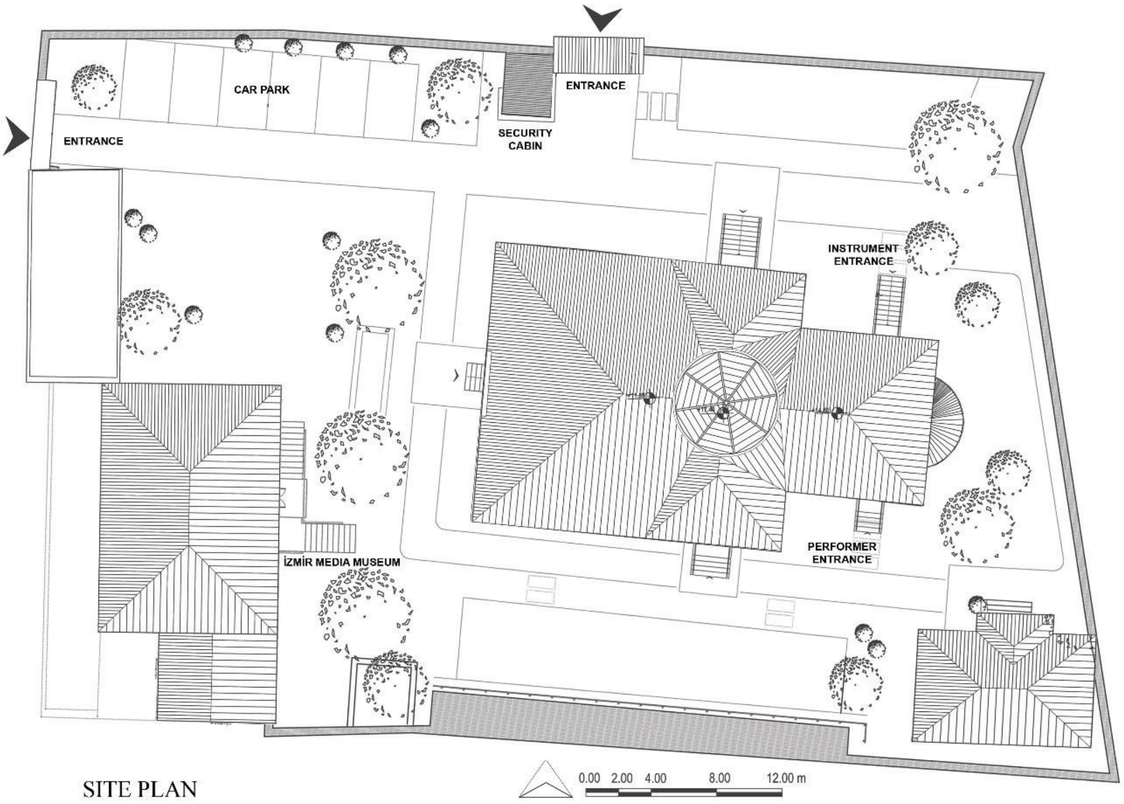

Figure 4.3. Site plan
(Source: Yardım et al., 2004-2007)

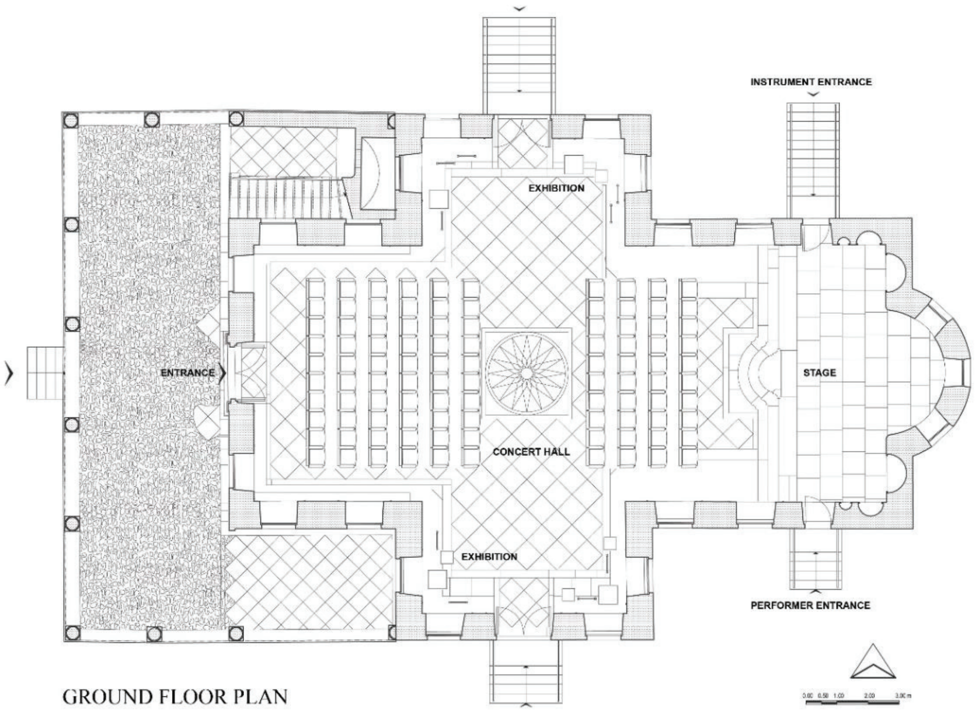

Figure 4.4. Ground floor plan
(Source: Yardım et al., 2004-2007)

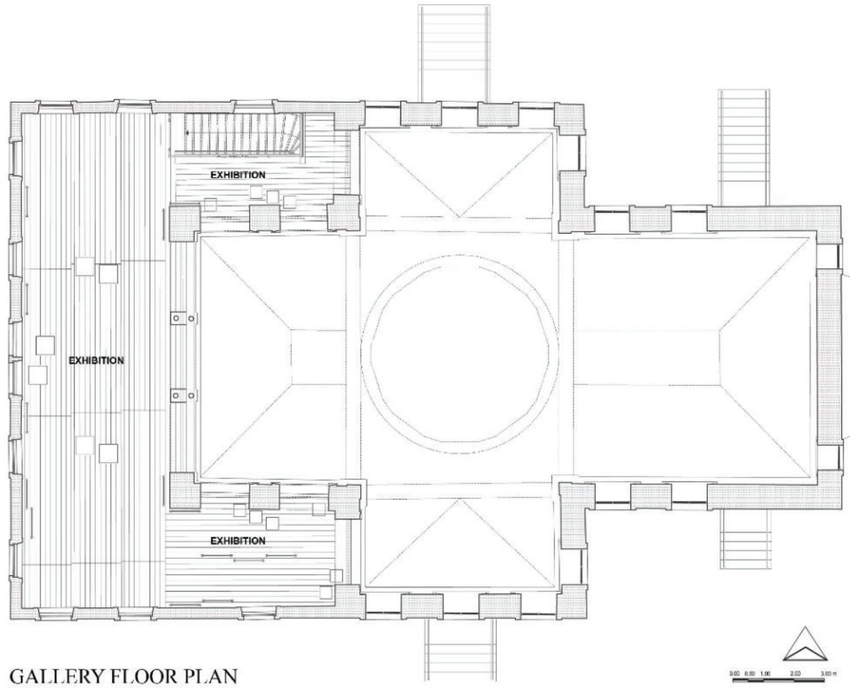

Figure 4.5. Gallery floor plan
(Source: Yardım et al., 2004-2007)

Figure 4.6. Section showing the interior and architectural elements of the church (Source: Yardım et al., 2004-2007)

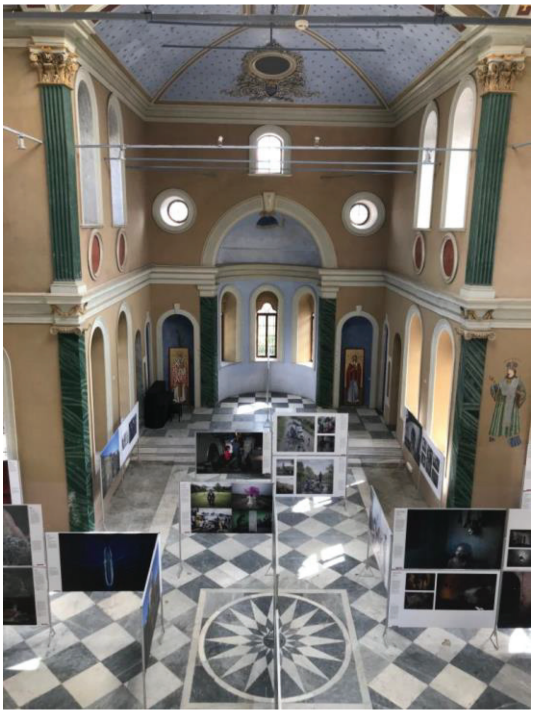

Figure 4.7. Interior view of the church during the exhibition (11.10.2019)

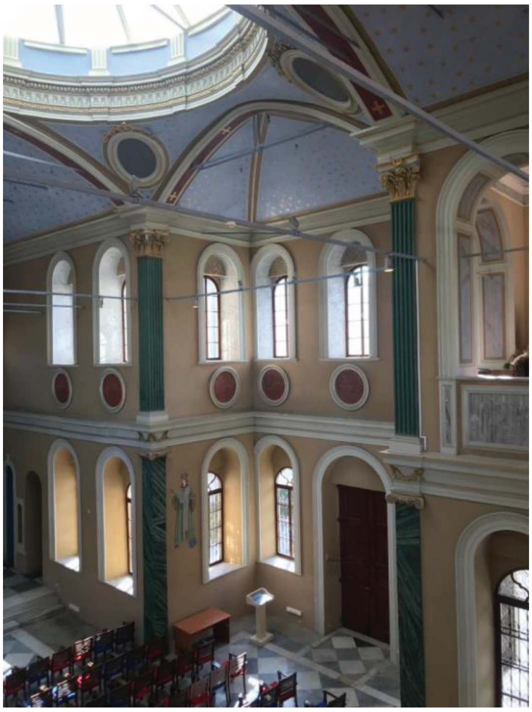

Figure 4.8. Interior view of the church (15.11.2019)

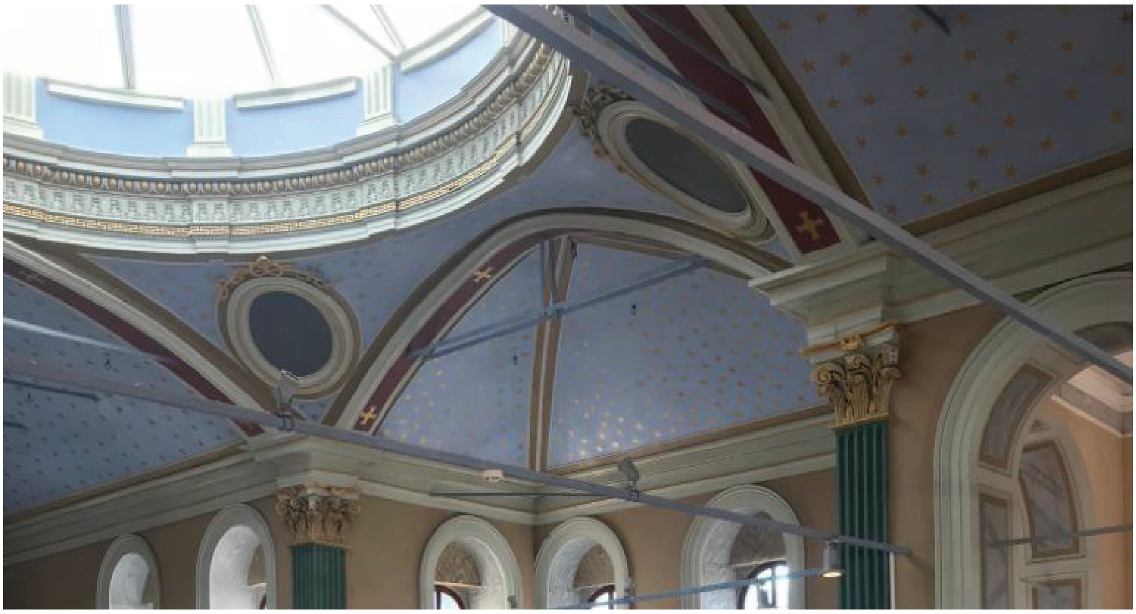

Figure 4.9. Gilded and ornamented vaults (11.10.2019)

The two storey high place has decorated walls (Figure 4.7, 4.8, 4.9, 4.10, 4.11). During the survey work in the church, it was understood that three layers of paint were applied to the wall surfaces in the interior of the building. With the detection of wall painting traces in the niche to the north of the apse, it was understood that there might be original paintings under three layers of paint, and it was decided that the paint layers should be removed (İpekoğlu et al., 2013; İpekoğlu et al., 2014). After the works, five secco paintings were partially seen on the apse semi-dome in the east, in the niche to the north of the apse, on the east wall of the south cross arm, and on both sides of the entrance on the west wall (Figure 4.10). The apse is the part where the figure of Jesus is usually located in Orthodox churches. In the 1st painting in the apse, although the inscription on the figure whose only a few letters are preserved cannot be read, it is thought that the figure holding the Bible in his left hand belongs to Jesus. It was not possible to detect the 2nd painting in the niche to the north of the apse. In the 3rd painting on the east wall of the south cross arm, one of the church fathers, Ioannes Khrysostomos (St. John of the Golden Mouth), was depicted standing with the mithras he wore during the rite. The name of Hagios Ioannes Khrysostomos can be read on the Greek inscription above his head. On the west wall, on either side of the entrance, there are two archangel figures. In the 4th painting, south of the west wall, Archangel Michael is shown holding his sword down in his right hand. In the 5th painting to the north of the entrance, Archangel Gabriel holding a flower in his right hand is identified by the Greek inscription above his head (Mercangöz, 2010). Paintings can be seen in Figure 4.11. During the restoration, the damaged and survived paintings were restored in a lighter tone than their original color (İpekoğlu et al., 2013; İpekoğlu et al., 2014).

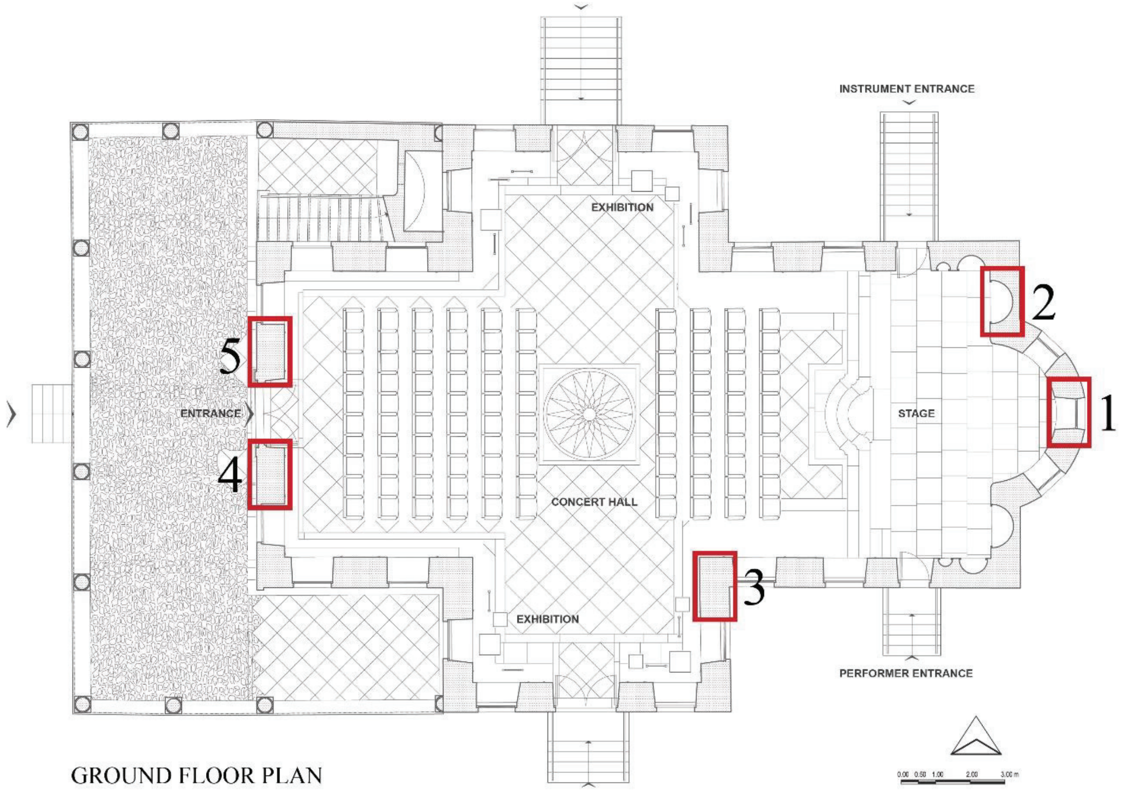

Figure 4.10. The positions of the five secco paintings in the church
(Drawing source: Yardım et al., 2004-2007)

1

2

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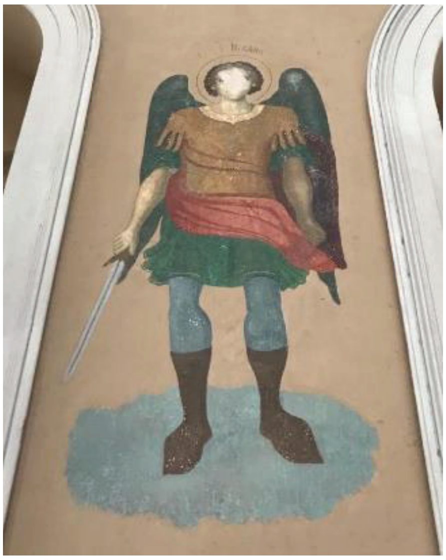

4

5

Wall paintings (Source: Mercangöz, 2010):
1. The figure supposedly representing Jesus[3]
2. Undetectable painting in niche (11.10.2019)
3. The figure of Ioannes Khrysostomos (St. John of the Golden Mouth) (11.10.2019)
4. The figure of Archangel Michael (11.10.2019)
5. The figure of Archangel Gabriel (11.10.2019)

Figure 4.11. Wall paintings of the Agios Voukolos Church

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[3] https://www.izmir.bel.tr/tr/Haberler/ayavukla-mucizesi/6682/156, access date: 25.07.2021

Figure 4.12. West elevation
(Source: Yardım et al., 2004-2007)

Figure 4.13. South elevation
(Source: Yardım et al., 2004-2007)

Figure 4.14. Exterior of the church (11.10.2019)

4.3. Facade Characteristics

The building has plain facades with rubble stone, rough cut stone and brick. Stone jambs around windows and doors, arches and relieving arches above openings are elements that complete the facade. In addition, the vertical tie-rods regularly located between the openings draw attention.

The marble columns on cubic marble bases and pointed arches of the narthex continue along the west facade. There are twin windows in the middle of the gallery facade on the narthex. This part is bordered by two brick pilasters and raised by a semicircular brick pediment. There are two more windows on each side of the twin windows. The west facade is seen in the Figure 4.12. There are two pointed arched openings on the north and south facades of the narthex. On both facades, the last openings were closed with brick walls and two rectangular windows were opened. In this part, there are three windows on the gallery floor.

There are semi-circular arched entrances in the middle of the north and south cross arms, one window on each side of the entrances, and three windows on the upper floor. On the east-facing faces of the north and south cross arms, which protrude outward, there are windows at the top and bottom.

In the east cross arm, there are two windows each at the top and the bottom and one enterance on each side. The half-cylinder apse ends lower than the roof and is covered with a conical roof covered with tiles. There are 3 windows on the apse. Also there is a window on the facade and a round window on each side; but these windows were covered (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014).

4.4. Construction Technique and Material Use

The walls were built in an alternating technique using rubble stone, rough cut stone, bricks and lime mortar. The walls built in the masonry technique using wooden beams are 80 cm thick, and the walls of the gallery floor on the narthex are built of wooden skeleton system inside and rubble stone and brick material outside and 30 cm thick. Horizontal tie-rods located in the vaults, arches, gallery floor openings and between the opposite walls of the cross arms are locked to the vertical tie-rods seen on the outer wall surfaces. There are brick relieving arches on all door and window openings. The walls are unplastered on the outside and plastered on the inside. Inside, there are three layers of plaster: rough plaster, straw-tempered lime plaster and 2-3 mm lime plaster. The transition to the dome was provided by pendantives made in the wooden system, and a pyramidal skylight was made with a steel structure and glass on the original dome drum. The roof was built in a wooden system, and the surfaces were formed and plastered with wood laths. The north and south cross arms are covered with half cross vaults, and the east and west cross arms are covered with paneled half cloister vaults. The building is covered with hipped roof and covered with marseilles tiles (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014).

4.5. The Restoration Process

During the restoration process, conservation interventions were carried out without damaging the historical, documentary and aesthetic values of the building. Precautions were taken to protect the building from moisture by constructing a drainage system in the garden and around the building. The patina of the building elements, or traces in surfaces, were taken into account and the original values were preserved without making unnecessary renovations. In this context,

- The west wall of the gallery floor, which was vertically separated, was stabilized.
- Cracks in the south wall of the naos were repaired using hydraulic lime mortar.
- Wooden roof, wooden vaults and woodworks were repaired.
- Steel structured skylight was reinforced with additional profiles and polycarbonate coating was made.
- Plasters were repaired, the survived wall paintings and damaged parts were repaired in accordance with their original color (Tunçoku et al., 2006; İpekoğlu et al., 2013; İpekoğlu et al., 2014).

Considering that there is no heating-cooling system in the church, a new heating-cooling system was not recommended in the intervention decisions. During events in the church, which is used as a Culture and Art Center, four 900 or 1800 W electric radiant heaters are used in the winter (Figure 4.15), and cooling is provided by keeping the windows open during the summer. Within the scope of the study, this situation was examined with both measurements and surveys studies.

Figure 4.15. Electric radiant heaters used during events in the church (14.01.2020)

4.6. Climatic Characteristics of İzmir

According to Köppen-Geiger Climate Classification System, climate conditions of İzmir are referred as Csa (Mediterranean Climate) class as seen in Figure 4.16 and 4.17. The Csa class is defined as a warm winter, dry and hot summer climate (Kottek et al., 2006; Climate Change & Infectious Diseases Group, 2017).

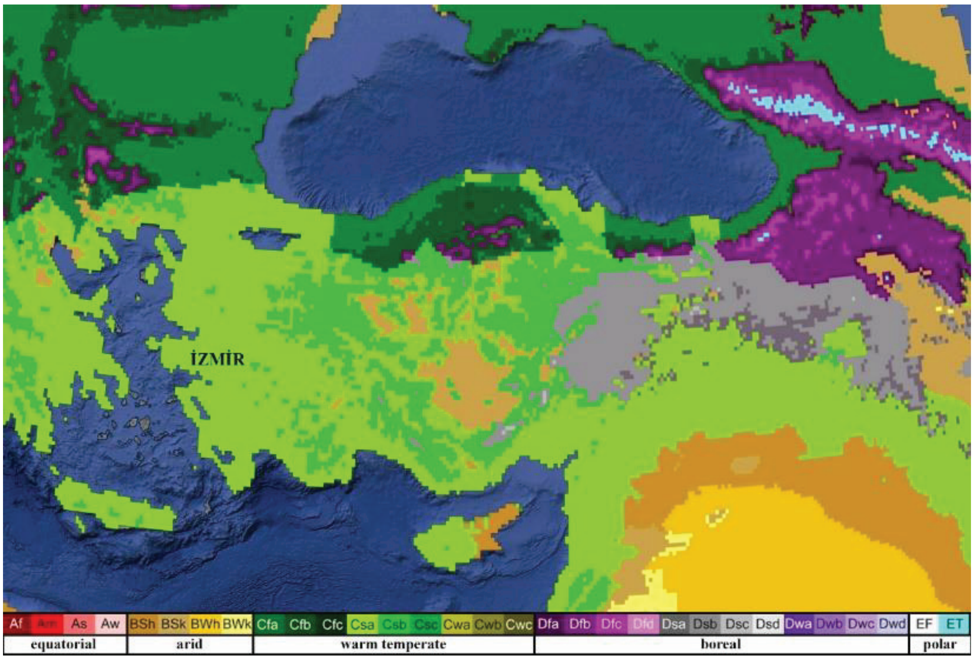

Figure 4.16. Köppen-Geiger climate classification of Turkey between 1986-2010
(Source: Climate Change & Infectious Diseases Group, 2017)

According to the data provided by the Turkish State Meteorological Service, the annual average temperature of İzmir is 17.9 ^{o}C, the maximum average temperature is 22.7 ^{o}C, and the minimum average temperature is 13.5 ^{o}C. The maximum temperature detected was 43°C and the minimum temperature was -8.2°C (Table 4.1 and Figure 4.18). Relative humidity values are around 50% in summer and around 70% in winter (Figure 4.19). Average wind speed is 3.0 m/s. Dominant wind direction is southeast, secondary wind direction is west-northwest depending on seasonal changes (Figure 4.20). The average annual total precipitation is 710.5 mm (Table 4.1 and Figure 4.21).

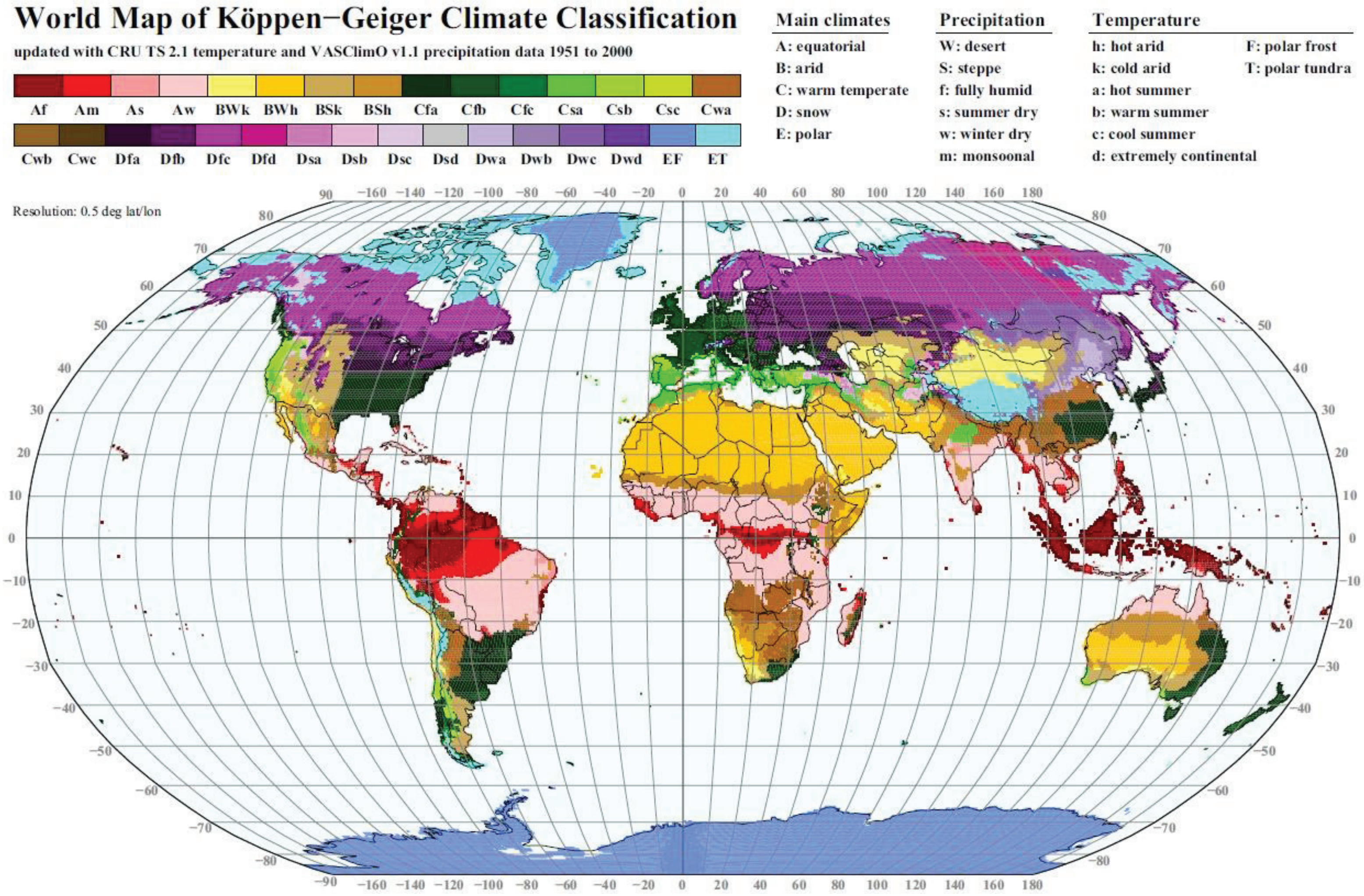

Figure 4.17. Köppen-Geiger Climate Classification (Source: Kottek et al., 2006)

Table 4.1. Climate data of İzmir between 1938 - 2020[4]

Months	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Annual**
Average Temperature (ºC)	8.8	9.6	11.7	15.8	20.7	25.3	27.9	27.6	23.7	18.9	14.2	10.5	17.9
Average Max. Temperature (ºC)	12.4	13.6	16.3	20.9	26.1	30.7	33.2	32.9	29.2	24.0	18.6	14.0	22.7
Maximum Temperature (ºC)	22.4	27.0	30.5	32.5	37.6	41.3	42.6	43.0	40.1	36.0	30.3	25.2	43.0
Average Min. Temperature (ºC)	5.7	6.2	7.7	11.1	15.4	19.8	22.4	22.3	18.7	14.6	10.7	7.5	13.5
Minimum Temperature (ºC)	-8.2	-5.2	-3.8	0.6	4.3	9.5	15.4	11.5	10.0	3.6	-2.9	-4.7	-8.2
Sunshine Duration (hour)	4.3	5.2	6.4	8.0	9.8	11.6	12.3	11.9	10.1	7.6	5.6	4.2	8.1
Average Number of Rainy Days	14.0	11.7	10.7	9.1	7.0	3.5	0.7	0.9	2.7	6.6	10.1	14.4	91.4
Average Total Rainfall (mm)	135.0	101.9	75.4	46.1	31.8	12.0	4.1	5.6	15.5	44.8	92.6	145.7	710.5

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[4] https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=IZMIR, access date: 28.03.2021

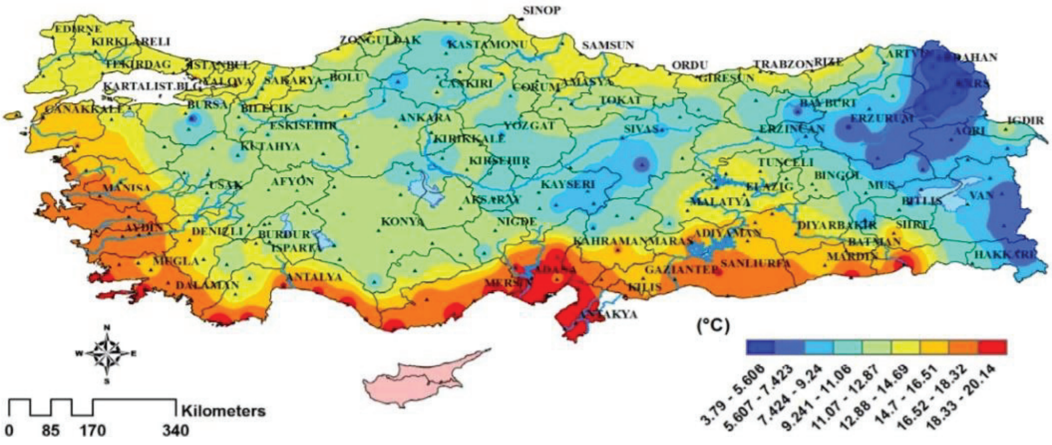

Figure 4.18. Average temperature distribution in Turkey between 1970-2020[5]

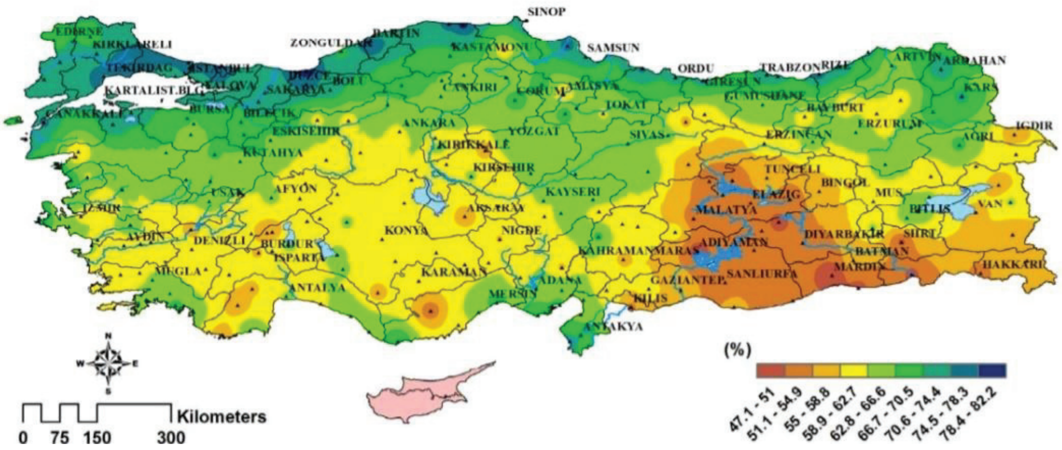

Figure 4.19. Average humidity distribution in Türkiye betweeen 1970-2020[6]

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[5] https://www.mgm.gov.tr/FILES/resmi-istatistikler/parametreAnalizi/Turkiye-Ortalama-Sicaklik-2020.pdf, access date: 28.03.2021

[6] https://www.mgm.gov.tr/FILES/resmi-istatistikler/parametreAnalizi/Turkiye-Ortalama-Nem-2020.pdf, access date: 28.03.2021

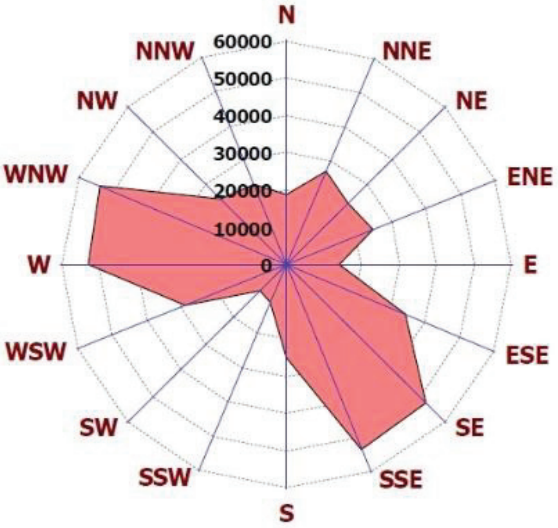

Figure 4.20. Dominant wind direction of İzmir[7]

Figure 4.21. Annual precipitation normals in Turkey between 1981-2010[8]

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[7] https://izmir.mgm.gov.tr/files/iklim/izmir_iklim.pdf, access date: 28.03.2021

[8] https://www.mgm.gov.tr/FILES/arastirma/yagis-degerlendirme/2020alansal.pdf, access date: 28.03.2021

CHAPTER 5

RESULTS AND DISCUSSION

According to the measurements made in the Agios Voukolos Church, air temperature and relative humidity analyzes were carried out with indoor and outdoor data collected by six data logger devices placed on the walls. Annual diagrams were prepared and the minimum, maximum and average values were examined.

Thermal comfort analysis was carried out by calculating hourly and monthly PMV - PPD values using the clothing insulation, metabolic rate and air temperature, relative humidity, mean radiant temperature and air velocity data determined by the measurements.

The thermal comfort conditions of the church were examined in detail for the winter season by comparing the AMV values from survey studies and calculated PMV values.

Measured air temperature and relative humidity values were analyzed in terms of conservation of the wall paintings.

The results obtained were compared with indoor microclimate studies on thermal comfort and conservation of historical artifacts in historical churches and thermal comfort improvement strategies were developed.

5.1. Air Temperature and Relative Humidity Data Analysis

Air temperature and relative humidity were measured both indoors and outdoors during the year (9 July 2019 – 22 May 2020) in the Agios Voukolos Church, thermo-hygrometric conditions were determined by measurements and thermal comfort analysis was carried out.

5.1.1. Outdoor Air Temperature and Relative Humidity Data Analysis

The thermo-hygrometric properties of the Agios Voukolos Church are affected by the outdoor climate data. Outdoor air temperature data was obtained from the data logger device No. 1 (Figure 3.2) placed outdoors as shown in Figure 5.1 and relative humidity data are shown in Figure 5.2.

The minimum air temperature was measured as 3.27 °C on February 9, 2020, and the maximum air temperature was measured as 35.21 °C on August 24, 2019. The average temperature was 18.9 °C. The minimum relative humidity was measured as 22.15% on April 12, 2020, and the maximum relative humidity was measured as 91.74% on August 28, 2019. Average relative humidity was 62.3%. The determined maximum, minimum and average air temperature and relative humidity values are shown in Table 5.1.

Table 5.1. Monthly outdoor air temperature and relative humidity values of data logger No. 1

Data Logger No. 1 Air Temperature and Relative Humidity Values						
	Air Temperature (ºC)			**Relative Humidity (%)**		
Months	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
July 2019	23.59	28.84	33.91	27.23	50.33	74.76
August 2019	25.55	30.11	35.21	24.79	47.99	91.74
September 2019	19.70	25.26	31.10	25.70	56.60	84.20
October 2019	16.99	21.80	28.57	42.16	68.32	86.73
November 2019	13.45	18.25	23.40	43.04	72.31	89.84
December 2019	7.77	12.16	21.99	43.40	72.97	91.36
January 2020	4.82	9.02	17.42	35.56	64.25	90.99
February 2020	3.27	11.51	19.89	38.87	67.59	91.43
March 2020	7.90	14.26	20.72	25.49	65.05	91.14
April 2020	10.79	17.08	23.91	22.15	59.07	89.60
May 2020	16.13	23.47	32.51	23.64	55.64	82.95
June 2020	Data not available					

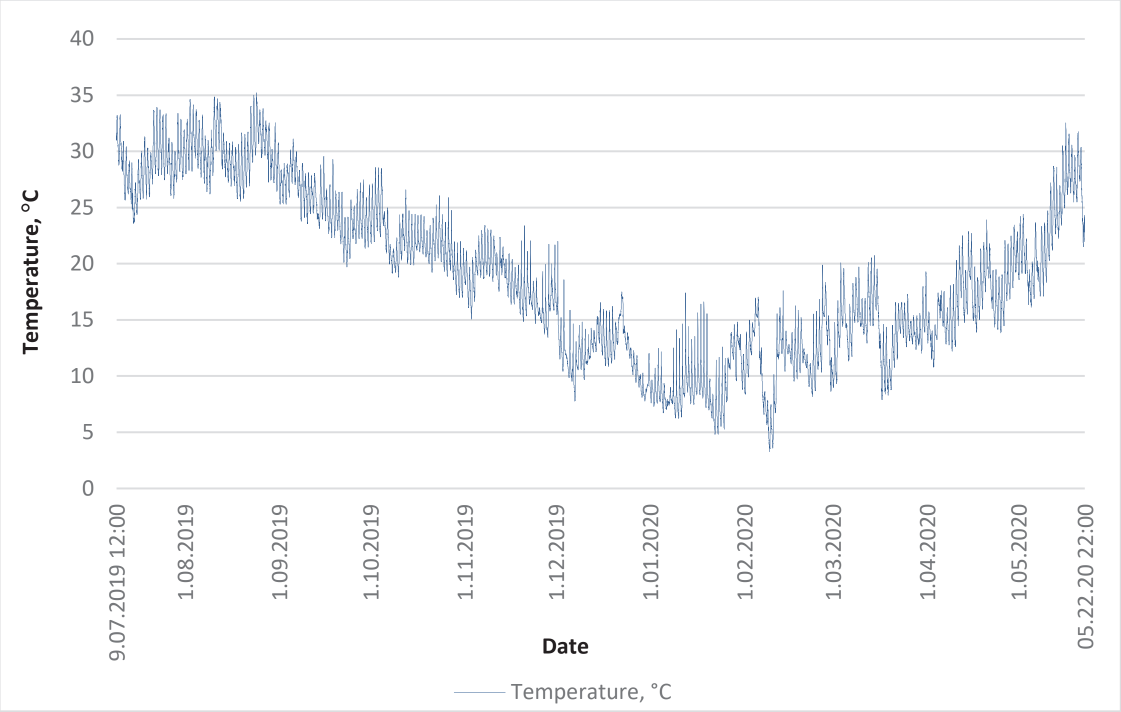


Figure 5.1. Hourly outdoor air temperature values of data logger No. 1 during the year

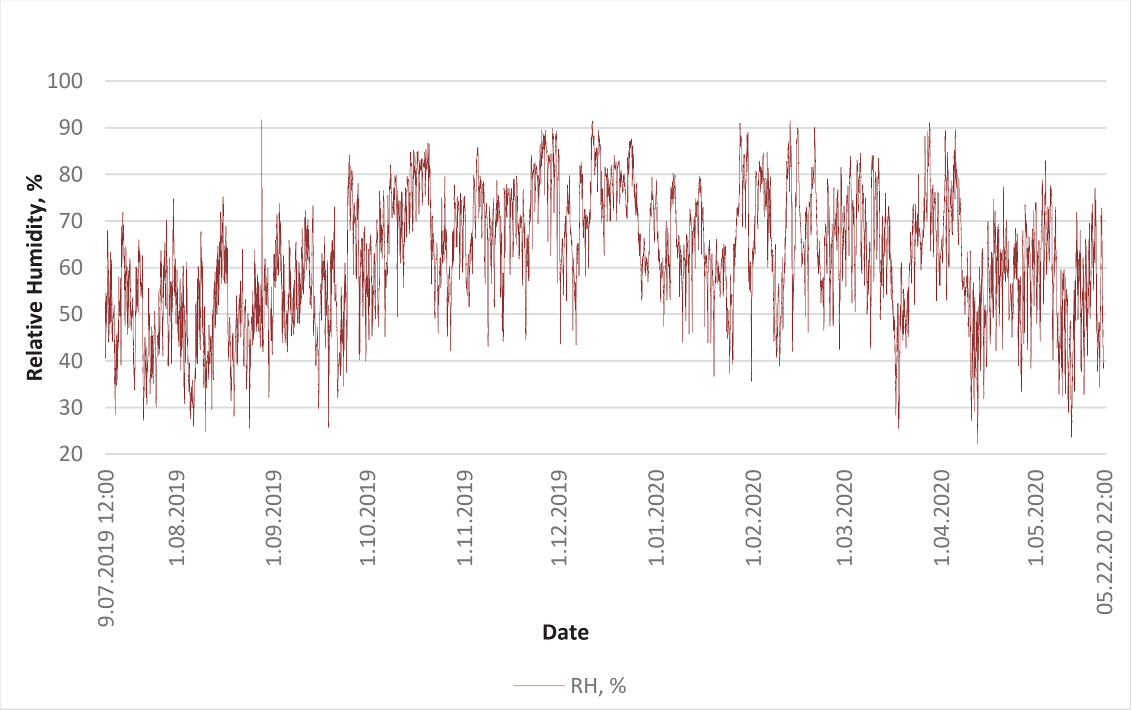


Figure 5.2. Hourly outdoor relative humidity values of data logger No. 1 during the year

5.1.2. Indoor Air Temperature and Relative Humidity Data Analysis

Five data logger devices numbered 2, 3, 4, 5 and 6, which were placed for indoor air temperature and relative humidity measurements during the year, are shown in Figure 3.2 and 3.3.

For the device No. 2 placed between the windows on the north wall at the entrance, the minimum air temperature value was measured as 7.19 ^{o}C on February 10, 2020 and the maximum value was measured as 33.73 ^{o}C on 24 August 2019. The minimum relative humidity value was measured as 34.46% on August 6, 2019 and the maximum value was measured as 78.44% on February 13, 2020. The average of the minimum and maximum air temperature difference of the months was 8.1 ^{o}C, the average of the minimum and maximum relative humidity difference was 29.1%. Air temperature and relative humidity measurements during the year are shown in Figure 5.3 and 5.4. Maximum, minimum and average air temperature and relative humidity values are shown in Table 5.2.

Table 5.2. Monthly air temperature and relative humidity values of data logger No. 2

Data Logger No. 2 Air Temperature and Relative Humidity Values						
	Air Temperature (^{o}C)			**Relative Humidity (%)**		
Months	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
July 2019	27.78	30.41	32.95	37.85	50.44	60.11
August 2019	28.94	31.57	33.73	34.46	49.02	61.98
September 2019	23.76	27.43	30.90	38.61	53.42	67.92
October 2019	19.91	23.88	27.97	49.83	61.45	72.74
November 2019	16.89	20.37	23.67	50.48	63.55	75.51
December 2019	10.93	14.63	22.87	42.64	63.18	75.35
January 2020	8.87	11.01	17.03	45.48	58.05	73.84
February 2020	7.19	12.97	18.11	39.10	61.89	78.44
March 2020	11.47	15.44	19.37	35.17	60.77	74.03
April 2020	14.55	18.37	22.18	44.77	56.82	73.66
May 2020	19.91	24.26	30.17	41.27	55.72	65.75
June 2020	Data not available					

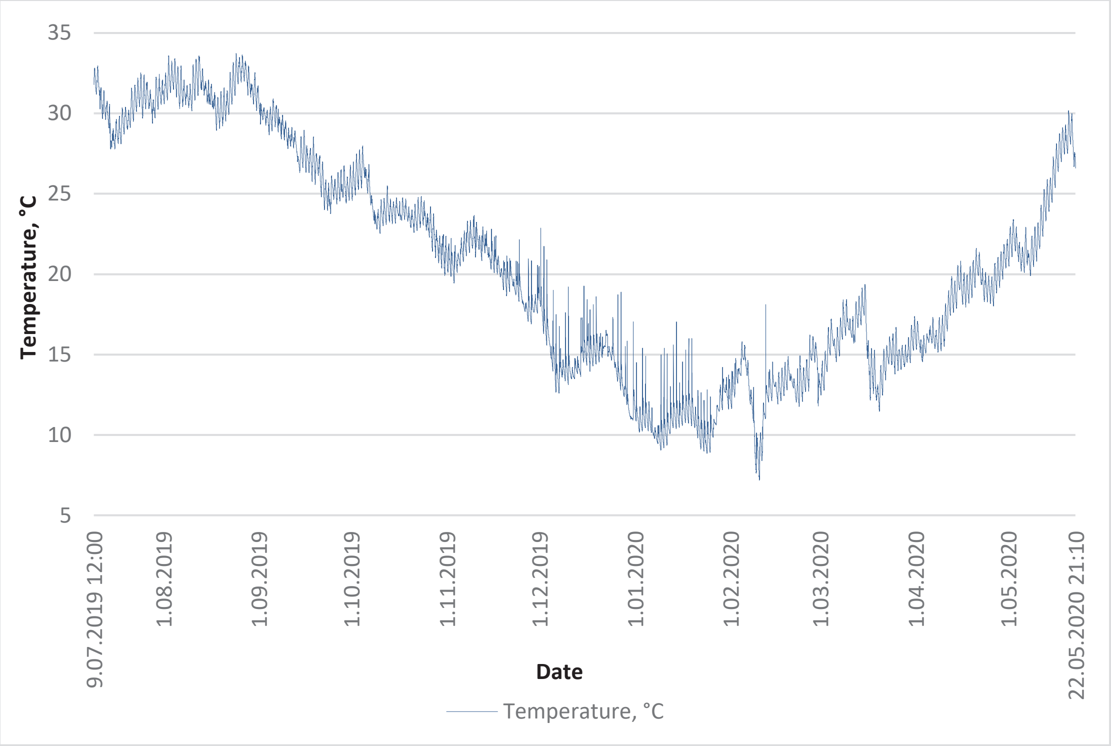


Figure 5.3. Hourly air temperature values of data logger No. 2 during the year

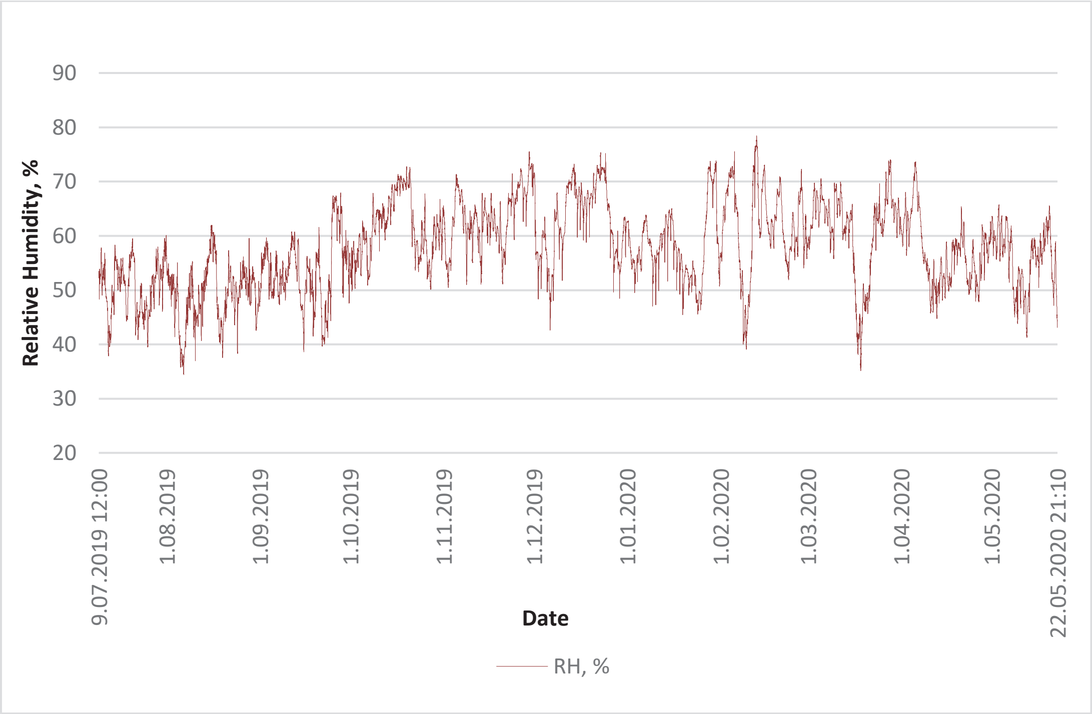


Figure 5.4. Hourly relative humidity values of data logger No. 2 during the year

For the device No. 3 placed on the north wall of the cross arm in the north-south direction, on the surface between the window and the door, the air temperature during the year varied between the minimum value 6.97 ºC measured on February 10, 2020 and the maximum value 34.20 ºC measured on August 24, 2019. Relative humidity during the year varied between the minimum value 25.01% measured on August 6, 2019 and the maximum value 81.74% measured on February 13, 2020. The average of the minimum and maximum air temperature difference of the months was 8.2 ºC, the average of the minimum and maximum relative humidity difference was 36.8%. Air temperature and relative humidity measurements during the year are shown in Figure 5.5 and 5.6. The determined maximum, minimum and average air temperature and relative humidity values are shown in Table 5.3.

Table 5.3. Monthly air temperature and relative humidity values of data logger No. 3

Data Logger No. 3 Air Temperature and Relative Humidity Values						
	Air Temperature (ºC)			**Relative Humidity (%)**		
Months	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
July 2019	28.05	30.88	33.55	28.44	43.45	55.11
August 2019	29.14	31.92	34.20	25.01	41.92	57.69
September 2019	23.81	27.71	31.46	29.24	47.63	66.66
October 2019	19.98	24.12	28.49	42.56	57.77	71.92
November 2019	16.89	20.53	23.95	43.18	60.99	76.46
December 2019	11.03	14.90	22.23	34.77	60.62	77.09
January 2020	8.87	11.23	17.56	37.19	54.53	74.23
February 2020	6.97	13.21	16.58	31.80	59.12	81.74
March 2020	11.52	15.74	19.96	25.56	57.36	74.95
April 2020	14.82	18.73	22.63	37.31	51.93	73.46
May 2020	20.20	24.74	30.72	32.86	49.96	63.47
June 2020	Data not available					

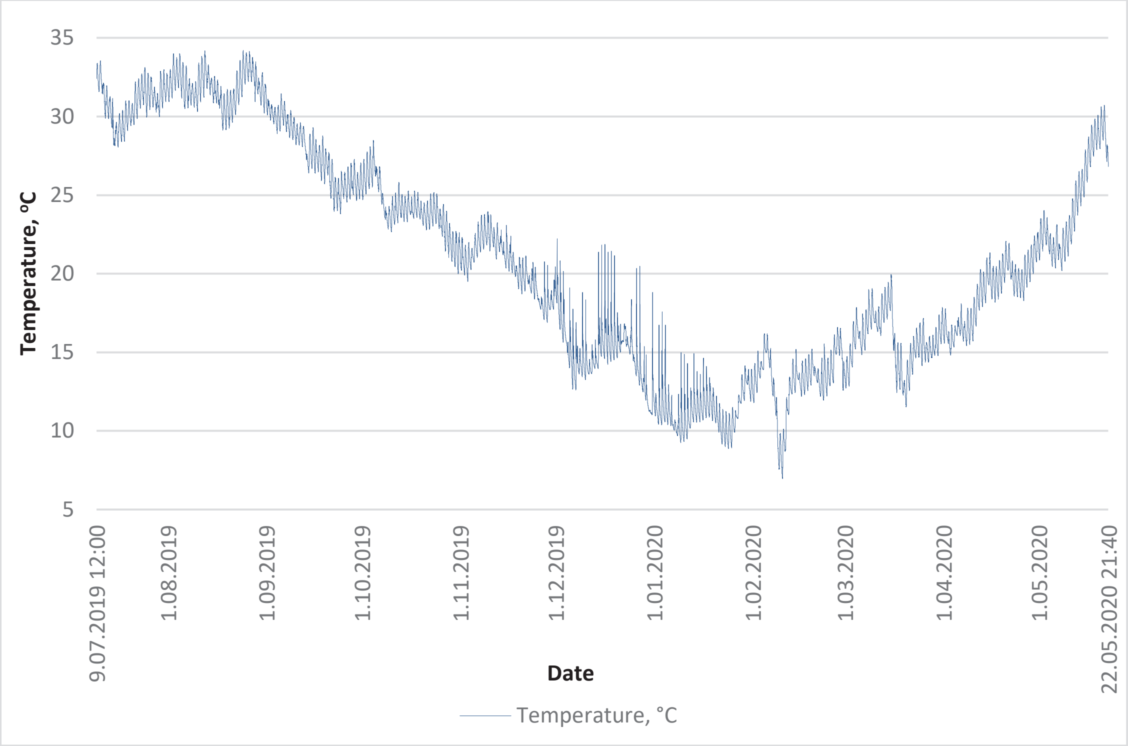


Figure 5.5. Hourly air temperature values of data logger No. 3 during the year

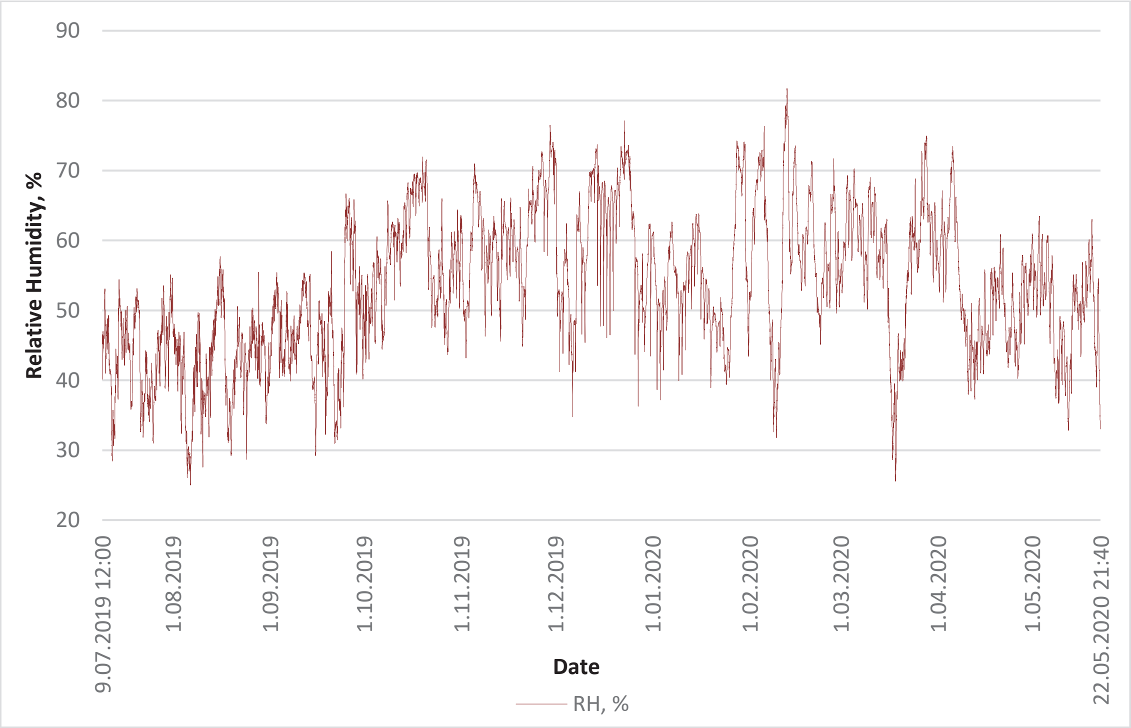


Figure 5.6. Hourly relative humidity values of data logger No. 3 during the year

For the device No. 4 placed between the windows on the north wall in the apse, the air temperature during the year varied between the minimum value 6.94 °C measured on February 10, 2020 and the maximum value 33.91 °C measured on August 24, 2019. Relative humidity during the year varied between the minimum value 25.10% measured on August 6, 2019 and the maximum value 80.62% measured on February 13, 2020. The average of the minimum and maximum air temperature difference of the months was 9.6 ºC, the average of the minimum and maximum relative humidity difference was 37.6%. Air temperature and relative humidity measurements during the year are shown in Figure 5.7 and 5.8. The determined maximum, minimum and average air temperature and relative humidity values are shown in Table 5.4.

Table 5.4. Monthly air temperature and relative humidity values of data logger No. 4

Data Logger No. 4 Air Temperature and Relative Humidity Values						
	Air Temperature (ºC)			**Relative Humidity (%)**		
Months	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
July 2019	28.10	30.76	33.29	28.94	43.28	54.53
August 2019	29.22	31.85	33.91	25.10	41.63	56.77
September 2019	24.03	27.77	31.33	29.53	46.91	65.47
October 2019	20.15	24.17	29.07	42.15	56.79	70.74
November 2019	17.13	20.76	29.27	36.56	59.35	74.85
December 2019	11.08	15.07	26.82	29.72	59.25	76.95
January 2020	9.11	11.58	21.18	28.48	52.80	73.24
February 2020	6.94	13.28	20.65	32.11	58.13	80.62
March 2020	11.69	15.78	20.15	25.69	56.48	73.00
April 2020	14.91	18.70	22.49	36.93	51.32	72.76
May 2020	20.25	24.63	30.50	32.78	49.57	62.33
June 2020	Data not available					

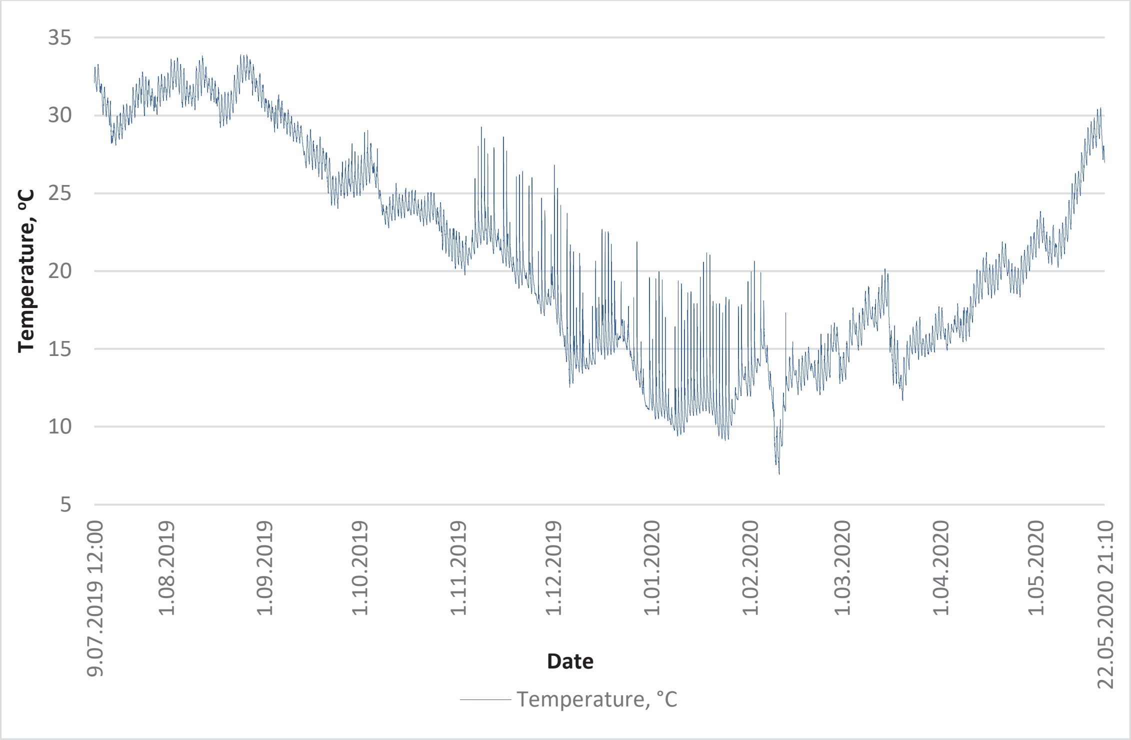


Figure 5.7. Hourly air temperature values of data logger No. 4 during the year

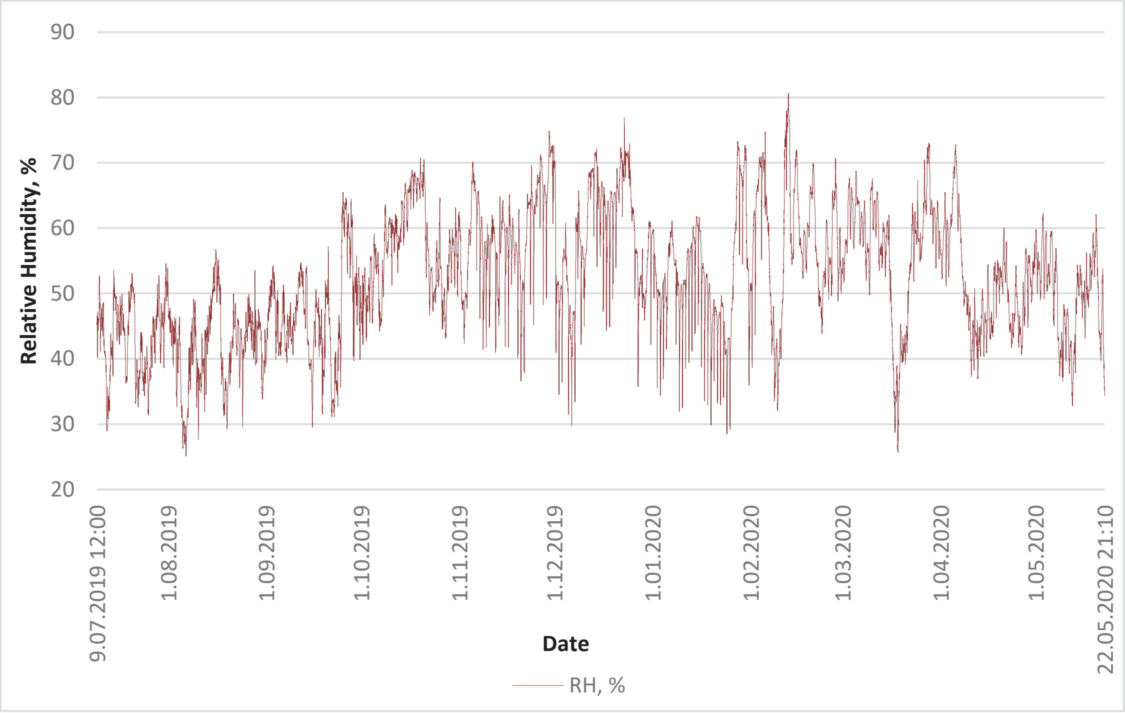


Figure 5.8. Hourly relative humidity values of data logger No. 4 during the year

For the device No. 5 placed between the windows on the south wall in the apse, the air temperature during the year varied between the minimum value 6.66 °C measured on February 10, 2020 and the maximum value 34.68 °C measured on August 12, 2019. Relative humidity during the year varied between the minimum value 25.61% measured on August 6, 2019 and the maximum value 77.88% measured on February 13, 2020. The average of the minimum and maximum air temperature difference of the months was 7.4 ºC, the average of the minimum and maximum relative humidity difference was 34.3%. Air temperature and relative humidity measurements during the year are shown in Figure 5.9 and 5.10. The determined maximum, minimum and average air temperature and relative humidity values are shown in Table 5.5.

Table 5.5. Monthly air temperature and relative humidity values of data logger No. 5

Data Logger No. 5 Air Temperature and Relative Humidity Values						
	Air Temperature (ºC)			**Relative Humidity (%)**		
Months	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
July 2019	28.32	30.92	33.39	29.43	43.47	54.53
August 2019	29.49	32.06	34.68	25.61	41.72	56.50
September 2019	24.39	28.03	31.41	29.81	46.83	64.30
October 2019	20.72	24.50	28.69	42.45	56.44	70.45
November 2019	17.25	20.84	24.15	42.66	59.70	74.53
December 2019	11.25	14.98	19.58	40.44	60.07	75.15
January 2020	9.41	11.43	14.00	39.20	53.81	72.59
February 2020	6.66	13.46	16.75	29.31	58.03	77.88
March 2020	12.12	16.02	19.98	26.64	56.38	72.67
April 2020	15.20	18.89	23.21	37.93	51.43	72.17
May 2020	20.48	24.78	30.72	33.13	49.81	62.66
June 2020	Data not available					

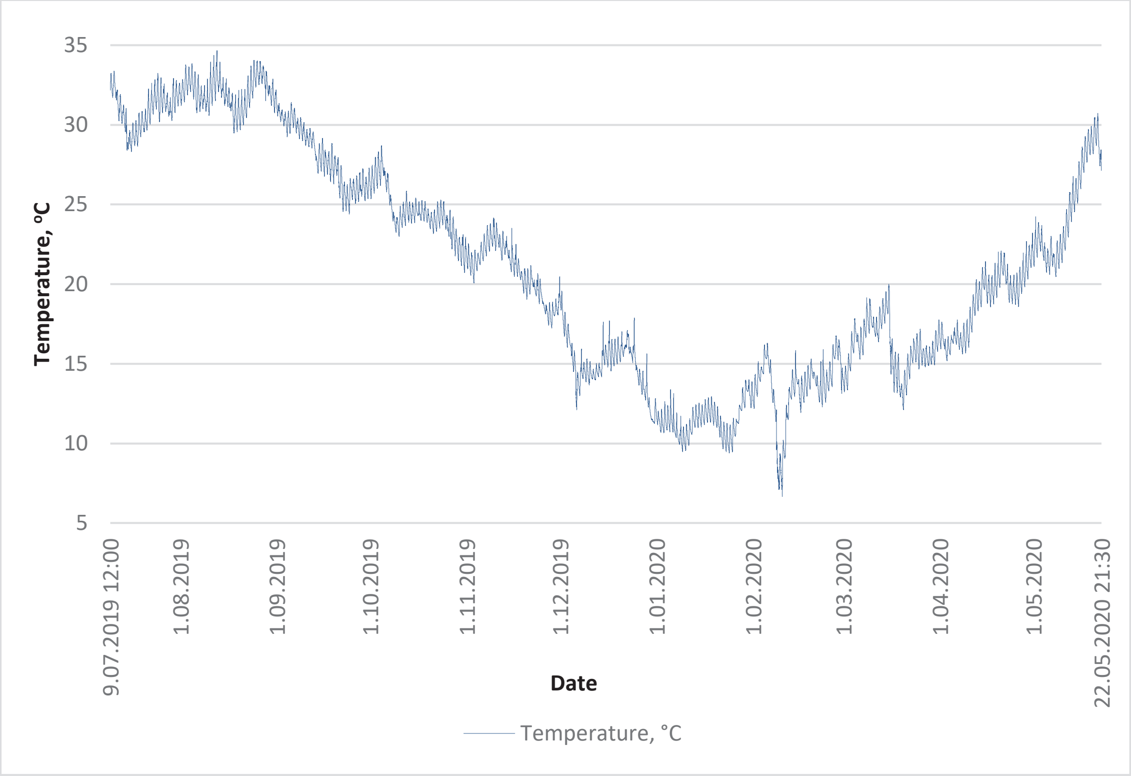


Figure 5.9. Hourly air temperature values of data logger No. 5 during the year

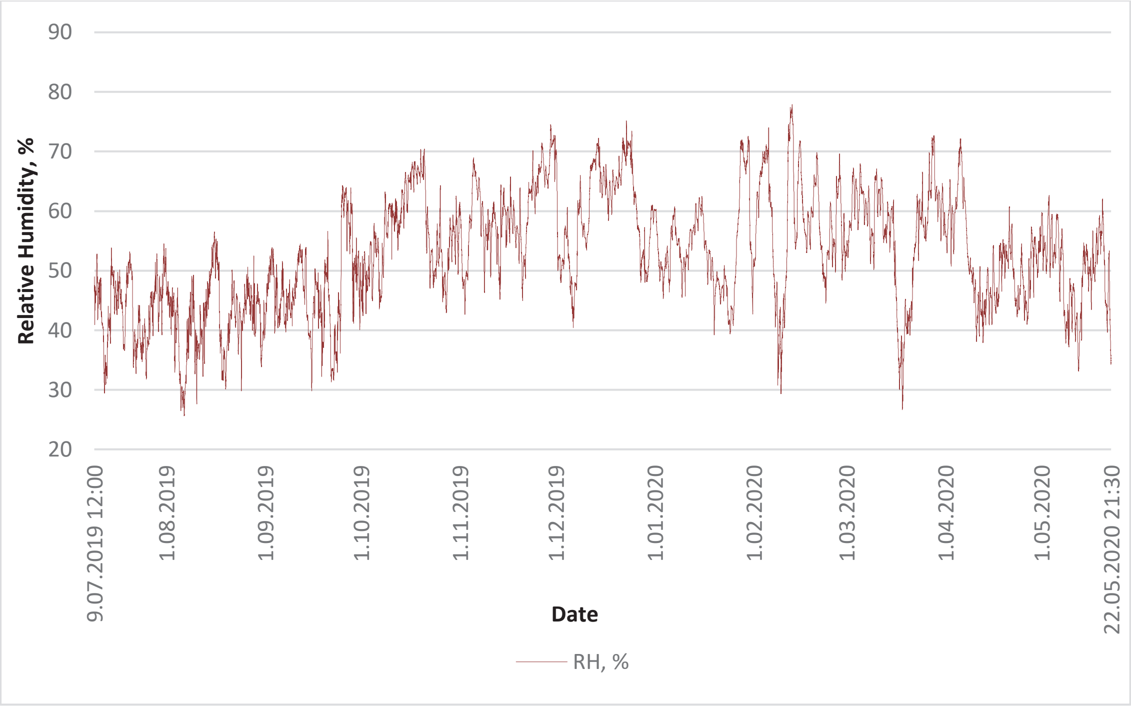


Figure 5.10. Hourly relative humidity values of data logger No. 5 during the year

For the device No. 6 placed on the north wall facing the gallery space on the gallery floor, the air temperature during the year varied between the minimum value 7.65 °C measured on February 10, 2020 and the maximum value 34.47 °C measured on August 12, 2019. Relative humidity during the year varied between the minimum value 25.84% measured on August 6, 2019 and the maximum value 82.70% measured on February 13, 2020. The average of the minimum and maximum air temperature difference of the months was 7.7 ºC, the average of the minimum and maximum relative humidity difference was 35.8%. Air temperature and relative humidity measurements during the year are shown in Figure 5.11 and 5.12. The determined maximum, minimum and average air temperature and relative humidity values are shown in Table 5.6.

Table 5.6. Monthly air temperature and relative humidity values of data logger No. 6

Data Logger No. 6 Air Temperature and Relative Humidity Values						
	Air Temperature (ºC)			**Relative Humidity (%)**		
Months	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
July 2019	28.05	30.99	33.73	29.72	43.17	54.12
August 2019	29.39	32.12	34.47	25.84	41.70	56.83
September 2019	24.12	27.70	31.33	31.00	47.63	64.17
October 2019	20.17	24.09	28.39	43.30	57.59	70.98
November 2019	16.68	20.37	23.95	44.84	61.25	77.83
December 2019	10.64	14.37	19.06	43.35	62.55	79.09
January 2020	8.44	10.72	14.07	41.64	56.48	79.69
February 2020	7.65	13.16	17.11	34.90	59.76	82.70
March 2020	11.66	15.76	19.75	27.37	57.28	75.03
April 2020	14.55	18.75	23.14	30.50	51.94	74.77
May 2020	20.27	25.08	31.36	29.62	48.72	60.20
June 2020	Data not available					

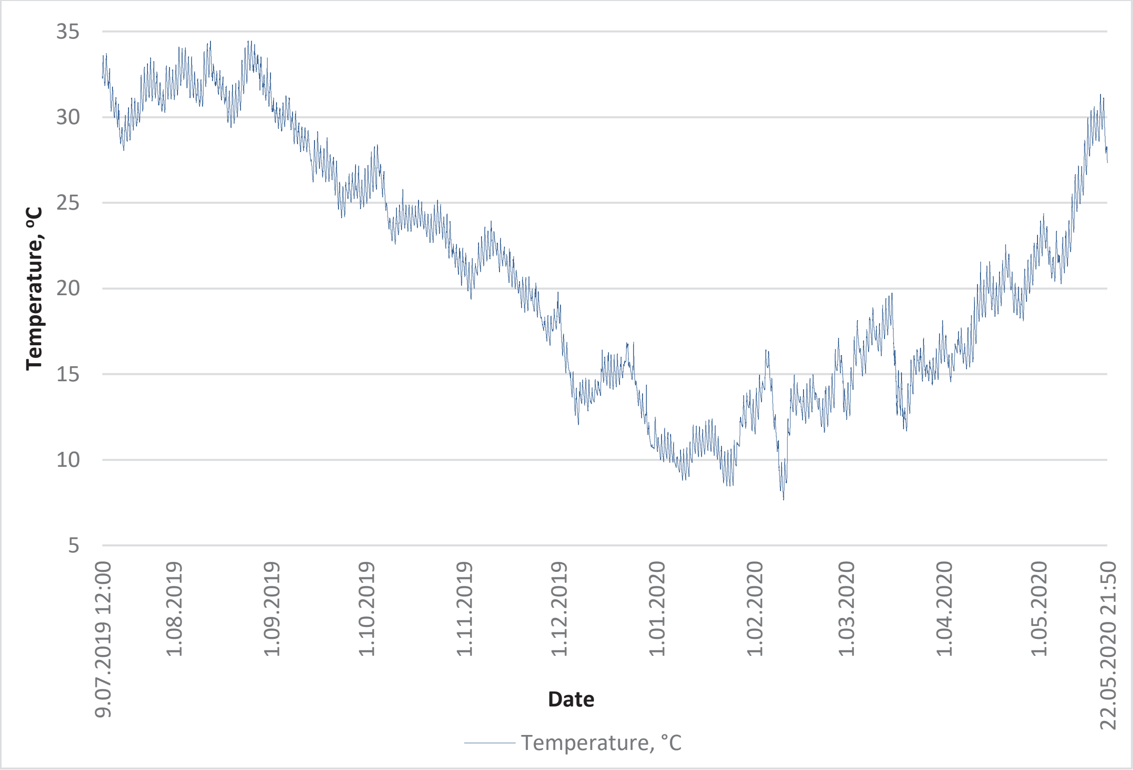


Figure 5.11. Hourly air temperature values of data logger No. 6 during the year

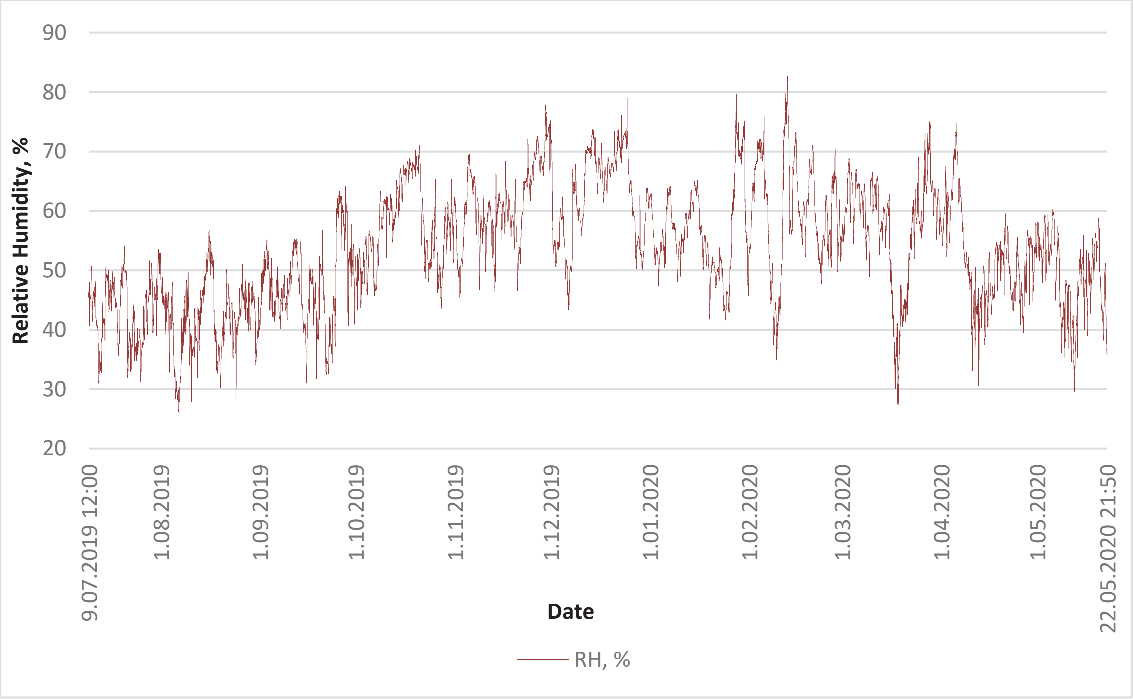


Figure 5.12. Hourly relative humidity values of data logger No. 6 during the year

In summary, the coldest month was February and the warmest was August. On 24 August 2019, device No. 1, 2, 3 and 4 measured the maximum temperature values (35.21 ºC, 33.73 ºC, 34.20 ºC, 33.91 ºC). Device No. 5 and 6 located on the south wall and gallery floor detected higher temperatures (34.30 ºC, 34.33 ºC) than device No. 2, 3 and 4 in the interior. However, device No. 5 and 6 detected the maximum temperature on 12 August 2019 (34.68 ºC, 34.47 ºC). On 12 August 2019, the temperature measurement of the device No. 5 and 6 is higher than device No. 1, 2, 3 and 4 (33.60 ºC, 33.47 ºC, 33.86 ºC, 33.65 ºC). As seen in Figure 5.13, Table 5.7, Figure 5.14 and Table 5.8, data loggers No. 3, 4 and 5 on the ground floor recorded similar data. According to recorded data, no significant difference was observed between the north, south and east measurement values. Device No. 2, placed between the windows on the north wall at the entrance, measured the lowest temperature and higher relative humidity values on the ground floor during the year. It is thought that the reason for this situation may be that the device is near the door at the entrance and is under the influence of the outdoor climate. Although the measurement results of the device No. 6 placed on the gallery floor were very close to the values measured on the ground floor during the year, the air temperature was lower and the relative humidity was higher on the gallery floor in winter season than on the ground floor.

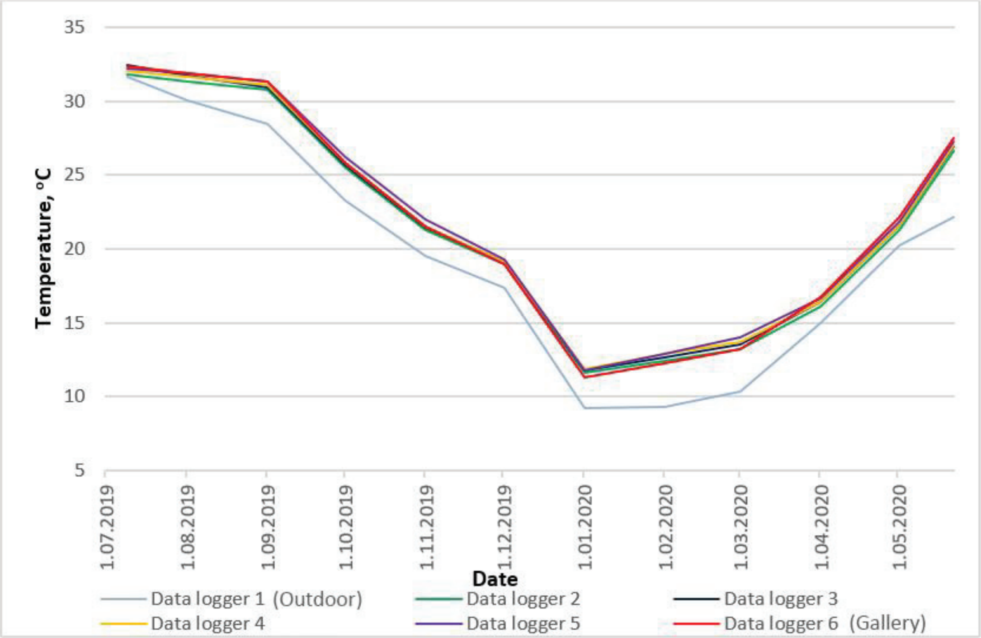


Figure 5.13. Comparison of monthly air temperature values measured by six devices

Table 5.7. Comparison of monthly average air temperature values measured by six devices

	Monthly Average Air Temperature (ºC)										
Devices	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
1	28.84	30.11	25.26	21.80	18.25	12.16	9.02	11.51	14.26	17.08	23.47
2	30.41	31.57	27.43	23.88	20.37	14.63	11.01	12.97	15.44	18.37	24.26
3	30.88	31.92	27.71	24.12	20.53	14.90	11.23	13.21	15.74	18.73	24.74
4	30.76	31.85	27.77	24.17	20.76	15.07	11.58	13.28	15.78	18.70	24.63
5	30.92	32.06	28.03	24.50	20.84	14.98	11.43	13.46	16.02	18.89	24.78
6	30.99	32.12	27.70	24.09	20.37	14.37	10.72	13.16	15.76	18.75	25.08

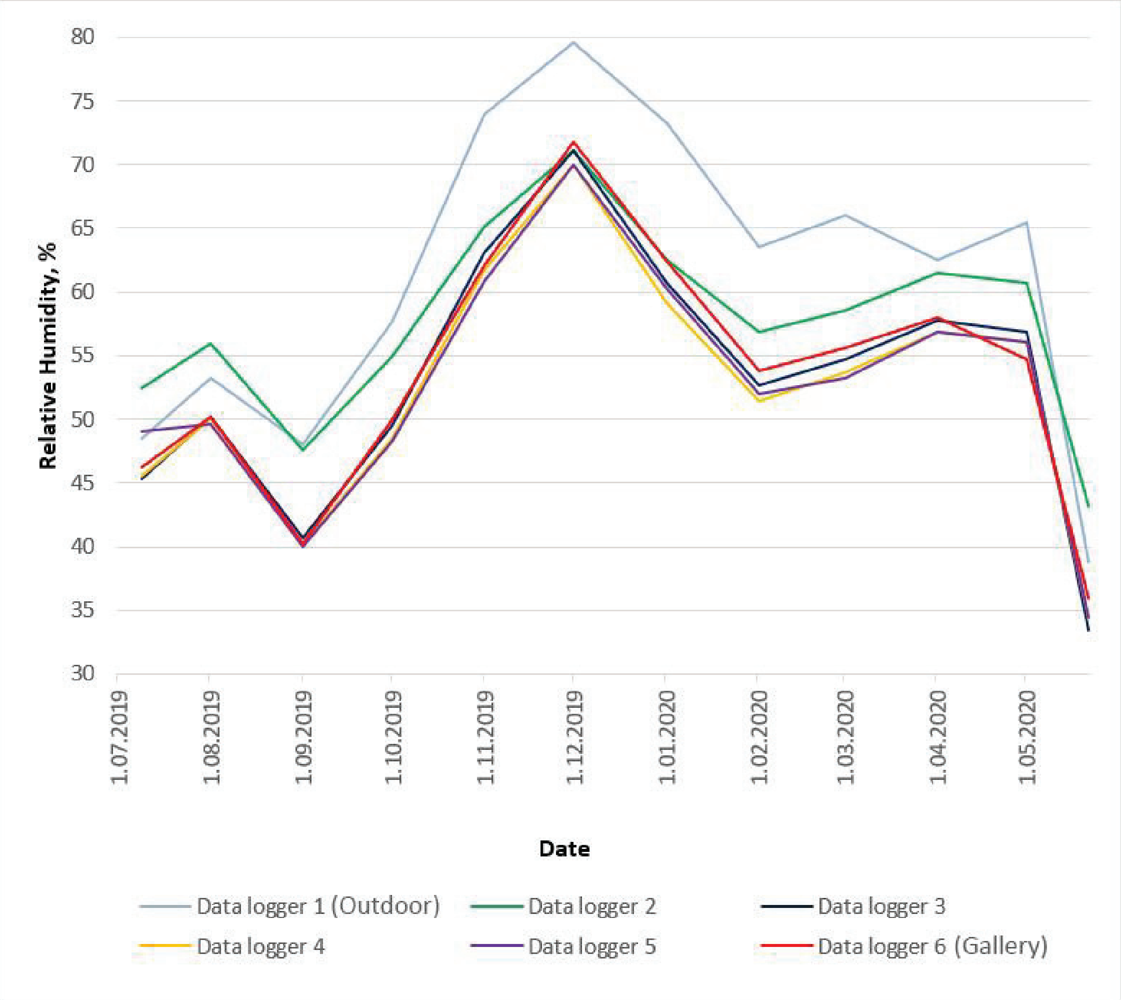


Figure 5.14. Comparison of monthly relative humidity values measured by six devices

Table 5.8. Comparison of monthly average relative humidity values measured by six devices

	Monthly Average Relative Humidity (%)										
Devices	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
1	50.33	47.99	56.60	68.32	72.31	72.97	64.25	67.59	65.05	59.07	55.64
2	50.44	49.02	53.42	61.45	63.55	63.18	58.05	61.89	60.77	56.82	55.72
3	43.45	41.92	47.63	57.77	60.99	60.62	54.53	59.12	57.39	51.93	49.96
4	43.28	41.63	46.91	56.79	59.35	59.25	52.80	58.13	56.48	51.32	49.57
5	43.47	41.72	46.83	56.44	59.70	60.07	53.81	58.03	56.38	51.43	49.81
6	43.17	41.70	47.63	57.59	61.25	62.55	56.48	59.76	57.28	51.94	48.72

5.1.3. Indoor Air Temperature and Relative Humidity Data Analysis During Event Times

In the event on 23 November, it was determined that the maximum air temperature was 20.67 ^{o}C, the minimum air temperature was 19.45 ^{o}C, the maximum relative humidity was 70.29 % and the minimum relative humidity was 66.22 % in the church. Although indoor temperature was correlated with outdoor temperature, between 20:00 and 21:20 the temperature increased from 20.06 ^{o}C to the maximum temperature of 20.67 ^{o}C and decreased to 19.49 ^{o}C at 22:50. At the end of the event, the temperature decreased to the minimum value of 19.45 ^{o}C and continued to decrease. Indoor relative humidity and outdoor relative humidity were also related. However, between 20:00 and 20:30 the relative humidity increased from 69.32 % to the maximum value of 70.29 % and decreased to 66.22 % at 22:30. At the end of the event, the indoor relative humidity reached to 66.44 % (Figure 5.15).

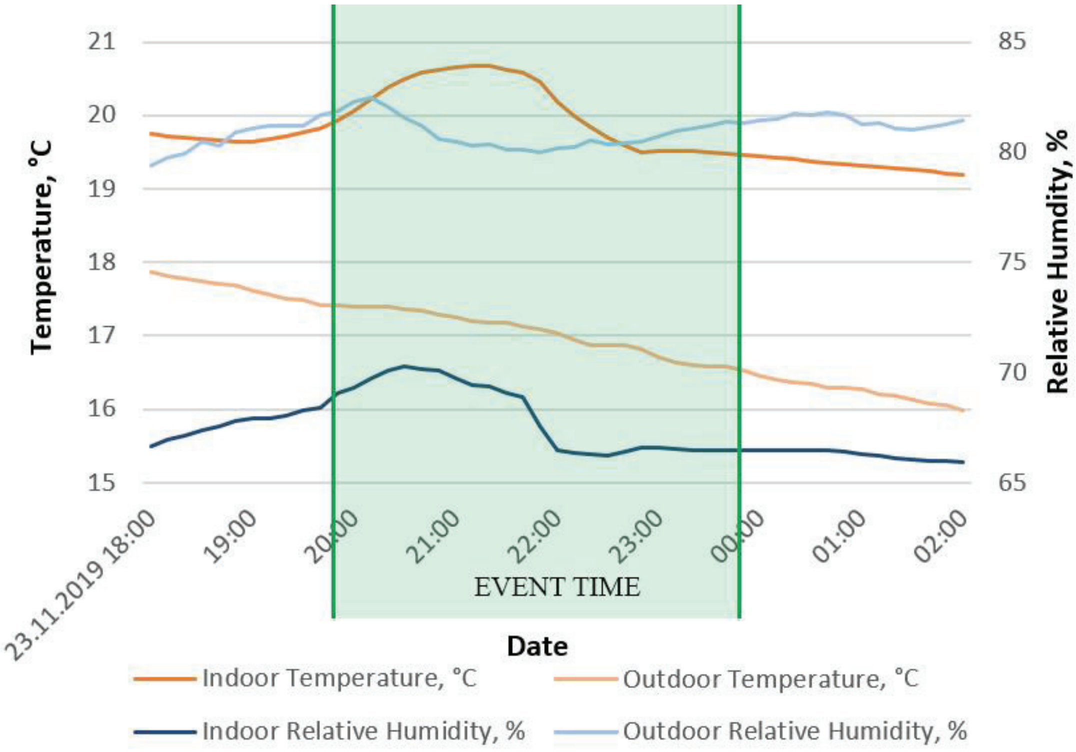


Figure 5.15. Air temperature and relative humidity values recorded in the 10-minute cycle at the event on 23 November 2019

In the event on 14 December, it was determined that the maximum air temperature was 17.40 °C, the minimum air temperature was 15.64 °C, the maximum relative humidity was 69.05 % and the minimum relative humidity was 64.69 % in the church. Although indoor temperature was correlated with outdoor temperature, between 20:00 and 21:30 the temperature increased from 16.33 °C to the maximum temperature of 17.40 °C. After 21:30, the indoor temperature decreased to the minimum value of 15.64 °C at the end of the event and continued to decrease. Indoor relative humidity and outdoor relative humidity were also related. Between 20:00 and 21:50 the relative humidity decreased from the maximum value of 69.05 % to the minimum value of 64.49 %. After 21:50, the indoor relative humidity increased to 66.48 % at the end of the event and continued to increase (Figure 5.16).

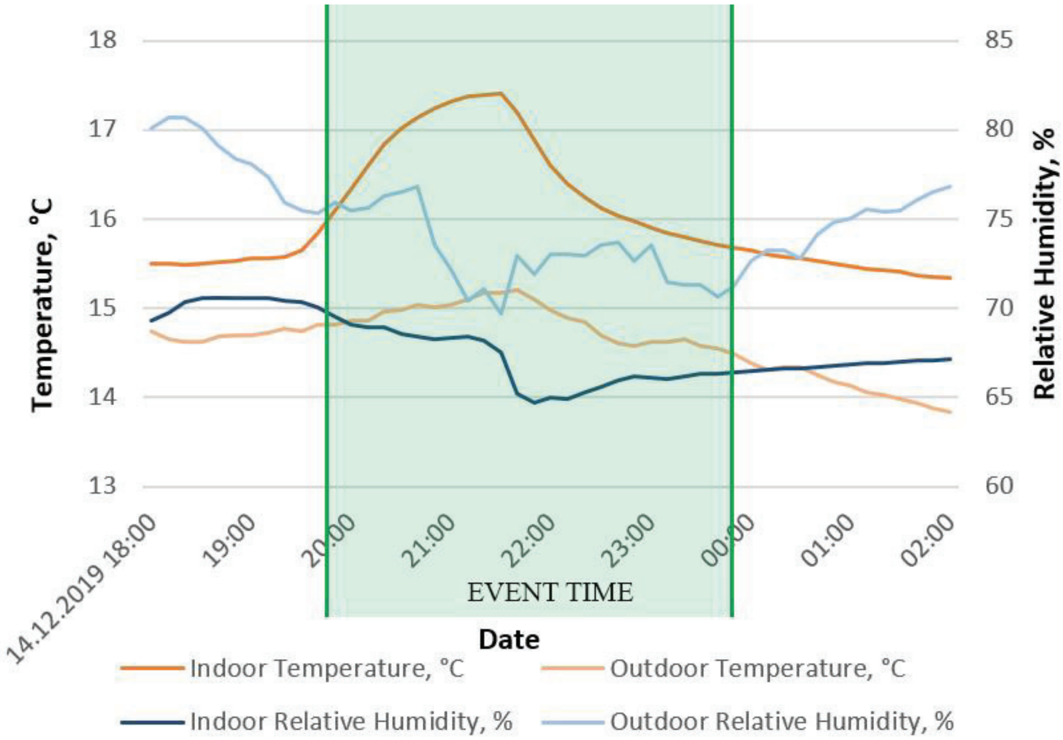


Figure 5.16. Air temperature and relative humidity values recorded in the 10-minute cycle at the event on 14 December 2019

In the event on 16 December, it was determined that the maximum air temperature was 17.37 ºC, the minimum air temperature was 15.72 ºC, the maximum relative humidity was 67.18 % and the minimum relative humidity was 65.47 % in the church. Although indoor temperature was correlated with outdoor temperature, between 20:00 and 21:00 the temperature increased from 16.72 ºC to the maximum temperature of 17.37 ºC. After 21:00, the indoor temperature decreased to the minimum value of 15.72 ºC and continued to decrease. Indoor relative humidity and outdoor relative humidity were also related. Between 20:00 and 21:30, the relative humidity decreased from 66.48 % to the minimum value of 65.47 % and reached to 66.02 % at the end of the event (Figure 5.17).

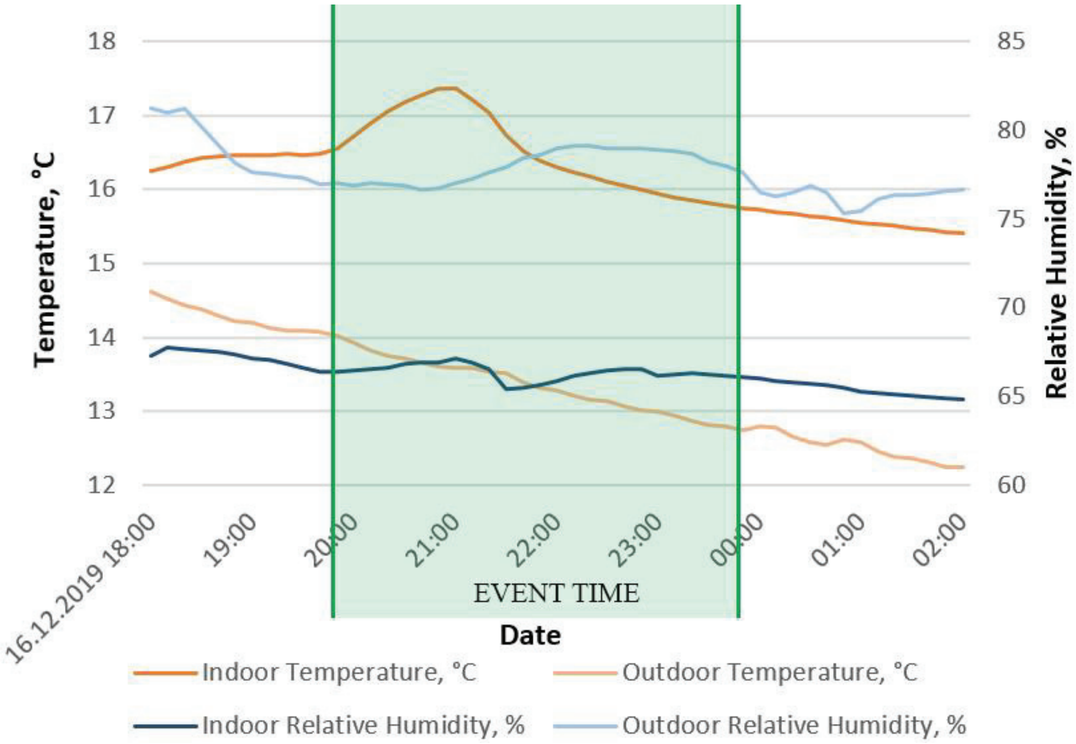


Figure 5.17. Air temperature and relative humidity values recorded in the 10-minute cycle at the event on 16 December 2019

In the event on 28 December, it was determined that the maximum air temperature was 15.47 ºC, the minimum air temperature was 13.23 ºC, the maximum relative humidity was 58.16 % and the minimum relative humidity was 49.50 % in the church. Although indoor temperature was correlated with outdoor temperature, between 20:00 and 21:20 the temperature increased from 14.21 ºC to the maximum temperature of 15.47 ºC. At the end of the event, the temperature decreased to the minimum value of 13.23 ºC and continued to decrease. Indoor relative humidity and outdoor relative humidity were also related. However, between 20:00 and 21:20 the relative humidity increased from 53.91 % to the maximum value of 58.16 % and decreased to the minimum value of 49.50 % at 22:20. At the end of the event, the indoor relative humidity reached to 51.25 % (Figure 5.18).

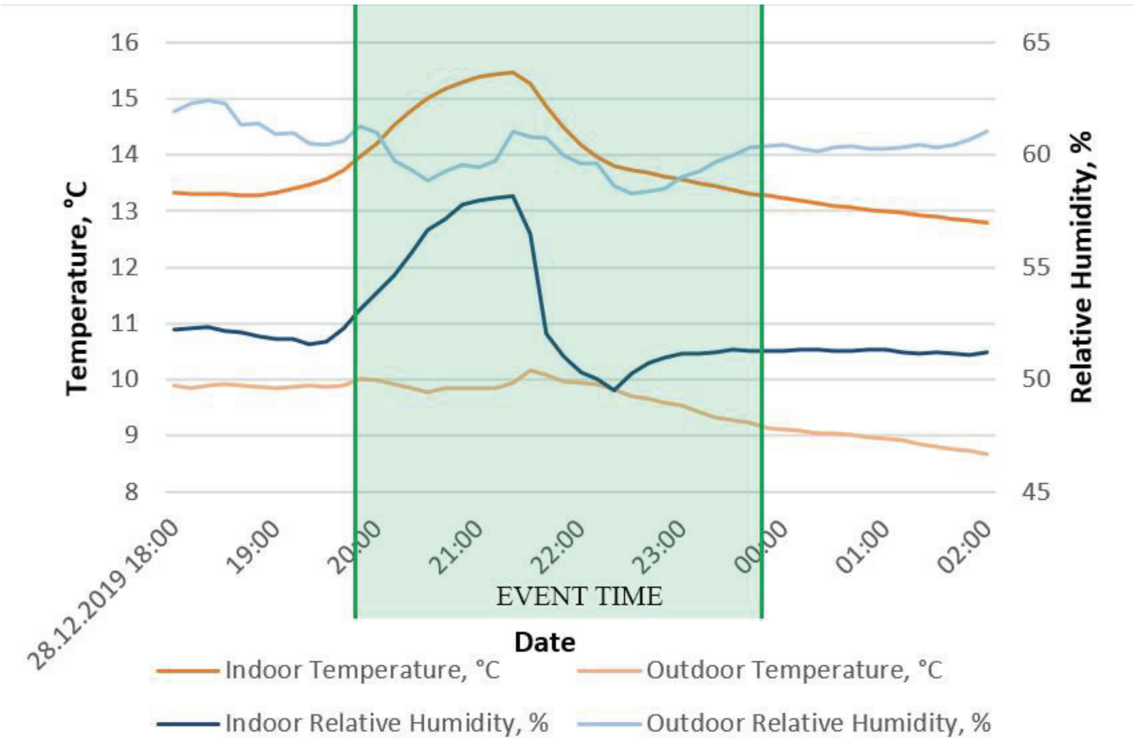


Figure 5.18. Air temperature and relative humidity values recorded in the 10-minute cycle at the event on 28 December 2019

In the event on 14 February, it was determined that the maximum air temperature was 15.23 °C, the minimum air temperature was 14.23 °C, the maximum relative humidity was 66.11 % and the minimum relative humidity was 57.60 % in the church. Indoor temperature was correlated with outdoor temperature. Between 14:00 and 16:00 the temperature increased from the minimum value of 14.23 °C to the maximum value of 15.23 °C. At the end of the event, the temperature decreased to 14.61 °C and continued to decrease. Indoor relative humidity and outdoor relative humidity were also related. During the event, between 14:00 and 17:00 the indoor relative humidity increased from the minimum value of 57.60 % to the maximum value of 66.11 % and continued to increased (Figure 5.19).

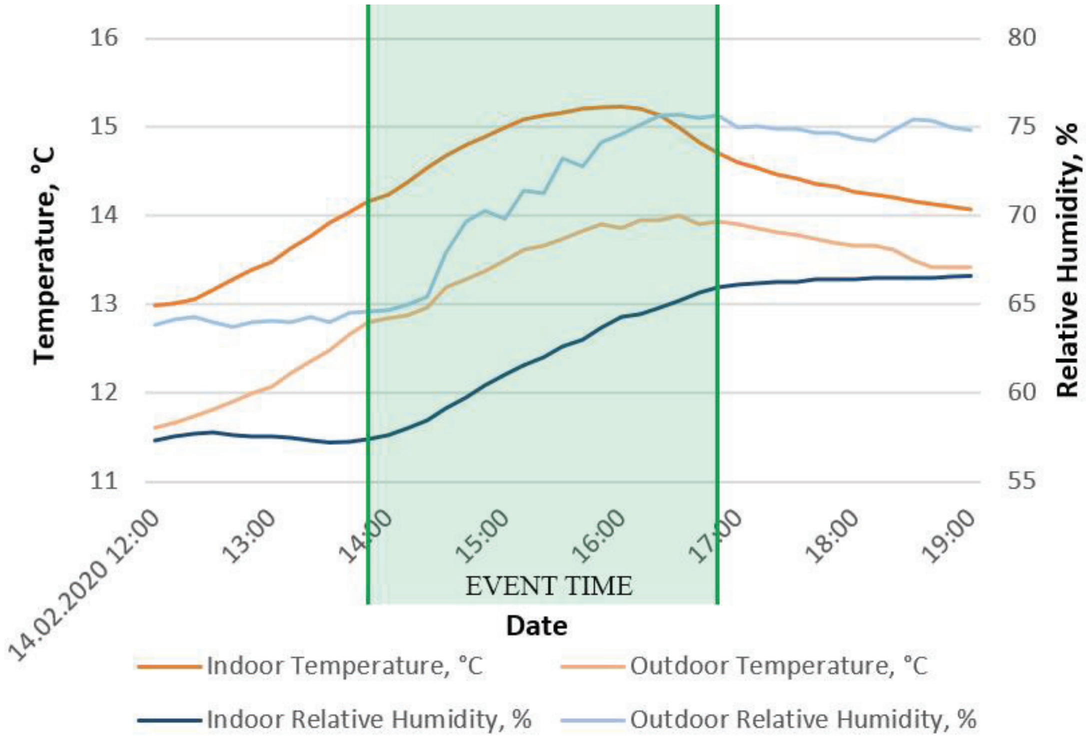


Figure 5.19. Air temperature and relative humidity values recorded in the 10-minute cycle at the event on 14 February 2020

In summary, it has been determined that indoor and outdoor temperature and relative humidity values were related. Despite the presence of four radiant heaters and people at the events, the indoor air temperature increased by 0.61 °C on 23 November 2019, 1.07 °C on 14 December 2019, 0.65 °C on 16 December 2019, 1.26 °C on 28 December and 1.00 °C on 14 February 2020. After reaching its maximum values, indoor air temperature decreased by 1.23 °C on 23 November 2019, 1.76 °C on 14 December 2019, 1.64 °C on 16 December 2019, 2.25 °C on 28 December 2019 and 0.62 °C on 14 February 2020 in line with the outdoor temperature during the events. Maximum and minimum relative humidity differences were 4.08 % on 23 November 2019, 4.36 % on 14 December 2019, 1.71 % on 16 December 2019, 8.66 % on 28 December 2019 and 8.51 % on 14 February 2020.

5.2. Thermal Comfort Analysis

Thermal comfort analysis was carried out by calculating hourly and monthly PMV - PPD values using measured air temperature, relative humidity, mean radiant temperature and air velocity between 9 July 2019 - 22 May 2020 in the Agios Voukolos Church and the determined clothing insulation and metabolic rate values.

In addition, the thermal comfort status of the church for the winter season was examined in detail by comparing calculated PMV value and obtained after survey studies AMV value.

5.2.1. Thermal Comfort Analysis by PMV-PPD Method According to Measurement Data

The PMV-PPD method developed by Fanger was used to calculate the thermal comfort for the users of the Agios Voukolos Church. Evaluations were made by taking into account the monthly and hourly averages of the data. Environmental variables affecting thermal comfort conditions are air temperature, relative humidity, mean radiant temperature and air velocity, and personal variables are metabolic rate and clothing insulation.

Clothing insulation values were given in Table 5.9. The monthly average values of air temperature, relative humidity, mean radiant temperature and air velocity measurements are shown in Table 5.10.

Since historical buildings must be preserved with their original characteristics, the requirements of thermal comfort were evaluated differently from modern buildings. In this direction, it was suggested that historical buildings be evaluated according to Category III in four categories (Table 2.2) defined according to the thermal comfort conditions expected from the buildings in the EN 16798-1. According to the Category III, as seen in Table 2.3, the appropriate PMV value should vary between -0.7 and 0.7 and the PPD value should be less than 15%. Table 2.2 and Table 2.3 are shown in Chapter 3 under the heading "2.3.1.2. Predicted Percentage Dissatisfied (PPD)". Thermal comfort was calculated using the CBE Tool shown in Figure 3.10, taking into account the hourly and monthly averages of the measured variables. The tool is shown in Chapter 3 under the heading "3.2. Thermal Comfort Calculations".

According to ISO 7730:2005, the metabolic rate was accepted as 1 met for seated occupants (Table 2.4). Clothing insulation values were created by calculating according to clothing combinations, using the values determined in ISO 7730:2005. The clothing insulation values of the combinations determined by surveys and estimates for each month are shown in Table 5.9. The values vary between 0.26 – 1.39 clo.

Table 5.9. Clothing combinations and insulation values according to the months

Months	**Clothing Combinations and Thermal Insulation Values (clo)**		**Clothing Thermal Insulation (clo)**
July August	Underwear	0.07	0.26
	T-shirt	0.09	
	Shorts	0.06	
	Socks	0.02	
	Thin Soled Shoes	0.02	
September	Underwear	0.07	0.46
	Short Sleeves	0.15	
	Light-weight Trousers	0.20	
	Socks	0.02	
	Thin Soled Shoes	0.02	
May October November	Underwear	0.07	0.88
	Normal, Long Sleeves	0.25	
	Light, Jacket	0.25	
	Normal Trousers	0.25	
	Socks	0.02	
	Thick Soled Shoes	0.04	
March April December	Underwear	0.07	1.32
	Sweater	0.28	
	Normal Trousers	0.25	
	Coat	0.60	
	Socks	0.02	
	Boots	0.10	
January February	Underwear	0.07	1.39
	Thick Sweater	0.35	
	Normal Trousers	0.25	
	Coat	0.60	
	Socks	0.02	
	Boots	0.10	

For July, the metabolic rate of sitting individuals was 1 met, the clothing insulation value was 0.26 clo (Table 5.9), and the measurements starting on 9 July 12:00 were taken into account in the thermal comfort analysis. When the hourly PMV values were examined, it is seen that the PMV values were generally above the acceptable 0.7 value. Only on 14 July 20:00 – 00:00, 15 July 00:00 – 09:00 and 23:00 – 00:00, 16 July 00:00 – 10:00, 17 July 04:00 – 10:00, 18 July 02:00 – 09:00 PMV values were between -0.7 and 0.7 and thermal comfort level was found to be sufficient. According to hourly calculations, it was felt warm 93% and comfortable 7% of the time. Hourly thermal comfort conditions are shown in Table A.1 for July.

For August, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 0.26 clo (Table 5.9). According to the hourly PMV values examined, the results were found to be above the acceptable value of 0.7 and the place was felt warm 100% of the time. Thermal comfort conditions are shown in Table A.2 for August.

For September, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 0.46 clo (Table 5.9). Based on hourly calculations, PMV values were above the acceptable 0.7 value on 1 September – 12 September, 13 September 00:00 – 08:00, 14 September 13:00 – 21:00, 15 September 13:00 – 22:00, 16 September 12:00 – 17:00. PMV values were below the acceptable value of -0.7 on 22 September 05:00 – 10:00, 23 September 04:00 – 10:00, 24 September 03:00 – 09:00. The PMV values were between 0.7 and -0.7 at other measurement times. The place was felt warm 45%, cold 2.5%, and comfortable 52.5% of the time. Thermal comfort status is shown in Table A.3 for September.

For October, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 0.88 clo (Table 5.9). Based on hourly calculations, PMV values were above the acceptable 0.7 value on 1 October 12:00 – 00:00, 2 October 11:00 – 00:00, 3 October 00:00 – 02:00 and 10:00 – 00:00, 4 October 00:00 – 06:00 and 09:00 – 00:00, 5 October, 6 October 00:00 – 01:00 ve 10:00 – 20:00. PMV values were below the acceptable value of -0.7 on 29 October 06:00 – 10:00, 30 October 03:00 – 10:00, 31 October 01:00 – 11:00. The PMV values were between 0.7 and -0.7 at other measurement times. The place was felt warm 13%, cold 3%, and comfortable 84% of the time. Thermal comfort status is shown in Table A.4 for October.

For November, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 0.88 clo (Table 5.9). Based on hourly calculations, PMV values were below the acceptable -0.7 value on 1 November 02:00 – 11:00 and 19:00 – 00:00, 2 November 00:00 – 13:00 and 18:00 – 00:00, 3 November 00:00 – 13:00 and 22:00 – 00:00, 4 November 00:00 – 13:00, 5 November 04:00 – 09:00, 12 November 07:00 – 09:00, 15 November 00:00 – 11:00, 16 November 00:00 – 12:00, 17 November 00:00 – 12:00 and 18:00 – 00:00, 18 November – 30 November. The PMV values were between 0.7 and -0.7 at other measurement times. The place was felt cold 58.5%, and comfortable 41.5% of the time. Thermal comfort status is shown in Table A.5 for November.

For December, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 1.32 clo (Table 5.9). Based on hourly calculations, The PMV values were between 0.7 and -0.7 only on 1 December 00:00 – 20:00 and 2 December 12:00 – 15:00. PMV values were below the acceptable -0.7 value at other measurement times. The place was felt cold 97%, and comfortable 3% of the time. Thermal comfort status is shown in Table A.6 for December.

For January, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 1.39 clo (Table 5.9). Based on hourly calculations, The PMV values were below the acceptable -0.7 value. The place was felt cold 100% of the time. Thermal comfort status is shown in Table A.7 for January.

For February, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 1.39 clo (Table 5.9). Based on hourly calculations, The PMV values were below the acceptable -0.7 value. The place was felt cold 100% of the time. Thermal comfort status is shown in Table A.8 for February.

For March, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 1.32 clo (Table 5.9). Based on hourly calculations, The PMV values were between 0.7 and -0.7 only on 8 March 11:00 – 15:00, 9 March 11:00 – 19:00, 12 March 14:00 – 20:00, 13 March 13:00 – 23:00, 14 March 12:00 – 00:00, 15 March 00:00 – 02:00 and 10:00 – 21:00. PMV values were below the acceptable -0.7 value at other measurement times. The place was felt cold 93%, and comfortable 7% of the time. Thermal comfort status is shown in Table A.9 for March.

For April, the metabolic rate of sitting individuals was 1 met, and the clothing insulation value was 1.32 clo (Table 5.9). Based on hourly calculations, The PMV values were below the acceptable -0.7 value on 1 April – 10 April, 11 April 00:00 – 13:00 and 23:00 – 00:00, 12 April 00:00 – 10:00, 13 April 03:00 – 10:00, 17 April 05:00 – 08:00, 26 April 05:00 – 08:00. The PMV values were between 0.7 and -0.7 at other measurement times. The place was felt cold 38.5%, and comfortable 61.5% of the time. Thermal comfort status is shown in Table A.10 for April.

For May, the metabolic rate of sitting individuals was 1 met, the clothing insulation value was 0.88 clo (Table 5.9), and the measurements completing on 22 May 22:00 were taken into account in the thermal comfort analysis. Based on hourly calculations, The PMV values were below the acceptable -0.7 value on 1 May 03:00 – 08:00, 4 May 23:00 – 00:00, 5 May 00:00 – 12:00 and 23:00 – 00:00, 6 May 00:00 – 10:00, 7 May 02:00 – 09:00 and 20:00 – 00:00, 8 May 00:00 – 12:00, 9 May 00:00 – 10:00, 10 May 04:00 – 08:00. The PMV values were above the acceptable 0.7 value on 14 May 14:00 – 20:00, 15 May 11:00 – 00:00, 16 May 00:00 – 03:00 and 09:00 – 00:00, 17 May – 22 May. The PMV values were between 0.7 and -0.7 at other measurement times. The place was felt cold 12.5%, warm 34%, and comfortable 53.5% of the time. This situation is shown in Table A.11 for May.

Table 5.10. Monthly thermal comfort variables and PMV-PPD values

	Air Temperature (ºC)	**Relative Humidity (%)**	**Mean Radiant Temperature (ºC)**	**Air Velocity (m/s)**	**Clothing Insulation (clo)**	**Metabolic Rate (met)**	**PMV**	**PPD (%)**
July 2019	30.74	45.16	30.65	0.01	0.26	1	1.55	53
Aug. 2019	31.85	43.57	31.78	0.01	0.26	1	2.03	78
Sep. 2019	27.74	48.70	27.66	0.01	0.46	1	0.61	13
Oct. 2019	24.17	58.11	24.10	0.02	0.88	1	0.18	6
Nov. 2019	20.63	60.90	20.57	0.01	0.88	1	-0.87	21
Dec. 2019	14.90	60.78	14.77	0.02	1.32	1	-1.47	49
Jan. 2020	11.31	54.80	11.81	0.01	1.39	1	-2.11	82
Feb. 2020	13.23	59.29	13.81	0.01	1.39	1	-1.66	60
Mar. 2020	15.75	57.75	15.70	0.01	1.32	1	-1.28	39
Apr. 2020	18.67	52.88	18.61	0.01	1.32	1	-0.62	13
May 2020	24.60	51.27	24.52	0.01	0.88	1	0.25	6
June 2020	Data not available							

Categories (Table 2.2 ve 2.3): ⬜ Category I 🟦 Category II ■ Category III 🟧 Category IV

When the monthly PMV and PPD calculations are analyzed (Table 5.10), it is seen that the PMV value was 1.55 in July and 2.03 in August. The fact that these values were above the acceptable upper limit of 0.7 indicates that the place was felt warm. Also it is observed that the PPD values for these months were 53% and 78%, and these values, which show the percentage of dissatisfaction, were above the acceptable value of 15%. As indicated in Figure B.1 and B.2, the thermal comfort levels in July and August were in the Category IV according to the EN 16798-1. This situation shows that the thermal comfort conditions of the church were insufficient during these months.

It is seen that the PMV value was 0.61 in September, 0.18 in October, -0.62 in April and 0.25 in May (Table 5.10). The fact that these values were in the acceptable range of -0.7 and 0.7 indicates that the place was perceived as comfortable. Also it was observed that the PPD values for these months were 13%, 6%, 13% and 6%, and these values, which show the percentage of dissatisfaction, were below the acceptable value of 15%. Thermal comfort level was in Category III in September (Figure B.3), in Category I in October (Figure B.4), in Category III in April (Figure B.10), in Category II in May (Figure B.11). This situation shows that the thermal comfort conditions of the church were sufficient in September, October, April and May.

It is seen that the PMV value was -0.87 in November, -1.47 in December, -2.11 in January, -1.66 in February and -1.28 in March (Table 5.10). The fact that these values were below the acceptable lower limit of -0.7 indicates that the place was felt cold. Also it was observed that the PPD values for these months were 21%, 49%, 82%, 60% and 39%, and these values, which show the percentage of dissatisfaction, were above the acceptable value of 15%. As indicated in Figure B.6, B.7, B.8 and B.9, the thermal comfort level in November, December, January, February and March was in the Category IV according to the EN 16798-1. This situation shows that the thermal comfort conditions of the church were insufficient during these months.

As seen in the formula shown in Chapter 3 under the heading “3.2. Thermal Comfort Calculations”, air temperature is the factor that highly affects thermal comfort conditions. When the October and November calculations are examined, the 4 ^{o}C air temperature difference caused insufficient thermal comfort conditions.

As a result of the examination made with the PMV – PPD method, it was determined that the Agios Voukolos Church was felt the warmest in August and the coldest in January in terms of thermal comfort. In order for the occupants to feel comfortable during the event periods, cooling methods compatible with the historical building should be developed for July and August, and an appropriate heating system should be developed for November, December, January, February and March. PMV values according to monthly calculations are shown in Figure 5.20 and PPD values are shown in Figure 5.21.

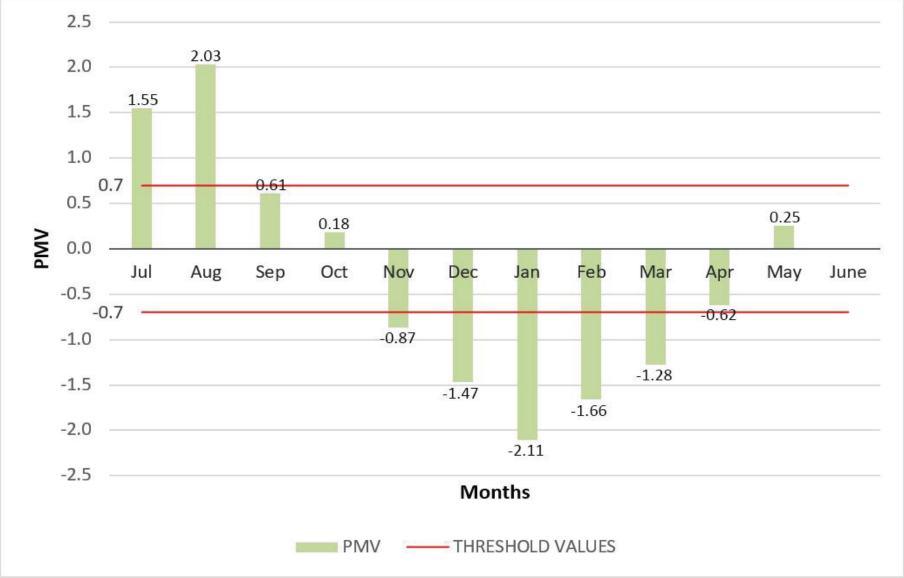


Figure 5.20. Threshold values and PMV values according to monthly calculations

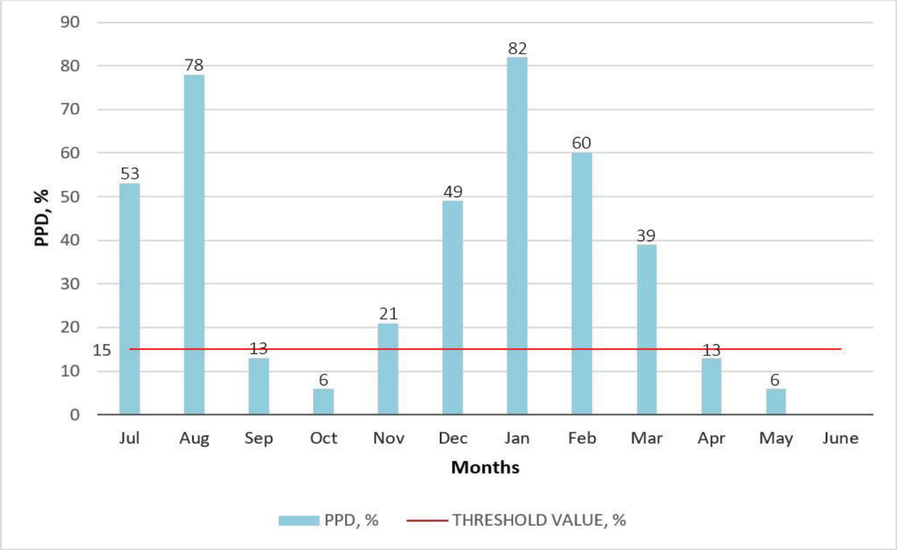


Figure 5.21. Threshold values and PPD values according to monthly calculations

5.2.2. Comparison of Indoor Microclimate Conditions in terms of Thermal Comfort Calculated by PMV-PPD Method in Historical Churches in Hot-summer Mediterranean Climate

The performance of the low-temperature radiant floor heating system and its effects were investigated in the Matera Cathedral, built in the 13th century in Sassi, Italy in hot-summer Mediterranean climate. According to the measurements conducted on 13-23 April 2013, after the installation of the underfloor heating system, the average air temperature was 18 ^{o}C, the relative humidity was 54%, the air velocity was 1 m/s with the adequate clothing insulation, PMV was 0.25 and PPD was 5.3% (Table 5.11). The place was found comfortable according to the expected -0.5 < PMV < 0.5, PPD < 10% (ISO, 2005) conditions (Cardinale et al., 2014). Within the scope of the thesis, -0.7 < PMV < 0.7, PPD < 15% (CEN, 2019) conditions were expected for thermal comfort in the Agios Voukolos Church under the influence of hot-summer Mediterranean climate. In April, without a heating system, average air temperature was 18.67 ^{o}C, relative humidity was 52.88%, mean radiant temperature was 18.61 ^{o}C, air velocity was 0.01 m/s, metabolic rate was 1 met, clothing insulation was 1.32 clo, PMV was -0.62 and PPD 13%. PMV and PPD values obtained in April showed that the place was felt thermally comfortable (Table 5.11). In April, Matera Cathedral and Agios Voukolos Church have similar average air temperature (18 ^{o}C and 18.67 ^{o}C) and relative humidity (54 % and 52.88 %) conditions. In both buildings, the thermal comfort level was sufficient.

Measurements were conducted between September 2012 and November 2013 in Our Lady of Assumption Church in Algete, Spain, under the influence of hot-summer Mediterranean climate. During its restoration in 2006, a natural gas-fuelled, centralised, intermittently operated heating system with network of underfloor hot water (70-80 ^{o}C) pipes was installed. During the winter months, its effects were examined. The system was operated at a temperature of 18.5 °C, with indoor air temperature of 18±1°C and relative humidity of 55-58%. By heating for 30-60 minutes, PMV was obtained between -0.11 and -0.43, PPD 13-15% in the lower part of the choir. This indicates the Category II thermal comfort level according to the EN 15251. In the coldest parts, with heating for 60 minutes, PMV was determined in the range of -0.9 and -2.0, PPD in the range of 22-77%. This indicates the Category IV thermal comfort level according to the EN 15251 and the place was considered uncomfortable. In other parts of the church, with heating for more than 60 minutes, PMV was determined between -0.5 and -0.7, PPD between 13-15%. This indicates Category III thermal comfort level according to the EN 15251 (Varas-Muriel and Fort, 2018) (Table 5.11). Within the scope of the thesis, $-0.7 < \text{PMV} < 0.7$, $\text{PPD} < 15\%$ (CEN, 2019) conditions were expected for thermal comfort in the Agios Voukolos Church under the influence of hot-summer Mediterranean climate. Considering the average measurement values in the winter months (December, January and February) without a heating system, in December the air temperature was 14.90 ^{o}C, the relative humidity was 60.78%, the mean radiant temperature was 14.77 ^{o}C, the air velocity was 0.02 m/s, the clothing insulation was 1.32 clo, the metabolic rate was 1 met, PMV was -1.47 and PPD was 49%, in January air temperature was 11.31 ^{o}C, relative humidity was 54.80%, mean radiant temperature was 11.81 ^{o}C, air velocity was 0.01 m/s, clothing insulation was 1.39 clo, metabolic rate was 1 met, PMV was -2.11 and PPD was 82%, in February the air temperature was 13.23 ^{o}C, the relative humidity was 59.29%, the mean radiant temperature was 13.81 ^{o}C, the air velocity was 0.01 m/s, the clothing insulation was 1.39 clo, the metabolic rate was 1 met, the PMV was -1.66 and PPD was 60%. According to the results, the thermal comfort level was found to be insufficient (Table 5.11). With the underfloor heating system in the Our Lady of Assumption Church, the temperature was maintained at 18±1°C and the relative humidity at 55-58%. Depending on the varying heating times, sufficient thermal comfort conditions could be provided in some parts of the building in winter. However, even if the relative humidity values (60.78%, 54.80%, 59.29%) were suitable in the Agios Voukolos Church in winter, low air temperature values (14.90 ^{o}C, 11.31 ^{o}C, 13.23 ^{o}C) caused insufficient thermal comfort conditions to be provided. It does not seem possible to provide thermal comfort conditions without a compatible heating system in Agios Voukolos Church.

Table 5.11. Comparison of indoor microclimate conditions in terms of thermal comfort calculated by PMV-PPD method in historical churches in hot-summer Mediterranean climate

References	**Building & Location**	**Indoor Microclimate Measurement Values & HVAC Systems**	**Expected Thermal Comfort Conditions**	**Thermal Comfort State**
According to measurements in April;				
Cardinale et al. (2014)	Cathedral of Matera (13.th Century) Matera, Italy	**13-23 April 2013;** Air temperature = 18 °C Relative humidity = 54 % Air velocity = 1 m/s Activity = sitting (1 met) Enough clothing insulation Low-temperature radiant floor heating system	-0.5 < PMV < 0.5 PPD < 10 % **(ISO, 2005)**	PMV = 0.25 PPD = 5.3 % Acceptable thermal comfort level
This thesis study	Agios Voukolos Church (19.th Century) İzmir, Turkey	**April 2020;** Air temperature = 18.67 °C Relative humidity = 52.88 % M. rad. temperature = 18.61°C Air Velocity = 0.01 m/s Metabolic rate = 1 met Clothing Insulation = 1.32 clo No heating system	-0.7 < PMV < 0.7 PPD < 15 % **(CEN, 2019)**	PMV = -0.62 PPD = 13 % Acceptable thermal comfort level
According to measurements during winter months (December, January, February);				
Varas-Muriel And Fort (2018)	Our Lady of the Assumption Church (16.th Century) Algete, Spain	**During 2013 winter months;** Air temperature = 18±1 °C Relative humidity = 55-58 % Activity = sitting (1 met) Clothing insulation = 1.5 clo Floor heating system with hot water pipes	**Category I:** -0.2 < PMV < 0.2 PPD < 6 % **Category II:** -0.5 < PMV < 0.5 PPD < 10 % **Category III:** -0.7 < PMV < 0.7 PPD < 15 % **(CEN, 2007)**	Underneath the choir: PMV = -0.11 to -0.43 PPD = 13-15 % (Cat. II) The coolest areas: PMV = -0.9 to -2.0 PPD = 22-77 % (Cat. IV) Rest of the areas: PMV = -0.5 to -0.7 PPD = 13.-15 % (Cat. III)
This thesis study	Agios Voukolos Church (19.th Century) İzmir, Turkey	**December 2019;** Air temperature = 14.90 °C Relative humidity = 60.78 % M. rad. temperature = 14.77 °C Air Velocity = 0.02 m/s Metabolic rate = 1 met Clothing Insulation = 1.32 clo **January 2020;** Air temperature = 11.31 °C Relative humidity = 54.80 % M. rad. temperature = 11.81 °C Air Velocity = 0.01 m/s Metabolic rate = 1 met Clothing Insulation = 1.39 clo **February 2020;** Air temperature = 13.23 °C Relative humidity = 59.29 % M. rad. temperature = 13.81 °C Air Velocity = 0.01 m/s Metabolic rate = 1 met Clothing Insulation = 1.39 clo No heating system	-0.7 < PMV < 0.7 PPD < 15 % **(CEN, 2019)**	December 2019; PMV = -1.47 PPD = 49 % January 2020; PMV = -2.11 PPD = 82 % February 2020; PMV = -1.66 PPD = 60 % Unacceptable thermal comfort levels

5.2.3. Thermal Comfort Analysis by Survey Method

In order to determine the thermal perceptions in the survey studies, occupants were asked to choose cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3) options in 7-point thermal sensation scale. As a result, the Actual Mean Vote (AMV) value was calculated by weighted average of the answers and the felt temperature was determined. If the value found is -0.7 and below, it is felt cold, between -0.7 and +0.7 it is felt comfortable, if it is +0.7 and above it shows that it is felt warm. Samples of surveys applied in the events are shown in Figure D.1, D.2, D.3, D.4 and D.5.

The gender and age of the occupants surveyed are given in Table 5.12. The votes given in the surveys and the calculated AMV values are shown in Table 5.13.

Table 5.12. The gender and age of the occupants surveyed

Date	**Number of Occupants**	**Gender**		**Age**		
		Number of Women	**Number of Men**	**Minimum**	**Average**	**Maximum**
23.11.2019 19:30-20:00	20	14	6	18	33	50
14.12.2019 19:30-20:00	24	18	6	18	32	50
16.12.2019 19:30-20:00	25	16	9	20	39	75
28.12.2019 19:30-20:00	21	10	11	21	38	62
14.02.2020 13:30-14:00	20	14	6	20	46	68

Table 5.13. The votes in the surveys and the calculated AMV values

Date	Outdoor Air Temperature / Weather Condition	Number of Occupants	Options and Votes							AMV
			(-3)	(-2)	(-1)	(0)	(+1)	(+2)	(+3)	
23.11.2019 19:30-20:00	15 ºC Cloudy	20	-	-	7	5	4	3	1	+0.30
14.12.2019 19:30-20:00	15 ºC Cloudy	24	3	3	9	6	3	-	-	-0.88
16.12.2019 19:30-20:00	12 ºC Clear	25	5	6	5	3	4	2	-	-0.96
28.12.2019 19:30-20:00	8 ºC Cloudy	21	12	7	1	1	-	-	-	-2.43
14.02.2020 13:30-14:00	14 ºC Cloudy	20	1	4	8	4	3	-	-	-0.80

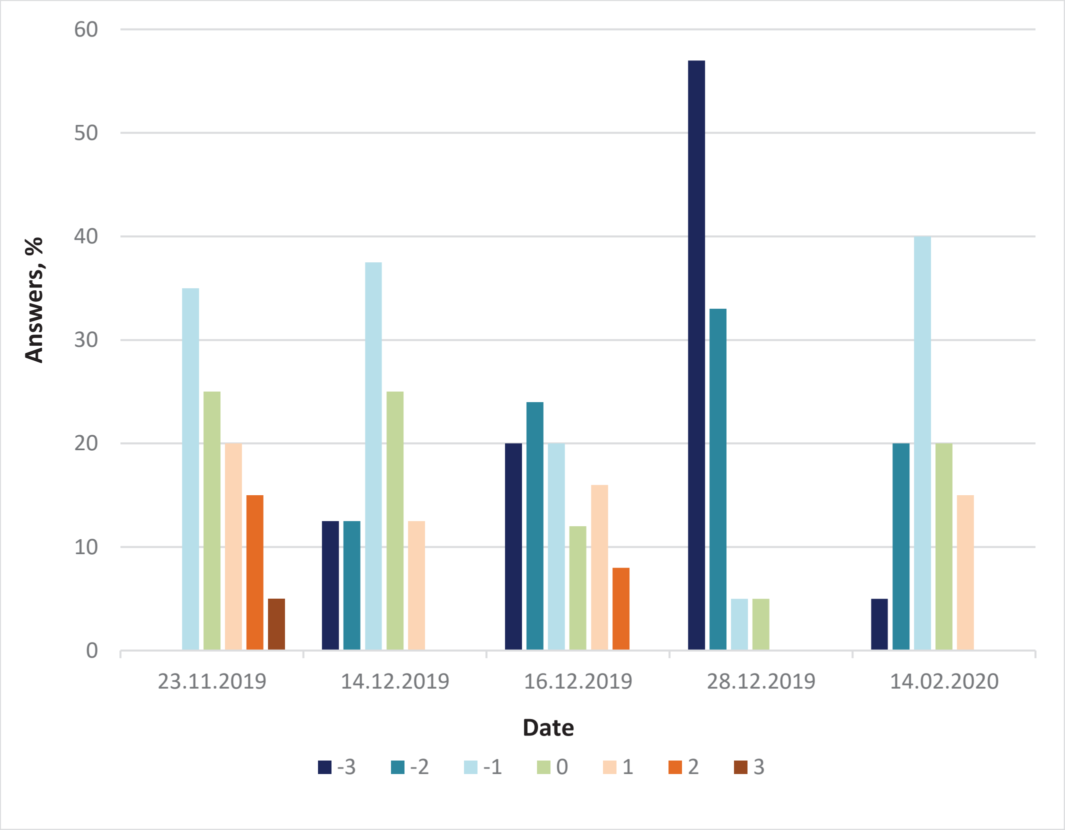


Figure 5.22. Answer percentages in survey studies

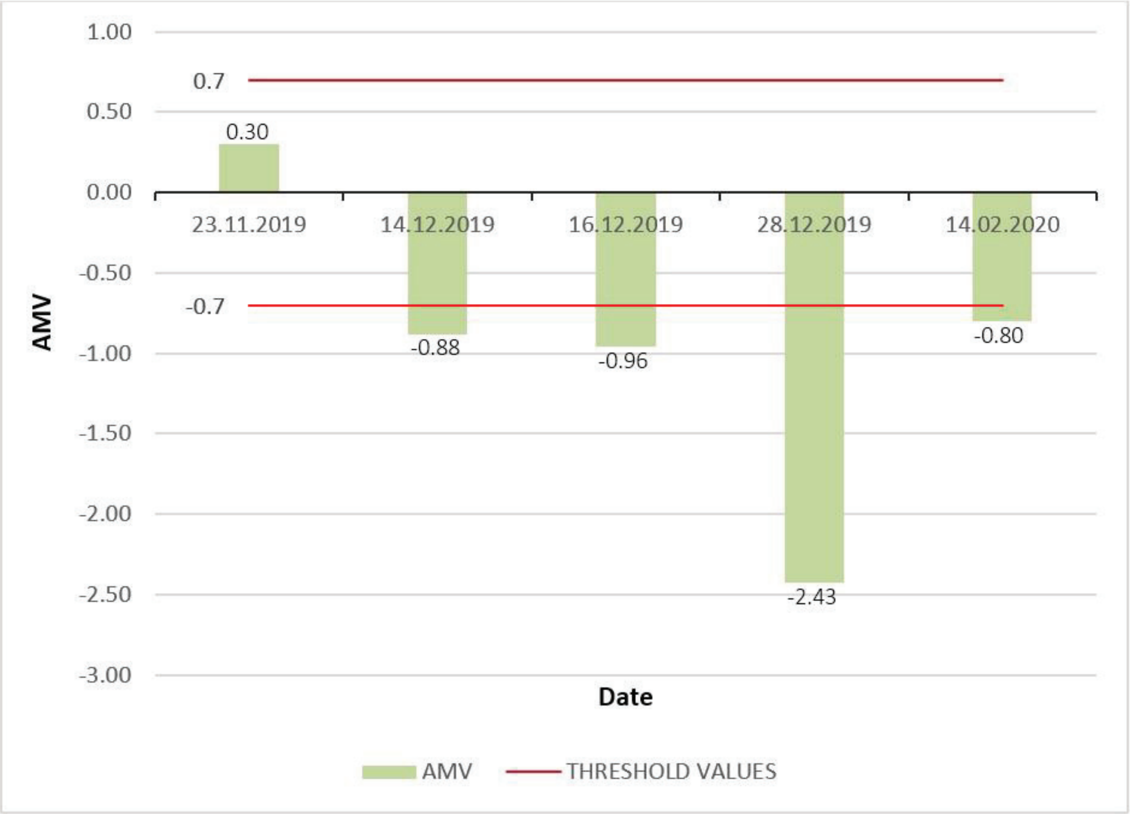


Figure 5.23. Threshold values and AMV values

In the first survey study on 23 November 2019, 35% of 20 occupants answered as slightly cool (-1), 25% neutral (0), 20% slightly warm (+1), 15% warm (+2) and 5% hot (+3) (Figure 5.22). As a result, the AMV value was calculated as 0.30 (Table 5.13) and this value was between -0.7 and 0.7 threshold values (Figure 5.23).

On 14 December 2019, 12.5% of 24 occupants answered as cold (-3), 12.5% cool (-2), 37.5% slightly cool (-1), 25% neutral (0) and 12.5% slightly warm (+1). As a result, the AMV value was calculated as -0.88 and this value was below -0.7 threshold value. The survey study shows that the place was felt cold.

On 16 December 2019, 20% of 25 occupants answered as cold (-3), 24% cool (-2), 20% slightly cool (-1), 12% neutral (0), 16% slightly warm (+1) and 8% warm (+2). As a result, the AMV value was calculated as -0.96 and this value was below -0.7 threshold value. This situation shows that the place was felt cold.

On 28 December 2019, 57% of 21 occupants answered as cold (-3), 33% cool (-2), 5% slightly cool (-1) and %5 neutral (0). As a result, the AMV value was calculated as -2.43 and this value was below -0.7 threshold value. This survey study shows that the place was felt cold.

On 14 February 2020, 5% of 20 occupants answered as cold (-3), 20% cool (-2), 40% slightly cool (-1), 20% neutral (0) and 15% slightly warm (+1). As a result, the AMV value was calculated as -0.80 and this value was below -0.7 threshold value. This situation shows that the place was felt cold.

According to the results of the survey studies, it is seen that the visitors who come to the church generally was felt cold in the winter season. The church was thermally uncomfortable.

In order to obtain more accurate results in the study, the AMV values obtained after the survey studies and the PMV values calculated by CBE Tool (Figure 3.10) for the event times were compared. Calculated PMV values are shown in Table 5.14 and compared values are shown in Figure 5.24.

Table 5.14. Thermal comfort variables and PMV values during activities

Date	**Air Temperature (ºC)**	**Relative Humidity (%)**	**Mean Radiant Temperature (ºC)**	**Air Velocity (m/s)**	**Clothing Insulation (clo)**	**Metabolic Rate (met)**	**PMV**
23.11.2019 19:30-20:00	19.90	68.75	19.84	0.01	0.88	1	-1.04
14.12.2019 19:30-20:00	15.38	70.09	15.25	0.02	1.32	1	-1.32
16.12.2019 19:30-20:00	16.53	66.75	16.39	0.02	1.32	1	-1.06
28.12.2019 19:30-20:00	13.87	52.77	13.75	0.02	1.32	1	-1.74
14.02.2020 13:30-14:00	14.07	57.30	14.69	0.01	1.39	1	-1.47

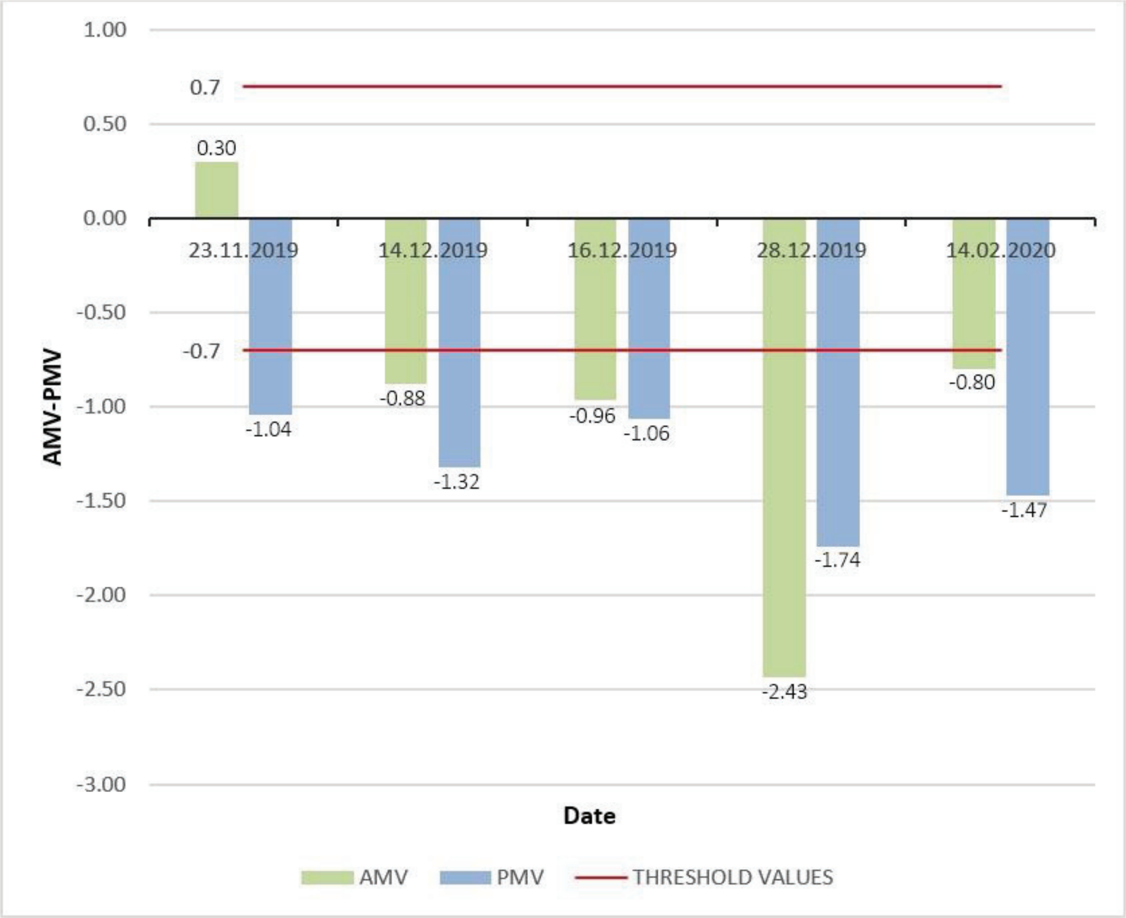


Figure 5.24. Comparison of AMV-PMV values and threshold values

Considering the AMV values that show thermal comfort as a result of the survey studies and the PMV values obtained as a result of the calculations, the AMV value was 0.30 and the PMV value was -1.04 on 23 November 2019. According to the AMV value, the church was thermally comfortable; however, it was felt cold according to the PMV value. The AMV value was -0.88 and the PMV value was -1.32 on 14 December 2019, and the AMV value was -0.96 and the PMV value -1.06 on 16 December 2019. As a result of the study, even though the AMV values were higher than the calculated PMV values, it was understood that the place was felt cold. On 28 December 2019, the AMV value was -2.43 and the PMV value was -1.74. It was seen that the AMV value obtained as a result of the survey study was quite low compared to the calculated PMV value; however, it was determined that the church was felt cold. On 14 February 2020, the AMV value was -0.80 and the PMV value was calculated as -1.47. Even if the AMV value is higher than the calculated PMV value, it is seen that the place was felt cold.

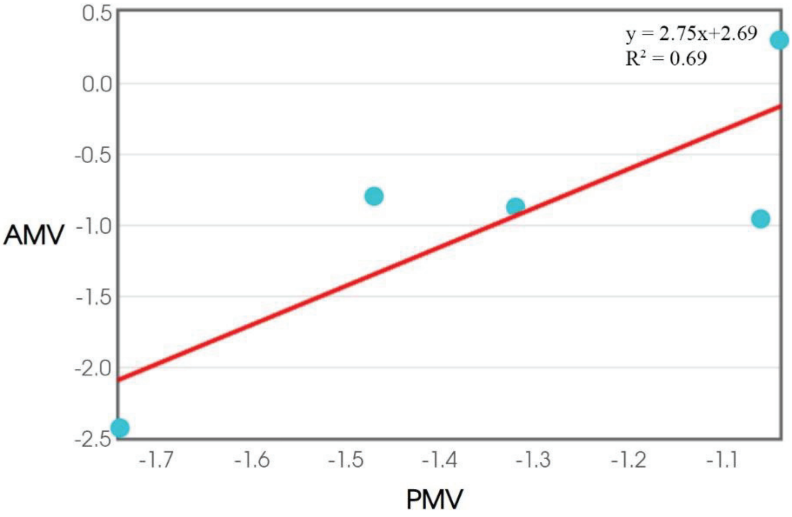


Figure 5.25. Linear regression analysis of AMV and PMV values

After calculations, the significance and the relationship between PMV – AMV values were controlled by regression equation. The correlation coefficient (R) is 0.83. This value is between -1 and +1. If R values close to 0, this situation shows that the relationship between the variables is meaningless. The linear regression equation can be expressed with formula 5.1:

$$AMV = 2.75PMV + 2.69 \tag{5.1}$$

According to this equation (Figure 5.25), while the occupants have a neutral thermal feeling (AMV = 0), the calculations can show cooler thermal feeling (PMV = -0.98). While the calculations show the neutral thermal feeling (PMV = 0), occupants can perceive warmer (AMV = +2.69). Comparison of PMV and AMV values reveals that occupants in Mediterranean climate feel warmer than the calculations according to measurements and different values were determined. The reason for this difference may be that thermal comfort varies according to the body and dynamics of each individual.

In summary, as a result of the examination and comparison of the PMV values calculated with the measurement data and the AMV values calculated with the winter survey study data, it was determined that the church was felt cold in winter and the place was uncomfortable. In order for the occupants to feel comfortable during the event, a heating system compatible with the historical building should be developed. In addition, it was understood that the four radiant heaters (900W or 1800W) used during the concerts were quite insufficient to provide thermal comfort.

5.3. Effects of Indoor Microclimate on Historical Wall Paintings

The interior of the Agios Voukolos Church, which has survived from the 19th century in İzmir, is richly ornamented. Information on the wall paintings in the church is given in Chapter 4 under the heading “4.2. Plan and Interior Characteristics”. The historical climate in which the artifacts were preserved cannot be determined. Therefore, the UNI 10829 Standard (UNI, 1999) and the decree announced by the Italian Ministry of Culture (MiBAC, 2001) were used to determine the appropriate thermo-hygrometric values (Canistraro and Restivo, 2018; Aste et al., 2019; De Rubeis et al., 2020). The appropriate thermo-hygrometric values determined for the preservation of wall paintings are given in Table 3.5.

The air temperature and relative humidity values measured during the year were analyzed according to UNI 10829 and MiBAC D.M. to preserve the wall paintings. First of all, monthly average air temperature and relative humidity values were examined. Considering both UNI 10829 and MiBAC D.M., indoor microclimate should provide values of 10-24 ºC for air temperature and 55-65% for relative humidity (Table 3.5).

In terms of the preservation of wall paintings, the average air temperature values were high (30.7 ºC, 31.9 ºC, 27.7 ºC, 24.6 ºC) and the relative humidity values were low (45.2%, 43.6%, 48.7%, 51.3%) in July, August, September and May. Even though the average relative humidity value was acceptable (58.1%) in October, the average air temperature value was slightly higher (24.2 °C). Although the average air temperature values were suitable (11.3 °C, 18.7 °C), the relative humidity values were slightly low (54.8%, 52.9%) in January and April. Average air temperature (20.6 °C, 14.9 °C, 13.2 °C, 15.8 °C) and relative humidity values (60.9%, 60.8%, 59.3%, 57.8%) in November, December, February and March were considered appropriate. Mentioned values are shown in Table 5.15.

Table 5.15. Examination of monthly average air temperature-relative humidity values according to UNI 10829 and MiBAC D.M.

	July	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
T (ºC)	🟧 30.7	🟧 31.9	🟧 27.7	🟧 24.2	🟩 20.6	🟩 14.9	🟩 11.3	🟩 13.2	🟩 15.8	🟩 18.7	🟧 24.6	-
RH (%)	🟦 45.2	🟦 43.6	🟦 48.7	🟩 58.1	🟩 60.9	🟩 60.8	🟦 54.8	🟩 59.3	🟩 57.8	🟦 52.9	🟦 51.3	-

🟧 T > 24 ºC, RH > 65 % 🟩 24 ºC ≥ T ≥ 10 ºC, 65 % ≥ RH ≥ 55 % 🟦 T < 10 ºC, RH < 55 %

In order to preserve the wall paintings, the air temperature and relative humidity values were turned into performance index tables with their hourly averages (Tables 5.16 and 5.17). The performance index (PI) shows the percentage of time in the recommended range of air temperature and relative humidity (Schito and Testi, 2017; Balocco et al., 2020). The performance index (PI) method is mentioned in Chapter 3 under the heading "3.4. Analysis of the Effect of Indoor Air Temperature and Relative Humidity on the Wall Paintings".

When the measurement data were evaluated according to both UNI 10829 and MiBAC DM, the most suitable climatic conditions for the preservation of wall paintings were provided in March with a performance index of 60.75% on the ground floor, 63.44% on the gallery floor, and in November with a performance index of 55.28% on the ground floor and 52.78% on the gallery floor. Especially in July, August and September, artworks were in danger with a performance index of 0.00%.

The performance index values on the ground floor and the gallery floor were quite similar during the year; however, performance index values on the ground floor (28.63%, 31.85%, 38.07% and 60.75%) were found to be lower than the gallery floor (29.44%, 33.33%, 40.66% and 63.44%) in October, January, February and March (Table 5.16 and 5.17).

Table 5.16. Hourly air temperature and relative humidity performance index (PI) to preserve the wall paintings on the ground floor

	UNI 10829 (UNI, 1999)			**MiBAC D.M.** (MiBAC, 2001)			**UNI 10829** (UNI, 1999) & **MiBAC D.M.** (MiBAC, 2001)		
	PI_{TEMP}	PI_{RH}	PI_{TEMP} & PI_{RH}	PI_{TEMP}	PI_{RH}	PI_{TEMP} & PI_{RH}	PI_{TEMP}	PI_{RH}	PI_{TEMP} & PI_{RH}
July 2019	0.00%	0.56%	0.00%	0.00%	54.81%	0.00%	0.00%	0.56%	0.00%
Aug 2019	0.00%	2.82%	0.00%	0.00%	45.16%	0.00%	0.00%	2.82%	0.00%
Sep 2019	0.00%	13.89%	0.00%	6.81%	67.92%	3.19%	0.00%	13.89%	0.00%
Oct 2019	50.27%	46.77%	28.63%	77.55%	79.97%	58.33%	50.27%	46.77%	28.63%
Nov 2019	100%	55.28%	55.28%	100%	73.06%	73.06%	100%	55.28%	55.28%
Dec 2019	100%	36.02%	36.02%	100%	61.02%	61.02%	100%	36.02%	36.02%
Jan 2020	88.84%	33.20%	31.85%	100%	83.74%	83.74%	88.84%	33.20%	31.85%
Feb 2020	90.80%	38.07%	38.07%	100%	60.78%	60.78%	90.80%	38.07%	38.07%
Mar 2020	100%	60.75%	60.75%	100%	71.10%	71.10%	100%	60.75%	60.75%
Apr 2020	100%	28.47%	28.47%	100%	83.47%	83.47%	100%	28.47%	28.47%
May 2020	51.52%	30.23%	18.82%	57.79%	78.33%	42.02%	51.52%	30.23%	18.82%
June 2020	Data not available								

Table 5.17. Hourly air temperature and relative humidity performance index (PI) to preserve the wall paintings on the gallery floor

	UNI 10829 (UNI, 1999)			**MiBAC D.M.** (MiBAC, 2001)			**UNI 10829** (UNI, 1999) & **MiBAC D.M.** (MiBAC, 2001)		
	PI_{TEMP}	PI_{RH}	PI_{TEMP} & PI_{RH}	PI_{TEMP}	PI_{RH}	PI_{TEMP} & PI_{RH}	PI_{TEMP}	PI_{RH}	PI_{TEMP} & PI_{RH}
July 2019	0.00%	0.00%	0.00%	0.00%	44.63%	0.00%	0.00%	0.00%	0.00%
Aug 2019	0.00%	0.81%	0.00%	0.00%	28.90%	0.00%	0.00%	0.81%	0.00%
Sep 2019	0.00%	12.36%	0.00%	5.42%	63.06%	1.81%	0.00%	12.36%	0.00%
Oct 2019	53.49%	42.61%	29.44%	78.63%	79.44%	59.01%	53.49%	42.61%	29.44%
Nov 2019	100%	52.78%	52.78%	100%	69.86%	69.86%	100%	52.78%	52.78%
Dec 2019	100%	33.60%	33.60%	100%	54.97%	54.97%	100%	33.60%	33.60%
Jan 2020	72.98%	41.94%	33.33%	100%	84.81%	84.81%	72.98%	41.94%	33.33%
Feb 2020	90.80%	40.80%	40.66%	100%	61.35%	61.35%	90.80%	40.80%	40.66%
Mar 2020	100%	63.44%	63.44%	100%	74.06%	74.06%	100%	63.44%	63.44%
Apr 2020	100%	21.25%	21.25%	100%	76.81%	76.81%	100%	21.25%	21.25%
May 2020	49.24%	16.16%	12.36%	53.23%	71.29%	38.59%	49.24%	16.16%	12.36%
June 2020	Data not available								

The threshold values determined in the UNI 10829 and MiBAC D.M. for the preservation of wall paintings and hourly air temperature and relative humidity data during the year are shown in the diagrams (Figures 5.26 and 5.27). As seen in Figure 5.26, according to UNI 10829 and MiBAC DM, the air temperature values in July, August and September were well above 24 °C for preservation. Until 8 October, the air temperature values were high and after 24 October, appropriate air temperature values were reached. In November and December, the air temperature values were in the appropriate range. The air temperature is generally suitable for preservation in January and February, except when the air temperature droped below 10 °C. Air temperature values in March and April were in the appropriate range. After 11 May, the air temperature values increased.

According to Figure 5.26, higher performance indexes were obtained as a result of examining the measured relative humidity data only according to the 45-65% limit values determined in the MiBAC D.M. However, if the relative humidity values were below 45% in July and August, it posed a danger for wall paintings. According to the MiBAC D.M. and the UNI 10829, the performance indexes for relative humidity were quite low, especially in July, August, September, April and May.

When both air temperature and relative humidity data were evaluated according to MiBAC D.M., it was seen that indoor microclimate values in July, August, September and May posed a risk for wall paintings. According to UNI 10829, performance indexes in terms of air temperature and relative humidity were lower during the year. Especially in July, August, September, October, April and May, the indoor microclimate conditions were not suitable for wall paintings.

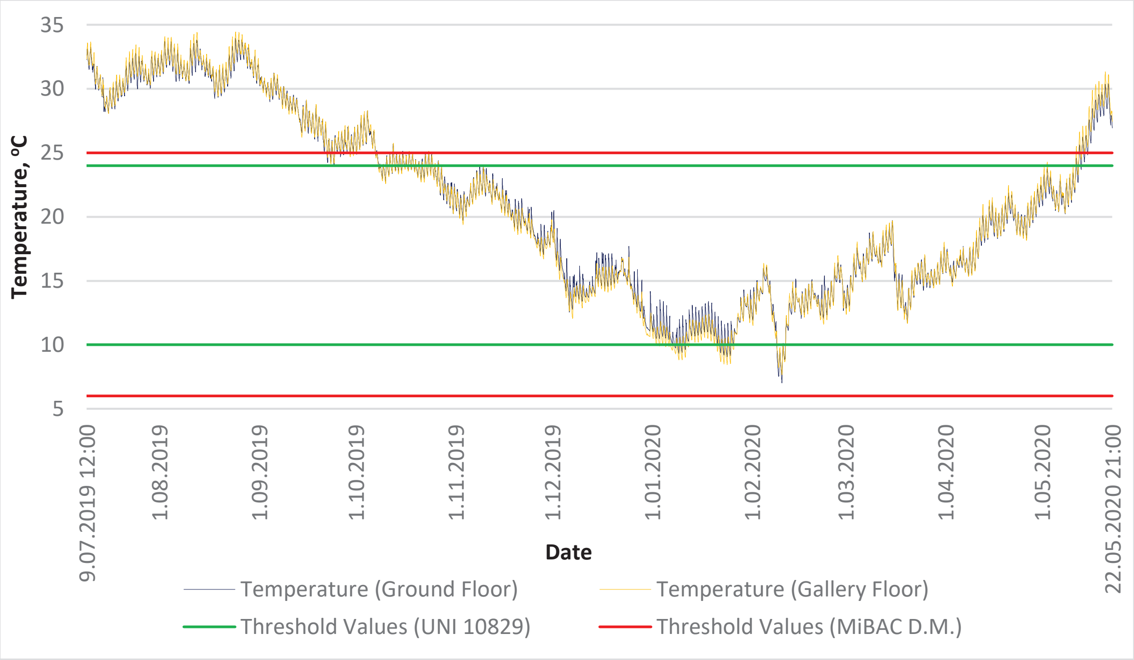


Figure 5.26. Diagram showing hourly indoor air temperature values and the appropriate air temperature range to preserve wall paintings

Figure 5.27. Diagram showing hourly indoor relative humidity values and the appropriate relative humidity range to preserve wall paintings

5.4. Comparison of Indoor Microclimate Conditions in Historical Churches in terms of Thermal Comfort and Effects on Historical Artifacts

Research on indoor microclimate conditions in historical churches in terms of thermal comfort and effects on historical artifacts were examined and compared with the results obtained from the study carried out in the Agios Voukolos Church. Comparison of studies was grouped according to seasonal periods.

Comparison of Studies Conducted in Winter Season:

As a result of the measurements carried out in January in Gotland, Sweden, in two historical churches without heating system with the effect of Temperate Oceanic climate, the expected -0.5 < PMV < 0.5, PPD < 10% (ISO, 2005) conditions in terms of thermal comfort could not be met. Average air temperature was 9.2 ºC, relative humidity was 57%, air velocity was 0.00 m/s, metabolic rate was 1 met and with 1.5 clo clothing insulation, PMV and PPD were obtained as -2.3 and 90%, with 2 clo clothing insulation PMV-PPD were obtained as -1.5 and 50%. After radiant heaters were placed on the chandeliers, the average air temperature was 17.9 ºC, the relative humidity was 40%, the air velocity was 0.16 m/s, the metabolic rate was 1 met, the clothing insulation was 2 clo, and PMV-PPD were obtained as -0.3 and 7%. The place was considered thermally comfortable. In addition, no damage was detected in the church as a result of the local heating (Nilsson and Broström, 2008) (Table 5.18).

Before the underfloor heating system was installed in Matera Cathedral under the influence of Hot-summer Mediterranean climate, after measurements conducted on 20-30 January 2013 in Matera, Italy, the air temperature was determined as 11.2 ºC and the relative humidity as 59.5%. For the preservation of the artworks, the air temperature should be 16-22 ºC and the relative humidity should be 45-55% (D'Agostino, 2006) and the indoor microclimate conditions were not found suitable (Cardinale et al., 2014) (Table 5.18).

The data obtained by the measurements conducted in January 2015 in The Mother of God Church in Jassy, Romania, under the influence of Humid Subtropical climate, were examined. In terms of thermal comfort, the performance of existing static heaters and recommended underfloor heating systems were analyzed to provide 12-15 ºC air temperature and 30-70% relative humidity conditions. The thermal comfort conditions determined in the study were met, but it was seen that static heaters carry the risk of damaging the building (Turcanu et al., 2016) (Table 5.18).

In L'Aquila, Italy, in The Basilica di Collemaggio without heating system with the effect of Temperate Oceanic climate, according to the measurements conducted in October – April, the indoor air temperature varied between 7.4 - 12.4 ºC and the average air temperature is 9 ºC. The place was felt uncomfortable and cold. -0.5 < PMV < 0.5 (ISO, 2005) conditions were taken into consideration in terms of thermal comfort. According to the studies carried out for the coldest month of January, when the pew heating system was examined, the average radiant temperature was 22 ºC, the relative humidity was 30-70%, the air velocity was 0.08 m/s, the metabolic rate was 0.9 met, the clothing insulation was 2.1 clo, and PMV was obtained between -0.3 and -0.1. Thermal comfort was provided. Local heating did not damage the building and the artworks (Aste et al., 2016; Aste et al., 2017) (Table 5.18).

Measurements were conducted between September 2012 and November 2013 in Our Lady of Assumption Church in Algete, Spain, under the influence of Hot-summer Mediterranean climate. During the winter months, the underfloor heating system was operated intermittently in the church and its effects were examined. The system was operated at a temperature of 18.5 °C, with indoor air temperature of 18±1°C and relative humidity of 55-58%. By heating for 30-60 minutes, PMV was obtained between -0.11 and -0.43, PPD 13-15% in the lower part of the choir. This indicates the Category II thermal comfort level according to the EN 15251. In the coldest parts, with heating for 60 minutes, PMV was determined in the range of -0.9 and -2.0, PPD in the range of 22-77%. This indicates the Category IV thermal comfort level according to the EN 15251 and the place was considered uncomfortable. In other parts of the church, with heating for more than 60 minutes, PMV was determined between -0.5 and -0.7, PPD between 13-15%. This indicates Category III thermal comfort level according to the EN 15251. In order to preserve the historical artifacts, the air temperature was determined as 6-25 °C and the relative humidity as 35-65%. According to the study, daily heating for 60 minutes causes the desired relative humidity value to decrease and fluctuations. In order not to cause mechanical deterioration in the artworks, it was found appropriate to operate the heating system only for 30 minutes per day on the weekend (Varas-Muriel and Fort, 2018) (Table 5.18).

Within the scope of the thesis, $-0.7 < PMV < 0.7$, $PPD < 15\%$ (CEN, 2019) conditions were expected for thermal comfort in the Agios Voukolos Church under the influence of Hot-summer Mediterranean climate. Considering the average measurement values in the winter months (December, January and February) without a heating system, in December the air temperature was 14.90 ^{o}C, the relative humidity was 60.78%, the mean radiant temperature was 14.77 ^{o}C, the air velocity was 0.02 m/s, the clothing insulation was 1.32 clo, the metabolic rate was 1 met, PMV was -1.47 and PPD was 49%, in January air temperature was 11.31 ^{o}C, relative humidity was 54.80%, mean radiant temperature was 11.81 ^{o}C, air velocity was 0.01 m/s, clothing insulation was 1.39 clo, metabolic rate was 1 met, PMV was -2.11 and PPD was 82%, in February the air temperature was 13.23 ^{o}C, the relative humidity was 59.29%, the mean radiant temperature was 13.81 ^{o}C, the air velocity was 0.01 m/s, the clothing insulation was 1.39 clo, the metabolic rate was 1 met, the PMV was -1.66 and PPD was 60%. According to the results, the thermal comfort level was found to be insufficient (Table 5.10). Considering the average values, indoor microclimatic conditions in December and February met the conditions of 10 °C ≤ T ≤ 24 °C, 55% ≤ RH ≤ 65% (UNI, 1999; MiBAC, 2001) for the wall paintings to be preserved. It was determined that the average relative humidity value in January was slightly below the required conditions (Table 5.15).

Comparison of Studies Conducted in Spring Season:

According to the measurements conducted on 13-23 April 2013, after the installation of the underfloor heating system in Matera Cathedral under the influence of Hot-summer Mediterranean climate in Matera, Italy, the average air temperature was 18 °C, the relative humidity was 54%, the air velocity was 1 m/s with the adequate clothing insulation, PMV was 0.25 and PPD was 5.3%. The place was found comfortable according to the expected -0.5 < PMV < 0.5, PPD < 10% (ISO, 2005) conditions. In addition, it was determined that the air temperature and relative humidity level were suitable for the preservation of the artifacts (Cardinale et al., 2014) (Table 5.18).

Within the scope of the thesis, -0.7 < PMV < 0.7, PPD < 15% (CEN, 2019) conditions were expected for thermal comfort in the Agios Voukolos Church under the influence of Hot-summer Mediterranean climate. Considering the average measurement values for the spring months (March, April and May) without a heating system, in March the average air temperature was 15.75 °C, the relative humidity was 57.75%, the mean radiant temperature was 15.70 °C, the air velocity was 0.01 m/s, the metabolic rate was 1 met, the clothing insulation was 1.32. clo, PMV was -1.28 and PPD 39%. This shows that the place was felt cold in March. In April, average air temperature was 18.67 °C, relative humidity was 52.88%, mean radiant temperature was 18.61 °C, air velocity was 0.01 m/s, metabolic rate was 1 met, clothing insulation was 1.32 clo, PMV was -0.62 and PPD 13%. In May, average air temperature was 24.60 °C, relative humidity was 51.27%, mean radiant temperature was 24.52 °C, air velocity was 0.01 m/s, metabolic rate was 1 met, clothing insulation was 0.88 clo, PMV was 0.25 and PPD was 6%. PMV and PPD values obtained in April and May showed that the place was felt thermally comfortable (Table 5.10). Considering the average values, indoor microclimatic conditions in March met the conditions of 10 °C ≤ T ≤ 24 °C, 55% ≤ RH ≤ 65% (UNI, 1999; MiBAC, 2001) for the wall paintings to be preserved. However, it was observed that the average relative humidity value in April was slightly below the required conditions. In May, it was determined that the air temperature value was high and the relative humidity value was low (Table 5.15) in terms of preservation of the wall paintings.

Comparison of Studies Conducted in Summer Season:

In Milazzo, Italy, the effect of indoor microclimate on the artworks in the building was examined by the measurements conducted during July - August in the SS. Crucifix Church under the influence of Hot-summer Mediterranean climate. Within the scope of the study, 21 °C < T < 23 °C, 20% < RH < 50% conditions for the protection of historical organic artifacts and 19 °C < T < 24 °C, 30% < RH < 50% conditions for historical religious clothing (UNI, 1999; MiBAC, 2001) must be met. However, since the relative humidity and air temperature values were not suitable for the required conditions, the artifacts are at risk of being damaged (Cannistraro and Restivo, 2018) (Table 5.18).

Within the scope of the thesis, 10 °C ≤ T ≤ 24 °C, % 55 ≤ RH ≤ % 65 (UNI, 1999; MiBAC, 2001) conditions were expected for preservation of the wall paintings in the Agios Voukolos Church under the influence of Hot-summer Mediterranean climate. When the average measured values of the summer months (July and August) were examined, it was seen that the air temperature in July was 30.74 °C, the relative humidity was 45.16%, in August the air temperature was 31.85 °C, and the relative humidity was 43.57%. In this case, the wall paintings are at risk of deterioration because the temperature values were higher than the expected values and the relative humidity values were lower than the expected values for both months (Table 5.15). In addition, considering the conditions of -0.7 < PMV < 0.7, PPD < 15% (CEN, 2019) for thermal comfort, when the monthly average values were examined, in July the air temperature was 30.74 °C, relative humidity was 45.16%, mean radiant temperature was 30.65 °C, air velocity was 0.01 m/s, metabolic rate was 1 met and clothing insulation was 0.26 clo, PMV was 1.55 and PPD 53%. In August air temperature was 31.85 °C, relative humidity was 43.57%, mean radiant temperature was 31.78 °C, air velocity was 0.01 m/s, metabolic rate was 1 met, clothing insulation was 0.26 clo, PMV was 2.03 and PPD was 78%. This shows that the place was felt thermally uncomfortable and hot in summer (Table 5.10).

Comparison of Studies Conducted in Fall Season:

Measurements conducted during September - November in The Church of Santa Maria Annunziata of Roio in L'Aquila, Italy, under the effect of Temperate Oceanic climate, were evaluated in terms of preservation of historical artifacts and thermal comfort, in the absence of HVAC system and according to HVAC system scenarios. In the study, a temperature of 19 – 24 °C and a relative humidity of 55 – 60% were expected in order to preserve the wall paintings and wooden objects in the building (UNI, 1999). In addition, 20 °C air temperature and 55-60% relative humidity were required to provide thermal comfort (Italian Government, 1993). It was determined that the average temperature was 9.1 °C and the relative humidity was 33.3% without the HVAC system in the building. Climatic conditions were not found suitable for both the preservation of artifacts and thermal comfort. In the 4th HVAC scenario (floor heating system + air handling unit (AHU) + humidifier + dehumidifier and cooling systems), the air temperature in winter was 20 °C ± 2 °C and the relative humidity was 50% ± 10%, and the air temperature in summer was 26 °C ± 2 °C and relative humidity level was obtained as 50% ± 10%. Better conditions were created for thermal comfort and preservation of artifacts (De Rubeis et al., 2020) (Table 5.18).

Within the scope of the thesis, $10\ ^{o}C \leq T \leq 24\ ^{o}C$, $\%\ 55 \leq RH \leq \%\ 65$ (UNI, 1999; MiBAC, 2001) conditions were expected for preservation of the wall paintings in the Agios Voukolos Church under the influence of Hot-summer Mediterranean climate. Considering the average measurement values for the autumn months (September, October and November), the air temperature in September was 27.74 °C and the relative humidity was 48.7%. Compared to the expected range, the temperature was high and the relative humidity was low. In October, the air temperature was 24.17 °C and the relative humidity was 58.11%. Although the relative humidity level was within the expected values, the air temperature was a little high. In November, the air temperature was 20.6 °C and the relative humidity was 60.9%. In this month, average values were suitable for the preservation of wall paintings (Table 5.15). Considering the conditions of $-0.7 < PMV < 0.7$, $PPD < 15\%$ (CEN, 2019) for thermal comfort, when the monthly average values were examined, in September the air temperature was 27.74 °C, relative humidity was 48.70%, mean radiant temperature was 27.66 °C, air velocity was 0.01 m/s, metabolic rate was 1 met and clothing insulation was 0.46 clo, PMV was 0.61 and PPD was 13%. In October air temperature was 24.17 °C, relative humidity was 58.11%, mean radiant temperature was 24.10 °C, air velocity was 0.02 m/s, metabolic rate was 1 met, the clothing insulation was 0.88 clo, PMV was 0.18 and PPD was 6%. Thermal comfort was provided in September and October. In November, air temperature was 20.63 °C, relative humidity was 60.90%, mean radiant temperature was 20.57 °C, air velocity was 0.01 m/s, metabolic rate was 1 met, clothing insulation was 0.88 clo, PMV was -0.87 and PPD was 21%. The place was felt uncomfortable and cold in November (Table 5.10).

& Köppen Climate Classification	Buildings	Research Methods	HVAC Systems	for Conservation of Historic Artifacts	Climatic Conditions and Effects on Historic Artifacts and Building	Climatic Conditions Required for Thermal Comfort	Climatic C Th
Gotland, Sweden (Cfb) **emperate oceanic climate** Temperate – warm ummer without dry season)	**Two Swedish churches**	Microclimatic measurements during January 2008 PMV / PPD calculations	**Existing:** No heating system	-	-	-0.5 < PMV < 0.5, PPD < 10% **(ISO, 2005)**	Air temperat Operative ter Relative hum Air speed = 0 Metabolic rat Clothing insu PMV = -2.3 , Clothing insu PMV = -1.5 ,
			Proposal: Radiant heating system (on chandeliers) + bench heating pads	-	No risk of deterioration due to local heating	-0.5 < PMV < 0.5, PPD < 10% **(ISO, 2005)**	Air temperat Operative ter Relative hum Air speed = 0 Metabolic rat Clothing insu PMV = -0.3 ,
Matera, Italy (Csa) **Hot-summer Mediterranean climate** emperate – dry hot summer)	**Cathedral of Matera** (13.th Century)	Temperature and relative humidity measurements; - Before heating system installation 20-30 January 2013 - After heating system installation 13-23 April 2013 PMV / PPD calculations	**Existing 1:** No heating system	Air temperature = 16-22 °C Relative humidity = 45-55 % **(D'Agostino, 2006)**	Air temperature = 11.2 °C Relative humidity = 59.6 %	-0.5 < PMV < 0.5, PPD < 10% **(ISO, 2005)**	
			Existing 2: Low-temperature radiant floor heating system (40 °C operating temperature creates 29 °C floor temperature in 2.5 hours)	Air temperature = 16-22 °C Relative humidity = 45-55 % **(D'Agostino, 2006)**	Air temperature = 18 °C Relative humidity = 54 % Temperature and relative humidity fluctuations as natural	-0.5 < PMV < 0.5, PPD < 10% **(ISO, 2005)**	Air temperat Relative hum Air speed = 1 Activity = sit Enough cloth PMV = 0.25
Jassy, Romania (Cfa) **umid subtropical climate** (Temperate – hot ummer without dry season)	**The Mother of God Church** (18.th Century)	Temperature and relative humidity measurements in January 2015 during 5 days CFD simulation	**Existing:** Static heaters (cast iron – 80 °C) (maximum power = 5000 W)	-	Possible damage to the artworks because of rising warm air to upper part of the church Dust and dirt accumulation due to air movements	Air temperature = 12-15 °C Relative humidity = 30-70 %	Air temperat Relative hum Reaching cor because warr the upper par stratification.
			Proposal: Underfloor heating (20 °C floor temperature)	-	Stable conservation temperature	Air temperature = 12-15 °C Relative humidity = 30-70 %	Reaching cor static heaters
L'Aquila, Italy (Cfb) **emperate oceanic climate** Temperate – warm ummer without dry season)	**The Basilica di Collemaggio** (13.th Century)	Microclimatic measurements during heating period (15 October – 15 April)	**Existing:** No heating system	-	-	-0.5 < PMV < 0.5, PPD < 10% **(ISO, 2005)**	Air temperat
		Microclimatic measurements during January CFD simulation PMV calculations	**Proposal:** Hydronic high-efficiency pew-based heating system coupled with a ground-source heat pump	-	Air temperature rise of 2.7 °C in the upper part of the church No risk of deterioration due to local heating	-0.5 < PMV < 0.5, PPD < 10% **(ISO, 2005)**	Radiant temp Relative hum Air speed = 0 Activity = sit Clothing insu PMV = betw

& Köppen Climate Classification	Buildings	Research Methods	HVAC Systems	for Conservation of Historic Artifacts	Climatic Conditions and Effects on Historic Artifacts and Building	Climatic Conditions Required for Thermal Comfort	Climatic C Th
Algete, Spain (Csa) **Hot-summer Mediterranean climate** emperate – dry hot summer)	**Our Lady of the Assumption Church** (16.th Century)	Air temperature and humidity measurements (September 2012 – November 2013) PMV – PPD calculations	**Existing:** Natural gas-fuelled, centralised, intermittently operated heating system that has a network of underfloor hot water (70-80 ºC) pipes Operating Temp. = 18.5 ºC	Air temperature = 6-25 ºC Relative humidity = 35-65 % **(CEN, 2012)** **(Atkinson, 2014)** **(Cardinale et al., 2014)**	Daily heating for 60 min is risky for cultural heritage due to huge fluctuations Risk of mechanical deterioration (air temperature rises to 18±1 ºC and relative humidity drops to 1/3 in 1 hour)	Air temperature = 18-23 ºC Relative humidity = 30-70 % Category I: -0.2 < PMV < 0.2, PPD < 6 % Category II: -0.5 < PMV < 0.5, PPD < 10 % Category III: -0.7 < PMV < 0.7, PPD < 15 % **(CEN, 2007)**	Mean Tempe Mean Relativ Activity = sit Clothing insu Underneath t (Heated for 3 PMV = -0.11 PPD = 13-15 (Category II) The coldest a (Heated for 6 PMV = -0.9 t PPD = 22-77 (Category IV Rest of the ar (Heated for c PMV = -0.5 t PPD = 13-15 (Category III
Milazzo, Italy (Csa) **Hot-summer Mediterranean climate** emperate – dry hot summer)	**SS. Crucifix Church** (17.th Century)	Air temperature and relative humidity measurements during July – August 2011	**Existing:** No heating system	Organic relics; 21 ºC < T < 23ºC 20 % < RH < 35 % Religious vestments; 19 ºC < T < 24 ºC 30 % < RH < 50 % **(UNI, 1999; MiBAC, 2001)**	Risk of deterioration due to measurement values exceeding the expected range	-	
L'Aquila, Italy (Cfb) **emperate oceanic climate** Temperate – warm ummer without dry season)	**The Church of Santa Maria Annunziata of Roio** (12.th Century)	Air temperature, relative humidity, wind speed, atmospheric pressure and solar radiation measurements during September 28th - November 23rd, 2017 DesignBuilder + EnergyPlus simulations	**Existing:** No heating system	Air temperature = 19-24 ºC Relative humidity = 55-60 % **(UNI, 1999)**	Air temperature = 9.1 ºC Relative humidity = 33.3 %	Air temperature = 20 ºC Relative humidity = 55-60 % **(Italian Government, 1993)**	Unacceptable Air temperat Relative hum
			Proposal: Scenario 4: Floor heating system + air handling unit (AHU) + humidifier + dehumidifier and cooling systems	Air temperature = 19-24 ºC Relative humidity = 55-60 % **(UNI, 1999)**	Winter; Air temperature = 20 ºC ± 2 ºC Relative humidity = 50 % ± 10 % Summer; Air temperature = 26 ºC ± 2 ºC Relative humidity = 50 % ± 10 %	Air temperature = 20 ºC Relative humidity = 55-60 % **(Italian Government, 1993)**	Acceptable th Winter; Air temperat Relative hum Summer; Air temperat Relative hum

5.5. Thermal Comfort Improvement Strategies Compatible with the Agios Voukolos Church

It is not possible to implement some of the interventions that can be applied to modern buildings, as the historical buildings must preserve their original characteristics. In modern buildings, thermal performance can be increased by positioning the building according to the sun and wind direction, changing the shape of the building and the facade design during the design phase, but such changes cannot be applied in historical buildings (Timur et al., 2017). In historical buildings, interventions should be applied carefully, as the effects of failed air conditioning cannot be reversed (Larsen and Broström, 2015).

In interventions to be applied to historical buildings, the preservation of the physical and semantic integrity and the original material properties of the building, the compatibility of the new materials to be used with the original materials and the perceptibility of the difference of the added material, the scientifically proven effects of the proposed methods on the buildings, the conservation of the building should be considered as a priority and unnecessary interventions should be avoided. Interventions should be technically feasible and removable (Uğurlu and Böke, 2009; Timur et al., 2017; McCaig et al., 2018). Within the scope of the study, thermal comfort improvement strategies were examined as passive and active improvement strategies.

5.5.1. Passive Improvement Strategies

Passive design strategies include systems that enable heating or cooling to be realized by radiation, conduction, and convection methods without consuming energy sources such as electricity and natural gas (Sawhney et al., 1987; Kamal, 2012).

Within the scope of the study, thermal insulation, improvement of the thermal performance of the windows and nighttime ventilation were examined and evaluated for the Agios Voukolos Church. As a result of the examination, it was suggested to create secondary glazing system to the existing windows and nighttime ventilation for the Agios Voukolos Church as passive improvement methods. For the systems suggested by examining similar studies, application forms and the effects should be evaluated with various scenarios by creating digital simulations.

5.5.1.1. Improvements to Windows

In order to make thermal improvements in historical buildings, window joinery should be repaired and air tightness applications should be made. For airtightness, weather stripping / draught proofing can be applied for windows and doors. This should be the first method to be applied for the improvement of windows and doors. Weather stripping can increase thermal comfort and reduce energy use with the lowest cost without harming the appearance of the historical building (Pickles, 2012/2016a).

During the repairs for thermal improvement purposes, instead of damaging the original characteristics of the historical building by choosing new double glazed windows, the original windows can be preserved with the secondary glazing / double windows method (Figure 5.28) (Taylor, 2011; Pickles, 2012/2016a; Timur et al. , 2017).

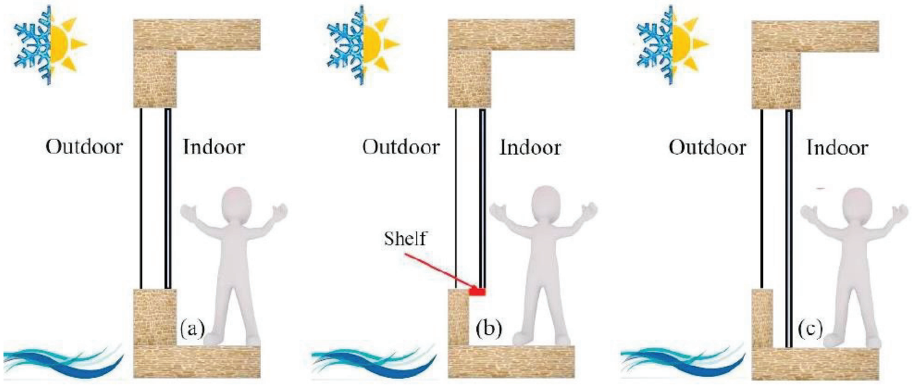


Figure 5.28. Secondary glazing installation types
(Source: Coillot et al., 2017)

The secondary glazing is a windows system that is mounted on the inside of the existing windows, can be removed when necessary and also has fixed variants. The purpose of the secondary glazing system is to increase the thermal performance by preventing air flow through the windows (Taylor, 2011; Larsen and Broström, 2015; Pickles, 2012/2016a; Coillot et al., 2017). The use of low emissivity (Low-E) glasses for the secondary glazing system increases thermal insulation by reflecting longwave radiation, reducing heat gain and loss (Taylor, 2011; Coillot et al., 2017). Secondary glazing with brushes or seals cut off the airflow. In the summer, the secondary glazing cuts off the airflow or the detachable systems prevent the ventilation, which can cause overheating. Therefore, the secondary glazing system can be removed in hot summer months (Taylor, 2011; Pickles, 2012/2016a).

The secondary glazing system can be developed as an air exchange system. Air intake and outlet parts are placed for air exchange. This system is called the air flow window (Figure 5.29). Convection within the air flow windows can be accomplished by natural or mechanical methods. In cold periods, the intake air is heated and given inside, or heat loss is reduced by reheating the indoor air. In hot periods, the outlet air or the air moving between the two windows reduces solar heat gain (Coillot et al., 2017).

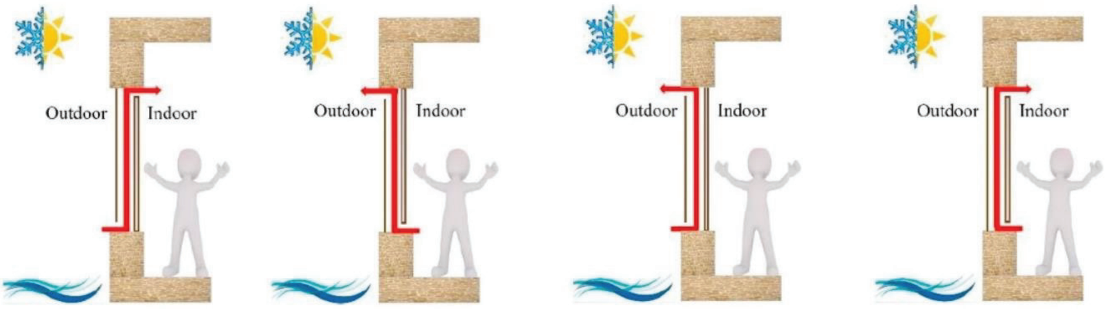


Figure 5.29. Air flow through double windows
(Source: Coillot et al., 2017)

In cold weather, condensation may occur when warm moist air from inside leaks between two windows (Taylor, 2011; Coillot et al., 2017). In order to prevent condensation, natural or mechanical ventilation systems can be created in the system that allow the air flow to pass through the gap between the primary and secondary system (Taylor, 2011; Pickles, 2012/2016a).

In the Agios Voukolos Church, the wooden joinery that could not function and deteriorated, was renewed; however, they were created according to a west facade window that was determined to be original (İpekoğlu et al., 2013). It is thought that the secondary glazing system that can be built on the inside of the existing windows, especially in the cold winter months, will cut the air flow and make the place feel more comfortable. Secondary glazing to be placed inside the joinery should be removable or folding for nighttime ventilation and the proposed system should be compatible with the existing wooden joinery and should not damage the facade properties. The effects of the system to be implemented should be evaluated with various scenarios by creating digital simulations.

5.5.1.2. Nighttime Ventilation

Ventilation is carried out to ensure human health and comfort by removing excess heat, humidity, pollutants and malodor from the place (Larsen and Broström, 2015).

Natural ventilation is the ventilation of the building with natural openings. Air flow occurs with the temperature and pressure difference between indoor and outdoor (Geros et al., 1999).

It is possible to cool the building with ventilation at night when the outdoor temperature is lower than the indoor temperature. When nighttime ventilation is applied in hot summer months, it reduces the heat gain of the building during the day and cools the space (Geros et al., 1999; Santamouris, 2005; Timur, 2019).

It is thought that ventilation can be applied by opening the windows at night hours (09:00 p.m. – 06:00 a.m.) when the temperature is lower in the outdoor environment, especially in June, July, August and September, which are felt warm and thermally uncomfortable in the Agios Voukolos Church. However, ventilation effects should be evaluated by creating digital simulations.

5.5.1.3. Thermal Insulation

In historical buildings, visually ineffective thermal insulation can be applied to create a cooler environment in summer and warmer environment in winter and to save energy (Timur et al., 2017; Johansson et al., 2018; Castele and Webb, 2019). It is important to insulate with breathable, permeable materials that do not disturb the moisture balance in order to prevent deterioration in the building (Pickles, 2012/2016b). Hygroscopic insulation materials made with natural materials (cellulose fiber, wood fiber, sheep wool, hemp fiber) were found to be compatible for historical buildings since they allow moisture vapor to pass through (Pickles, 2012/2016b; Rehee-Duverne and Baker, 2015). It was determined that closed-cell plastic insulation materials (polyisocyanurate, polyurethane, polystyrene), plastic moisture barriers, cement or acrylic-based plasters, plastic-based paints are not suitable for historical buildings because they are not hygroscopic and pose a condensation risk (Pickles, 2012/2016c). Materials such as fiberglass or mineral wool, which are generally used for floor insulation, are not suitable for historical buildings since they are not hygroscopic, although they are partially permeable. The use of these materials carries the risk of mold and rot that may occur after condensation. (Pickles, 2012/2016b).

Insulation systems in the building can be applied to parts such as walls, floors and roofs; however, in some historical buildings, wall insulation is not an option (Larsen and Broström, 2015; Castele and Webb, 2019). In the Agios Voukolos Church, wall insulation and floor insulation will harm the unique appearance and the characteristics of the building. It is not recommended in order to not to damage the building. In addition, the presence of an opening on the gallery floor creates a constant air exchange, so even if thermal insulation is applied in the building, it will not be effective. In buildings with a heating system, thermal insulation increases thermal comfort by cutting off the cold air flow; but there is no advantage of thermal insulation in buildings that are not heated (Larsen and Broström, 2015).

5.5.2. Active Improvement Strategies

There is no authentic heating system in the Agios Voukolos Church. General information about the heating systems in historical churches and the points to be considered are given in Chapter 2 under the heading "2.5. Heating of Historic Churches with Compatible Methods". Within the scope of the study, the positive and negative effects of the systems applied in the churches or developed as suggestions were examined while researching the compatible heating system for the Agios Voukolos Church.

The studies examined in Table 5.18, the HVAC systems and their negative effects on the historical buildings and artifacts are summarized in Table 5.19.

Table 5.19. HVAC systems examined in historical churches and their negative effects on the buildings and artifacts

Research	Building	HVAC Systems	Effects
Camuffo et al. (2010b)	**Santa Maria Maddalena Church** (15.th Century) (Rocca Pietore, Italy)	**Existing:** Two warm-air heating systems (2.7 m/s and 0.4 m/s air speed) (70-80 ^oC warm air)	Possible cracks on artworks in the upper part of the church (Surface temperature increases 5-10 ^oC, air temperature increases sharply from 0 ^oC to 20 ^oC and relative humidity decreases from 70% to 20% in the upper part of the church) (Sharp vertical temperature gradient) Unacceptable thermal comfort level due to thermal stratification for sitting people (15 ^oC warm head - 0 ^oC cold feet)
Turcanu et al. (2016)	**The Mother of God Church** (18.th Century) (Jassy, Romania)	**Existing:** Static heaters (cast iron – 80 ^oC) (maximum power = 5000 W)	Possible damage to the artworks because of rising warm air and dust-dirt accumulation due to air movements Acceptable thermal comfort level (takes time due to thermal stratification)
Varas-Muriel and Fort (2018)	**Our Lady of the Assumption Church** (16.th Century) (Algete, Spain)	**Existing:** Intermittently operated heating system that has a network of underfloor hot water (70-80 ^oC) pipes Operating Temp. = 18.5 ^oC	Possible damage by huge fluctuations due to daily heating for 60 min Risk of mechanical deterioration (air temperature rises to 18±1 ^oC and relative humidity drops to 1/3 in 1 hour) Almost acceptable thermal comfort level
Pałupska and Kanaś (2018)	**The University Church** (17.th Century) (Wroclaw, Poland)	**Existing:** Warm air heating system	Risk of damaging paintings on the vault due to rising warm air towards the ceiling Risk of shrinkage, swelling of hygroscopic materials and cracks, dispersion of the ash, blackening ceiling and walls Acceptable thermal comfort level

According to the studies examined in Table 5.19, warm air heating system, which is based on heating the entire volume of the church, can damage the building and historical artifacts. When the heating system is on, warm air tends to rise and the occupants still feel cold. However, heating the entire space for thermal comfort of occupants causes thermal stratification. In addition, suddenly increasing surface temperatures, increasing air temperature and decreasing relative humidity can cause deterioration of artifacts. With the rapid decrease in relative humidity, historical materials can shrink or even crack (Limpens-Neilen, 2006; Camuffo et al., 2010b; Pałupska and Kanaś, 2018). With the closing of the heating systems, the surface and air temperature starts to decrease and the relative humidity starts to increase. Thus, a risk of condensation may occur and this situation accelerates the deterioration of objects (Limpens-Neilen, 2006). In addition, indoor air movements cause dust and dirt to accumulate on objects and walls (Pałupska and Kanaś, 2018). While designing warm air heating systems, care should be taken not to accumulate dirt and dust on the surfaces, to prevent the flow of hot air to cultural heritage objects, to minimize thermal stratification, and to prevent relative humidity fluctuations with heating (CEN, 2012).

Even though static heaters provide thermal comfort, they can cause dust and dirt to accumulate on cultural heritage objects with air movements. (CEN, 2012; Turcanu et al., 2016). Also heaters should not be placed close to sensitive surfaces and objects that need preservation (CEN, 2012).

Even though the underfloor heating system consisting of hot water pipes provides thermal comfort, it was observed that it causes relative humidity fluctuations when the system is operated for a long time. Sudden changes in temperature and relative humidity can damage cultural heritage objects (Varas-Muriel and Fort, 2018). Underfloor heating systems can cause dust and particle accumulation with air movement. In addition, the system cannot be applied to the original building floors (CEN, 2012).

The studies examined in Table 5.18 are summarized in Table 5.20 according to the HVAC systems that provide thermal comfort without damaging the historical structure and artifacts and their effects.

Table 5.20. HVAC systems that provide thermal comfort without damaging the historical building and artifacts and their effects

Research	Building	HVAC Systems	Effects
Nilsson ve Broström (2008)	**Two Swedish churches** (Gotland, Sweden)	**Proposal:** Radiant heating system (on chandeliers) + bench heating pads	No risk of deterioration due to local heating Acceptable thermal comfort level (PMV = -0.3 , PPD = 7 %)
Camuffo et al. (2010b)	**Santa Maria Maddalena Church** (15.th Century) (Rocca Pietore, Italy)	**Proposal:** Pew heating system (40-70 ^{o}C radiant heaters)	No risk of deterioration due to local heating Acceptable thermal comfort level for sitting people (6-8 ^{o}C cool head, 10-15 ^{o}C moderately cool leg and 18-25 ^{o}C warm feet)
Cardinale et al. (2014)	**Cathedral of Matera** (13.th Century) (Sassi, Italy)	**Existing:** Low-temperature radiant floor heating system (40 ^{o}C operating temperature creates 29 ^{o}C floor temperature in 2.5 hours)	No risk of deterioration due to stable conservation conditions (T = 18^{o}C, RH = 54%), natural temperature and relative humidity fluctuations Acceptable thermal comfort level (PMV = 0.25 , PPD = 5.3 %)
Turcanu et al. (2016)	**The Mother of God Church** (18.th Century) (Jassy, Romania)	**Proposal:** Underfloor heating (20 ^{o}C floor temperature)	Stable conservation temperature Acceptable thermal comfort level
Aste et al. (2016) Aste et al. (2017)	**The Basilica di Collemaggio** (13.th Century) (L'Aquila, Italy)	**Proposal:** Hydronic high-efficiency pew-based heating system coupled with a ground-source heat pump	No risk of deterioration due to local heating Acceptable thermal comfort level (PMV = between -0.3 and -0.1)
Pałupska and Kanaś (2018)	**The University Church** **(**17.th Century**)** (Wroclaw, Poland)	**Proposal:** Low temperature electrical radiant heaters in pews	No risk of deterioration due to local heating Acceptable thermal comfort level

According to the studies examined in Table 5.20, low-temperature underfloor heating systems can provide thermal comfort while creating stable preservation conditions. Natural temperature and relative humidity fluctuations can be observed. However, underfloor heating systems are only suitable for renovated floors of historical churches (Cardinale et al., 2014; Turcanu et al., 2016).

In line with the studies in Table 5.20, local heating systems do not harm the building and historical artifacts by providing thermal comfort by only heating the occupants without heating the entire volume of the churches (Figure 5.30) (Limpens-Neilen, 2006; Camuffo and Della Valle, 2007; Nilsson and Broström, 2008; Camuffo et al., 2010b; CEN, 2012; Aste et al., 2016; Aste et al., 2017; Pałupska and Kanaś, 2018).

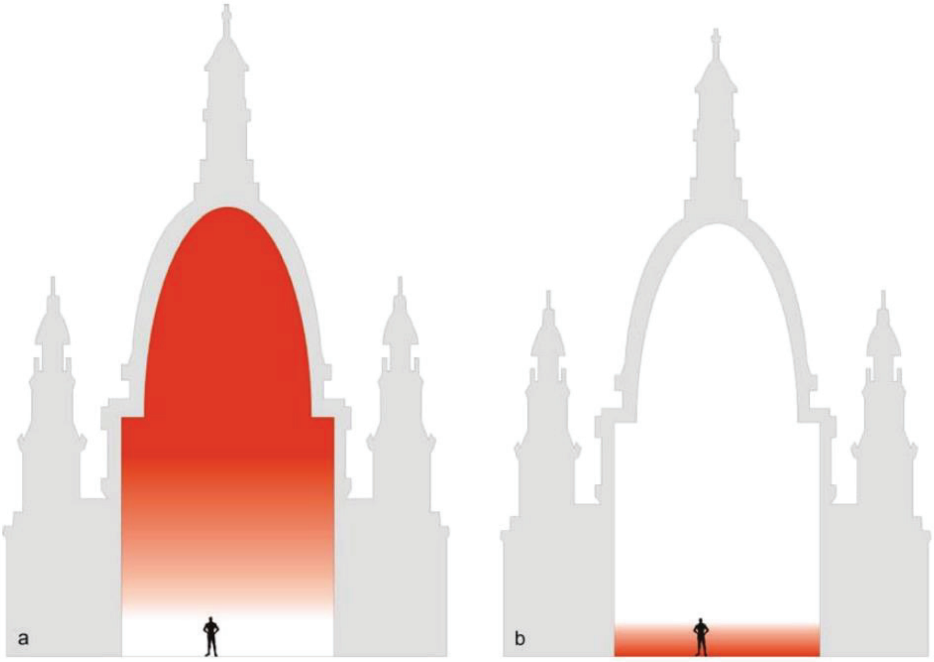
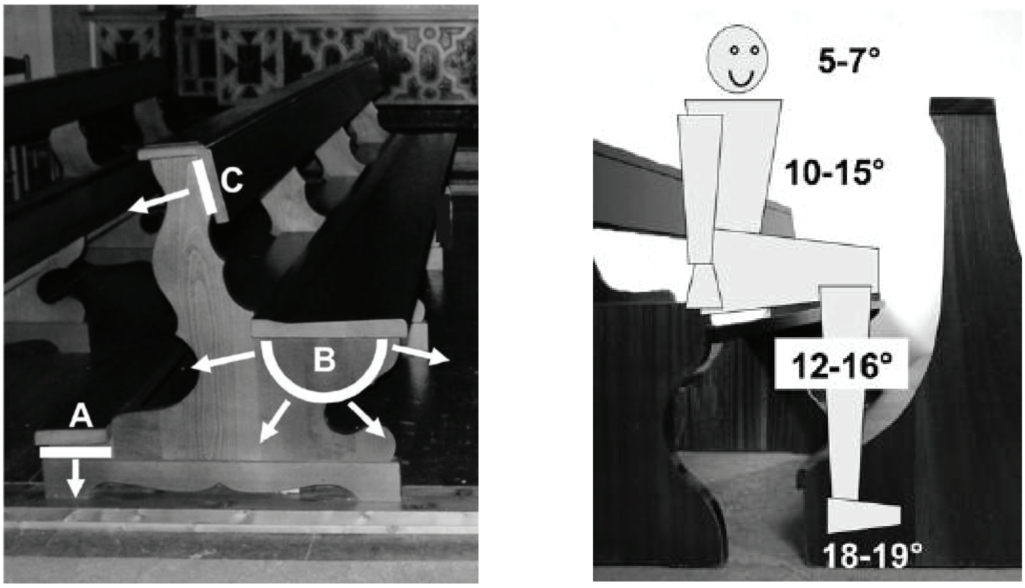


Figure 5.30. a) Central heating, b) Local heating
(Source: Camuffo ve Della Valle, 2007)

It was determined that the radiant heaters / infrared heaters, which are the local heating option, are operated at the event time and thus provide thermal comfort and do not change the general indoor climate of the building, so historical buildings and artifacts are preserved (Nilsson and Broström, 2008).

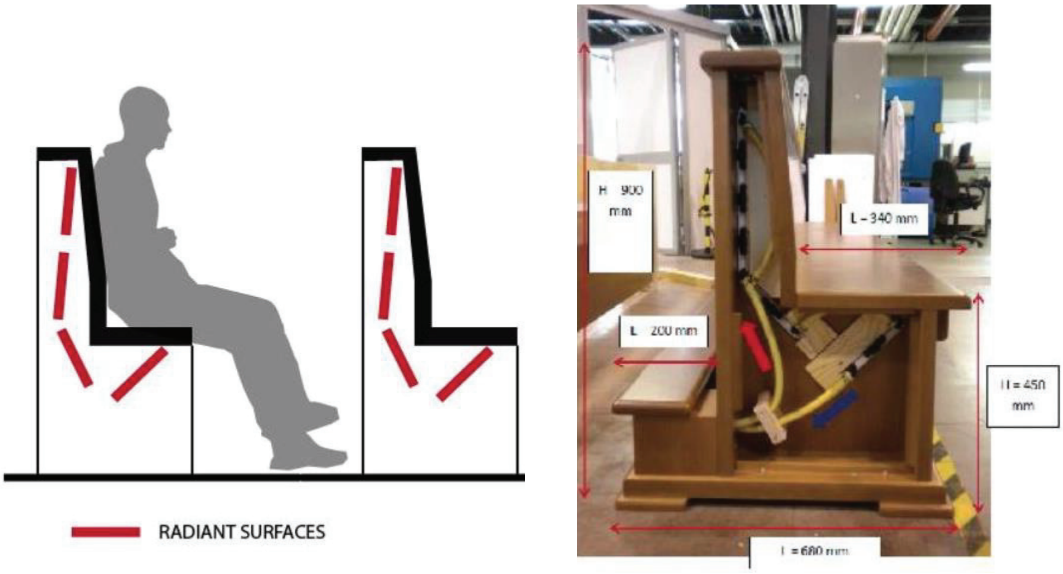
Pew heating system, which is another local heating option, provides thermal comfort without disturbing the general climate of the building. This heating system prevents the deterioration of historical buildings and artifacts (Nilsson and Broström, 2008; Camuffo et al., 2010b; Aste et al., 2016; Aste et al., 2017; Pałupska and Kanaś, 2018). Camuffo et al. (2010b) and Pałupska and Kanaś (2018) heated the pews using low-temperature radiant heaters (40-70 °C) inside the emitters (Figure 5.31 and 5.32). The emitters used consist of heating foils of varying sizes and temperatures. The foils are made from an electrically heated layer of graphite granules. Maintaining specially selected temperature levels (40-70 °C) for various parts of the body eliminates the risk of burning the skin. Aste et al. (2016, 2017) distributed the water heated by the heat pump to the sitting units via small pipes and heated the pews with hydronic radiant panels (Figure 5.33).



(a) (b)

Figure 5.31. Pew heating proposal using low temperature radiant heaters, a) Position and direction of action of the placed radiant heaters, b) Thermal comfort conditions created by the heating system (Source: Camuffo et al., 2010b)

Figure 5.32. Pew heating by using low temperature radiant heaters (Source: Pałupska and Kanaś, 2018)



(a) (b)

Figure 5.33. Pew heating proposal using radiant heaters, a) The location of the radiant heaters placed, b) Prototype showing the heating system (Source: Aste et al., 2017)

The EN 15759-1 describes different options for pew heating. By using single high-temperature electric heaters, thermal comfort can be provided by heating the leg part of the body. However, the comfort conditions may change negatively or the seating unit may be damaged due to overheating of the legs. By using single low-temperature heaters, hot water pipes or electric single heaters can be placed in the pews. It produces less convective movement than high temperature sources and reduces the risk of particle accumulation. However, it may be difficult to achieve thermal comfort with a low temperature single heater, the system must be run before the event. In order to use the warm air system, the system must be passed either under the floor or through the prepared duct. Underfloor systems can damage the original building floor. In addition, while warm air heats the feet and legs of sitting individuals, it can create unwanted air movements. This situation can cause particle accumulation. With the jet of warm air grazing the floor system, hot air is supplied to the feet and legs by the fan. Unwanted air movements can cause particle accumulation. In addition, the noise produced by this system can be disturbing. Integrated local heating systems are created by heating the pews, placing the heated pads on pews and heated carpets on the floor. Ergonomically distributed low-temperature radiative heating systems are created by placing low-temperature radiant heaters on seating units to heat various parts of the body. It is easier to provide thermal comfort with this system and is suitable for temperate climates (CEN, 2012).

In the scope of the study, in line with the examined the EN 15759-1 standard and studies, it is thought that continuous heating systems will completely change the climate of the building, and it will be harmful for the Agios Voukolos Church. It was seen that local heating systems to be operated only during event times will be the most compatible system. For pew heating, the chairs, which are not the original sitting units of the church, should be replaced, a suitable heating system should be designed and the heaters should be placed in them. However, it is not possible to install this fixed system on the sitting units of the building used for different functions (worship, concert, exhibition, conversation, etc.). According to the results obtained in line with the studies carried out in the Agios Voukolos Church, it is thought that radiant heaters that only heat the sitting individuals can be preferred. The use of radiant heaters in sufficient quantity and power will be sufficient to ensure thermal comfort during the events. However, digital simulation should be prepared and different scenarios should be examined in order to provide the most suitable heating conditions in terms of thermal comfort and conservation of the building.

CHAPTER 6

CONCLUSION

The aim of this thesis is to examine the effects of indoor microclimate characteristics of the Agios Voukolos Church on the occupants and the wall paintings of the building, and to bring improvement suggestions that consider the values of the historical church by evaluating the thermal comfort conditions. The method of the study consists of on-site examination, on-site measurements of air temperature, relative humidity, mean radiant temperature and air velocity between 9 July 2019 – 22 May 2020, thermal comfort calculations and survey studies that determine the thermal perception of occupants. To determine the thermal comfort of the church, the Predicted Mean Vote – Predicted Percentage Dissatisfied (PMV-PPD) method was used and the threshold values specified in ISO 7730 were taken into account in the evaluation of the results. During the events in the building, survey studies were conducted to determine the thermal perception of the occupants and the obtained Actual Mean Vote (AMV) values were compared with the calculated PMV values. In order to evaluate the effect of the current indoor microclimate on the wall paintings and ornaments, the threshold values specified in the UNI 10829 Standard and the decree announced by the Italian Ministry of Culture in 2001 were used.

Agios Voukolos Church was restored in 2009-2010 and the church is used as a Culture and Art Center today. Considering that there is no original heating-cooling system in the church, a new heating-cooling system was not recommended when making intervention decisions. According to the Köppen-Geiger Climate Classification, the church, which is in the Csa class (Mediterranean Climate – warm winter, dry and hot summer), uses four 900/1800 W electric radiant heaters for heating in winter during events. Cooling is provided by keeping the windows open in summer. Within the scope of the study, this situation was examined with both measurements and surveys.

Considering the monthly and hourly averages of the measurement data, as a result of the examination made with Fanger's Predicted Mean Vote - Predicted Percentage Dissatisfied (PMV - PPD) method (Fanger, 1967; Fanger, 1970), it was determined that the warmest month of August and the coldest January were felt in terms of thermal comfort. It is thought that cooling methods appropriate to the historical building should be developed for July and August, which are felt warm, and a compatible heating system should be developed for November, December, January, February and March when it is felt cold, in order to the occupants feel comfortable thermally during the events. As a result of the survey studies conducted in November, December and February, and examined and compared the PMV and AMV values, it was confirmed that the church was felt cold in winter and the place was uncomfortable. It was understood that the four radiant heaters (900/1800W) used during the events were quite insufficient to provide thermal comfort.

When the effects of temperature and relative humidity conditions on the wall paintings were examined, according to the decree announced by the Italian Ministry of Culture (MiBAC D.M.) in 2001, indoor microclimate values in July, August, September and May pose a risk for wall paintings. According to UNI 10829, it was determined that the indoor microclimate was not suitable for wall paintings, especially in July, August, September, October, April and May. Considering the climate conditions for Turkey, a standard for the conservation of wall paintings can be developed.

In historical buildings, since the effects of unsuccessful air conditioning cannot be reversed, interventions should be made carefully and conservation should always be a priority while providing thermal comfort. Within the scope of the study, intervention suggestions were developed as passive and active thermal improvement methods. For passive improvement methods, a review was made on improvement of windows, nighttime ventilation and thermal insulation. As improvement of windows, it was thought that the secondary glazing system that can be built inside the existing joinery for the cold winter months will cut the air flow and make the place feel more comfortable. However, the proposed system should be compatible with the existing wooden joinery and should not damage the facade features. In June, July, August and September, which were felt warm and thermally uncomfortable, it was thought that ventilation can be done at night hours (09:00 p.m. – 06:00 a.m.) when the temperature is lower in the outside and the place can be cooled in this way. As thermal insulation, wall insulation and floor insulation were not found suitable and can damage the original characteristics of the building. It was thought that the presence of an opening for entrance on the gallery floor of the church will reduce the effect of insulation. In addition, it is not recommended for buildings that are not heated continuously in winter, as it was thought that thermal insulation will not be advantageous. The application forms and effects of the proposed systems should be determined with different scenarios by creating digital simulations.

Similar studies and the EN 15759-1 standard were examined to determine active improvement methods for the historical church. The positive and negative effects of the examined warm air heating system, static heaters, underfloor heating systems, radiant heaters and pew heating systems were taken into consideration. For the Agios Voukolos Church, it was thought that continuous heating systems would completely change the climate of the building when it was felt cold in terms of thermal comfort, and would be harmful. It was seen that local heating systems to be operated only during event times will be the most compatible system. According to the results obtained for the Agios Voukolos Church in line with the studies carried out in historical churches, it was thought that radiant heaters that heat only the occupants can be preferred. It was thought that the use of radiant heaters in sufficient quantity and power will be sufficient to provide thermal comfort. However, digital simulations should be prepared and different scenarios should be examined in order to provide the most suitable thermal comfort conditions and conservation of the building.

In the Agios Voukolos Church, indoor microclimate variables were monitored during a year, and the thermal comfort status for the occupants was evaluated with the data obtained. In addition, the effects of the obtained air temperature and relative humidity levels on the wall paintings were investigated. Suggestions were developed for improving the indoor microclimate conditions. This study has importance in terms of creating data for the evaluation of the indoor microclimate condition of the building.

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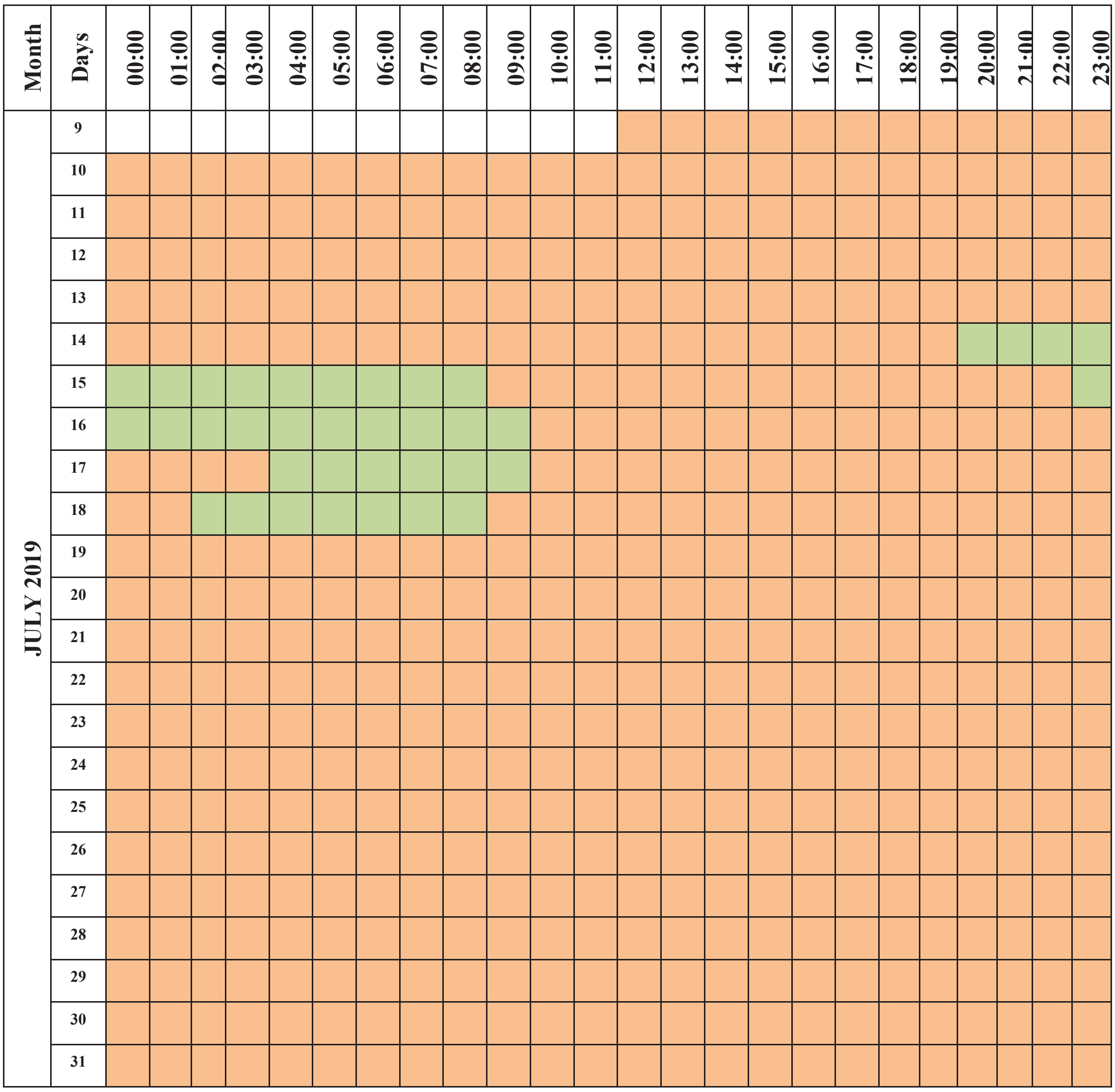
APPENDIX A

THERMAL COMFORT CONDITIONS BY HOURS FOR EACH MONTH

Table A.1. Thermal comfort conditions by hours for July 2019



Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
JULY 2019	9													🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	10	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	11	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	12	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	13	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	14	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟩
	15	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟩
	16	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	17	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	18	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	19	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	20	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	21	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	22	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	23	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	24	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	25	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	26	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	27	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	28	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	29	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	30	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	31	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧

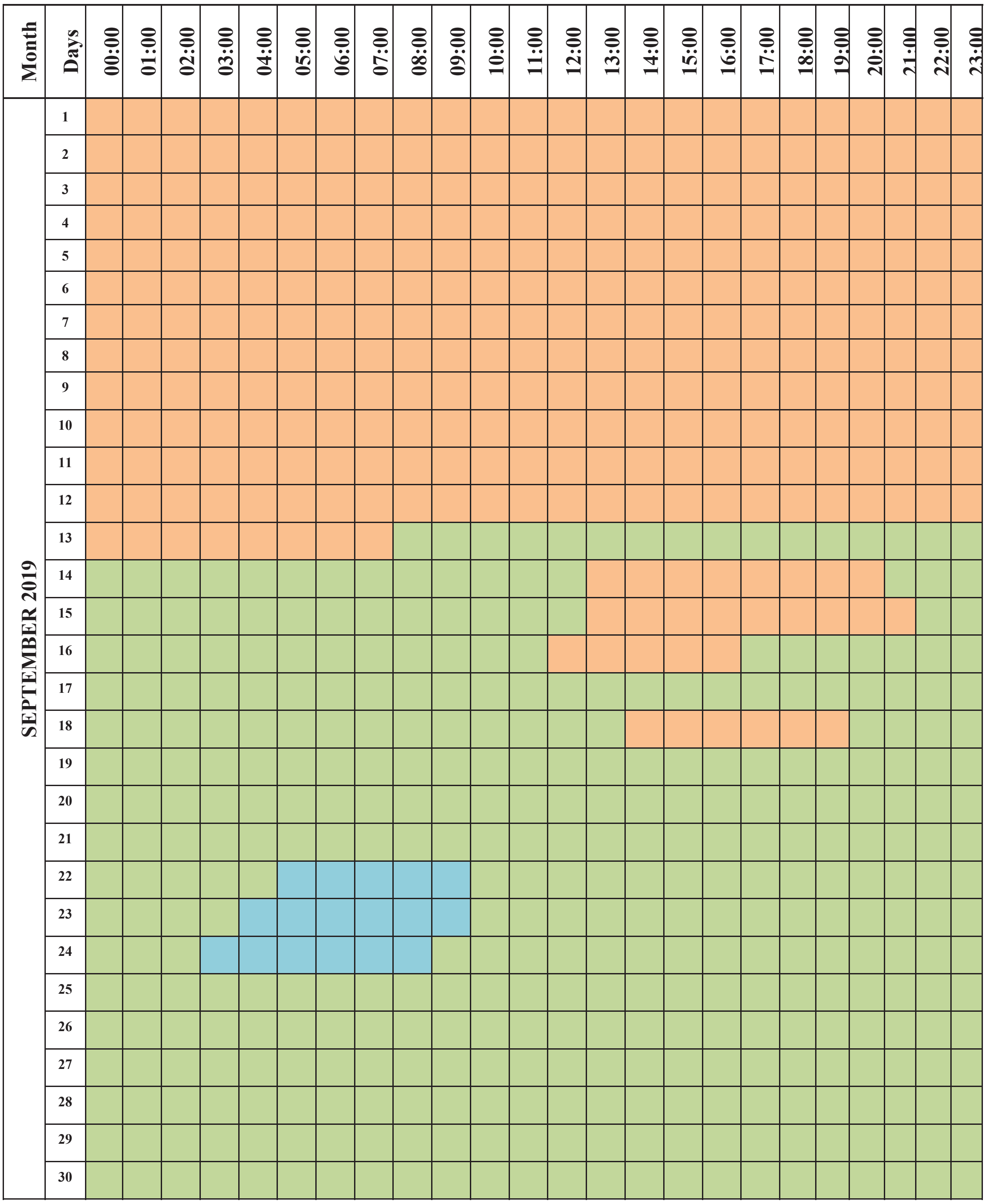
🟧	PMV ≥ 0.7 , PPD ≥ %15
🟩	0.7 > PMV > -0.7 , PPD < %15
🟦	-0.7 > PMV , PPD ≥ %15

Table A.2. Thermal comfort conditions by hours for August 2019

Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
AUGUST 2019	1	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	4	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	6	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	7	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	8	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	9	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	10	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	11	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	12	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	13	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	14	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	15	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	16	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	17	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	18	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	19	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	20	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	21	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	22	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	23	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	24	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	25	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	26	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	27	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	28	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	29	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	30	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	31	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧

🟧	PMV ≥ 0.7 , PPD ≥ %15
🟩	0.7 > PMV > -0.7 , PPD < %15
🟦	-0.7 > PMV , PPD ≥ %15

Table A.3. Thermal comfort conditions by hours for September 2019



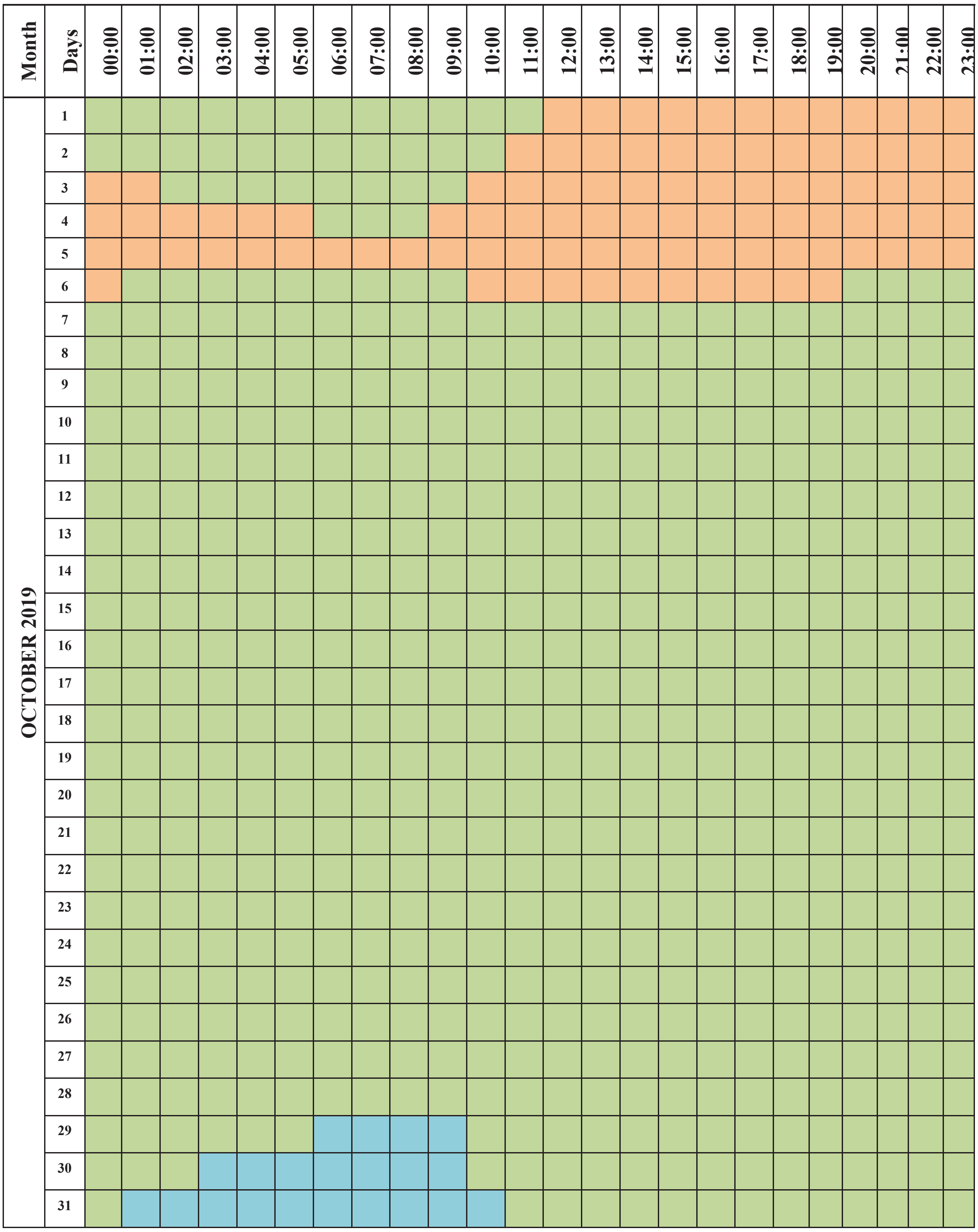
Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
SEPTEMBER 2019	1	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	4	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	6	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	7	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	8	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	9	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	10	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	11	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	12	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	13	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	14	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩
	15	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩
	16	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	17	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	18	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟩
	19	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	20	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	21	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	22	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	23	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	24	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	25	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	26	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	27	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	28	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	29	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	30	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟧 PMV ≥ 0.7 , PPD ≥ %15

🟩 0.7 > PMV > -0.7 , PPD < %15

🟦 -0.7 > PMV , PPD ≥ %15

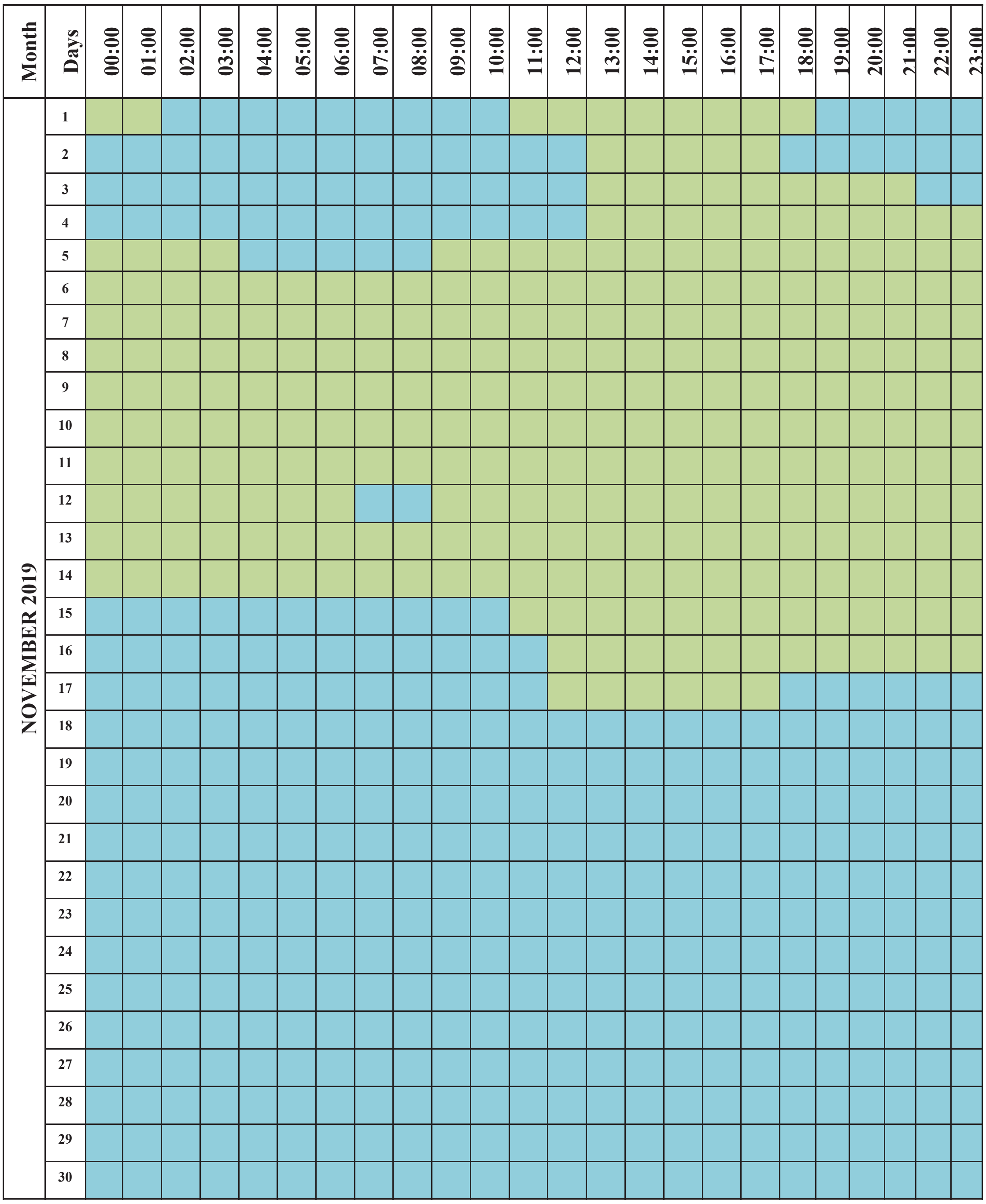
Table A.4. Thermal comfort conditions by hours for October 2019



Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
OCTOBER 2019	1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	3	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	4	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	5	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	6	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟩
	7	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	8	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	9	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	10	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	11	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	12	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	13	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	14	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	15	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	16	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	17	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	18	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	19	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	20	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	21	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	22	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	23	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	24	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	25	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	26	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	27	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	28	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	29	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	30	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	31	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟧	PMV ≥ 0.7 , PPD ≥ %15
🟩	0.7 > PMV > -0.7 , PPD < %15
🟦	-0.7 > PMV , PPD ≥ %15

Table A.5. Thermal comfort conditions by hours for November 2019



Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
NOVEMBER 2019	1	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦
	4	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	5	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	6	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
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	8	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	9	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	10	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	11	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	12	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	13	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	14	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	15	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	16	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	17	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦
	18	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	19	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	20	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	21	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	22	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	23	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	24	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	26	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	27	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	28	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	29	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	30	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

🟧 PMV ≥ 0.7 , PPD ≥ %15

🟩 0.7 > PMV > -0.7 , PPD < %15

🟦 -0.7 > PMV , PPD ≥ %15

Table A.6. Thermal comfort conditions by hours for December 2019

Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
DECEMBER 2019	1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	4	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	6	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	7	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	8	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	9	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	10	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	11	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	12	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	13	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	14	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	15	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	16	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	17	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	18	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	19	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	20	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	21	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	22	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	23	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	24	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	26	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	27	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	28	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	29	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	30	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	31	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

🟧 PMV ≥ 0.7 , PPD ≥ %15
🟩 0.7 > PMV > -0.7 , PPD < %15
🟦 -0.7 > PMV , PPD ≥ %15

Table A.7. Thermal comfort conditions by hours for January 2020

Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
JANUARY 2020	1	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	4	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	6	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	7	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	8	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	9	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	10	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	11	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	12	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	13	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	14	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	15	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	16	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	17	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	18	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	19	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	20	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	21	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	22	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	23	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	24	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	26	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	27	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	28	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	29	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	30	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	31	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

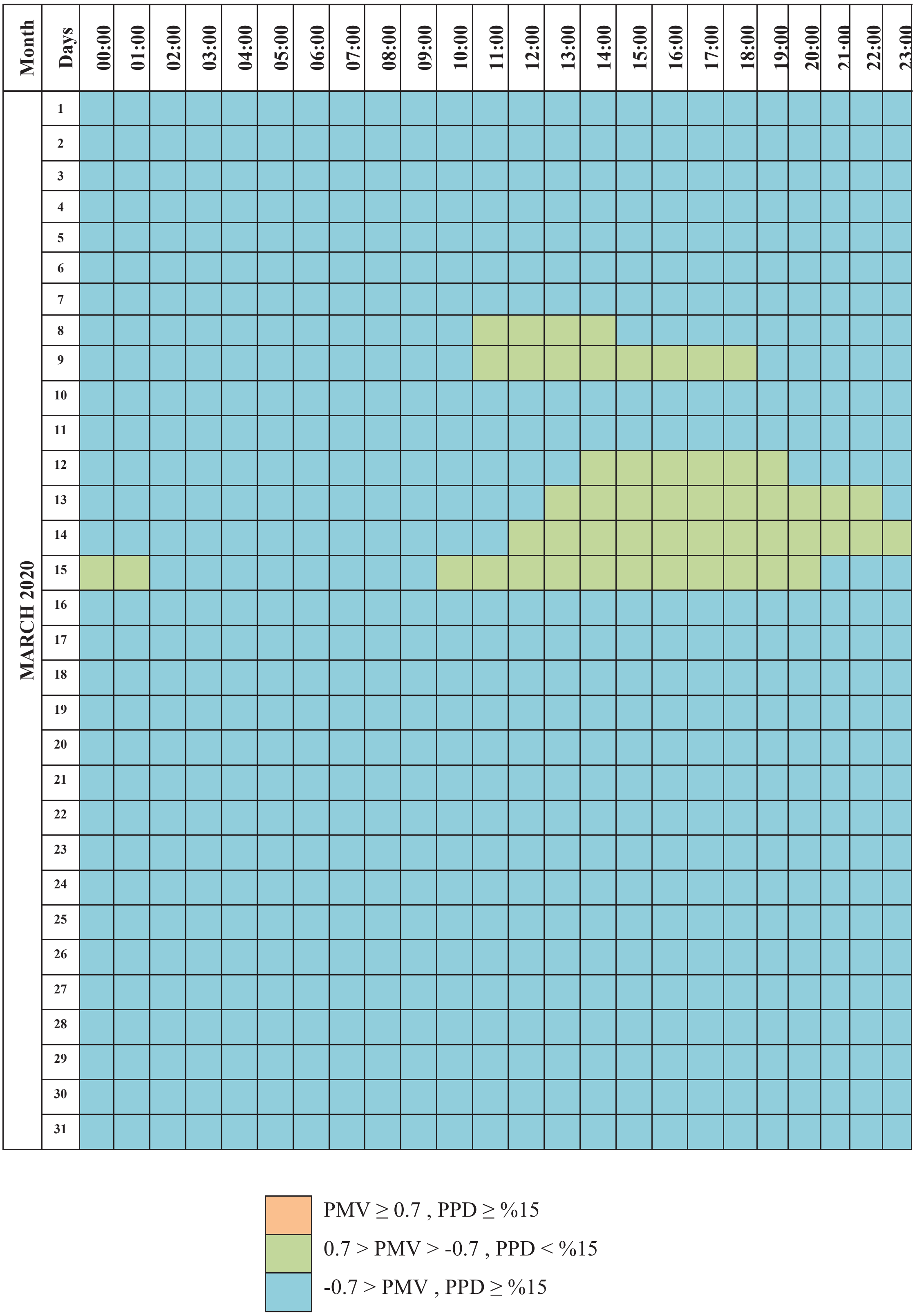
🟧	PMV ≥ 0.7 , PPD ≥ %15
🟩	0.7 > PMV > -0.7 , PPD < %15
🟦	-0.7 > PMV , PPD ≥ %15

Table A.8. Thermal comfort conditions by hours for February 2020

Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
FEBRUARY 2020	1	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	4	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	6	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	7	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	8	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	9	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	10	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	11	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	12	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	13	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	14	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	15	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	16	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	17	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	18	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	19	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	20	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	21	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	22	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	23	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	24	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	26	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	27	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	28	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	29	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

🟧	PMV ≥ 0.7 , PPD ≥ %15
🟩	0.7 > PMV > -0.7 , PPD < %15
🟦	-0.7 > PMV , PPD ≥ %15

Table A.9. Thermal comfort conditions by hours for March 2020



Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
MARCH 2020	1	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	4	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	6	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	7	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	8	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	9	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦
	10	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	11	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	12	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦
	13	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦
	14	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	15	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦
	16	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	17	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	18	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	19	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	20	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	21	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	22	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	23	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	24	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	25	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	26	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	27	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	28	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	29	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	30	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	31	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

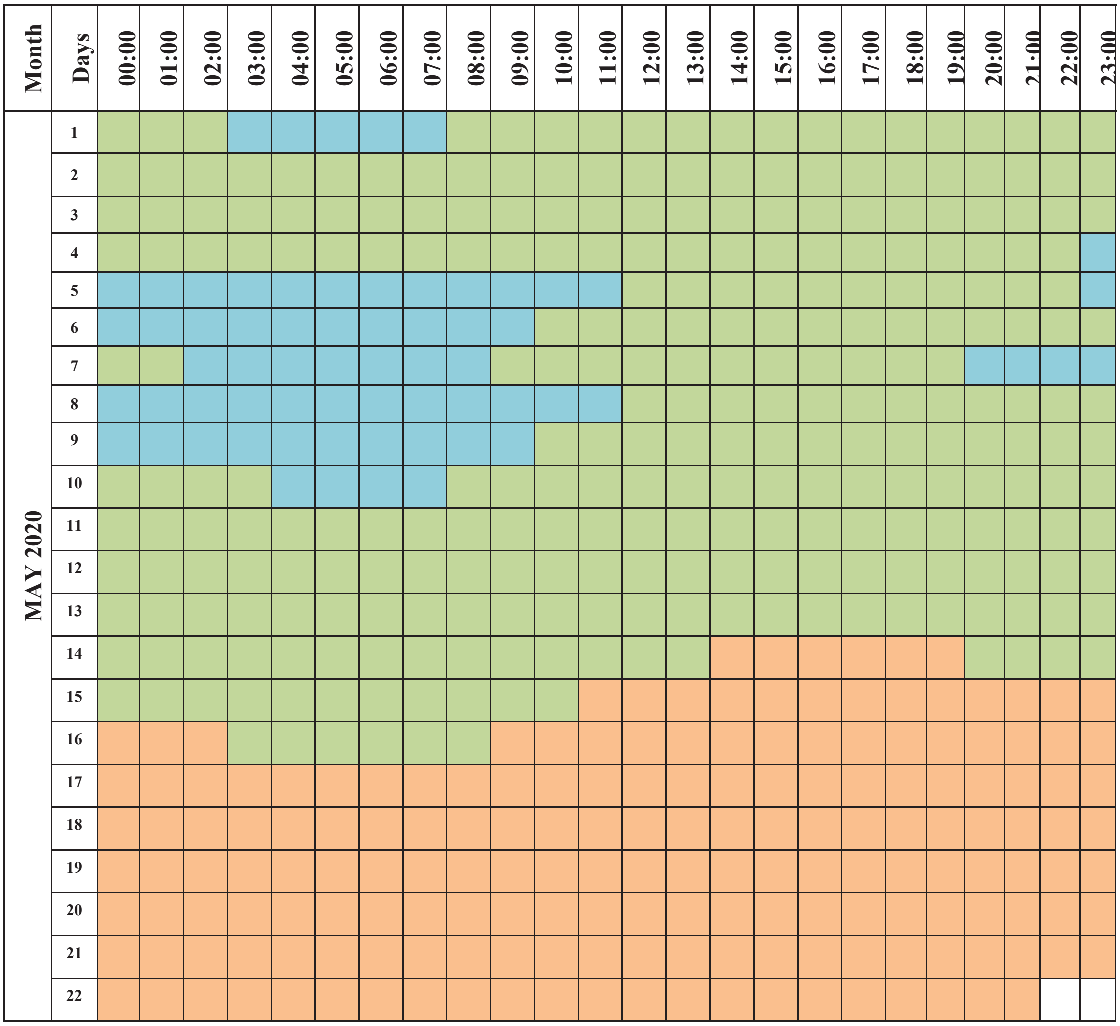
🟧 PMV ≥ 0.7 , PPD ≥ %15
🟩 0.7 > PMV > -0.7 , PPD < %15
🟦 -0.7 > PMV , PPD ≥ %15

Table A.10. Thermal comfort conditions by hours for April 2020

Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
APRIL 2020	1	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	4	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	6	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	7	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	8	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	9	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	10	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	11	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦
	12	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	13	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	14	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	15	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	16	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	17	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	18	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	19	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	20	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	21	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	22	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	23	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	24	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	25	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	26	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	27	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	28	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	29	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	30	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟧 PMV ≥ 0.7 , PPD ≥ %15
🟩 0.7 > PMV > -0.7 , PPD < %15
🟦 -0.7 > PMV , PPD ≥ %15

Table A.11. Thermal comfort conditions by hours for May 2020

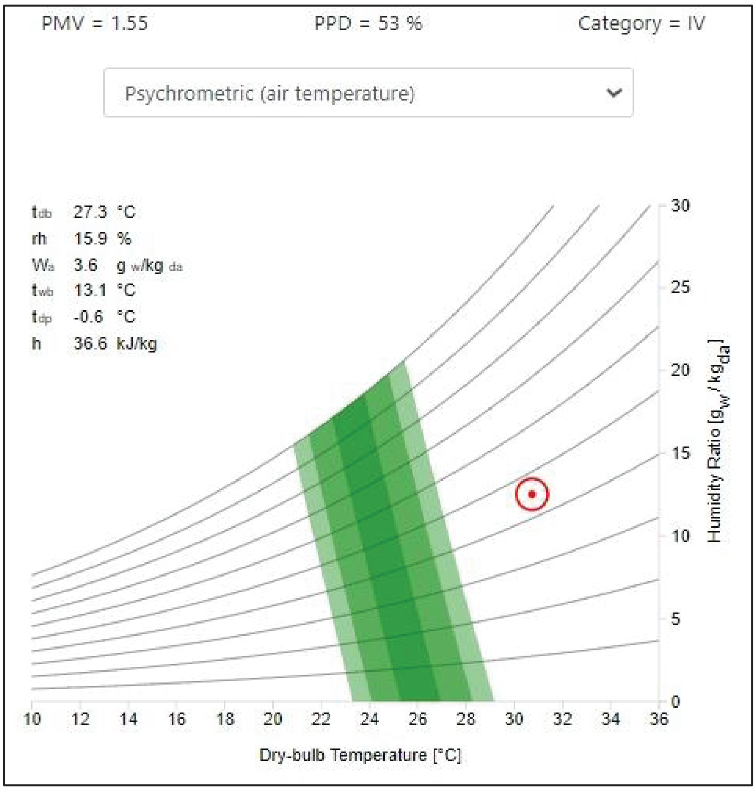


Month	Days	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
MAY 2020	1	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	3	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦
	5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦
	6	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	7	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦
	8	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	9	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	10	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	11	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	12	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	13	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	14	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟩	🟩	🟩	🟩
	15	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	16	🟧	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	17	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	18	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	19	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	20	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	21	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	22	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		

🟧 PMV ≥ 0.7 , PPD ≥ %15
🟩 0.7 > PMV > -0.7 , PPD < %15
🟦 -0.7 > PMV , PPD ≥ %15

APPENDIX B

PSYCHROMETRIC DIAGRAMS FOR EACH MONTH DETERMINING THE THERMAL COMFORT CATEGORY



PMV = 1.55

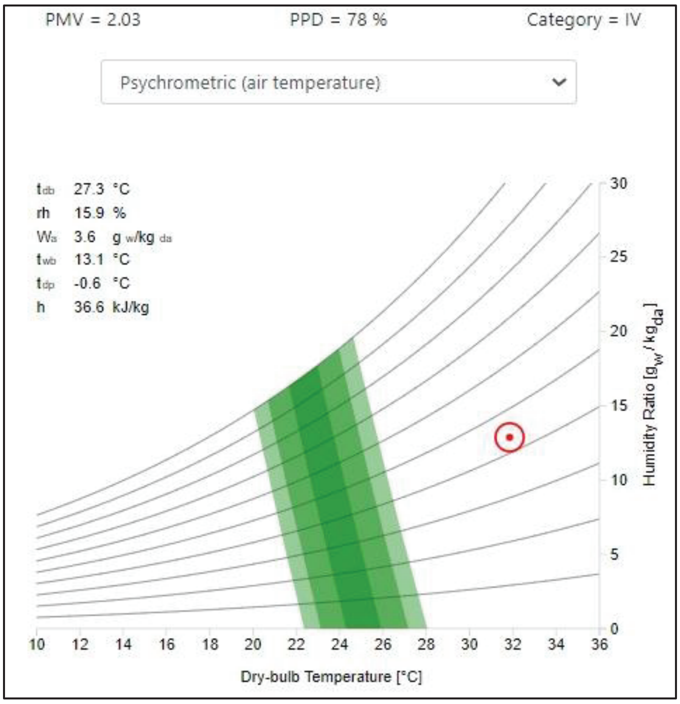
PPD = 53 %

Category = IV

Psychrometric (air temperature)

t_{db} 27.3 °C
rh 15.9 %
W_a 3.6 g w/kg da
t_{wb} 13.1 °C
t_{dp} -0.6 °C
h 36.6 kJ/kg

Figure B.1. Psychrometric diagram for July 2019 determining the thermal comfort category (Tartarini et al., 2020)

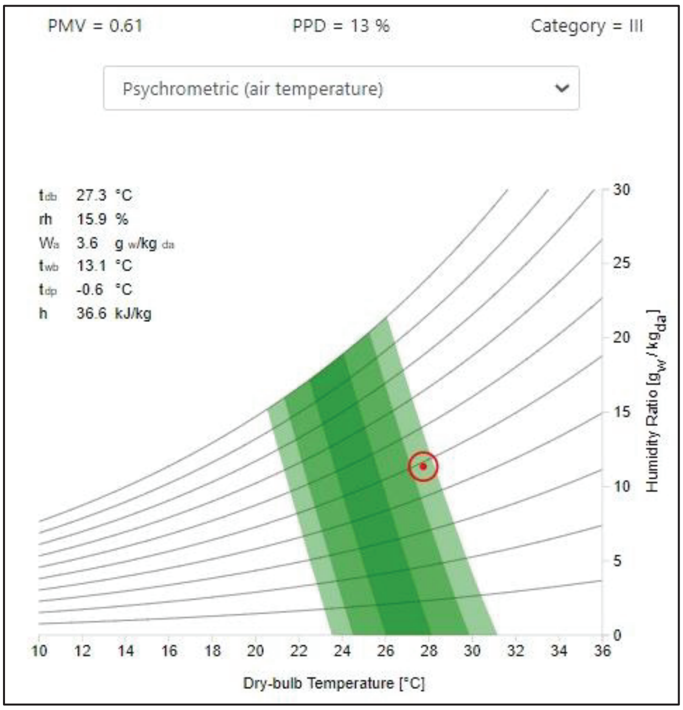


PMV = 2.03 PPD = 78 % Category = IV

Psychrometric (air temperature)

t_{db} 27.3 °C
rh 15.9 %
W_a 3.6 g w/kg da
t_{wb} 13.1 °C
t_{dp} -0.6 °C
h 36.6 kJ/kg

Figure B.2. Psychrometric diagram for August 2019 determining the thermal comfort category (Tartarini et al., 2020)

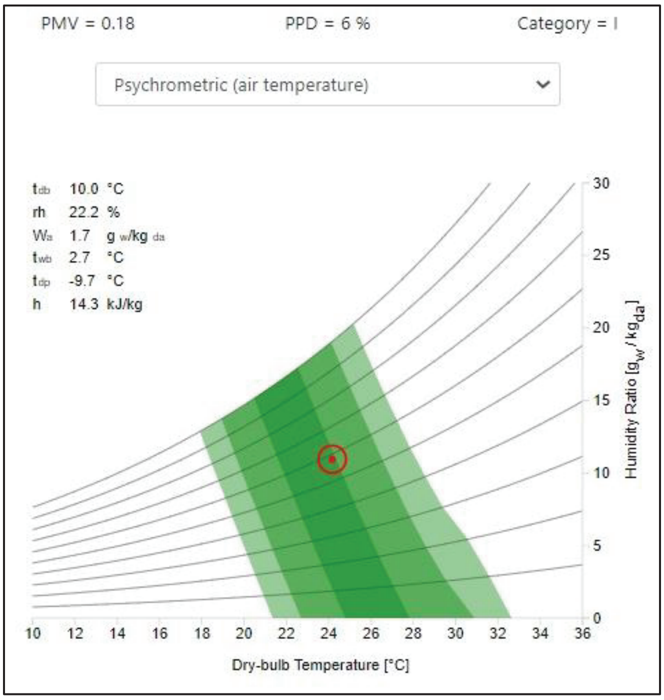


PMV = 0.61 PPD = 13 % Category = III

Psychrometric (air temperature)

t_{db} 27.3 °C
rh 15.9 %
W_a 3.6 g w/kg da
t_{wb} 13.1 °C
t_{dp} -0.6 °C
h 36.6 kJ/kg

Figure B.3. Psychrometric diagram for September 2019 determining the thermal comfort category (Tartarini et al., 2020)

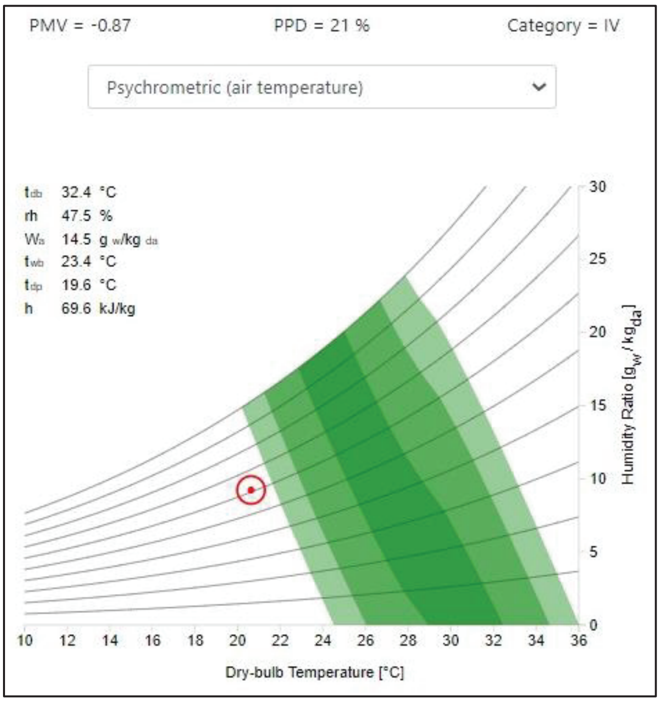


PMV = 0.18 PPD = 6 % Category = I

Psychrometric (air temperature)

t_{db} 10.0 °C
rh 22.2 %
W_a 1.7 g w/kg da
t_{wb} 2.7 °C
t_{dp} -9.7 °C
h 14.3 kJ/kg

Figure B.4. Psychrometric diagram for October 2019 determining the thermal comfort category (Tartarini et al., 2020)

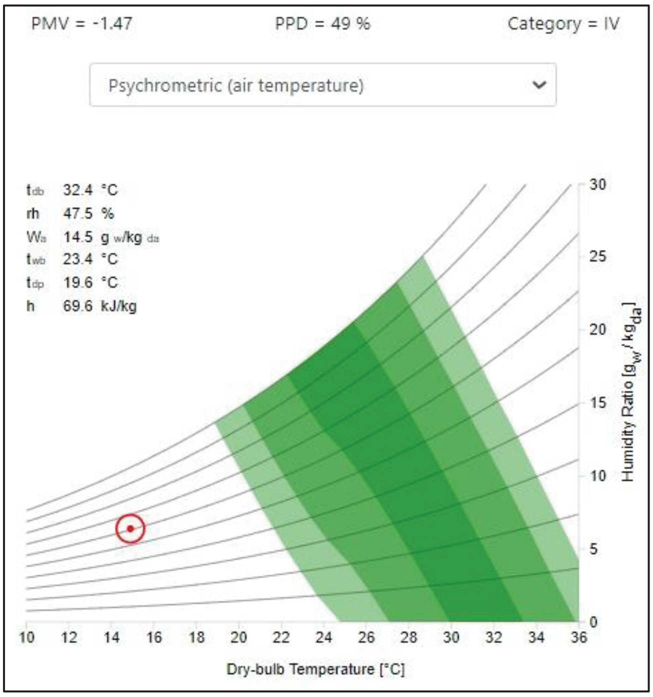


PMV = -0.87 PPD = 21 % Category = IV

Psychrometric (air temperature)

t_{db} 32.4 °C
rh 47.5 %
W_a 14.5 g w/kg da
t_{wb} 23.4 °C
t_{dp} 19.6 °C
h 69.6 kJ/kg

Figure B.5. Psychrometric diagram for November 2019 determining the thermal comfort category (Tartarini et al., 2020)



PMV = -1.47

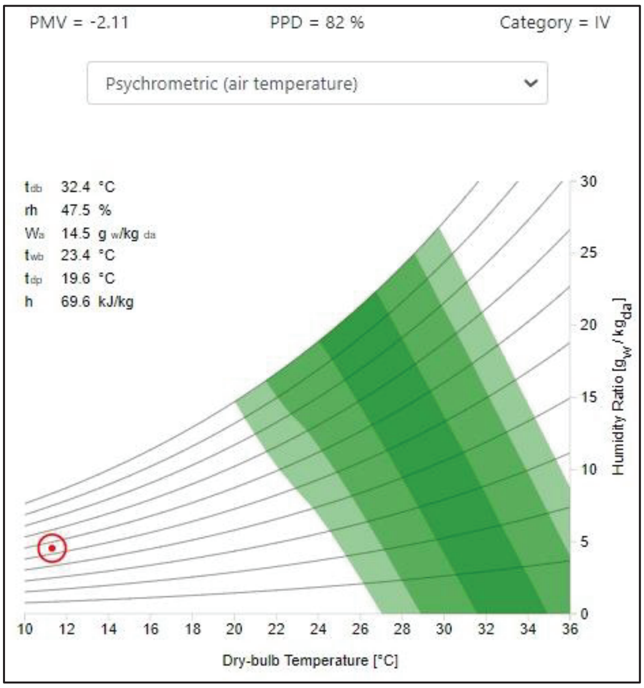
PPD = 49 %

Category = IV

Psychrometric (air temperature)

t_{db} 32.4 °C
rh 47.5 %
W_a 14.5 g w/kg da
t_{wb} 23.4 °C
t_{dp} 19.6 °C
h 69.6 kJ/kg

Figure B.6. Psychrometric diagram for December 2019 determining the thermal comfort category (Tartarini et al., 2020)



PMV = -2.11

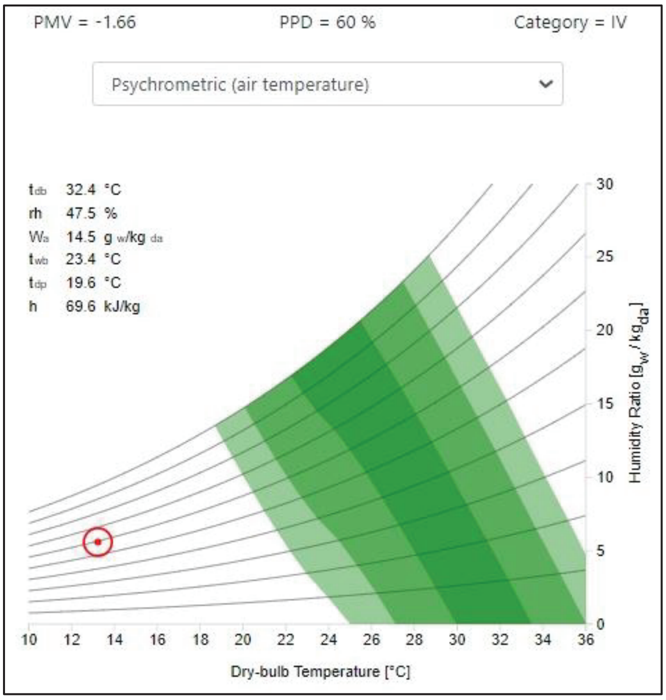
PPD = 82 %

Category = IV

Psychrometric (air temperature)

t_{db} 32.4 °C
rh 47.5 %
W_a 14.5 g w/kg da
t_{wb} 23.4 °C
t_{dp} 19.6 °C
h 69.6 kJ/kg

Figure B.7. Psychrometric diagram for January 2020 determining the thermal comfort category (Tartarini et al., 2020)

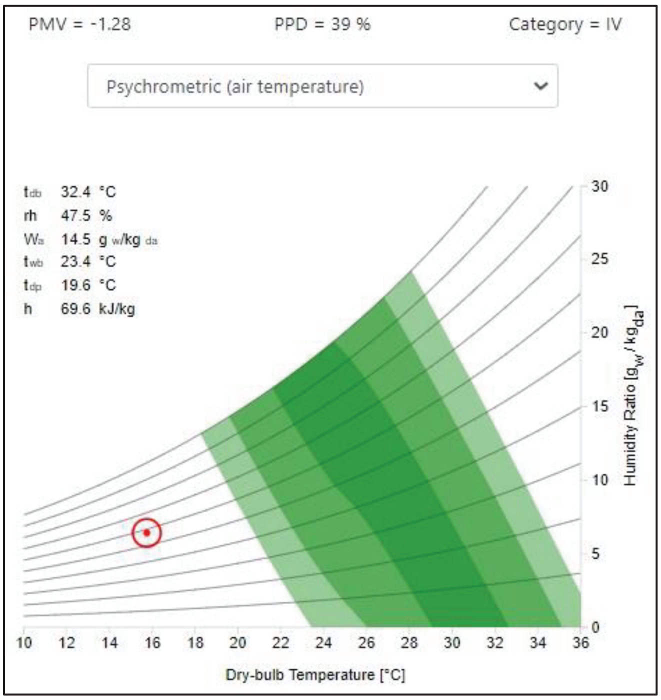


PMV = -1.66 PPD = 60 % Category = IV

Psychrometric (air temperature)

t_{db} 32.4 °C
rh 47.5 %
W_a 14.5 g w/kg da
t_{wb} 23.4 °C
t_{dp} 19.6 °C
h 69.6 kJ/kg

Figure B.8. Psychrometric diagram for February 2020 determining the thermal comfort category (Tartarini et al., 2020)

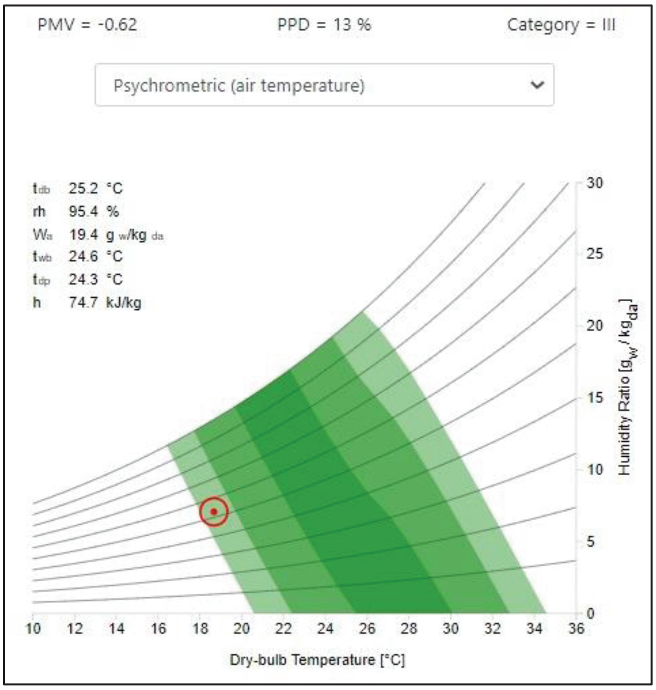


PMV = -1.28 PPD = 39 % Category = IV

Psychrometric (air temperature)

t_{db} 32.4 °C
rh 47.5 %
W_a 14.5 g w/kg da
t_{wb} 23.4 °C
t_{dp} 19.6 °C
h 69.6 kJ/kg

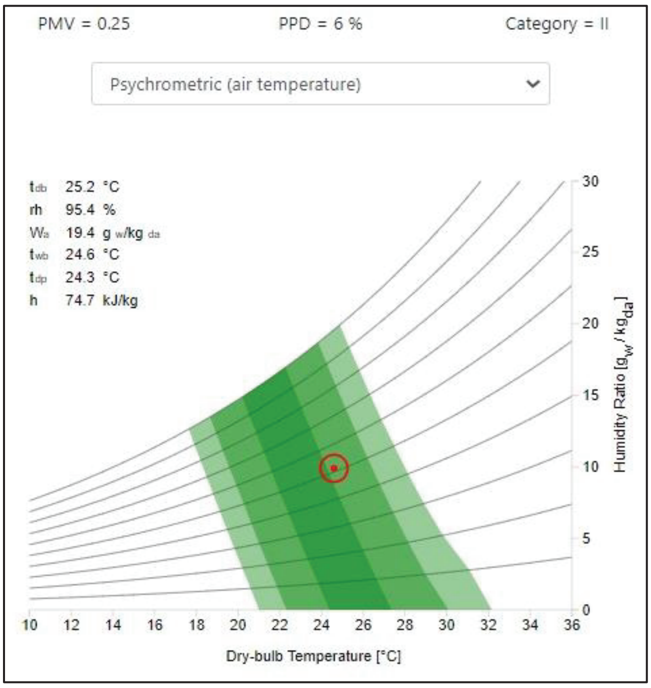
Figure B.9. Psychrometric diagram for March 2020 determining the thermal comfort category (Tartarini et al., 2020)


PMV = -0.62 PPD = 13 % Category = III

Psychrometric (air temperature)

t_{db} 25.2 °C
rh 95.4 %
W_a 19.4 g_w/kg_{da}
t_{wb} 24.6 °C
t_{dp} 24.3 °C
h 74.7 kJ/kg

Figure B.10. Psychrometric diagram for April 2020 determining the thermal comfort category (Tartarini et al., 2020)


PMV = 0.25 PPD = 6 % Category = II

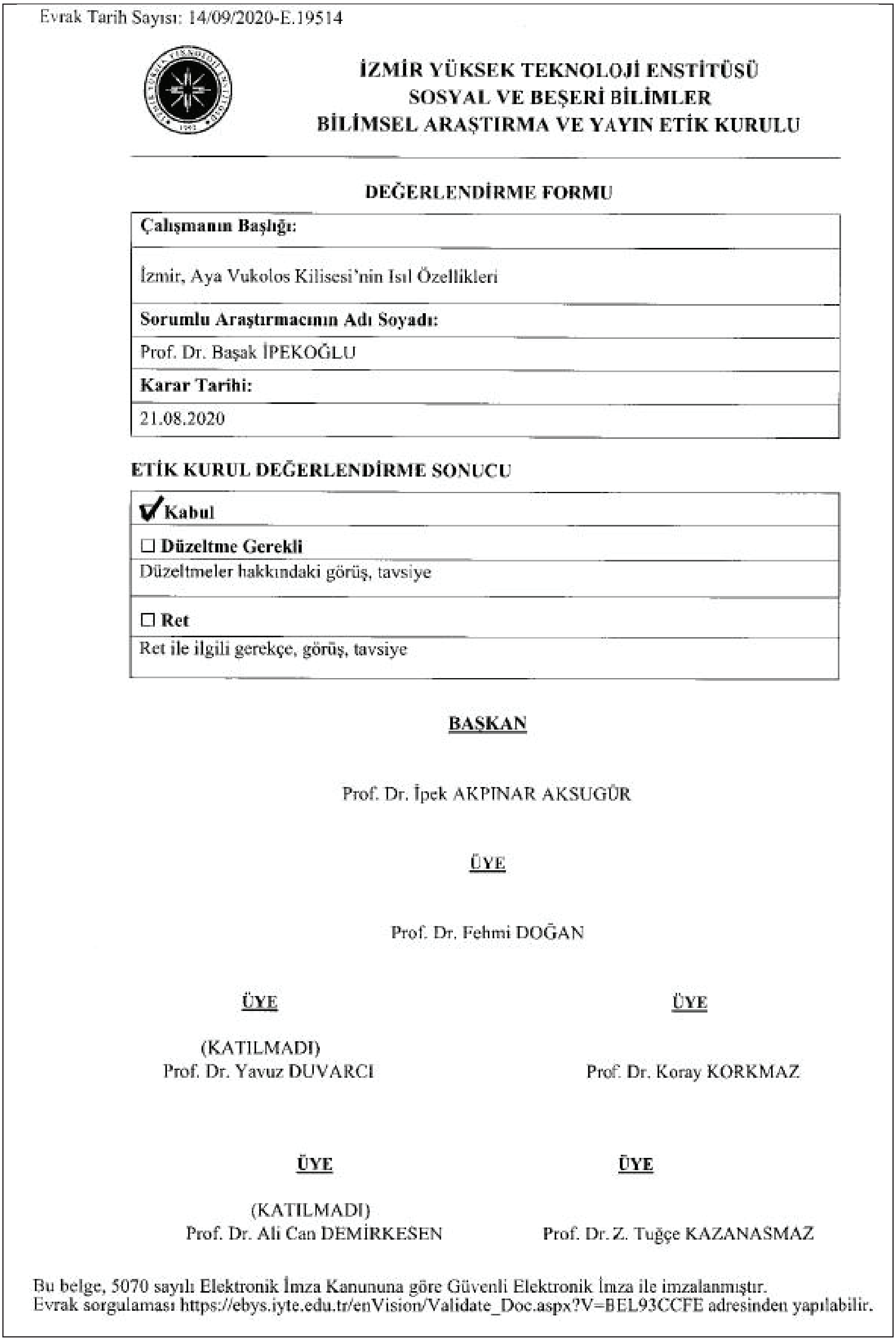
Psychrometric (air temperature)

t_{db} 25.2 °C
rh 95.4 %
W_a 19.4 g_w/kg_{da}
t_{wb} 24.6 °C
t_{dp} 24.3 °C
h 74.7 kJ/kg

Figure B.11. Psychrometric diagram for May 2020 determining the thermal comfort category (Tartarini et al., 2020)

APPENDIX C

İZMİR INSTITUTE OF TECHNOLOGY SOCIAL AND HUMAN SCIENCES RESEARCH AND PUBLICATION ETHICS COMMITTEE EVALUATION FOR THE SURVEY STUDY



Evrak Tarih Sayısı: 14/09/2020-E.19514

İZMİR YÜKSEK TEKNOLOJİ ENSTİTÜSÜ
SOSYAL VE BEŞERİ BİLİMLER
BİLİMSEL ARAŞTIRMA VE YAYIN ETİK KURULU

DEĞERLENDİRME FORMU

Çalışmanın Başlığı:

İzmir, Aya Vukolos Kilisesi'nin Isıl Özellikleri

Sorumlu Araştırmacının Adı Soyadı:

Prof. Dr. Başak İPEKOĞLU

Karar Tarihi:

21.08.2020

ETİK KURUL DEĞERLENDİRME SONUCU

☑ **Kabul**

☐ **Düzeltme Gerekli**

Düzeltmeler hakkındaki görüş, tavsiye

☐ **Ret**

Ret ile ilgili gerekçe, görüş, tavsiye

BAŞKAN

Prof. Dr. İpek AKPINAR AKSUGÜR

ÜYE

Prof. Dr. Fehmi DOĞAN

ÜYE

(KATILMADI)
Prof. Dr. Yavuz DUVARCI

ÜYE

Prof. Dr. Koray KORKMAZ

ÜYE

(KATILMADI)
Prof. Dr. Ali Can DEMİRKESEN

ÜYE

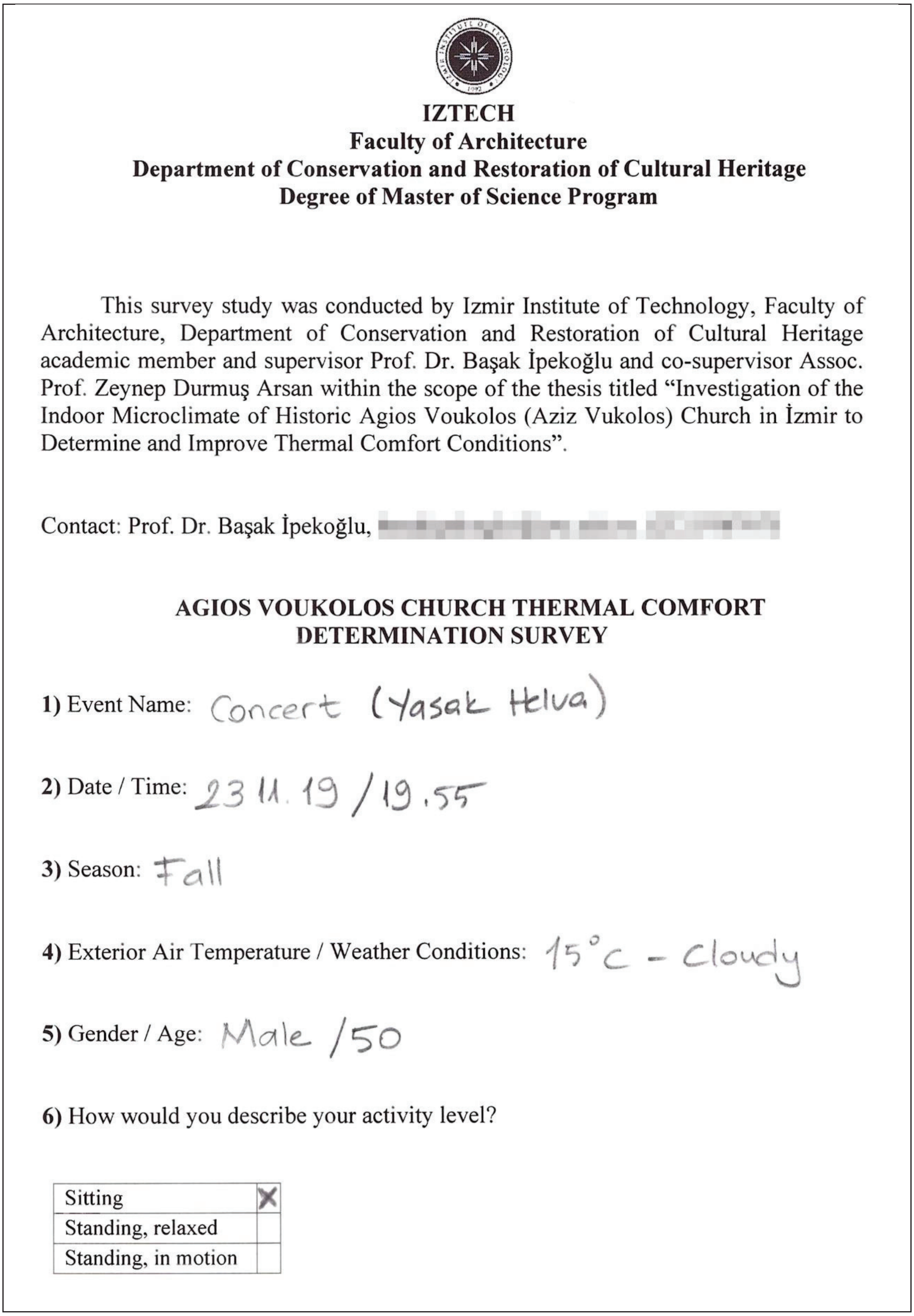
Prof. Dr. Z. Tuğçe KAZANASMAZ

Bu belge, 5070 sayılı Elektronik İmza Kanununa göre Güvenli Elektronik İmza ile imzalanmıştır.
Evrak sorgulaması https://ebys.iyte.edu.tr/enVision/Validate_Doc.aspx?V=BEL93CCFE adresinden yapılabilir.

Figure C.1. İzmir Institute of Technology Social and Human Sciences Research and Publication Ethics Committee Evaluation for the survey study

APPENDIX D

SURVEY STUDY SAMPLES



IZTECH
Faculty of Architecture
Department of Conservation and Restoration of Cultural Heritage
Degree of Master of Science Program

This survey study was conducted by Izmir Institute of Technology, Faculty of Architecture, Department of Conservation and Restoration of Cultural Heritage academic member and supervisor Prof. Dr. Başak İpekoğlu and co-supervisor Assoc. Prof. Zeynep Durmuş Arsan within the scope of the thesis titled "Investigation of the Indoor Microclimate of Historic Agios Voukolos (Aziz Vukolos) Church in İzmir to Determine and Improve Thermal Comfort Conditions".

Contact: Prof. Dr. Başak İpekoğlu, [redacted]

AGIOS VOUKOLOS CHURCH THERMAL COMFORT DETERMINATION SURVEY

1) Event Name: Concert (Yasak Helva)

2) Date / Time: 23.11.19 / 19.55

3) Season: Fall

4) Exterior Air Temperature / Weather Conditions: 15°C - Cloudy

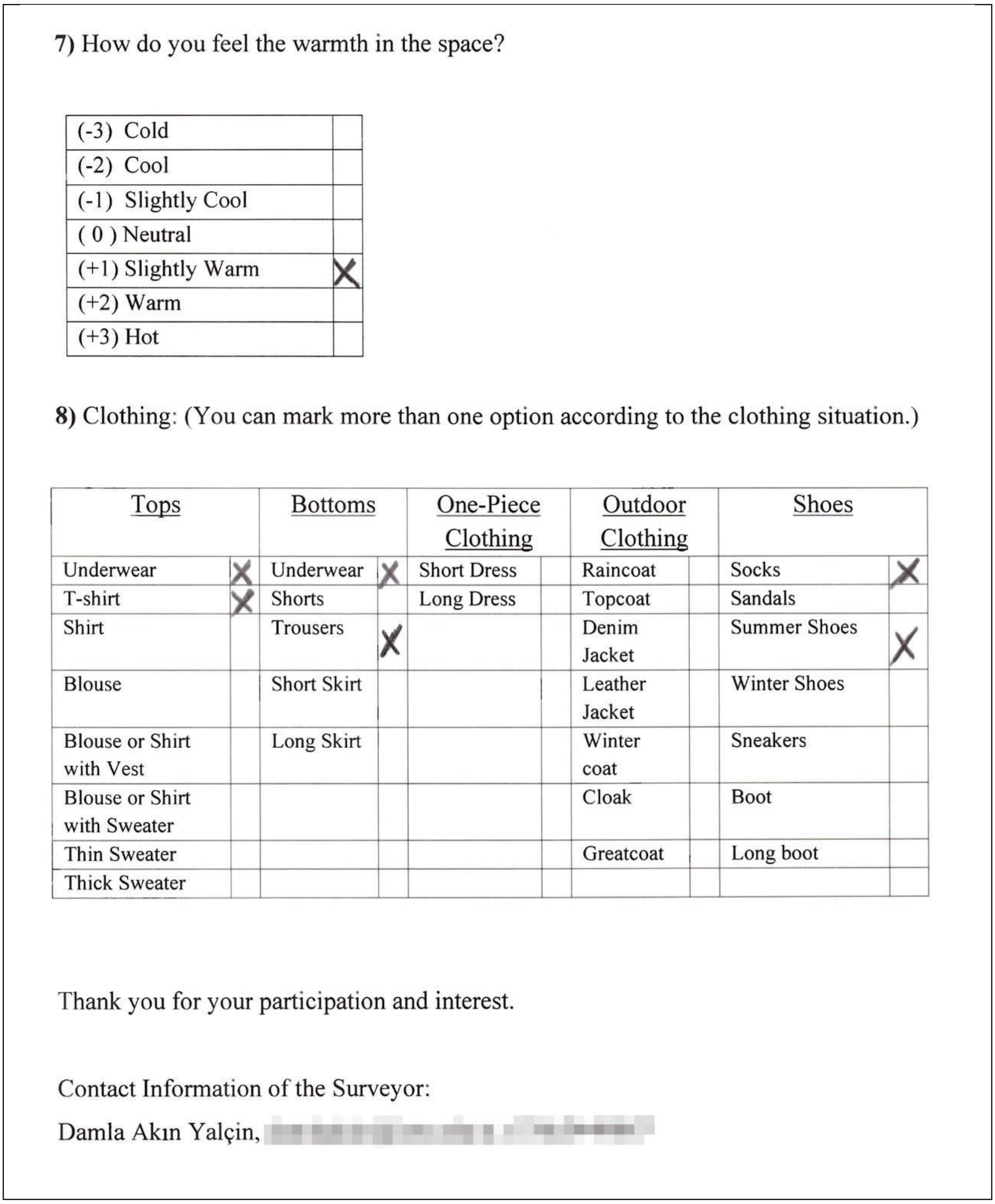
5) Gender / Age: Male / 50

6) How would you describe your activity level?

Sitting	☒
Standing, relaxed	☐
Standing, in motion	☐

Figure D.1. Survey study sample in the concert event on 23 November 2019 at the Agios Voukolos Church

(cont. on next page)



7) How do you feel the warmth in the space?

(-3) Cold	
(-2) Cool	
(-1) Slightly Cool	
(0) Neutral	
(+1) Slightly Warm	X
(+2) Warm	
(+3) Hot	

8) Clothing: (You can mark more than one option according to the clothing situation.)

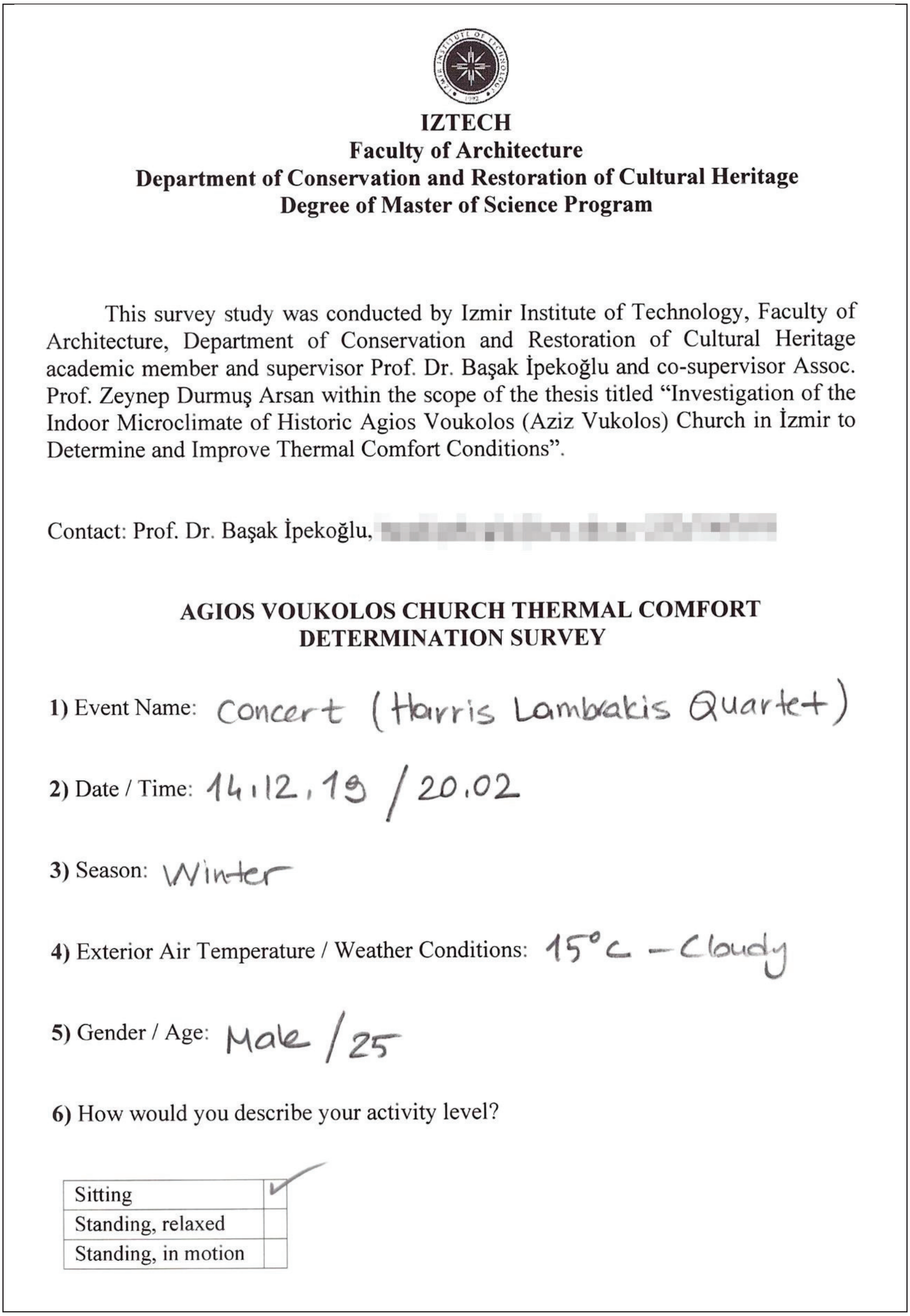
Tops		Bottoms		One-Piece Clothing		Outdoor Clothing		Shoes	
Underwear	X	Underwear	X	Short Dress		Raincoat		Socks	X
T-shirt	X	Shorts		Long Dress		Topcoat		Sandals	
Shirt		Trousers	X			Denim Jacket		Summer Shoes	X
Blouse		Short Skirt				Leather Jacket		Winter Shoes	
Blouse or Shirt with Vest		Long Skirt				Winter coat		Sneakers	
Blouse or Shirt with Sweater						Cloak		Boot	
Thin Sweater						Greatcoat		Long boot	
Thick Sweater									

Thank you for your participation and interest.

Contact Information of the Surveyor:

Damla Akın Yalçin, [redacted]

Figure D.1 (cont.)



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Department of Conservation and Restoration of Cultural Heritage
Degree of Master of Science Program

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Contact: Prof. Dr. Başak İpekoğlu, [redacted]

AGIOS VOUKOLOS CHURCH THERMAL COMFORT DETERMINATION SURVEY

1) Event Name: Concert (Harris Lambrakis Quartet)

2) Date / Time: 14.12.19 / 20.02

3) Season: Winter

4) Exterior Air Temperature / Weather Conditions: 15°C – Cloudy

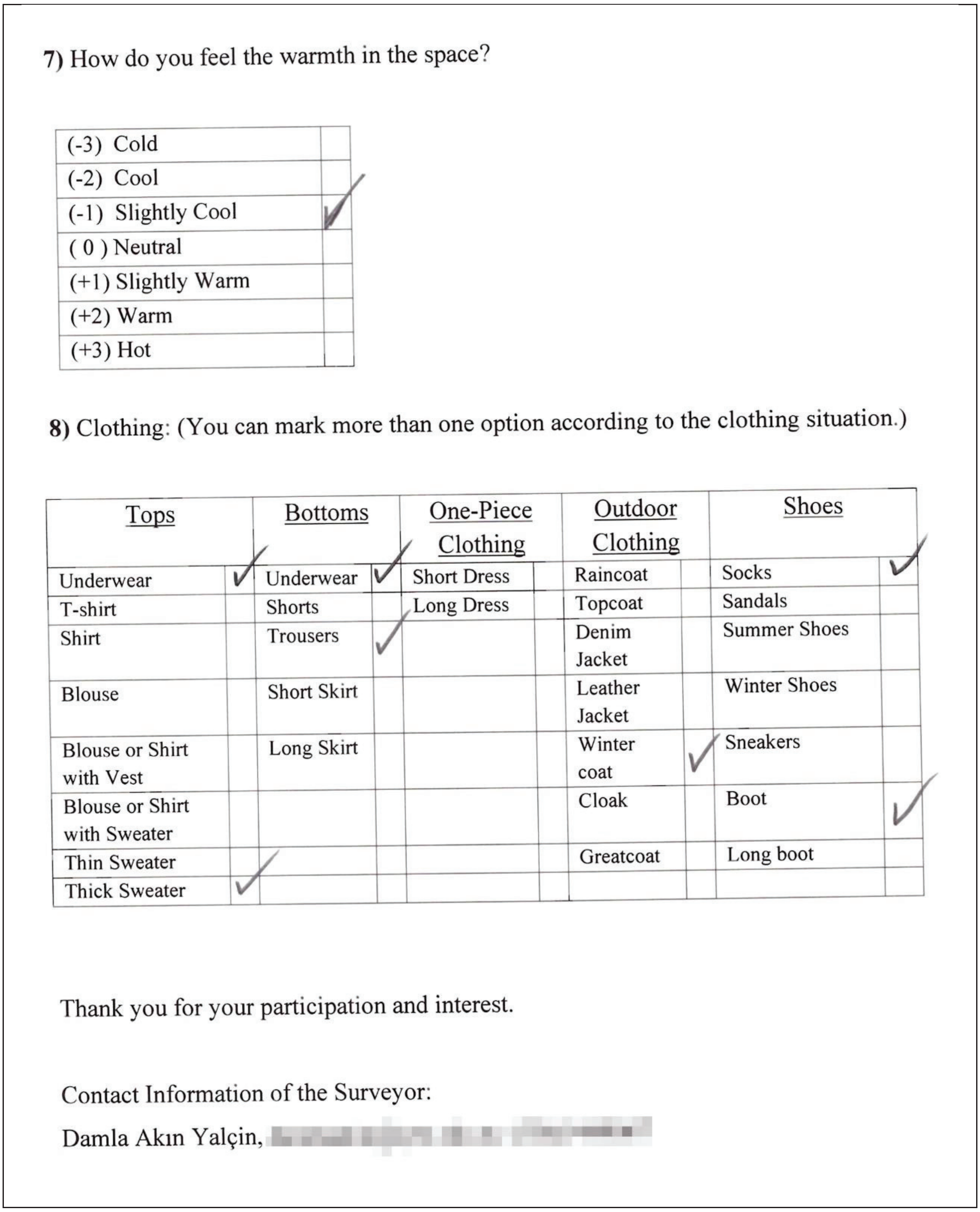
5) Gender / Age: Male / 25

6) How would you describe your activity level?

Sitting	✓
Standing, relaxed	
Standing, in motion	

Figure D.2. Survey study sample in the concert event on 14 December 2019 at the Agios Voukolos Church

(cont. on next page)



7) How do you feel the warmth in the space?

(-3) Cold	
(-2) Cool	
(-1) Slightly Cool	✓
(0) Neutral	
(+1) Slightly Warm	
(+2) Warm	
(+3) Hot	

8) Clothing: (You can mark more than one option according to the clothing situation.)

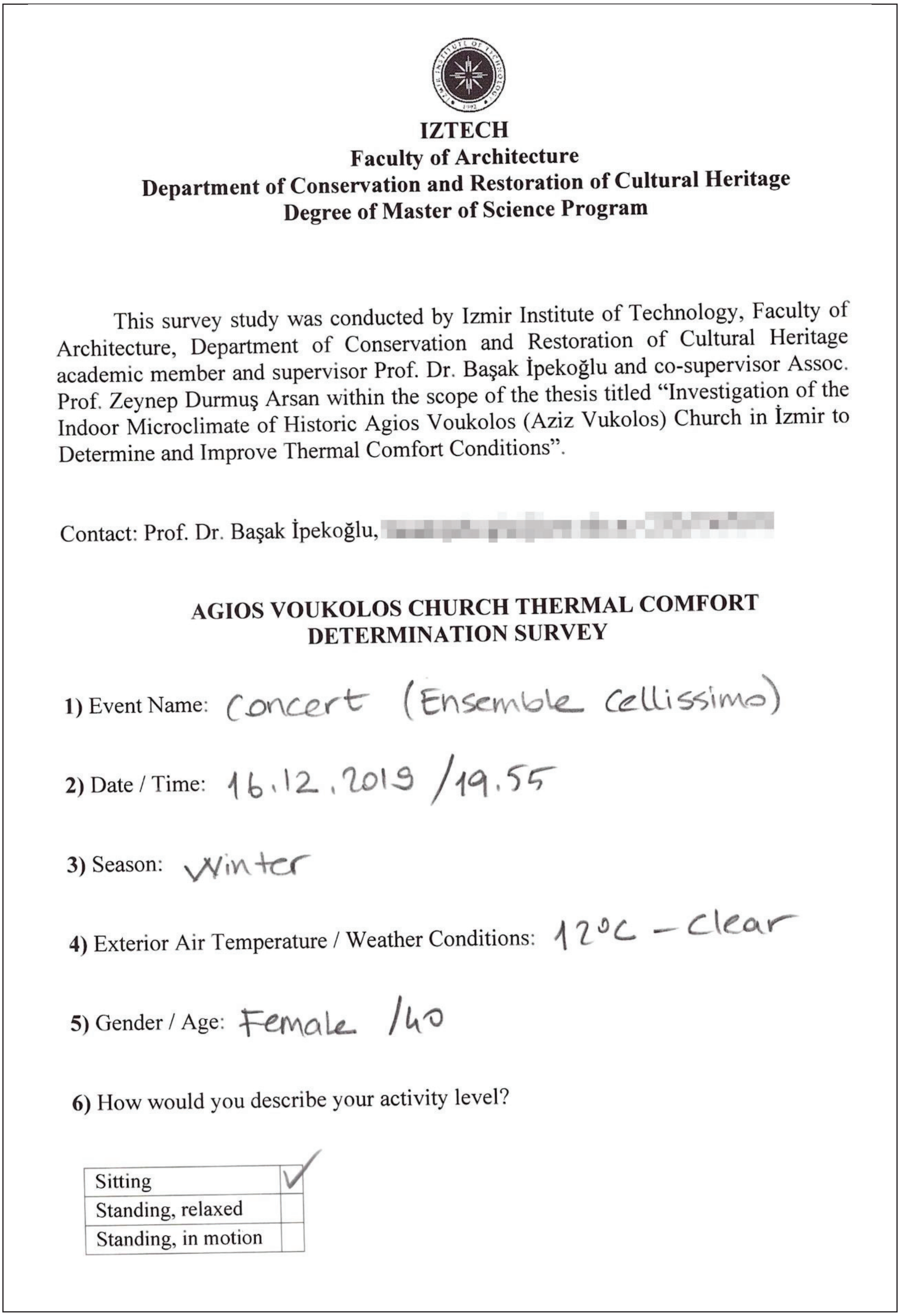
Tops		Bottoms		One-Piece Clothing		Outdoor Clothing		Shoes	
Underwear	✓	Underwear	✓	Short Dress		Raincoat		Socks	✓
T-shirt		Shorts		Long Dress		Topcoat		Sandals	
Shirt		Trousers	✓			Denim Jacket		Summer Shoes	
Blouse		Short Skirt				Leather Jacket		Winter Shoes	
Blouse or Shirt with Vest		Long Skirt				Winter coat	✓	Sneakers	
Blouse or Shirt with Sweater						Cloak		Boot	✓
Thin Sweater						Greatcoat		Long boot	
Thick Sweater	✓								

Thank you for your participation and interest.

Contact Information of the Surveyor:

Damla Akın Yalçin, [redacted]

Figure D.2 (cont.)



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Contact: Prof. Dr. Başak İpekoğlu, [redacted]

AGIOS VOUKOLOS CHURCH THERMAL COMFORT DETERMINATION SURVEY

1) Event Name: Concert (Ensemble Cellissimo)

2) Date / Time: 16.12.2019 /19.55

3) Season: Winter

4) Exterior Air Temperature / Weather Conditions: 12°C – Clear

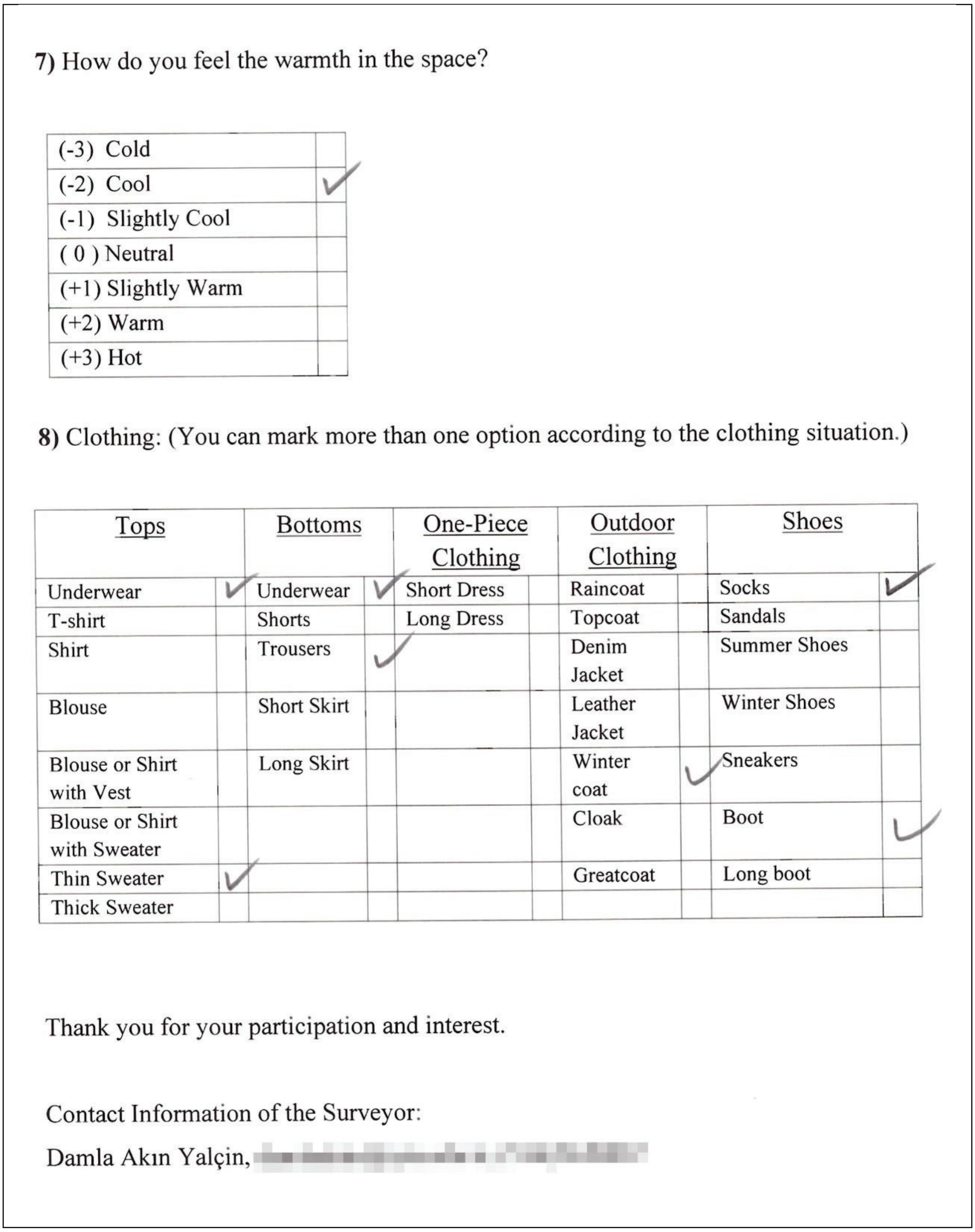
5) Gender / Age: Female /40

6) How would you describe your activity level?

Sitting	✓
Standing, relaxed	
Standing, in motion	

Figure D.3. Survey study sample in the concert event on 16 December 2019 at the Agios Voukolos Church

(cont. on next page)



7) How do you feel the warmth in the space?

(-3) Cold	
(-2) Cool	✓
(-1) Slightly Cool	
(0) Neutral	
(+1) Slightly Warm	
(+2) Warm	
(+3) Hot	

8) Clothing: (You can mark more than one option according to the clothing situation.)

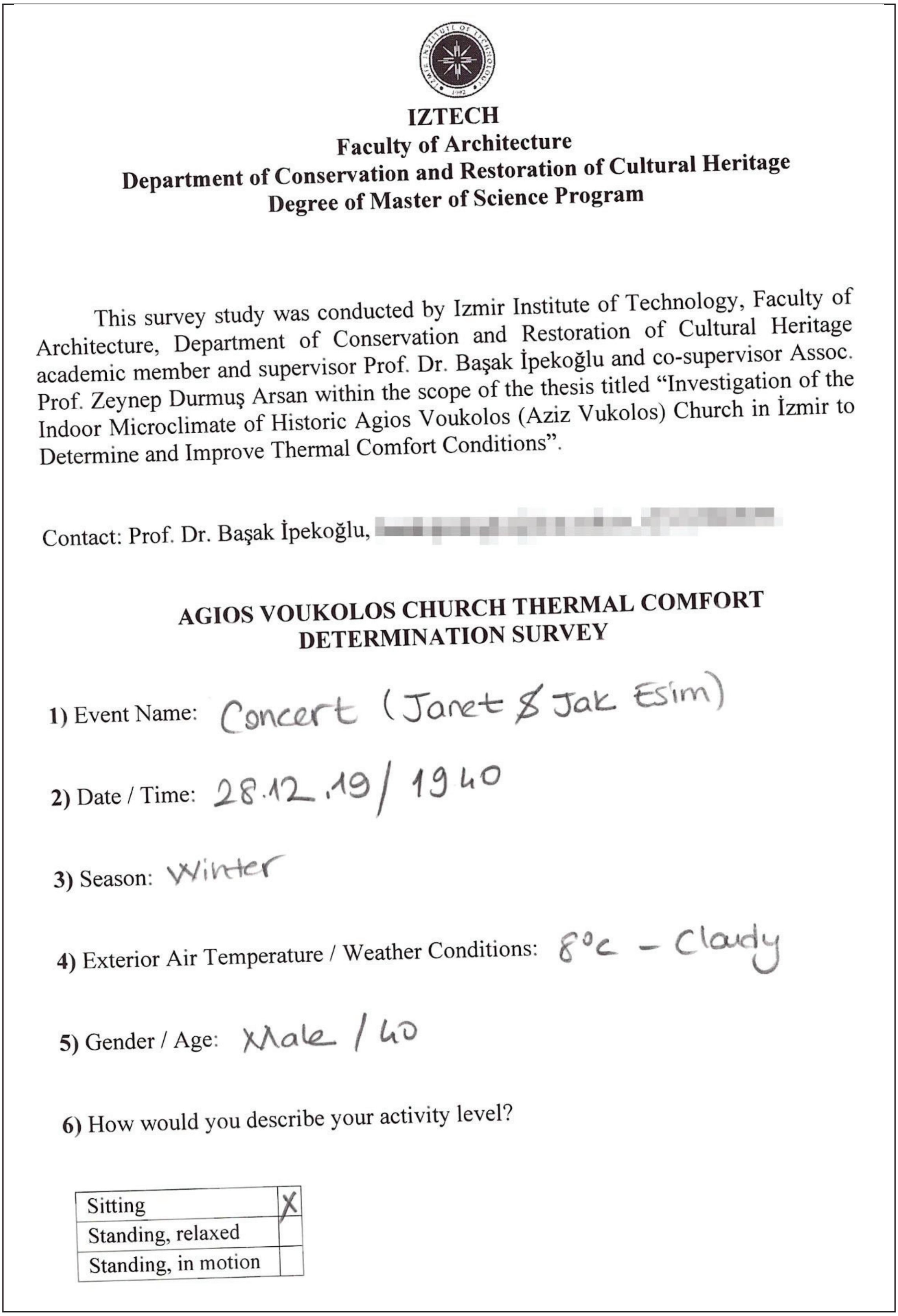
Tops		Bottoms		One-Piece Clothing		Outdoor Clothing		Shoes	
Underwear	✓	Underwear	✓	Short Dress		Raincoat		Socks	✓
T-shirt		Shorts		Long Dress		Topcoat		Sandals	
Shirt		Trousers	✓			Denim Jacket		Summer Shoes	
Blouse		Short Skirt				Leather Jacket		Winter Shoes	
Blouse or Shirt with Vest		Long Skirt				Winter coat	✓	Sneakers	
Blouse or Shirt with Sweater						Cloak		Boot	✓
Thin Sweater	✓					Greatcoat		Long boot	
Thick Sweater									

Thank you for your participation and interest.

Contact Information of the Surveyor:

Damla Akın Yalçin, [redacted]

Figure D.3 (cont.)



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Contact: Prof. Dr. Başak İpekoğlu, [redacted]

AGIOS VOUKOLOS CHURCH THERMAL COMFORT DETERMINATION SURVEY

1) Event Name: Concert (Janet & Jak Esim)

2) Date / Time: 28.12.19 / 19 40

3) Season: Winter

4) Exterior Air Temperature / Weather Conditions: 8°c - Claudy

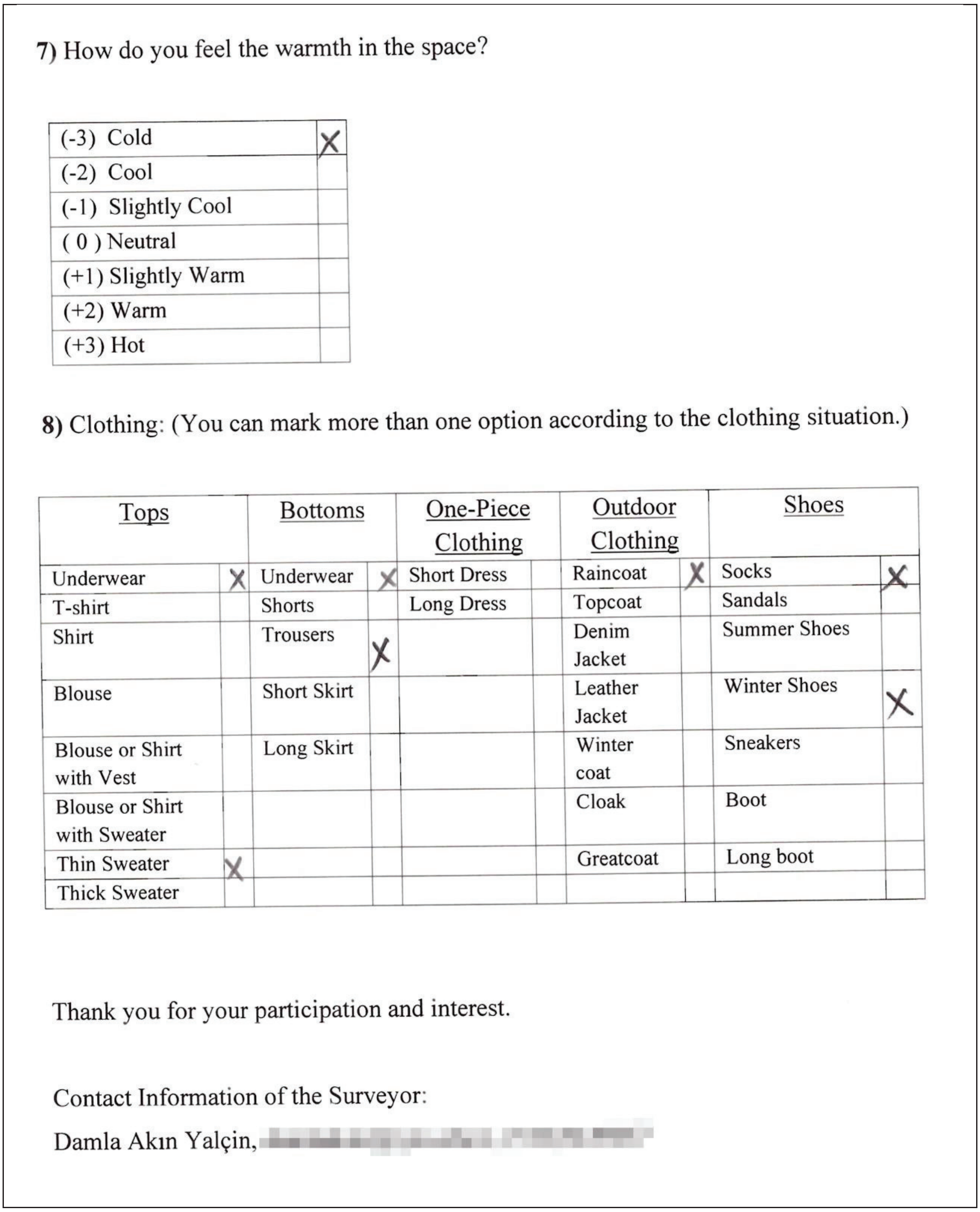
5) Gender / Age: Male / 40

6) How would you describe your activity level?

Sitting	☒
Standing, relaxed	☐
Standing, in motion	☐

Figure D.4. Survey study sample in the concert event on 28 December 2019 at the Agios Voukolos Church

(cont. on next page)



7) How do you feel the warmth in the space?

(-3) Cold	X
(-2) Cool	
(-1) Slightly Cool	
(0) Neutral	
(+1) Slightly Warm	
(+2) Warm	
(+3) Hot	

8) Clothing: (You can mark more than one option according to the clothing situation.)

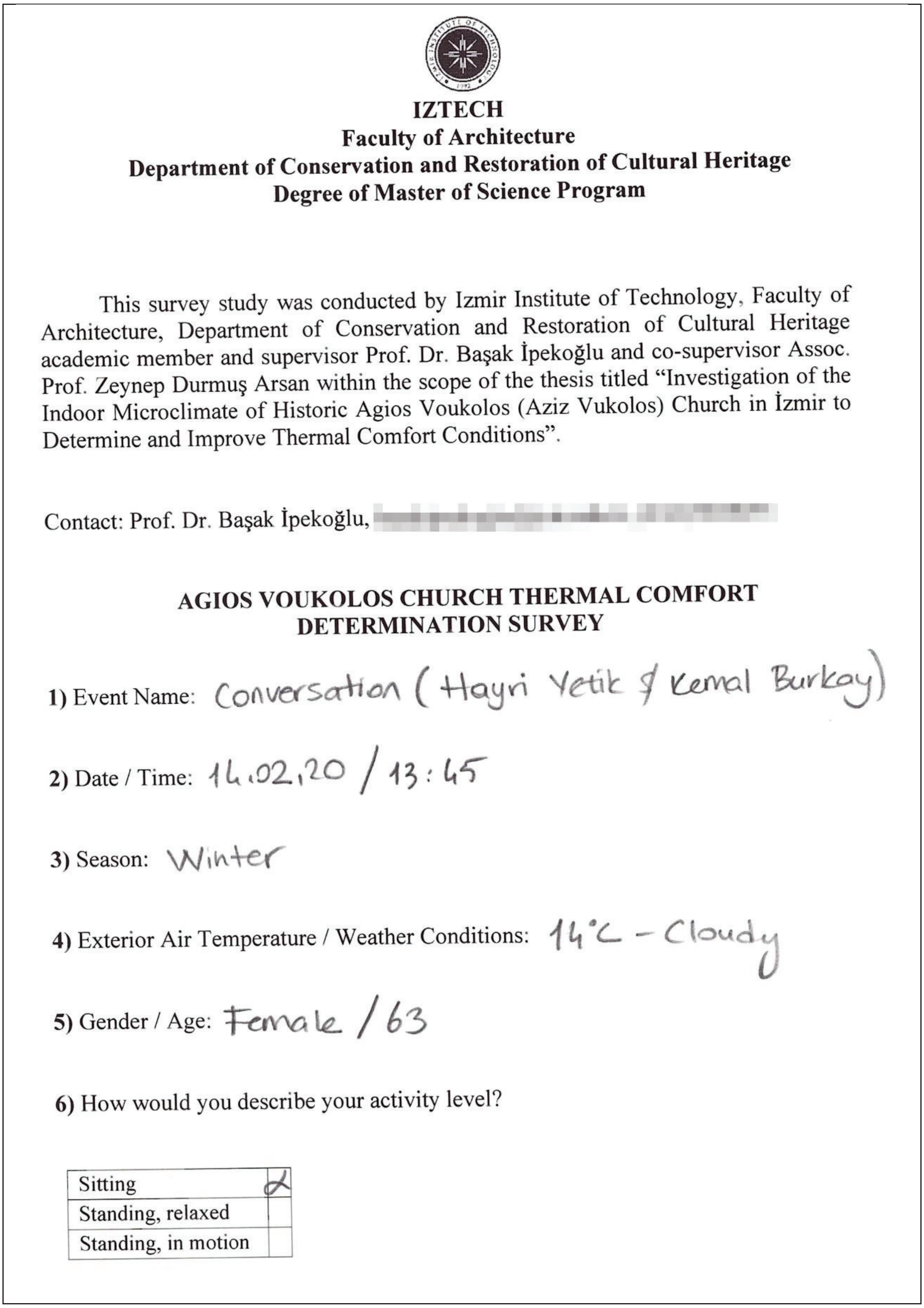
Tops		Bottoms		One-Piece Clothing		Outdoor Clothing		Shoes	
Underwear	X	Underwear	X	Short Dress		Raincoat	X	Socks	X
T-shirt		Shorts		Long Dress		Topcoat		Sandals	
Shirt		Trousers	X			Denim Jacket		Summer Shoes	
Blouse		Short Skirt				Leather Jacket		Winter Shoes	X
Blouse or Shirt with Vest		Long Skirt				Winter coat		Sneakers	
Blouse or Shirt with Sweater						Cloak		Boot	
Thin Sweater	X					Greatcoat		Long boot	
Thick Sweater									

Thank you for your participation and interest.

Contact Information of the Surveyor:

Damla Akın Yalçin, [redacted]

Figure D.4 (cont.)



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Contact: Prof. Dr. Başak İpekoğlu, [redacted]

AGIOS VOUKOLOS CHURCH THERMAL COMFORT DETERMINATION SURVEY

1) Event Name: Conversation (Hayri Yetik & Kemal Burkay)

2) Date / Time: 14.02.20 / 13:45

3) Season: Winter

4) Exterior Air Temperature / Weather Conditions: 14°C - Cloudy

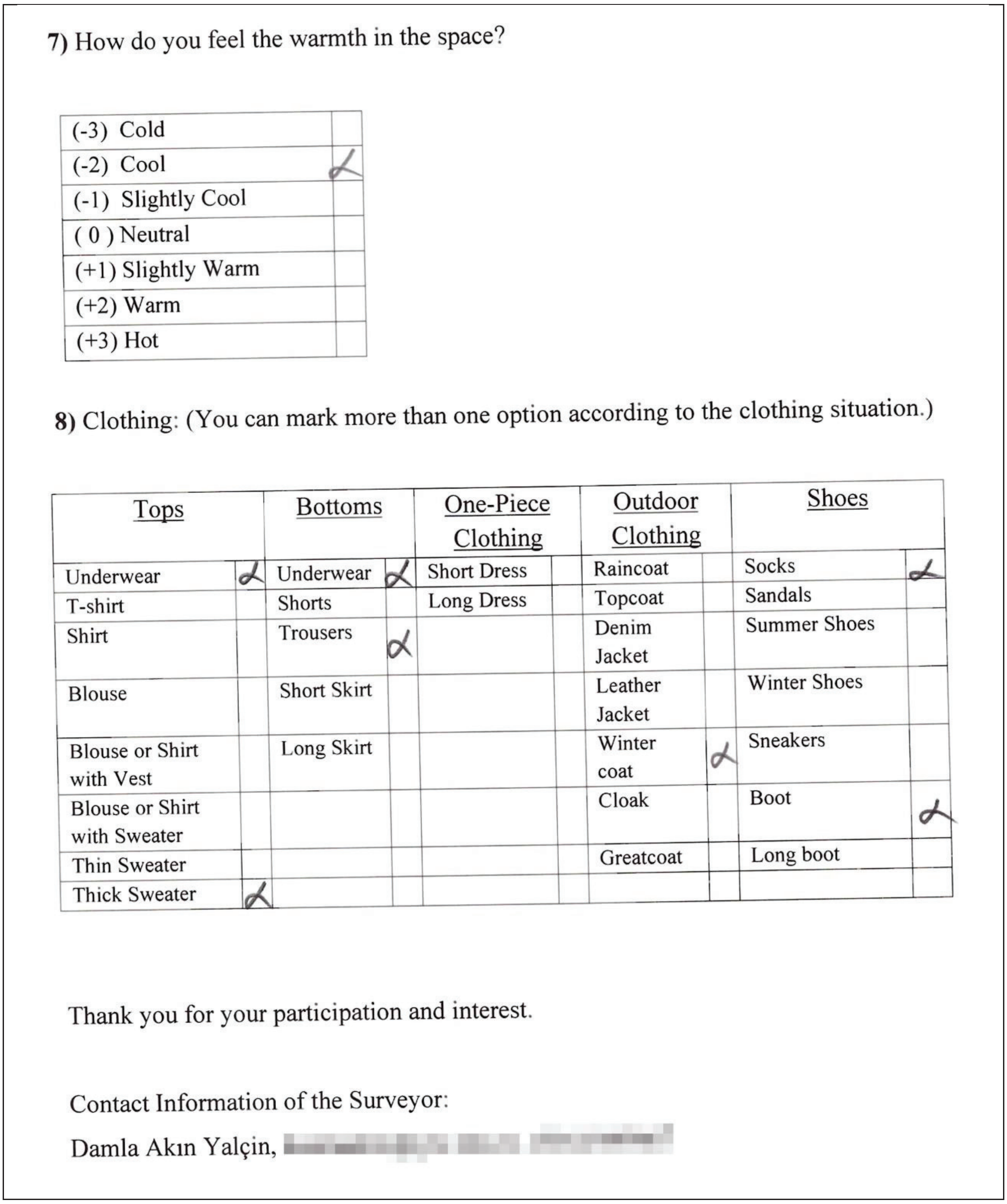
5) Gender / Age: Female / 63

6) How would you describe your activity level?

Sitting	✓
Standing, relaxed	
Standing, in motion	

Figure D.5. Survey study sample in the conversation event on 14 February 2020 at the Agios Voukolos Church

(cont. on next page)



7) How do you feel the warmth in the space?

(-3) Cold	
(-2) Cool	✓
(-1) Slightly Cool	
(0) Neutral	
(+1) Slightly Warm	
(+2) Warm	
(+3) Hot	

8) Clothing: (You can mark more than one option according to the clothing situation.)

Tops		Bottoms		One-Piece Clothing		Outdoor Clothing		Shoes	
Underwear	✓	Underwear	✓	Short Dress		Raincoat		Socks	✓
T-shirt		Shorts		Long Dress		Topcoat		Sandals	
Shirt		Trousers	✓			Denim Jacket		Summer Shoes	
Blouse		Short Skirt				Leather Jacket		Winter Shoes	
Blouse or Shirt with Vest		Long Skirt				Winter coat	✓	Sneakers	
Blouse or Shirt with Sweater						Cloak		Boot	✓
Thin Sweater						Greatcoat		Long boot	
Thick Sweater	✓								

Thank you for your participation and interest.

Contact Information of the Surveyor:

Damla Akın Yalçin, [redacted]

Figure D.5 (cont.)