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Research Paper

Determining Appropriate Thermal Comfort Period based on PET and PMV using the RayMan Model: A Case Study in the Subtropical City of Sari

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Abstract
Given the different climate conditions worldwide, the need for climate zone-based architectural designs is evident. This need is more felt, particularly in critical thermal conditions, and is the most important challenge for an architect. One of the main sub-climates that require a special design is the humid subtropical climate in which winters are cold and rainy, and usually, the ambient temperature is lower than the comfort zone, with hot and humid summers that demand a temperature drop to achieve a comfort zone. The most fundamental problem is thus to provide cooling and heating systems in such environments. Accordingly, the present work aims at providing critical climate conditions with potential solutions. Here, Sari, with a humid subtropical climate, was selected as a case study, and its thermal conditions were investigated utilizing Physiological Equivalent Temperature (PET) and Predicted Mean Vote (PMV) indices, and the Rayman model. The results of our first study question revealed that the percentage of days with thermal comfort was 16.9%. Also, 16.3% and 17% of the days had slight and mild cold stress, respectively. Subsequently, the results from data analysis indicated that the ventilation and dehumidification cooling systems can be considered the most appropriate passive methods. In addition, the elements of the indigenous architecture including Iwan, Talaar, upstairs house, and sloping roof, which all are rooted in the vernacular architecture of the city of Sari can be introduced as the most effective architectural solutions. Our findings are of great importance for architects and designers because such findings will guide the design of complex site conditions and even the building construction by considering the thermal comfort factor.

Keywords: *Thermal comfort, PET, PMV, the RayMan Model, Subtropical.*

1. INTRODUCTION

Thermal comfort refers to a state of mind reflecting pleasure in the thermal environment (Liaison et al., 2004), almost a set of thermally conditions are acceptable for at least 80% of people. In a very unusual way, people no longer experience cold or warmth on a number of occasions, the conditions under which the human body can preserve its thermal equilibrium correctly without facing power superfluity or electricity shortage (Streinu-cercel et al., 2008). However, preceding researchers have not considered thermal comfort indices in environmental conditions, affecting the acceptance or rejection of microclimate conditions significantly. However, significant thermal comfort factors are seasonal, metabolic rates, body posture changes, and adaptation to native conditions (van Hoof & Hensen, 2007).

The basic factors affecting thermal comfort are relative humidity, airspeed, mean radiant temperature, air temperature, clothing insulation, and metabolic rate. The psychological parameters also affect thermal comfort, such as individual expectations (Liaison et al., 2004). However, the configuration of human comfort conditions is greatly affected by four factors, including wind, radiation, humidity, and temperature (C R de Freitas & Grigorieva, 2017), of which temperature and humidity make a greater contribution

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to human health comfort, two elements based on which many models and factors measuring human well-being work (Asghari et al., 2017).

Human thermal comfort is the result of body surface-environment energy balance affecting people's physiology, psychology, and behavior. In comparison, thermal comfort models utilize compound metabolic mechanisms, such as clothing insulation and level of physical activity (Jendritzky et al., 2012). These elements present climate data to reflect people's reactions to climatic conditions, in a numerical category ranging from very unsuitable to very suitable (Chris R de Freitas, 2003). By these indices, the analysis of compound effects of atmospheric indices can be facilitated on human comfort, and different locations can be compared from a climatic comfort perspective (Błażejczyk, 2011; Ghalhari et al., 2019; Nassiri et al., 2018).

Temperature and relative humidity are very limited due to ignorance of temperature. Physiological relationships cannot come into conflict with the researchers' vital needs. It is worth mentioning that their outcomes are not comparable regularly, and researchers describe temperature margins but do not adequately reflect the outdoor environmental impacts on people (Nassiri et al., 2018). In the global tendency towards unrestricted urbanization, thermal comfort has become an increasingly critical issue. Many studies have also been carried out to provide an ideal thermal comfort calendar in subtropical cities, focusing primarily on temperate and cold climates (Eliasson et al., 2007; Nikolopoulou et al., 2001; Nikolopoulou & Lykoudis, 2006, 2007; Salata et al., 2016; Taleghani et al., 2015; Thorsson et al., 2004, 2007; Toudert, 2005; Zacharias et al., 2001).

One of the types of methods used to provide thermal comfort to the building is the use of passive systems. The use of passive systems has a long history and these systems have always been used in the design of buildings. In recent years, the spread of fuel supply problems and environmental pollution has doubled the importance of these systems. In order to use passive systems for cooling and heating the building, the formation of elements in the architectural body of the building is necessary. The elements of passive systems are in relation to the initial and main design decisions by the architect completely and then affect the second stage of designing and organizing the form and structure of the building (Lechner, 2014).

RQ1. *What is the effect of PMV, PET, and climate conditions on the determination of an appropriate thermal comfort calendar in Sari?*

Moreover, some gaps have been pointed out in the research on the determination of an appropriate thermal comfort calendar in Sari. On the other hand, it emerges that little work has been lead to establish suitable climate conditions concerning humidity and temperature in Iran. In order to overcome this problem, the present study tried to determine the suitable calendar of thermal comfort for the subtropical climate in Sari, Iran, using the available data.

RQ2*.What are the recommended strategies for utilizing climatic passive design systems in Sari?*

Since on some days of the year according to PMV and PPD factors and climatic data, the weather is such that passive climatic design systems can be used, the question arises what kind of passive systems are suitable for the climate of Sari.

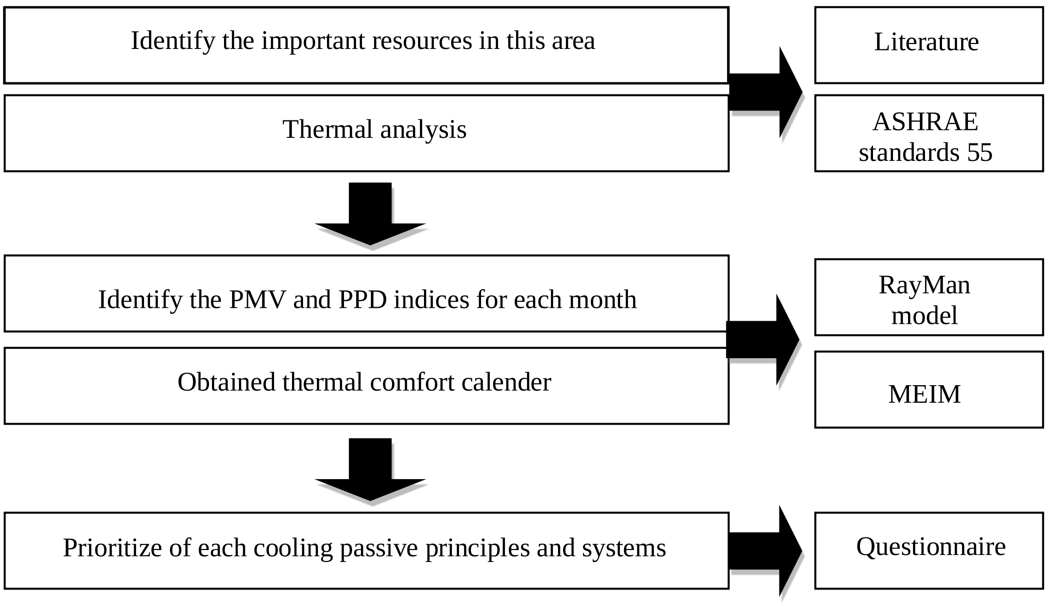


Fig 1. Research Methodology Flowchart

1.1. Review of the Literature

Numerous studies have been conducted on the warm and dry (Ahmed, 2003; Ali-Toudert & Mayer, 2006, 2007; Johansson, 2006; Yahia & Johansson, 2013) and the tropical climate (Emmanuel et al., 2007; Emmanuel & Johansson, 2006; Ignatius et al., 2015; Villadiego & Velay-Dabat, 2014; Yang et al., 2013). In 2005, Yan investigated human thermal comfort in China during 1960-1998 (Yan, 2005). In 2008, Lin and Matzarakis evaluated the thermal comfort in Sun Moon Lake in Taiwan (Lin & Matzarakis, 2008). In another work, Lin and Matzarakis studied a few climatic elements in the tropical and temperate regions in Taiwan and Eastern China, their relationships with tourism thermal comfort, and provided an ideal length for tourism in those cities (Lin & Matzarakis, 2011). In 2017, in order to determine the quality time to visit historical areas, the thermal comfort of numerous historical regions in Isfahan, Iran, was evaluated throughout the day (Nasrollahi et al., 2017).

According to Potchter et al., (Potchter et al., 2018), few Mediterranean cities have been further researched; in 2021, Labdaoui showed the neutral sensation range for this Mediterranean climate (Algeria) varies between 20°C and 26°C. The scientific method involved combining two software. Envi-met was used to calibrate microclimatic data; in comparison, RayMan was used to calculate PET (Labdaoui et al., 2021). Labdaoui et al., (2021) revealed that 80% of the study respondents in the Csa (Mediterranean) climate was slightly comfortable in a temperature ranging from 28.50°C to 31.50°C (Labdaoui et al., 2021). Also, Bruno et al., (2022), Forcado et al., (2020), Vella et al., (2020), and Bienvenido-Huertas (2019) studied the thermal comfort and perception in the Csa climate (Bienvenido-Huertas et al., 2020; Forcada et al., 2020; Labdaoui et al., 2021; Vella et al., 2020).

It is worth mentioning that the best way to evaluate a thermal environment is using a single climate factor, such as air temperature, relative humidity, or the number of sunshine hours. Heat waves, lack of rain, and even sea surface temperatures were also utilized to evaluate the thermal environments (Adrian et al., 2008). These factors address only some suitable meteorological elements and do not include human body thermal equilibrium or thermal physiology. While these factors can be operational in certain conditions, they have major disadvantages (Matzarakis et al., 1999). By thoroughly applying thermal factors to the human energy equilibrium, important data on thermal comfort measurement can be achieved (Meteorology, 1998). The usual applications are PMV, PET, Standard Effective Temperature (SET), and Perceived Temperature (PT) (Matzarakis, 2006), all of which include significant meteorological and thermophysiological elements (Matzarakis, 2007). The advantage of these thermal factors is that they all need the same meteorological input elements, including wave radiation, wind speed, air humidity, and air temperature (Lin, 2009). Thermal factors are widely utilized in human thermal biometeorology to evaluate the thermal comfort and heat stress of people exposed to the local meteorological conditions.

PET (Staiger et al., 2012), Universal Thermal Climate Index (UTCI)-Fiala mathematical model (Jendritzky et al., 2012), as well as PET (Höppe, 1999), are the most widely utilized thermal factors. All the factors are based on the common four meteorological input elements, wind speed (WS), vapor pressure (VP), and air temperature (Ta). With a comprehensive thermophysiological basis, PET is ideal for studying the thermal elements of different climate conditions (Höppe, 1999).

PET deals with many climatic elements whose temporal and spatial behaviors are affected by the meso-and micro-scale natural and artificial morphology (Matzarakis et al., 2010a; Zaninović & Matzarakis, 2009). Compared to other thermal factors, PET provides the advantage of a widely known unit (ºC) and makes the results easy to understand for regional planners (Matzarakis et al., 2010a). In 1997, in Germany, Matzarakis and Mayer investigated the heat stress of 12 meteorological stations primarily based on the PMV index during 1980-1989 and transformed the PMV value per station into a climatology map (Matzarakis & Mayer, 1997).

Deb and Ramachandraiah (2011) studied thermal comfort at the southern railway terminals in India using the PET index to estimate passenger satisfaction in June and gave suggestions to improve passenger comfort (Deb & Ramachandraiah, 2010). In 2012, the thermal comfort indices of PET and Tourism Climate Index (TCI) were examined in a study on northwest Iran utilizing the data provided by 15 meteorological stations during the intended years (Farajzadeh & Matzarakis, 2012).

In 2019, outdoor thermal comfort conditions and summer PET range were investigated through discipline surveys in a high population density city located in the tropical zone in Dhaka, where considerable microclimatic monitoring was conducted concerning the subjective responses of the pedestrians (Sharmin et al., 2019). By reviewing these studies on different climate conditions, it was found that the majority of them were carried out on a large scale (city, country, or continent) based on the data given by various meteorological stations to evaluate the pertinent indices and eventually to decide the suitable range of thermal comfort for people concerning appropriate days or months in a year.

When the Fanger model-derived Klima Michel version (KMM) was developed in 1979, the energy balance of the human body gained particular attention (Kim et al., 2009). In 1999, Hoppe presented the Munich Energy-Balance Model (MEMI) for people, which calculates sweat as well as controls heat fluxes and the body temperature with and without clothing (Höppe, 1999; Thomson et al., 2008). In the model, pores and skin heat dissipation are thought to correspond to the warmth generated by the blood and the heat conveyed from the center to the skin floor. Some basic consequences can be obtained by this model, based on the human body's electricity stability and the PET and PMV indices (Fallah Ghalhari et al., 2015; Thomson et al., 2008).

In 1999, a commission was founded by the International Society of Biometeorology to develop a UTCI to extract the most advanced thermophysiological model-based thermal index. Since 2005, the Cooperation in Science and Technical Development (CSTD) Action7300 enhanced these attempts by bringing together influential climatologists, meteorologists, and human thermophysiological modeling experts for UTCI development (Asghari et al., 2019).

Bioclimatic studies are today the foundation of several management strategies, in particular treatment and health, from the human comfort perspective. Accordingly, the thermal energy equilibrium has been investigated in three different climates of Iran based on the PET as well as PMV indices in addition to the thermophysiological UTCI, using the meteorological data (i.e., temperature, wind speed, relative humidity, and solar radiation) and environmental variables collected from the meteorological organization. It is worth mentioning that such information can be utilized for upcoming planning, prevention/control plans to preserve people in outdoor environments.

In 2012, the potential thermal perceptions were identified by analyzing thermal comfort conditions in various months of Iran based on the PET index (Daneshvar et al., 2013). In 2016, the PET and PMV indices were analyzed in northeastern Iran to decide the best thermal comfort calendar utilizing the RayMan model (AHMADI et al., 2016). In 2019, in Iran, an analysis was carried out utilizing PET, PMV, and UTCI indices on outdoor environments' thermal discomfort, focusing on two different climate conditions for future planning, prevention/control measures strategies to protect people in outdoor environments (Asghari et al., 2019). These studies offer valuable insights into the effect of climatic conditions on people's thermal sensations that can differ depending on the environment and microclimate of the metropolis where they reside (Eliasson et al., 2007).

One of the types of methods used to provide thermal comfort to the building is the use of passive systems. The use of passive systems has a long history and these systems have always been used in the design of buildings.

1.1.1. Methods of Creating Thermal Comfort

The environmental conditions inside the building must be balanced in such a way that it can provide physical and mental comfort for the residents. Physical comfort refers to providing thermal comfort conditions (heating and cooling) and visual comfort (providing light and lighting) which requires energy consumption. According to the type of energy consumption to provide thermal comfort in the building (Watson, 1983), four general methods can be used according to Table 1.

1.1.2. Types of Passive Systems

A passive heating system is a system which collects and stores the main elements of a building, on the other hand, redistributes solar energy. Passive heating is based on the use of solar thermal energy and passive cooling is based on the use of various heat reducers (Brown & DeKay, 2001). In a general classification, the types of passive solar systems can be classified as follows:

In these studies, the thermal comfort range and suitable solutions have been established for climatic design by determining the climate conditions and PPD and PMV indices. Sari has ahumid subtropical climate. The humid subtropical climate is one of the important sub-climates that need special design, with rainy and cold winters, the ambient temperature lower than the comfort zone, hot and humid summers, and a need for a reduction in temperature to reach a comfort zone. Therefore, in indoor environments, providing the cooling and heating systems is the most critical challenge.

According to the literature, it emerges that little work has been lead to establish suitable climate conditions concerning humidity and temperature in Iran. In order to overcome this problem, in accordance with some studies (e.g. Ahmadi et al., 2016; Asghari et al., 2019; Daneshvar et al., 2013; Heidari & Ghafari, 2011; Höppe, 1999), the present study tried to determine a suitable calendar of thermal comfort for the subtropical climate in Sari, Iran, using the available data.

2. MATERIALS AND METHODS

Case study

Sari, located in northern Iran, between the northern slopes of the Alborz Mountains and the southern coast of the Caspian Sea, is the provincial capital of Mazandaran and the previous capital of Iran (Liaison et al., 2004). As mentioned before, Sari has a humid subtropical climate, with a Mediterranean climate (Csa) impact, and cool and wet winters yet hot and humid summers (Streinu-cercel et al., 2008). Statistical climate data of Sari compared to other cities located in Mazandaran, represents the average climate of Sari, with relatively sunnier and extra rainy springs. However, the current rainfall rate has declined in Sari. Figure 1 presents the studied city.

Table 1. Methods of Creating Thermal Comfort Conditions (Vakilinezhad et al., 2013)

The role of the architect	Sample	Required energy sources		Method of creating thermal comfort conditions
		Energy transfer	Energy supply	
Equipment layout and passage of system components	Radiator, fan coil and water cooler	Nonrenewable energy		Extra active
The role of the architect in the coordinated location of the system and its incorporation into the body of the building	Solar hot water collectors, photovoltaic systems	Renewable energy has a small share	Most of the source is nonrenewable energy	Active
The important role of the architect in the coordinated design of the system and the architectural elements of the building	Trumpet wall, water-roof, greenhouse space	Nonenewable energy has a small share	Most of the source is renewable energy	Passive
The special role of architect decisions in architectural features and solutions	Orientation, Proportions, Form, Size of windows, Shading	Renewable energy		Extra passive

Table 2. Types of Passive Systems (Brown & DeKay, 2001)

Cooling heating	Passive heating
Ventilation cooling (ventilation with wind force and the effect of chimney and night ventilation and double-walled roof)	Direct absorption
Evaporative cooling (direct and indirect evaporation)	Thermal storage wall (thrombus wall and water-wall)
Radiation cooling (direct and indirect)	Solar space (greenhouse, atrium)
Mass cooling (direct and indirect connection)	Air movement cycle (double wall system)
Cooling through dehumidification	

Table 3. Climatic Data of Sari (Liaison et al., 2004)

Founded	Position of station	Type of station	Altitude	Latitude	Longitude
1952	Dasht-e-Naz	Synoptic	106 (m)	53:06 E	36:56 N

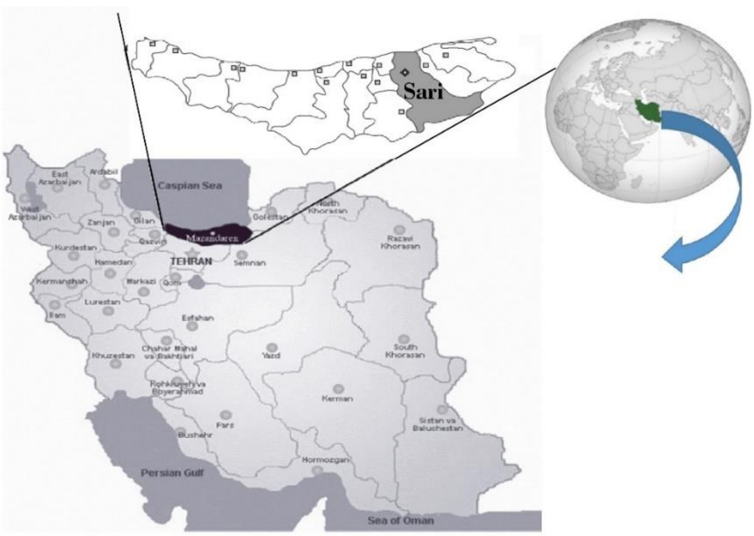


Fig 1. Position of the Studied City

Model specifications

In the present paper, a living room of a residential building is considered. It is assumed that the room is located on one of the middle floors of the building so that all of its envelopes including walls, ceiling, and floor are internal ones without heat transfer except the wall with a window which is external. The room has length, width, and height of 7, 5, and 3 m, respectively, which are typical dimensions of living rooms in residential buildings in Iran. In addition, the U values of the envelope elements are according to the Iranian National Building Regulations as summarized in Table 4 (Naderi et al., 2020).

Sample Size

The sample size in this study consists of 15 professional experts who have been trained in the field of architecture and climatology. As this study focuses on Sari, experts who are involved in Sari projects are included nine males and six females. Background information of respondent experts is below in Table 5.

Instrumentation

Climate Data

This paper evaluated the PET and PMV indices utilizing 30 years of long-term average climate parameters (2010-2020) of the Sari synoptic station, including air temperature (Ta), mean daily minimum temperature, mean daily maximum temperature, dry air temperature (ºC), vapor pressure (hPa), relative humidity (%), wind speed(m/s), and cloud cover (okta).

Thermal Comfort Indices

Table 6 presents the numerical thresholds for classifying thermal comfort indices along with a descriptive state of physiological conditions and thermal sensitivity. The data needed to estimate the PET index could be explained in four types of variables:

1. The first category consists of situational variables, including latitude, longitude, and altitude;
2. The second category consists of climatic variables, including wind, cloud cover, relative humidity, vapor pressure, and dry air temperature;
3. The third category consists of powerful physiological characteristics, including weight, height, gender, and age;

The final category consists of the variables relevant to the type of coverage and activity (Asghari et al., 2019; Roshan et al., 2010)

Table 4. Building Material Specifications (Naderi et al., 2020)

Elements	Properties	Unit	Value
Interior wall	Total heat transfer coefficient (U)	W/m2K	٢,٥٨
Exterior wall	Total heat transfer coefficient (U)	W/m2K	٠,٧
Floor/ceiling	Total heat transfer coefficient (U)	W/m2K	١,٤٥
Double-glazed windows	Total heat transfer coefficient (U)	W/m2K	٢,٦٧

Table 5. Background Information of Respondent Experts

Category	Classification	Number
Working background	Member of architecture faculty	7
	Architects	5
	Climatologist	3
Educational level	Master	4
	Ph.D	11
Sex	Male	9
	Female	6
Work experience	Less than 10 years	3
	Between 10 and 15 years	8
	More than 15 years	4

MEMI

The PMV model includes physical and physiological temperature aspects formed based on all meteorological parameters. This model is based on the sensible heat loss from the skin equal to the blood-generated heat and heat transferred from the center to the skin surface. PET is one of the Munich Energy-Balance Model for Individuals (MEMI) outputs, one of the best available indicators used to evaluate thermal comfort conditions (Höppe, 1999; Thomson et al., 2008). This model's complexity has also provided a tool for reliable estimation and fast access to results by experts and researchers. One of the most suitable models for estimating and evaluating the results from the MEMI model is the RayMan model (Pecelj et al., 2021).

The RayMan Model

The RayMan model was developed according to Guideline 3787 of the German Engineering Society, which estimates the radiation flux considering different parameters in a simple and complicated environment (Matzarakis et al., 2010b). The model also estimates the effects of clouds and solid boundaries on fluxes of short-wave radiation. This model's final output is the mean radiant temperature needed in the human strength equilibrium. Consequently, it is also required to assess bioclimatic comfort and thermal indices, including PMV, and PET (Pecelj et al., 2021).

Questionnaire

As mentioned earlier, the basic data are gathered from the available and accessible references. However, to find out the response to the research questions, two questionnaires were designed for the purpose of extracting the knowledge of the experts to prioritize passive climatic design systems.

Various information collecting tools were used in this research. Questionnaires were one of the most useful tools and were used besides the other ones including the existing literature. General information of the respondents constituting working background, educational level, and sex are illustrated in section 3.3. The 5-point Likert scale was exploited in questionnaires which is presented as 1 = Very Undesirable; 2 = Undesirable; 3 = neither Undesirable nor desirable; 4 = Desirable; 5 = Very desirable. The reliability of the designed questionnaires was assessed by calculating Cronbach's alpha in SPSS software. If the amount of Cronbach's alpha is greater than 0.7, the reliability of the questionnaires is proved (Gliem & Gliem, 2003). The amount of Cronbach's alpha is illustrated in Table 7.

Table 6. The Numerical Thresholds for the Thermal Indices alongside Physiological Conditions and Thermal Sensations (Asghari et al., 2019)

Thermal sensation	Indices range	
	PMV	PET
Extremely cold[1] (Extremely severe cold stress[1,2])	-3	<4
(Severe cold stress[2])		
Cold[1] (Moderate cold stress[1,2])	-2.5	4-8
Cool[1] (Mild cold stress[1,2])	-1.5	8-13
Slightly cool[1] (slight cold stress[1,2])	-0.5	13-18
Comfortable[1] (no thermal stress[1,2])	0	18-23
Slightly warm[1] (slight heat stress[1])	0.5	23-29
Warm[1] (Mild heat stress[1,2])	1.5	29-35
Hot[1] (Moderate heat stress[1,2])	2.5	35-41
(Severe heat stress[2])		
Extremely hot[1] (extremely severe heat stress[1,2])	3	>41

[1]PET and PMV

Table 7. Cronbach's alpha values for the designed questionnaires

Questionnaire	Aim of the questionnaire	Cronbach's alpha
Questionnaire 1	Obtaining non-architectural solutions	0.728
Questionnaire 2	Obtaining architectural solutions	0.896

DATA COLLECTION AND ANALYSIS

In the present study, thermal analysis has been performed based on the Iran Meteorological Organization data utilizing ASHRAE Standard 55 and the RayMan model for 30 years (1990-2020) considering the PMV and PET indices affecting thermal comfort. As input data in RayMan software, we considered 5 categories of data, including date and time, geographic data, current data, personal data, and clothing and activity. In the Date and time classification, we entered the desired date, time and also the local time of Sari.

Then, in the geographic data section, the latitude, longitude, and altitude of this city were given to the software. In the personal data section, data related to a person's weight, height, sex, and age were considered by default. The current data include air temperature, vapor pressure, wind velocity, and relative humidity which were entered into the software through meteorological data of Sari during 30 years (1990-2020).

Subsequently, in the clothing and activity category, the coverage rate is 0.9 Clo, the activity is 80 W, and the Position is standing was supposed 0.9 Clo, 80 W, and standing, respectively. The input data in RayMan software is given in Table 8. This analysis helps us decide which days of the year we can reach thermal comfort conditions with a proper climatic design and use mechanical systems with climate-friendly design.

3. RESULTS

As stated previously, the present study aimed to determine the suitable thermal comfort calendar based on the PMV and PET indices for Sari and provide a strategy for utilizing mechanical cooling and heating systems in different months of the year.

The results related to our first research question were summarized in Table 9. As can be seen in the table, the mean environmental variables affecting thermal comfort in different months of the year are mainly based on 10-year data within the study climate. Throughout the surveyed years, the highest mean temperature (26.2) was recorded in August, and the lowest mean temperature (7.6) was recorded in January and February. On the other hand, the lowest values of daily minimum and maximum temperatures are 3.3 and 11.9, respectively. The highest value of daily minimum temperature is 21 in August, and the highest value of daily maximum temperature is 31.2 in July and August.

In addition, the highest relative humidity rate (76) was recorded in February, March, November, and December, and the lowest relative humidity rate (66) was recorded in June and July. As given in Table 9, the highest wind speed (4.1) was recorded in March, and the lowest wind speed (2.2) was recorded in October. According to the table, the highest cloud cover (5.8) was recorded in April, and the lowest cloud cover (2.2) was recorded in June.

Table 10 presents thermal comfort indices within the surveyed climate. In Sari, as a representative of the subtropical climate, the mean UTCI for study years was 15.7, and the maximum index was recorded in August (27.5). The minimum index was recorded in January (3.9). Based on the UTCI index, perceived thermal sensations of individuals begin from extremely severe cold stress (<-40; dark blue), severe cold stress (-40 to -27; muddy blue), moderate cold stress (-27 to -13; sky blue), mild cold stress (-13 to 0; lead grey), slight cold stress (0 to +9; bright grey), no heat stress (+9 to +26; white), mild heat stress (+26 to +32; lemon), moderate heat stress (+32 to +38; lemon), moderate heat stress (+32 to +38; yellow), severe heat stress (+32 to +46; brown), to extremely severe heat stress (>+46; red), as given in Table 6.

As can be seen in Table 10, considering the UTCI index for Sari, the cold stress is slight in January, February, March, and December. April, June, and November have no heat stress. Heat stress in September and October is slight, and July and August have mild heat stress.

The average PET index in Sari for study years changed to 18.9. According to Table 10, the maximum value of the index was recorded in August (32.6), and the minimal value of the index was recorded in January (5.3). The PET index provided a different temperature threshold with the equal meaning of thermal sensations or the alert physiological stress. The thermal sensation can range from extremely cold (<4; dark blue), cold (4 to 8; sky blue), cool (8 to 13; lead grey), slightly cool (13 to 18; bright grey), comfortable (18 to 23; white), slightly warm (23 to 29; cream), warm (29 to 35; lemon), hot (35 to 41; yellow), to extremely hot (>41; pink) (Table 6).

Based on the PET index for Sari, the cold stress is moderate in January and February. March, December, April, and November have mild cold stress, May and October have no heat stress, June has slight heat stress, and ultimately, July, August, and September have mild heat stress.

The PMV index for the study years was -0.6. The maximum value of the index was recorded in August (2.1). As shown in Table 10, the minimum value of the index was recorded in January (-3.4). As given in Table 6, the thermal sensation varies from extremely cold (-3), cold (-2.5), cool (-1.5), barely cool (-0.5), comfortable (0), barely warm (0.5), warm (1.5), extremely warm (2.5), to hot (3). The order of colors is almost the same as for the PET index.

Utilizing the PMV index, it was found that January and February have extremely severe cold stress, March has severe cold stress, December has moderate cold stress, April and November have mild cold stress, May and October have no thermal stress, June and September have slight heat stress, and July and August have mild heat stress.

Figure 2 represents the thermal changes of the indices examined in some areas in the study years. The results of UTCI indicated that 16.9% of days have mild heat stress. The percentage of the days with slight heat stress was 16.8%. On the other hand, 33.1% of the days have no heat stress, and 33.4% have slight cold stress. Based on the PET index and results, 25.2% and 8.2% of the days exhibited mild and moderate heat stresses, respectively.

The percentage of days with thermal comfort was 16.9%. However, 16.3% and 17% of the days had mild and moderate cold stresses, respectively. It was also revealed that 16.4%, 16.7%, 8.5%, and 8.1% of the days had severe, moderate, mild, and slight cold stress, respectively. The percentage of days with no thermal stress was 17%. On the other hand, 8.2% and 25.2% of days had slight and mild heat stresses, respectively.

Table 8. The Input Data in RayMan Software

Date and time			Geographic data			Current data				Personal data				Clothing and activity		
Date	Day of year	Local time	Longtitude	Latitude	Altitude	Air temperature	Vapour pressure	Wind velocity	Relative humidity	Weight	Height	Sex	Age	Clothing	Activity	Position

Table 9. The Mean Deviation of Environmental Variables Affecting Thermal Comfort in Different Months of the Year according to a 30-Year Period

Month	Air temperature (˚C)	Mean daily minimum temperature (˚C)	Mean daily maximum temperature (˚C)	Relative humidity (%)	Wind speed (ms^{-1})	Cloud cover (okta)
Jan	7.6±4.3	3.3	11.9	77±2.1	3.5±0.18	3.8±0.38
Feb	7.6±4.3	3.4	11.9	76±2.2	3.1±0.23	4.7±0.37
Mar	9.5±4.5	5.0	14.0	76±1.6	4.1±0.21	4.1±0.39
Apr	15.1±5.7	9.4	20.9	72±1.8	2.8±0.26	5.8±0.22
May	19.5±5.7	13.8	25.2	69±1.8	3±0.15	3.8±0.18
Jun	23.2±5.7	17.8	29.2	66±2.5	2.8±0.12	2.2±0.52
Jul	25.9±5.2	20.7	31.2	66±1.6	2.5±0.8	5.2±0.41
Aug	26.2±5	21.2	31.2	70±2.3	2.6±0.32	3.8±0.68
Sep	23.5±5	18.6	28.5	73±2.1	2.8±0.24	5.6±0.42
Oct	18.9±5.1	13.8	24.1	75±1.5	2.2±0.39	3.6±0.13
Nov	14.1±4.8	9.3	19.0	76±3.2	2.5±0.46	3.7±0.54
Dec	9.8±4.6	5.2	14.4	76±1.6	2.4±0.8	3.2±0.32

Table 10. The Mean Deviation of Thermal Comfort Indices in Sari

Month	PMV	PET (˚C)	UTCI (˚C)
Jan	-3.4±0.6	5.3±1.9	3.9±1.3
Feb	-3.2±0.6	6.5±1.9	5.7±1.4
Mar	-2.8±0.8	8.6±2.5	8±2.2
Apr	-0.9±0.9	16.9±3.2	16.4±2.4
May	0.2±1.2	22±6.1	20.5±3.8
Jun	1.3±1.3	28.7±6.2	24.9±4.1
Jul	1.9±1.0	32.1±3.9	27.2±2.5
Aug	2.1±0.9	32.6±3.9	27.5±2.7
Sep	1.2±0.8	27.3±3.6	23.8±2.4
Oct	0±0.8	21.1±3.0	19.7±3.4
Nov	-1.5±0.7	13.9±2.0	13.6±1.1
Dec	-2.5±0.3	9.3±0.7	8.7±0.2

Figure 3 represents the scatterplots and regression lines for the correlation between study indices in the study climates. There are very intense correlations between the indices applied for the subtropical city of Sari.

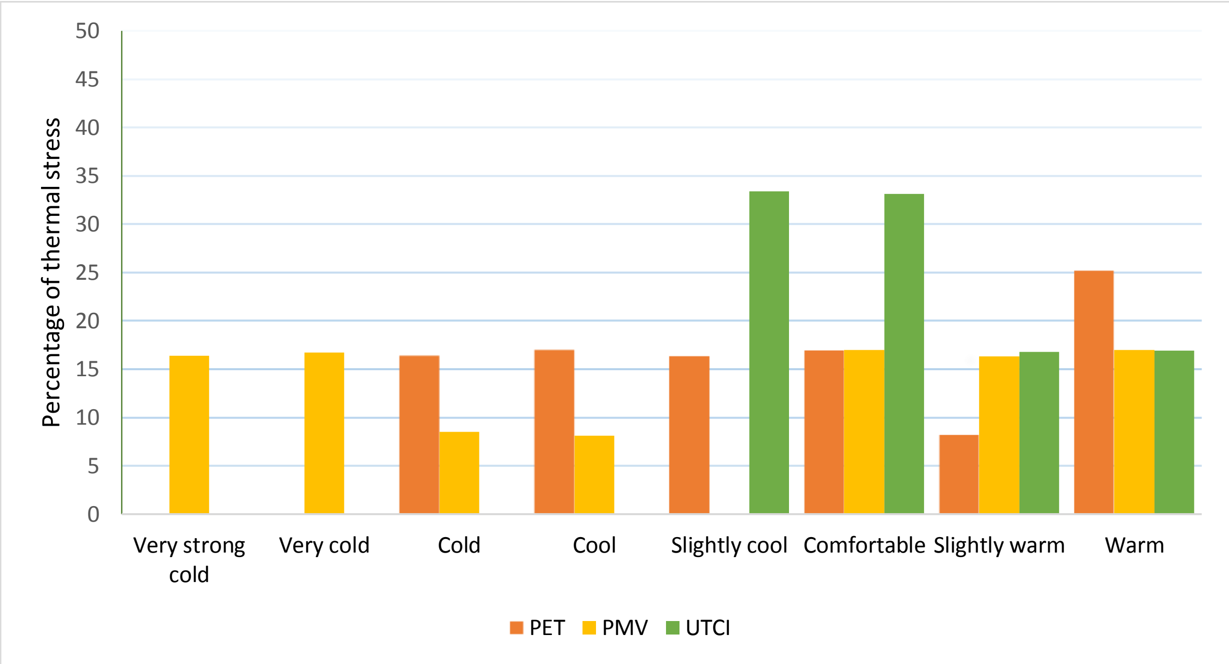


Fig 2. Percent Thermal Stress according to Study Indices during the Study Years

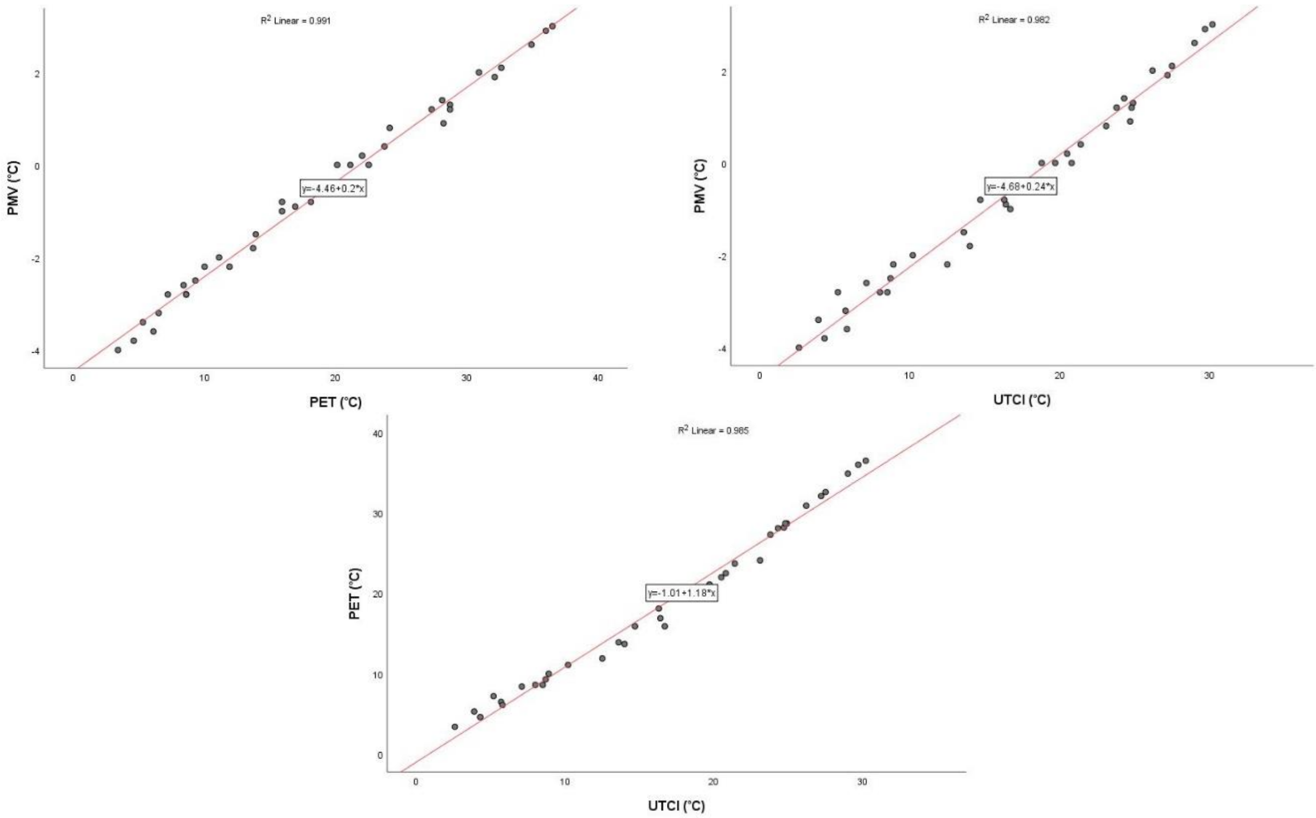


Fig 3. Correlation between Study Indices: Subtropical Climate (Sari)

Our second research question is discussed in the rest of this section. As given in Table 11, we are under the comfort threshold based on the minimum temperatures in January, February, March, April, November, and December. Therefore, it is essential to use active equipment. In this range, we are in the comfort zone in May and October, and from June to September, we can reach the comfort zone with passive climatic design.

As shown in Table 11, active mechanical cooling and heating equipment and passive climatic design are required based on the mean temperatures in January, February, and March. We are in the comfort zone from October to June and from September to December. As can be seen in the table, passive equipment is only required in July and August.

It is worth mentioning that in Sari, the temperature is below the comfort zone based on the maximum temperatures (April, November, January, April, November, and December), indicating the need for active mechanical cooling and heating equipment. According to the table, the passive climatic design is only needed from May to November.

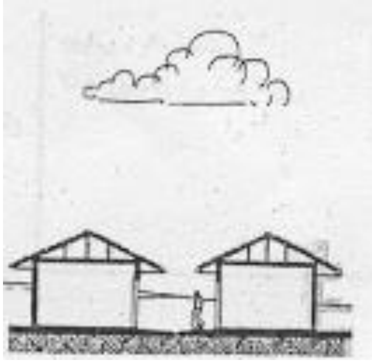
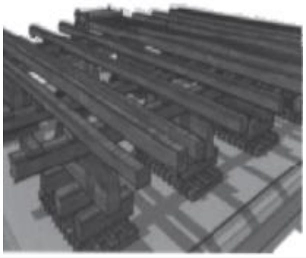
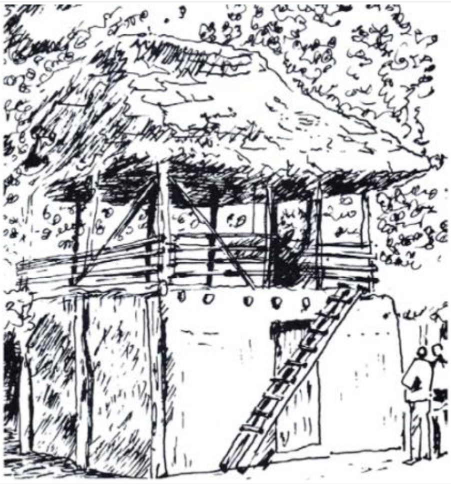
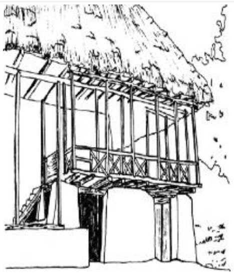
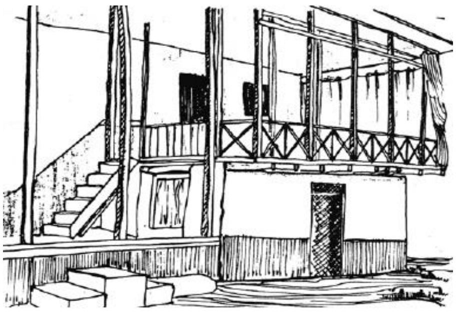
The results related to our second research question were summarized in Tables 12 and 13. In the below table, the architectural elements that have been used to create passive cooling in traditional and contemporary buildings in Sari and the cooling principles of each corresponding passive system have been prepared. As mentioned, some of these traditional elements, in terms of function and architectural form, correspond to some of today's static systems. It is important to note that in this climate, the choice of the passive cooling system and its corresponding architectural element, according to the total climatic conditions and the priority of factors to create comfort (cooling, ventilation, shading, etc.) has been done.

Table 11. The Months that Need only Passive Climatic Design

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Temperature				*	*	*			*	*	*	*
Min. temperature				*	*					*		
Max. temperature				*							*	

Table 12. Principles of Passive Cooling Systems in Traditional Architectural Elements of Sari

No.	Architectural element	description	Principles of passive cooling design	sample-schematic view
1	Iwan (Porch)	The purpose of constructing Iwans is to create a quaint atmosphere that according to different depths and heights can be alternately used for cooling and heating. It uses in hot and cold seasons or only for cooling in all seasons.	Ventilation Airflow view Ventilation cooling (cross ventilation and Chimney ventilation) Evaporative cooling (Direct and indirect) In combination with adjacent water bodies -shading	 
2	Ambulatory	Spaces with two rows of columns in front of the talaars are called round slaves. Also, to protect the wall of a “ambulatory", the roof is extended to the front of the ambulatory, which extends like an Iwan throughout the building.	Protecting the walls from rain and direct summer sunlight. Creating a suitable and shady space. Creating airflow and summer breeze around the building. Ventilation cooling (cross ventilation) Shading	 

No.	Architectural element	description	Principles of passive cooling design	sample-schematic view
3	Sloping roof	Due to the constant rain, the roofs in this area are steep. This prevents rainwater or snow from accumulating on the roof of the building.	A suitable place for storing food and agricultural products. Possibility of air supply and flow. Ventilation cooling (cross ventilation and Chimney ventilation) Shading	
4	sleeper wall	To prevent moisture from penetrating the floor of the building, the building should be raised from the ground to establish airflow between the floor and the ground surface.	Creating airflow Prevent moisture penetration Ventilation cooling (cross ventilation)	
5	Cotam	A kind of Iwan and summer building that was used as a sleeping spring. It is also called a shaded roof, a four-sided independent Iwan built on four tall pedestals. This space is considered as open spaces.	The construction of a semi-open space that is open on all four sides and away from the ground can be effective in achieving climatic comfort by creating a gentle breeze and draft from different directions. Ventilation cooling (cross ventilation) Shading	
6	Talaar (Hall)	The second or third floor Iwan is called Talaar. The Talaar is a few steps higher than the Iwan and usually, a barn is located below it. And in some examples, it is empty below it.	To Prevent moisture penetration draft Ventilation cooling (cross ventilation) Evaporative cooling (Direct and indirect) Shading	 
7	upstairs house	The room which is located the in front of the hall (Telar) is called the "upstairs house" and is often reserved for guests.	In this climate, ventilation and airflow play an essential role in the formation of architecture, so the "upper house" as the space in front of which the Talaar is located, is the best room in terms of ventilation, airflow, view, and landscape.	

Factors affecting the formation of passive climatic design in two indicators of natural environment (climatic factors) and climate-friendly architecture are classified below (Table 13). Based on the findings of the questionnaire, the components of cooling through dehumidification and cooling through ventilation were the most desirable (non-architectural solutions). Moreover, among the component of passive architecture, 5 items (building orientation and form, Iwan and yard, number of windows and their shape and size, and room height and openings (doors)) had the highest frequency 17, 15, 14, 13, and 10, respectively.

As mentioned above, the components of cooling through dehumidification and cooling through ventilation were the most desirable among the other components. It can be seen in Figures 4 and 5 that the thermal comfort zone in Sari was developed by dehumidification and cooling through ventilation.

Table 13. Descriptive Status of Natural Environmental Factors and Architectural Factors Affecting the Formation of Passive Climatic Design

No.	category	Importance	Item	Component	Indicator
1		38%	Ventilation and its types	Cooling through ventilation	
2		11%	Direct and indirect	Evaporative cooling	
3	Non-architectural solutions	12%	Direct and indirect	Radiant cooling	Natural environment (climatic factors)
4		9%	Ground connection type (direct, indirect)	Cooling through the effect of mass	
5		30%	Creating darft	Cooling through dehumidification	
1		15%	Building form		
2		20%	Building orientation		
3		13%	Number of windows and its shape and size		
4		5%	Size and material of the building wall		
5		7%	Roof shape and material		
6	Architectural solutions	14%	Iwan and yard	Passive architecture	Climate-friendly architecture
7		10%	Room height and openings (doors)		
8		6%	The density of buildings		
9		3%	Number of floors		
		3%	Shape, size and height of rooms		
10		4%	Foundation		

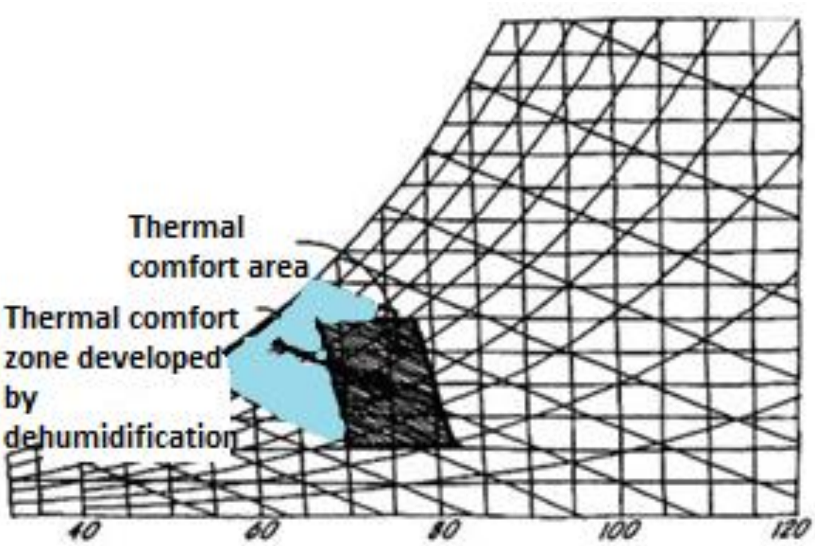


Fig 4. The Effect of Dehumidification on Increasing the Thermal Comfort Range in Sari (Moore & series, 1993)

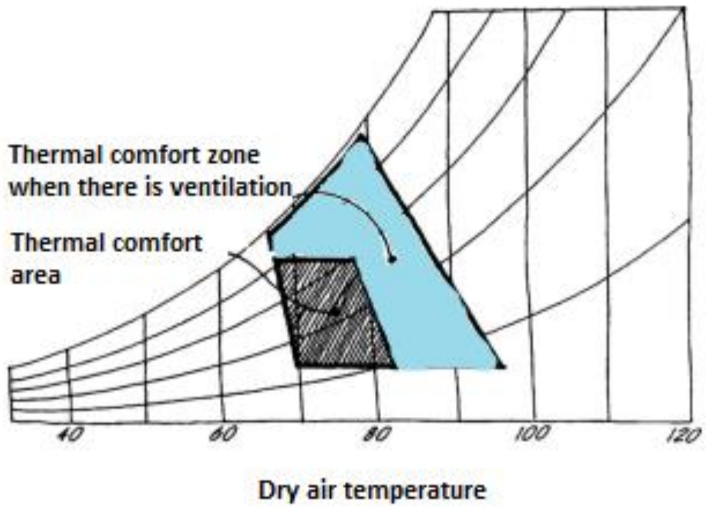


Fig 5. Ventilation Factor in the Thermal Comfort Range in Sari (Moore & series, 1993)

4. DISCUSSION

In order to be able to plan effectively in different climate conditions, our understanding of climate comfort effects on different human functions must be enhanced (Asghari et al., 2019). Once again, it is worth mentioning that the present work had two objectives; first, to determine the suitable thermal comfort calendar based on the PMV and PET indices, and second, to provide a strategy for utilizing passive climatic design along with mechanical cooling and heating systems in different months of the year in Sari.

In the present study, utilizing the databases of the meteorological organization to evaluate thermal comfort in different months of the year, the PET and PMV indices and the UTCI-Fiala mathematical model were evaluated in Sari having a subtropical climate. Considering the different climate conditions in Iran, the need for architectural design in accordance with climate zones is evident, especially in critical thermal conditions. This need is of great importance and turns into the most crucial challenge for architects (Heidari & Ghafari, 2011).

The study results confirmed that the maximum and minimum temperatures in the study climate are in January and August throughout the surveyed years, respectively. Therefore, by using the principles of passive cooling systems in the elements of the traditional architecture of Sari and, in addition, by using the results of the experts' questionnaire, ventilation cooling and dehumidification cooling are among the passive systems that are desirable for this climate and solutions such as using Iwan, Talaar, upstairs house, and sloping roof, which are derived from the principles of the traditional architecture of Sari, are useful. In addition, according to the questionnaire building orientation, the number and size of windows and the height of the building and rooms are the main principles of passive architectural design in this climate. In these months, using the mechanical cooling and heating systems besides the passive climatic design is needed. This was consistent with the results reported by Heidari and Ghafari (2011), who proposed a thermal comfort calendar for utilizing mechanical cooling and heating equipment and passive climatic design in Tabriz.

This was consistent with the findings of the study by Zare et al., who compared the UTCI-Fiala mathematical model and other heat indices (SET, PET, PMV, PPD, and WBGT) during the year in the Kerman climate, and found that the most severe stressful conditions occur in June. All indices' values increased from January to June, and then, a descending trend was observed over the other months of the year for all indices.

Based on the UTCI-Fiala mathematical model, there was mild cold to moderate heat stresses on a few days of the year in Sari. The days had extremely severe cold stress to slight heat stress depending on the PET index, and extremely severe cold stress to slight heat stress conditions occurred in accordance with the PMV index throughout the year. This differs from the results reported by Asghari et al. (2019), who evaluated thermal comfort based on the UTCI-Fiala mathematical model in specific months of the year in three different climates of Iran: semi-dry, hot, and dry climates.

The findings revealed a significant correlation between the study indices in a subtropical city of Iran, highlighting the suitability of utilizing these indices to determine thermal comfort in different climates. In previous studies, extremely good correlations were observed between UTCI-Fiala mathematical model, SET (r = 0.97) and the PET index (r = 0.96) [9], besides a considerable correlation between UTCI-Fiala mathematical model and PET index (r = 0.936).

It is worth mentioning that thermal indices have their own advantages and disadvantages, and reliable data cannot be achieved directly utilizing a single index. Alternatively, more accurate and better evaluations can be given by evaluating the indices for a single environment. Consequently, it is better to utilize different indices simultaneously.

According to the findings, cold stress in Sari has a higher priority. Therefore, adequate techniques for using mechanical cooling and heating systems along with the climate passive design must be followed to prevent unpleasant climate effects (Delgarm et al., 2016).

5. CONCLUSION

The present work had two objectives: first, determining the suitable thermal comfort calendar based on the PMV and PET indices, and second, providing a strategy for utilizing passive climatic design and mechanical cooling and heating systems in different months of the year in this city.

The results related to our first research question showed that the percentage of days with thermal comfort was 16.9%. Also, 16.3% and 17% of days had slight and mild cold stress, respectively. Based on the PMV index, the thermal comfort analysis of Sari revealed that 16.4%, 16.7%, 8.5%, and 8.1% of days had severe, extremely severe, slight, and mild cold stress, respectively. The percentage of days with no heat stress was 17%. However, 8.2% and 25.2% of the days had slight and mild heat stress, respectively.

The results related to our second research question showed that active mechanical cooling and heating equipment along with passive climatic design are required based on the mean temperatures in January, February, and March. The thermal comfort calendar is in the comfort zone from October to June and from September to December. Accordingly, in July and August, passive equipment is only required.

As stated before, according to findings, cooling and ventilation in this climate are more important than heating. Therefore, by using the results of the experts' judgment, ventilation cooling and dehumidification cooling are among the passive systems that are desirable for this climate and solutions such as using Iwan, Talaar, upstairs house, and sloping roof, which are derived from the principles of the traditional architecture of Sari, are useful. In addition, according to the questionnaire building orientation, the number and size of windows and the height of the building and rooms are the main principles of passive architectural design in this climate.

According to what was mentioned, it could be concluded that the PMV and PET indices have better results than the other approaches that do not consider these indices, in particular with respect to meteorological data and metabolic conditions in the agreement with clothing and the spectrum of human activities. It needs to be stated that architects and decision-makers should consider the given indices to decide on the appropriate thermal comfort calendar and design the buildings and cooling and heating systems in this climatic zone in the initial phase of building design (Sari).

Our results need to be carefully generalized since they are made according to the consequences of the present study. It architects and building designers are also recommended to adapt the results to their respective practice while considering their specific climatic conditions. It is also worth mentioning that future studies can focus on other aspects of thermal comforts, such as acoustic and visual aspects in different climate conditions, offering useful guidelines to architects and designers in the first phase of their design.

REFERENCES

Adrian, S.-C., Sergiu, C., Maria, M., Anca, S.-C., & Monica, M. (2008). Models for the indices of thermal comfort. *Journal of Medicine and Life*, *1*(2), 148.

Ahmadi, M., Asadi, M., & Dadashi, R. A. (2016). *Determining the Calendar of Thermal Comfort of Sabzevar using Physiological Equivalent Temperature (PET) and Predicted mean View (PMV).*

Ahmed, K. S. (2003). Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. *Energy and Buildings*, *35*(1), 103–110.

Ali-Toudert, F., & Mayer, H. (2006). *Effects of street design on outdoor thermal comfort.*

Ali-Toudert, F., & Mayer, H. (2007). Effects of asymmetry, galleries, overhanging facades and vegetation on thermal comfort in urban street canyons. *Solar Energy*, *81*(6), 742–754.

Asghari, M., Nassiri, P., Monazzam, M. R., Golbabaei, F., Arabalibeik, H., Shamsipour, A., & Allahverdy, A. (2017). Weighting Criteria and Prioritizing of Heat stress indices in surface mining using a Delphi Technique and Fuzzy AHP-TOPSIS Method. *Journal of Environmental Health Science and Engineering*, *15*(1), 1–11.

Asghari, M., Teimori, G., Abbasinia, M., Shakeri, F., Tajik, R., Ghannadzadeh, M. J., & Ghalhari, G. F. (2019). Thermal discomfort analysis using UTCI and MEMI (PET and PMV) in outdoor environments: case study of two climates in Iran (Arak & Bandar Abbas). *Weather*, *74*, S57–S64.

Bienvenido-Huertas, D., Sánchez-García, D., & Rubio-Bellido, C. (2020). Comparison of energy conservation measures considering adaptive thermal comfort and climate change in existing Mediterranean dwellings. *Energy*, *190*, 116448. https://doi.org/https://doi.org/10.1016/j.energy.2019.116448

Błażejczyk, K. (2011). Assessment of regional bioclimatic contrasts in Poland. *Miscellanea Geographica, 15*(1), 79–91.

Brown, G. Z., & DeKay, M. (2001). Sun, wind & light. *Architectural Design Strategies*, *2*, 4–44.

Daneshvar, M. R. M., Bagherzadeh, A., & Tavousi, T. (2013). Assessment of bioclimatic comfort conditions based on Physiologically Equivalent Temperature (PET) using the RayMan Model in Iran. *Central European Journal of Geosciences*, *5*(1), 53–60.

de Freitas, C R, & Grigorieva, E. A. (2017). A comparison and appraisal of a comprehensive range of human thermal climate indices. *International Journal of Biometeorology*, *61*(3), 487–512. https://doi.org/10.1007/s00484-016-1228-6

de Freitas, Chris R. (2003). Tourism climatology: evaluating environmental information for decision making and business planning in the recreation and tourism sector. *International Journal of Biometeorology*, *48*(1), 45–54.

Deb, C., & Ramachandraiah, A. (2010). Evaluation of thermal comfort in a rail terminal location in India. *Building and Environment*, *45*(11), 2571–2580.

Delgarm, N., Sajadi, B., Kowsary, F., & Delgarm, S. (2016). Multi-objective optimization of the building energy performance: A simulation-based approach by means of particle swarm optimization (PSO). *Applied Energy*, *170*, 293–303. https://doi.org/10.1016/j.apenergy.2016.02.141

Eliasson, I., Knez, I., Westerberg, U., Thorsson, S., & Lindberg, F. (2007). Climate and behaviour in a Nordic city. *Landscape and Urban Planning*, *82*(1–2), 72–84.

Emmanuel, R., & Johansson, E. (2006). Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka. *Climate Research*, *30*(3), 189–200.

Emmanuel, R., Rosenlund, H., & Johansson, E. (2007). Urban shading—a design option for the tropics? A study in Colombo, Sri Lanka. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *27*(14), 1995–2004.

Fallah Ghalhari, G. A., Mayvaneh, F., & Shakeri, F. (2015). Evaluation of thermal comfort and human health using Universal Thermal Climate Index (UTCI) Case Study: Kurdistan province. *Iranian Journal of Health and Environment*, *8*(3), 367–378.

Farajzadeh, H., & Matzarakis, A. (2012). Evaluation of thermal comfort conditions in Ourmieh Lake, Iran. *Theoretical and Applied Climatology*, *107*(3), 451–459.

Forcada, N., Gangolells, M., Casals, M., Tejedor, B., Macarulla, M., & Gaspar, K. (2020). Summer thermal comfort in nursing homes in the Mediterranean climate. *Energy and Buildings*, *229*, 110442. https://doi.org/https://doi.org/10.1016/j.enbuild.2020.110442

Ghalhari, G. F., Dehghan, S. F., Shakeri, F., Abbasinia, M., & Asghari, M. (2019). Thermal comfort and heat stress indices for outdoor occupations over 15 years: a case study from Iran. *Weather*, *74*, S40–S45.

Gliem, J. A., & Gliem, R. R. (2003). *Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales*.

Heidari, S., & GHAFARI, J. S. H. (2011). *Determining thermal comfort period for Tabriz*.

Höppe, P. (1999). The physiological equivalent temperature–a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, *43*(2), 71–75.

Ignatius, M., Wong, N. H., & Jusuf, S. K. (2015). Urban microclimate analysis with consideration of local ambient temperature, external heat gain, urban ventilation, and outdoor thermal comfort in the tropics. *Sustainable Cities and Society*, *19*, 121–135.

Jendritzky, G., de Dear, R., & Havenith, G. (2012). UTCI—why another thermal index? *International Journal of Biometeorology*, *56*(3), 421–428.

Johansson, E. (2006). Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco. *Building and Environment*, *41*(10), 1326–1338.

Kim, J., Kim, K. R., Choi, B.-C., Lee, D.-G., & Kim, J.-S. (2009). Regional distribution of perceived temperatures estimated by the human heat budget model (the Klima-Michel model) in South Korea. *Advances in Atmospheric Sciences*, *26*(2), 275–282.

Labdaoui, K., Mazouz, S., Reiter, S., & Teller, J. (2021). Thermal perception in outdoor urban spaces under the Mediterranean climate of Annaba, Algeria. *Urban Climate*, *39*, 100970. https://doi.org/https://doi.org/10.1016/j.uclim.2021.100970

Lechner, N. (2014). *Heating, cooling, lighting: Sustainable design methods for architects*. John wiley & sons.

Liaison, S., Jakob, F. E., Dunn, W. A., Brager, G. S., Brown, K. A., Clark, D. R., Deringer, J. J., Hogeling, J. J., Int-hout, D., Jones, B. W., Knapp, J. N., Kwok, A. G., Levin, H., Melikov, A. K., Simmonds, P., Sipes, J. M., Sterling, E. M., & Sun, B. P. (2004). *ASHRAE STANDARD Thermal Environmental Conditions for Human Occupancy*. *2004*.

Lin, T.-P. (2009). Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Building and Environment*, *44*(10), 2017–2026.

Lin, T.-P., & Matzarakis, A. (2008). Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. *International Journal of Biometeorology*, *52*(4), 281–290.

Lin, T.-P., & Matzarakis, A. (2011). Tourism climate information based on human thermal perception in Taiwan and Eastern China. *Tourism Management*, *32*(3), 492–500.

Matzarakis, A. (2006). Weather-and climate-related information for tourism. *Tourism and Hospitality Planning & Development*, *3*(2), 99–115.

Matzarakis, A. (2007). Assessment method for climate and tourism based on daily data. *Developments in Tourism Climatology*, *1*, 1–7.

Matzarakis, A., & Mayer, H. (1997). Heat stress in Greece. *International Journal of Biometeorology*, *41*(1), 34–39.

Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: physiological equivalent temperature. *International Journal of Biometeorology*, *43*(2), 76–84.

Matzarakis, A., Rutz, F., & Mayer, H. (2010a). Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. *International Journal of Biometeorology*, *54*(2), 131–139.

Matzarakis, A., Rutz, F., & Mayer, H. (2010b). Modelling radiation fluxes in simple and complex environments: Basics of the RayMan model. *International Journal of Biometeorology*, *54*(2), 131–139. https://doi.org/10.1007/s00484-009-0261-0

Meteorology, V. D. I. E. (1998). Methods for the Human Biometeorological Evaluation of Climate and Air Quality for the Urban and Regional Planning at Regional Level. *VDI: Berlin, Germany*, *3787*.

Moore, F., & series, M.-H. architecture and urban planninig. (1993). *Environmental control systems: Heating, cooling, lighting*. McGraw-Hill New York.

Naderi, E., Sajadi, B., Behabadi, M. A., & Naderi, E. (2020). Multi-objective simulation-based optimization of controlled blind specifications to reduce energy consumption, and thermal and visual discomfort: Case studies in Iran. *Building and Environment*, *169*, 106570. https://doi.org/10.1016/j.buildenv.2019.106570

Nasrollahi, N., Hatami, Z., & Taleghani, M. (2017). Development of outdoor thermal comfort model for tourists in urban historical areas; A case study in Isfahan. *Building and Environment*, *125*, 356–372.

Nassiri, P., Reza Monazzam, M., Golbabaei, F., Abbasinia, M., Chavoshi, M., Taheri, F., & Asghari, M. (2018). Exposure to heat stress in the workplace: A systematic review. *Iran Occupational Health*, *15*(2).

Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy*, *70*(3), 227–235.

Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: analysis across different European countries. *Building and Environment*, *41*(11), 1455–1470.

Nikolopoulou, M., & Lykoudis, S. (2007). Use of outdoor spaces and microclimate in a Mediterranean urban area. *Building and Environment*, *42*(10), 3691–3707.

Pecelj, M., Matzarakis, A., Vujadinović, M., Radovanović, M., Vagić, N., Đurić, D., & Cvetkovic, M. (2021). Temporal Analysis of Urban-Suburban PET, mPET and UTCI Indices in Belgrade (Serbia). In *Atmosphere* (Vol. 12, Issue 7). https://doi.org/10.3390/atmos12070916

Potchter, O., Cohen, P., Lin, T.-P., & Matzarakis, A. (2018). Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. *Science of The Total Environment*, *631–632*, 390–406. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.02.276

Roshan, G. R., Ranjbar, F., & Orosa, J. A. (2010). Simulation of global warming effect on outdoor thermal comfort conditions. *International Journal of Environmental Science & Technology*, *7*(3), 571–580.

Salata, F., Golasi, I., de Lieto Vollaro, R., & de Lieto Vollaro, A. (2016). Outdoor thermal comfort in the Mediterranean area. A transversal study in Rome, Italy. *Building and Environment*, *96*, 46–61.

Sharmin, T., Steemers, K., & Humphreys, M. (2019). Outdoor thermal comfort and summer PET range: A field study in tropical city Dhaka. *Energy and Buildings*, *198*, 149–159.

Staiger, H., Laschewski, G., & Grätz, A. (2012). The perceived temperature–a versatile index for the assessment of the human thermal environment. Part A: scientific basics. *International Journal of Biometeorology*, *56*(1), 165–176.

Streinu-cercel, A., Costoiu, S., Mârza, M., Streinu-cercel, A., & Mârza, M. (2008). *Models for the indices of thermal comfort*. *1*(2), 148–156.

Taleghani, M., Kleerekoper, L., Tenpierik, M., & Van Den Dobbelsteen, A. (2015). Outdoor thermal comfort within five different urban forms in the Netherlands. *Building and Environment*, *83*, 65–78.

Thomson, M. C., Garcia-Herrera, R., & Beniston, M. (2008). *Seasonal Forecasts, Climatic Change and Human Health*. Springer.

Thorsson, S., Lindberg, F., Eliasson, I., & Holmer, B. (2007). Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *27*(14), 1983–1993.

Thorsson, S., Lindqvist, M., & Lindqvist, S. (2004). Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden. *International Journal of Biometeorology*, *48*(3), 149–156.

Toudert, F. A. (2005). *Dependence of outdoor thermal comfort on street design in hot and dry climate*.

VAKILINEZHAD, R., MEHDIZADEH, S. F., & MOFIDI, S. S. M. (2013). *Principles of passive cooling systems in vernacular architectural elements of Iran*.

van Hoof, J., & Hensen, J. L. M. (2007). Quantifying the relevance of adaptive thermal comfort models in moderate thermal climate zones. *Building and Environment*, *42*(1), 156–170. https://doi.org/https://doi.org/10.1016/j.buildenv.2005.08.023

Vella, R. C., Martinez, F. J. R., Yousif, C., & Gatt, D. (2020). A study of thermal comfort in naturally ventilated churches in a Mediterranean climate. *Energy and Buildings*, *213,* 109843. https://doi.org/ https://doi.org/10.1016/j.enbuild.2020.109843

Villadiego, K., & Velay-Dabat, M. A. (2014). Outdoor thermal comfort in a hot and humid climate of Colombia: A field study in Barranquilla. *Building and Environment*, *75*, 142–152.

Watson, D. (1983). *Climatic design: Energy-Efficient Building Principles and Practices, copyright by McGraw-hill*. Inc.

Yahia, M. W., & Johansson, E. (2013). Influence of urban planning regulations on the microclimate in a hot dry climate: The example of Damascus, Syria. *Journal of Housing and the Built Environment*, *28*(1), 51–65.

Yan, Y. Y. (2005). Human thermal climates in China. *Physical Geography*, *26*(3), 163–176.

Yang, W., Wong, N. H., & Jusuf, S. K. (2013). Thermal comfort in outdoor urban spaces in Singapore. *Building and Environment*, *59*, 426–435.

Zacharias, J., Stathopoulos, T., & Wu, H. (2001). Microclimate and downtown open space activity. *Environment and Behavior*, *33*(2), 296–315.

Zaninović, K., & Matzarakis, A. (2009). The bioclimatological leaflet as a means conveying climatological information to tourists and the tourism industry. *International Journal of Biometeorology*, *53*(4), 369–374.

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