Summer Comfort Temperature in the Public Historic Buildings in the Old City of Tartous in Syria

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***Abstract*—Adaptive comfort survey data are not available for Syria. This paper is a thermal comfort study of the heritage buildings in the old city of Tartous in Syria. The selected historic structures were reused for public functions. Two of the survey locations are used as workplaces, the third is a multifunctional gallery, and the last is a print shop. The building elements, materials, and drawings were documented and described. Field measurements in the four public locations were continuously collected for seven days in August 2016 in conjunction with a subjective thermal survey in the office buildings. The sample size of the office questionnaires was 70 subjects, which is 80% of the total number of employees in both selected office buildings. The indoor climates of the surveyed buildings and the employees' satisfaction have been described and analyzed. Thermal comfort indices, a comfort band, and a predicted neutral temperature were determined and compared with the international standards. The primary objective of this thermal research was to evaluate whether the environments in the historic buildings are comfortable for the occupants. The results could be useful for further studies and could be used as a dataset for establishing a local thermal comfort standard.**

***Index Terms*—Thermal comfort, neutral temperature, heritage buildings, Tartous**

I. Introduction

Monitoring heritage buildings and sites is an essential part of preserving their architectural, artistic, historic, and social values and developing possible techniques to save their structures and environments. The prediction of potential risks is vital to consider the appropriate actions for preserving heritage buildings and sites through different conservation processes and interventions. Conserving the cultural heritage can extend the life of these valuable resources of past cultures and improve the economic conditions of a society. The interventions in historic buildings face many challenges and constraints. They should be able to achieve the contemporary requirements without altering the intrinsic values of the buildings [1]. The usage requirements, operation, maintenance and cost should be carefully defined. In many cases, the historic building is reused based on the investment objectives of the decision makers without much consideration of the building's character and the end-users' needs. Evaluating the passive thermal behavior of the building envelope and the thermal properties of the various components, such as the construction material and wall system, is necessary [2]. The introduction of heating, ventilation and air conditioning (HVAC) systems moved people away from passive design and rapidly increased energy demand and consumption. Recent studies have encouraged natural and passive systems and tend to combine passive and active design systems to achieve maximum energy efficiency in the building sector. Studies have also considered enhancing the thermal comfort and energy performance of all building sectors, including a high percentage of existing and historic buildings [3]. Furthermore, the concept of psychometrics to design HVAC systems has become common because it considers the factors of the local environment, thermal parameters, and occupants' comfort and satisfaction.

The evaluations of climate change problems and thermal comfort using human subjects and evidence are a superior contribution to knowledge, having a longer-

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lasting value to the research community than theoretical and simulated evaluations and models [4]. Several field studies based on the model of adaptive thermal comfort have been made in many countries worldwide with the aim of achieving a better understanding of thermal comfort to face climate change and the demands for more energy-efficient buildings and increased productivity [5]. Post-occupancy evaluation methods are used to provide feedback on the performance of a building after completion for quality assurance and for improving the service for future clients [6]. Based on the satisfaction and thermal acceptability of the users during summer, the researchers in different climate zones found that the users of the naturally ventilated offices are more tolerant concerning their thermal environment than the users of the offices with hybrid ventilation, despite experiencing higher temperatures [6], [7].

Kim and de Dear identified that the type of office conditioning influences the expectation of the users concerning indoor environment quality satisfaction. The proper thermal conditions improved overall satisfaction with the working environment and had positive effects in naturally ventilated buildings. However, in the air-conditioned buildings, the thermal conditions were associated with negative evaluations regarding the overall environment, and the thermal conditions provided both positive and negative impacts in the mixed-model structures [8]. A study in Cyprus emphasized the positive role of natural ventilation strategies for cooling purposes in the historic buildings in the eastern Mediterranean region in the summer period [9]. Other research in India highlighted the increased air velocity by fans as one of the measures used by participants to improve the comfort conditions [10]. Syria does not have adaptive environmental comfort standards. There are no field study data on the prevailing thermal conditions or occupant perceptions and preferences in the historic buildings and public buildings of Syria. Furthermore, there is no assessment approach for evaluating the performance of the buildings after completion/ refurbishment and their use/reuse. Based on the above, this field study was performed in the old city of Tartous in Syria during the summer of 2016 with the following objectives: to gather microclimatic data and determine the thermal comfort range of users of historic buildings in Tartous in order to perform a comparative analysis with the existing international standards through thermal surveys and the monitoring of the indoor environment.

II. Overview of the Case Studies

The survey was carried out in two historic office buildings, one public hall and one print shop, as shown in Fig. 1. The office buildings are located on the waterfront of the old city of Tartous and rise approximately 1 m above sea level. Both buildings share a cross-vaulted ground floor of massive sandstone masonry walls. The ground floor was built in the Crusader period, and it is currently used as a public multifunctional gallery (G). All selected public buildings have a western orientation and are built of sandstone with different thicknesses influenced by the building materials and types when they were built. The first selected office building is the Department of Antiquities in Tartous (D). It was renovated in 2007, and the distortions and additions were removed. The building has two floors, and the first floor contains two parts; the first part was built in the Ottoman period, and the other part has rooms that surround an inner yard and was built in the late Ottoman period. The second floor was built above the Ottoman part around the middle of the 19th century.

Air flow anemometer ■ Temperature and relative humidity data logger

Figure 1. Case study sites and the equipment locations: (a) The plan of the public multifunctional gallery (G), (b) Eastern façade of the Technical Office (T). (c) The western façade of the Technical Office (T). (d) The northern façade of Department of Antiquities (D). (e) The Department of Antiquities (D) from the alley. (f). The Print shop (g) Ground floor plan of (D) (h) First-floor plan of (D) (i) Ground floor plan of (T) (j) First-floor plan of (T)

The second selected building is the Technical Office of the old city of Tartous (T), and it belongs to the municipality of Tartous. This building also has two floors. The first floor was built in the late Ottoman period as a courtyard house with cross-vaulted rooms; then, it changed in the early 19th century to be a central hall building type by covering the courtyard with a concrete ceiling. The second floor was built around the middle of the 19th century in a similar plan of the first floor at that time (with a central hall). By comparing the plans and facades of both selected office buildings and the typical building style throughout Syrian historical periods, it is clear that the building facades and designs have been transformed and influenced by the common building style in the simultaneous building periods. The print shop (P) is located on the ground floor of a residential building near the Knights' hall with sandstone walls, a western facade and an open view to the old city square. All information about the materials and elements of the selected historic office buildings are shown in Table I, and an overview of all the measured rooms is shown in Table II.

TABLE I. MATERIALS AND ELEMENTS OF THE SELECTED HISTORIC OFFICE BUILDINGS.

	The department of Antiquities in Tartous (D)	The technical Office of the old city of Tartous (T)
Location and Building orientation	In the waterfront of the old city of Tartous, they rise about 1m above the sea level. Both buildings are oriented to the west (to the sea).	
Shape and Floors	The selected buildings share the cross-vaulted ground floor. The ground floor is used as a public multifunctional gallery	
	It is situated on two floors. First floor (8 rooms and inner yard) contains two parts; the first part contains the main block of four rooms and the other part is with four rooms surround an inner yard. The second floor is built above the main block and contains 8 rooms.	A Rectangular shape with central hall plan on the two floors. First floor contains 5 main rooms and the second floor contains 5 main rooms.
Material and construction	The first floor rooms have two kind of roofs. The rooms of the Ottoman parts haves sandstone cross-vaulted roofs. The rooms of the other periods have concrete flat ceiling with exposed iron and wooden beams. The second floor' rooms just have a concrete flat ceiling. The roofs are carried on sandstone pillars for the Ottoman parts and concrete columns for the other parts of the later period.	
Courtyard	It has an inner yard in a part of the first floor	No courtyard
Walls type	Sandstone walls of single layer	
External walls thickness	25-35 cm	25-30 cm
Internal walls thickness	25-20 cm	25-20 cm
Windows type	Two casements can wide open made of a single pane of glass and wooden frame with wooden shutters. Some of windows have thin iron bars.	
Windows shape	The external windows of the waterfront are simple rectangular openings and there are three arch ending upper windows in the center of the second floor. The internal openings have a rectangular shape. The other external fa ҫade openings are rectangular shape with wooden shutters.	The external windows of the waterfront are simple rectangular openings with the arch ending frames and there are three arch ending upper windows in the center of the second floor. The internal openings have a rectangular shape. The external eastern fa ҫade openings are with hollow wooden shutters.
Exterior doors	The main gate is wooden double panel door with external iron bars, and the upper opening of it is arched shape of single pane glass and iron bars.	The main gate is wooden single panel door with upper open arched opening.
Interior doors	The internal doors are made from wood with different sizes.	The internal doors of the first floor are made from wood with almost a same size. The internal doors of the second floor are the same size wooden doors with upper colorful glass part.
Insulations	The external skin of the fa ҫades is without insulation (natural sandstone).	
	The internal skin of walls and cross vaulted roofs of the first floor are coated by a traditional white lime plaster. Whereas the internal skin of walls of the second floor are coated by the lime-concrete plaster, as well as its ceiling.	The internal skin of walls are without insulation and just have the natural texture of sandstone. The ceiling of the second floor is coated by the lime-concrete.
Ancient systems and sun shading methods	No ancient systems. The sun shading methods are curtains and shutters. Balcony of the French period are removed from the center of the second floor fa ҫade, because it was considered as transgression.	
Energy upgrades	Most rooms have electric and Mazut heating devices and fans in summer. Air conditioners are used in three rooms.	The rooms have electric fans and heating devices. Air conditioner is just used in the main room of the first floor.

TABLE II. OVERVIEW OF ALL THE MEASURED ROOMS IN THE SELECTED HISTORIC OFFICE BUILDINGS.

Building	Floor	Room name	Room area (m^2)	Openings: Internal façade openings: Internal orientation & ordinary window number	upper window	door	openings to wall ratio (OWR)	External façade openings: External orientation & window number	upper window	door	openings to wall ratio (OWR)	Notes
The department of Antiquities in Tartous(D)	F1	Diwan Room (D-F1-DIR)	32.53	1	-	1	16%	West (2)	-	-	17%	The rooms (ER and TR) are open from two opposite sides, where their external facades are oriented to the west and the opposite sides are open to the inner yard from the east.
		Director Room (D-F1-DR)	52	1	-	2	23%	West (3)	-	-	13%	
		Engineers Room (D-F1-ER)	39.43	East (2)	1	1	18%	West (3)	-	-	14%	
								South (2)	-	-	14%	
		Technical Room (D-F1- TR)	32.05	East (1)	-	1	13%	West (3)	-	-	15%	
	F2	Buildings Room (D-F2-BR)	28.45	2	3	1	61%	West (3)	3	-	46%	
		Lobby Room (D-F2-LR)	50	3	3	6	13%	North (2)	-	-	15%	
The technical Office of the old city of Tartous (T)	F1	Director Room (T-F1-DR)	37.65	2	-	1	14%	West (3)	-	-	14%	The central rooms (DocR and ADocR) are open from two opposite sides, where their external facades are oriented to the west and the opposite sides are oriented to the east. The worker Room has a balcony from the eastern side.
		Study Room (T-F1-SR)	36.53	2	3	2	20%	West (3)	-	-	14%	
		Documenting Room (T-F1-DocR)	81.27	-	6	6	8%	West (3)	-	-	15%	
								East(2)	2	-	17%	
	F2	Worker Room (T-F1- ADocR)	69.17	-	-	8	16%	West (3)	3	-	39%	
								East(3)	3	-	45%	

III. METHODS

Tartous city has a moderate Mediterranean climate; it has a humid environment in summer and rainy winter weather with south and southwestern prevailing winds. Heat and humidity are the main issues to be considered for achieving comfort in this climate [11]. The monitoring period for each place was performed during the hottest month, which was August 2016. During this period, the prevailing winds were westerly winds; the wind velocity was approximately 0.9-4.5 m/s in the daytime, the highest temperature was 35 ℃, and the lowest temperature was 28 ℃. The relative humidity in the atmosphere was very high, with mean values ranging between 57% and 77% [12]. For the investigation and identification of the data needed to survey the selected structures, two data collection methods were used based on the thermal comfort international standard and previous studies [13], [14], [15]. A questionnaire was used as a subjective measurement to obtain the occupants' responses to their environment, and physical measurements were used to obtain quantitative data on the actual conditions in the buildings. The sample size of the questionnaire was 58 subjects in building (D) and 12 subjects in building (T), which is 80% of the total number of the employees in both selected office buildings. The employees were given 15 min to answer the questionnaire and to retain it. The survey was accompanied by measurements of the relevant thermal comfort parameters (relative humidity, air temperature, and wind speed) in the historical office buildings from the 3rd to 10th of August 2016. The public multifunctional gallery was also monitored for one week from the 10th to 17th of August 2016, and the print shop for one week from the 18th to 25th of August 2016. Each room was monitored continuously for seven days. Two personal parameters (clothing value and metabolic heat) were calculated and fixed according to ASHRAE Standard-55 and ISO7730. Measurement equipment included eight temperature and relative humidity data loggers and two Testo405 anemometers for measuring the indoor-outdoor airflow and temperature and two AZ8778 digital handheld black bulb thermometers. The data loggers were hung in four rooms in building (T): the central hall of the first floor (DocR), Director Room (DR), Study Room (SR), and the central hall of the second floor (ADocR). In addition, the equipment was hung in six rooms in building (D): the Diwan Room (DIR), Director Room (DR), Engineers Room (ER), and Technical Room (TR) on the first floor and the Buildings Room (BR) and Lobby Room (LR) on the second floor. Additionally, four points were chosen to fix the data loggers in the multifunctional gallery (G) and one in the print shop, as shown in Fig. 1. The results of this research were analyzed using Excel and SPSS software and then compared with previous studies and international standards.

IV. THE RESULTS OF THE QUESTIONNAIRE SURVEY

A. Basic Information

Most of the employees live in the city of Tartous, and only 10% of them travel to work every day from the nearby villages. All the survey participants in the (T) building worked on the first floor, and 90% of them performed professional activities related to cultural heritage. In the (D) building, 72.4% of the survey participants worked on the first floor, and 27.6% of them worked on the second floor; additionally, 80% of the total participants perform professional activities related to cultural heritage. The gender distribution of the participants was 30 males (51.7%) and 28 (48.3%) females in building (D) and nine females (75%) and three males (25%) in building (T). Most respondents had a high level of education. More than 50% of the respondents had worked in the same place for more than five years.

B. Indoor Environment Parameter Assessment

1) Indoor Air Temperature and Relative Humidity

The measured values of the indoor parameters during the questionnaire survey for the main monitored structures are shown in Table III. The Operative Temperature (OP) was calculated according to ASHRAE Standard-55-2004 [15]. The occupants were asked about their feelings in terms of humidity with a 7-point sensation scale, namely, “Humidity Predicted Vote”. Only 16.7% out of 12 respondents in building (T) and 50% out of 58 respondents in building (D) voted within the central three categories, showing that the occupants were not in acceptable thermal conditions within their residences according to the ASHRAE standard [15], Fig. 2. A total of 83.3% of the occupants in building (T) overall voted that they felt uncomfortable and found the workplace to be too humid, and half of the occupants in building (D) overall voted that they were satisfied/comfortable with the indoor relative humidity. A total of 39.7% felt too humid, and the remaining 10.3% felt much too humid. This result indicates that the occupants were very sensitive to humidity variations.

TABLE III. THE MEASURED AVERAGE VALUES OF THE INDOOR PARAMETERS FOR THE MAIN MEASURED STRUCTURES.

Occupant Location in Area	The average of the Inside Air Temperature (℃)	The average of the Relative Humidity (%)	The average of the Inside Air Speed (m/s)	The average of the Radiant Temperature (℃)	The average of the calculated Operative Temperature (℃)
D	30.99	69.69	0.27	33.47	32.23
T	30.36	70.40	0.06	32.06	31.21
G	27.50	87.61	0.04	29.01	28.25
P	29.70	75.90	0.15	31.68	30.69

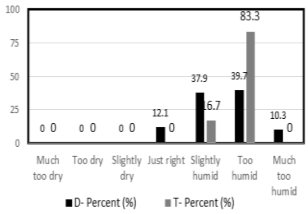


Figure 2. Indoor Humidity Perception Vote (HPV) result.

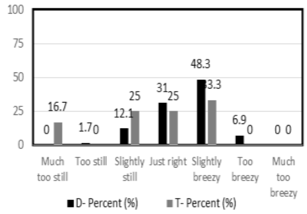


Figure 3. Indoor draft perception vote (DPV) results

2) *Air velocity*

Fig. 3 shows the draft perception vote (DPV) results. Only 16.7% of the occupants in (T) felt the velocity was much too still. A total of 1.7% of the occupants in (D) felt the velocity was too still, and 6.9% of them felt that the velocity was too high. A total of 83.3% of the occupants in (T) and 91.4% of the occupants in (D) voted within the central three categories, which shows the acceptance of the air movement in their buildings. All the occupants of (T) preferred the air flow to be higher than present, 50% of the occupants in (D) preferred the air flow to remain at the present rate, 46.6% of them preferred it to be higher than present, and 3.4% of them preferred it to be lower than present, Fig. 4.

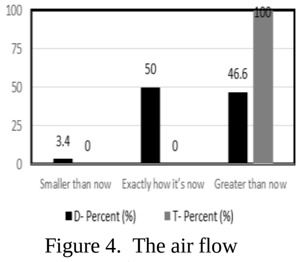


Figure 4. The air flow preference

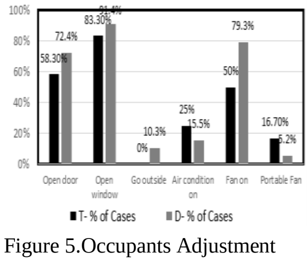


Figure 5.Occupants Adjustment /Control choice

3) *Clothing insulation*

Male and female occupants in both office buildings wore a relatively light formal type of clothing. Their outfits provided them more comfort and made them feel cooler. The male clothing consisted of light trousers with a short- or long-sleeve shirt and differed in small ways such as underwear and footwear. The males' outfits, as calculated according to ASHRAE55-2004, ranged between 0.42-0.5 Clo units in both office buildings. The female clothing consisted of light trousers with a short- or long-sleeve shirt/blouse and differed in small ways such as a head cover, underwear and footwear. The values associated with this clothing ranged between 0.4-0.54 Clo units in (D) and 0.4-0.57 Clo units in (T), as calculated according to ASHRAE55-2004.

4) *Personal adjustments*

A summary of the answers to the multiple response questions about the personal response to hot conditions is shown in Fig. 5. The reactions of the employees to a sense of being hot did not require the use of a fan or cooler, and this reaction was not generally the sole response. Adjusting the indoor ventilation by opening the doors and windows and altering activity levels were the common responses. The variety of passive reactions formed a positive factor in terms of energy efficiency.

C. *Thermal Response Vote Evaluation*

1) *Thermal preferences*

The results of the subjective thermal preference among the respondents are presented in Fig. 6. A high percentage of the respondents preferred slightly cooler conditions than the current indoor temperature in their buildings by a percentage of 83.3% in building (T) and 65.52% in building (D). The rest of the respondents, 16.7% of building (T) and 29.32% of the respondents in building (D), indicated that changes in the thermal environment were not required. A negligible percentage of the respondents (1.72%) wanted a slightly warmer indoor temperature, and approximately 3.44% wanted a too cool and much too cool indoor temperature in building (D).

2) Thermal Sensation Votes (TSV)

The results of the subjective responses to temperature (thermal sensation) are presented in Fig. 7. The results show that the majority of the respondents of building (T) (75%) voted between “warm and hot sensation” and preferred cooler conditions, and 25% found their environment slightly warm. More than half of the respondents of the building (D) (56.9%) voted between “neutral and slightly warm sensation”, and 41.4% voted between “warm and hot sensation”. The data have been binned in the interval of 0.5 ℃. The simple linear regression between the thermal sensation and operative temperature determined the strength of the relationship between them in both of the surveyed office buildings (D and T), as shown in Fig. 8. The fitted regression equations for the subjects’ sensation versus operative temperature were:

$$TSV\,(T) = OP - 28.625 \qquad R^2 = 0.8421 \qquad (1)$$

$$TSV\,(D) = 1.425\,OP - 43.463 \qquad R^2 = 0.7934 \qquad (2)$$

The coefficient of determination (R2) in both these office buildings indicates a high significance between the thermal sensation votes (TSV) and the indoor operative temperature (OP). It is approximately 1 ℃ per sensation unit for the observed gradient in building (T) and 1.425 ℃ per sensation unit for the observed gradient in building (D). The neutrality condition is derived by solving the regression equation for zero (neutral) and yields an estimated neutrality of 28.625 ℃ for building (T) and 30.5 ℃ for building (D). A comfort band of (27.63 to 29.63 ℃) for building (T) and a comfort band of (29.8 to 31.2 ℃) for building (D) coinciding with -1 and +1 sensation votes have been obtained using this regression equation [16]. The occupants showed more tolerance for hot conditions. Due to the group size after using BIN methods for the thermal sensation for an interval of 0.5 ℃ of the operative temperature (3 variables for building T, and 4 variables for building D), the comfort band in both office buildings fall in a narrow range of temperatures.

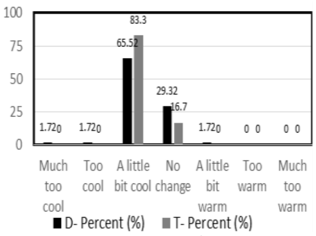


Figure 6. Thermal preference Vote results.

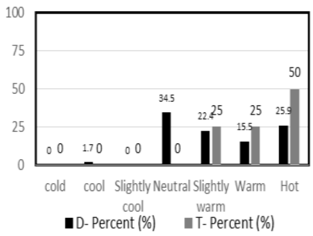
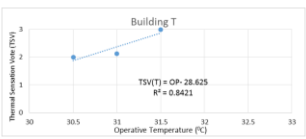
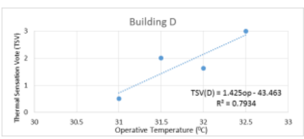


Figure 7: Thermal sensation Vote (TSV) results.



(a)



(b)

Figure 8. Linear regression of thermal sensation votes versus Operative temperature: (a) TSV of Building T. (b) TSV of Building D.

3) Thermal acceptability

The results of the subjective thermal acceptability in the selected office buildings are presented in Fig. 9. All the participants of building (T) reported their thermal sensation as not acceptable; half of the respondents reported that the reason for their dissatisfaction was due to the temperature being always too hot, and the other half found it often too hot; see Fig. 10. On the other hand, 72.4% of the participants in building (D) accepted the overall temperature of their building, and 27.6% reported their thermal sensation as not acceptable because they found it occasionally too hot; the level of acceptability is shown in Fig. 11. According to the survey, the discomfort time occurred during the mid-day and afternoon (between 11 am and 5 pm) in building (D) and at all times in building (T), as shown in Fig. 12.

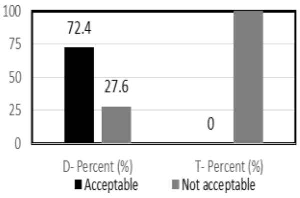


Figure 9. Thermal Acceptability Vote results.

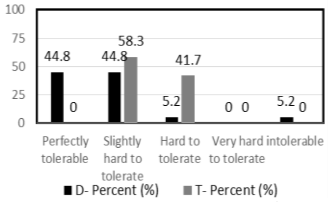


Figure 10.Acceptability level of the selected office buildings.

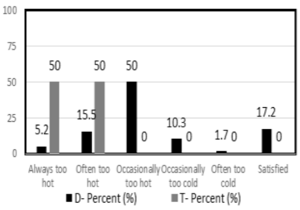


Figure 11. The reason for Thermal un/acceptability results

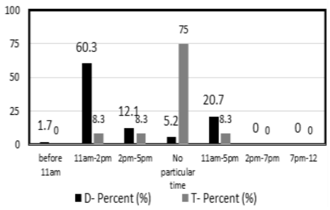


Figure 12. The discomfort time in the selected office buildings

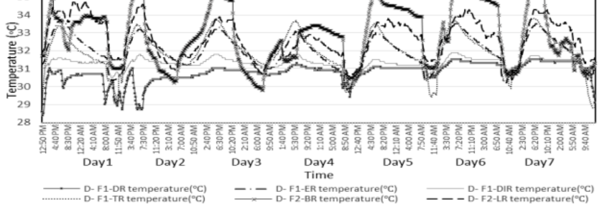
4) Staff Comments and Views of the Thermal Comfort Term and their Workplace Environment

The employees were asked about comfortable thermal conditions from their point of view, and their answers are shown below. The respondents in building (T) answered “feeling comfortable in the office during work time". The respondents in building (D) thought that the term “comfortable thermal conditions” means the following: "A sense of comfort and satisfaction with the thermal status of the building"; "The indoor temperature is not very cold and not intensely hot, just a moderate temperature to suit the body"; "The satisfaction of indoor thermal conditions", "Optimal temperature of the body"; "Moderate microclimate without humidity", "No high moisture and no high temperatures"; "Moderate atmosphere and a suitable temperature for work"; "Adjust the temperature to an acceptable level, which lets us adapt to the surrounding environment"; "The sense of the surrounding environment temperature, both in terms of comfort or discomfort"; "Work in a place with a moderate temperature and low humidity"; "Necessary state is always required to get the best results in the daily life and office work"; "Securing the heat that does not bother employees to do their work"; "Feeling comfortable as a result of suitable thermal conditions"; and "the status of thermal stability". On the other hand, the occupants in the office building commented in the open comments about their offices' environment and stated that the high temperatures in the building without an air conditioner are uncontrollable in the summer in building (T). Whereas most (D) building occupants accept the environment in summer due to the western direction of the rooms, which provides a nice atmosphere until 12:00 pm, later on, there is more glare and radiation. Approximately 70% of them mentioned the high air humidity in summer, especially in the absence of airflow that affects the electrical devices. The atmosphere of the rooms in building (D) in winter was cold and, in their opinions, needed thermal energy sources such as an oil fireplace.

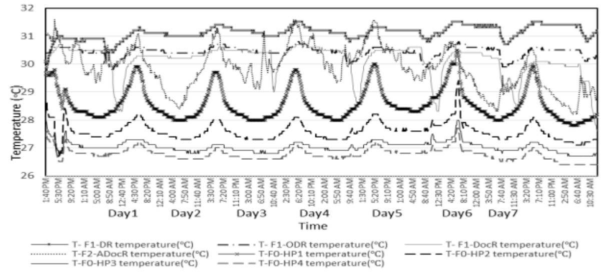
V. The Results of the Field Measurement

The measurement results of the indoor air temperature, indoor relative humidity, daily average of the indoor and outdoor wind speed, and indoor and outdoor air temperature are shown in Figs. 13, 14, 15, and 16, respectively. We can distinguish four kinds of thermal behavior for the rooms in proportion to the construction periods. High relative humidity and a slight difference in the indoor air temperature and relative humidity between the nighttime and daytime can be seen at the measured points of the Crusader public multifunctional gallery, and the difference increases at the points near the openings of the waterfront facade, as shown in HP1. The indoor relative humidity values decreased more than 20%, and the indoor air temperature values also increased more than 2 ℃ in the rooms built during other periods because of the different thermal mass. Relatively stable indoor air temperatures and relative humidity values and a slight difference between the nighttime and daytime can be seen in the cross-vaulted rooms, which belong to the Ottoman period in DIR and DR of the Department of Antiquities, in the DR, ODR, and DocR of the Technical Office, and in the print shop. A difference in the indoor air temperatures of approximately 3 ℃ between night and daytime can be seen in the rooms of the late Ottoman period ER and TR. In addition, there is an obvious difference in the indoor air temperature between night and daytime in the rooms that were built in the French period. The temperature difference reaches 6 ℃ in BR on the second floor of the Department of Antiquities and approximately 3.5 ℃ in the ADocR on the second floor of the Technical Office.

(a)



(b)



(c)

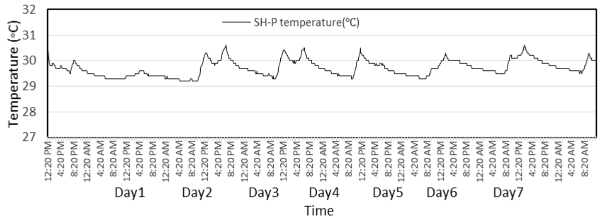
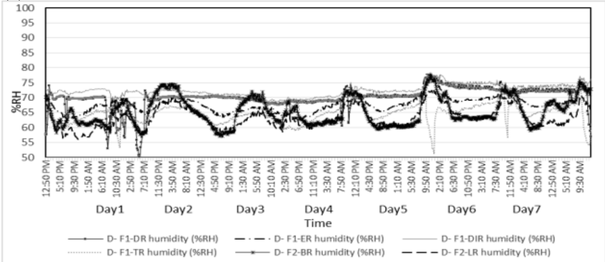
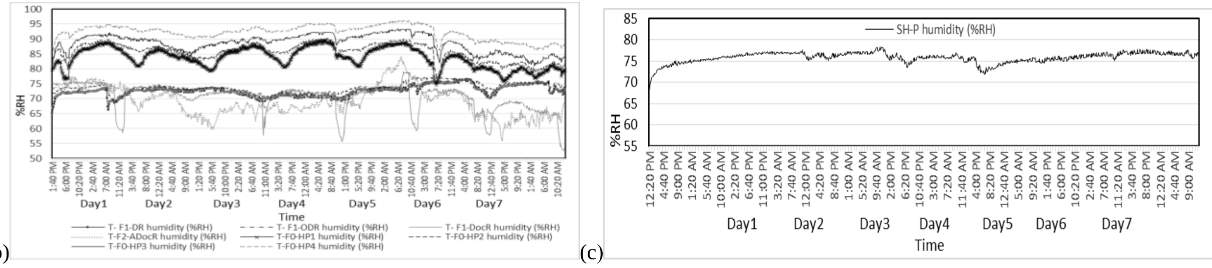


Figure 13: Indoor air temperatures: (a) The rooms of the building (D) (b) The rooms of the building (T) and the gallery (g) (c) The print shop.

The values of the indoor wind flow were generally slight values and ranged between 0.04 and 0.08 m/s in the first floor of the Technical Office (T) and the public multifunctional gallery (G) of the old city of Tartous. On the other hand, the values of the indoor wind flow in the rooms of the Department of Antiquities (D) in Tartous had high values and ranged between 0.16 and 0.67 m/s, and the average in the print shop (P) was 0.15 m/s. Furthermore, the second floor room of the Technical Office (ADocR) had an average value of approximately 0.55 m/s, as shown in Fig. 15. The indoor air temperature values in the measured rooms on the first floor of the Department of Antiquities (D) and the print shop (P) were lower than the outdoor air temperature by approximately 0.5-1 ℃. However, the indoor temperature values were more than the outdoor air temperature by approximately 0.5-1 ℃ in the measured rooms on the second floor of the Department of Antiquities (D). The natural ventilation played a positive role in decreasing the indoor air temperature on the second-floor room (ADocR) in the Technical office. The lack of ventilation in its first-floor rooms (DR, ODR, DocR) had a negative impact by increasing the indoor air temperature to be more or approximately equal to the outdoor air temperature, as shown in Fig. 16. The thermal mass of the public gallery (G) played a significant role in decreasing the indoor air temperature values by approximately 2 ℃ less than the outdoor temperatures.

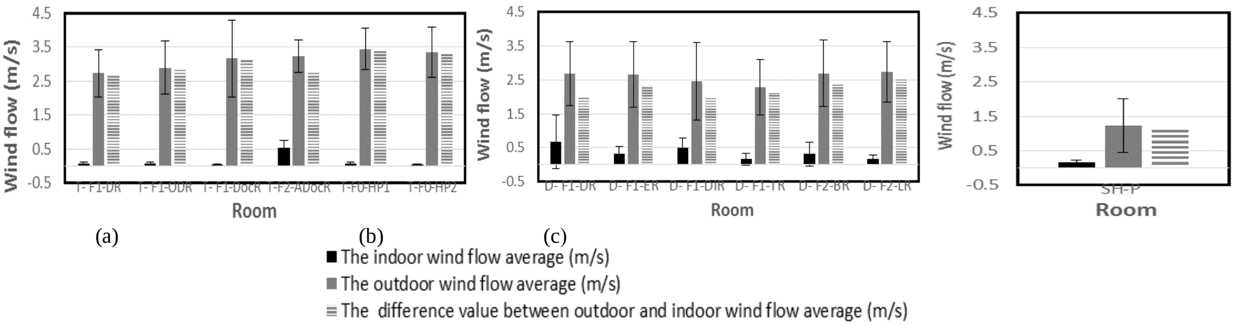
(a)





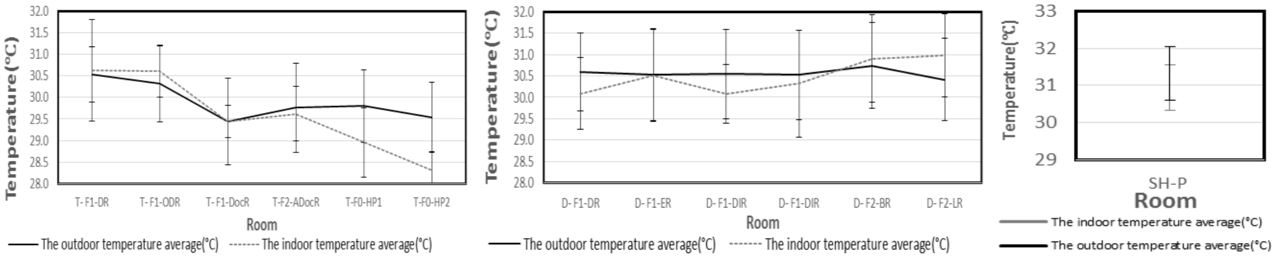
(b) (c)

Figure 14. Relative humidity: (a) The rooms of building (D) (b) The rooms of the building (T) and the gallery (G) (c) The print shop.



(a) (b) (c)

Figure 15. August daily average of indoor, outdoor and the difference of the wind flow for the rooms of (a) The building (D) (b) The building (T) and the gallery (g) (c) The print shop.



(a) (b) (c)

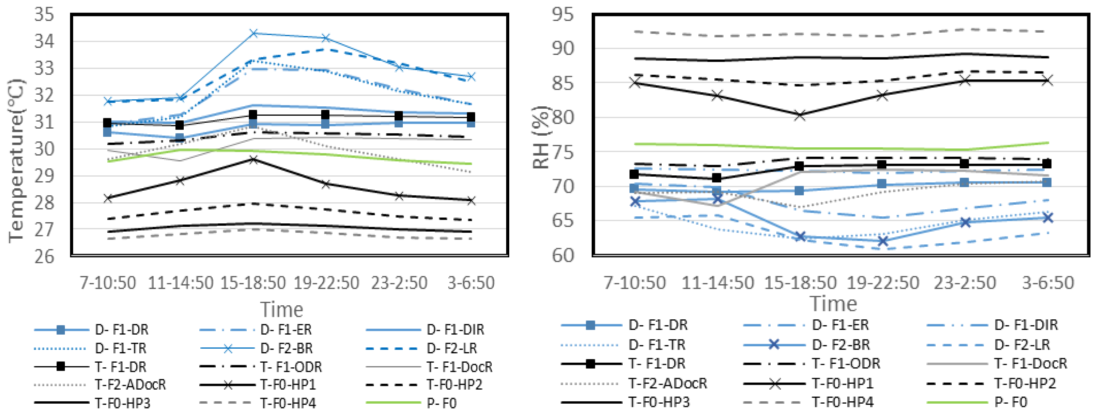
Figure 16. August daily average of indoor, outdoor and the difference of the temperature for the rooms of (a) The building (D) (b) The building (T) and the gallery (g) (c) The print shop.

Note: vertical error bar refers to the standard deviation

A. Variations in the Air Temperature and Relative Humidity Analysis of the Measured Rooms Occurred During the Time Intervals of the Day.

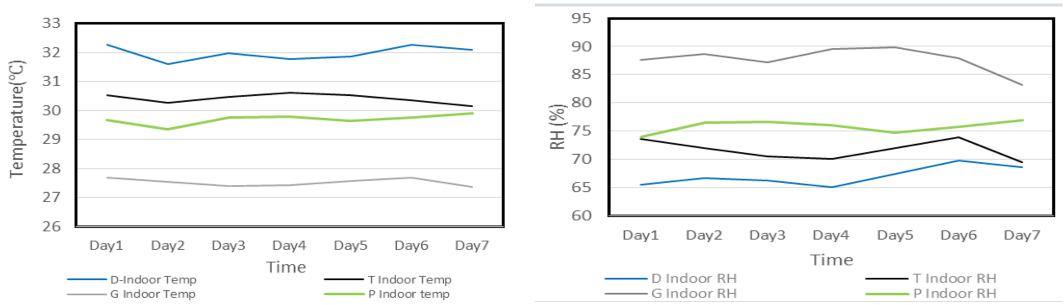
Fig. 17 shows the indoor parameter results of the selected public buildings in term of air temperature and relative humidity. The measured cross-vaulted rooms of the Department of Antiquities (D) showed stable air temperature and relative humidity values during the daytime. The other measured rooms of building (D) showed an increase in the air temperature (approximately 3 ℃) and a decrease in the relative humidity (approximately 6%) after working hours began from 2 pm to 11 pm, especially in the second-floor rooms. Therefore, their indoor space at morning and noon was better than during the daytime. The second-floor rooms had the highest temperature, especially in the afternoon and evening hours, because of the outdoor solar radiation on both the ceiling and western facades.

The measured rooms on the first floor of the Technical Office of the old city of Tartous (T) showed relatively similar averages of the air temperature and relative humidity during the daytime intervals. Although there was solar radiation on both the ceiling and the western facades of the second-floor room during the daytime, it had a relatively low temperature compared to the first-floor rooms. This indicates that the ventilation there played a role in reducing the indoor air temperature. The gallery (G) had a relatively steady indoor air temperature and relative humidity during the daytime intervals compared with the other measured rooms in the public buildings that were built in different periods and with different building envelopes. It had the lowest air temperature, with an average of 27.5 ℃, and the highest relative humidity, with an average 85.4%, during the measurement period. The print shop (P) had a relatively steady average indoor air temperature (between 29 and 30 ℃) and relative humidity (between 75 and 77%) during the daytime intervals of the measurement period.



(a) (b)

Figure 17. Input results during the day time intervals of the selected public buildings: (a) air temperature of all the measured rooms and points. (b) Relative humidity of all the measured rooms and points.



(a) (b)

Figure 18. The variation of Indoor Average air temperature and relative humidity between the selected public buildings: (a) indoor air temperature (b) indoor relative humidity

B. Variation in the Air Temperature and Relative Humidity of the Selected Public Buildings for Each Measured Day

All the selected public buildings have a western orientation and are built of sandstone, which may explain the reason for the parallel lines of the indoor parameter averages for each measured day, as shown in Fig. 18. The relative humidity was inversely proportional to the indoor air temperature in all the selected buildings. The public gallery (G) showed the highest averages of relative humidity and the lowest averages of indoor air temperature during the measurement period compared with the other measured spaces. Building (T) and the print shop (P) had high humidity levels in sync with the high indoor temperatures, which lead to an inefficient evaporative cooling of the skin that caused discomfort. Despite having the highest average temperature values, the indoor relative humidity average values in building (D) were better than those of the other buildings, which led to more human comfort inside the rooms.

C. Thermal Comfort Indices

The calculations of the thermal comfort indices, the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD), for the selected public buildings (D), (T), (G) and (P) were performed by using the CBE Thermal Comfort Tool of the University of California Berkeley that has been proposed based on ASHRAE Standard 55-2013 [17], [18]. The result obtained after calculating the PMV index for building (D) varied from 2.71 for the first floor to 4.21 for the second floor, with a mean value of 3.21 for the all the building rooms. For building (T), the range was from 1.15 for the second floor to 2.35 for the first floor, with a mean value of 2.05. The average for PMV of the gallery (G) was 1.23, and for the print shop (P) was 1.95. By equating to the ASHRAE thermal sensation scale (-3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot), the results show that building (D) was observed to be in the range of the "hot" category with average PPD 93.33%. Building (T) was in the range of the "warm" category with average PPD 75.25%. The public gallery (G) was "slightly warm", and average PPD 37.25%. The print shop (P) average PPD was 74% of dissatisfied users and classified in "warm" category. These case studies' results were expected to be dissatisfied (uncomfortable) with the thermal environment, where the required PPD value should be less than 10% according to ASHRAE standard, as shown in Table IV.

TABLE IV. THE AVERAGES VALUES OF THE THERMAL COMFORT INDICES FOR THE SELECTED PUBLIC BUILDINGS.

	D		T		G		p	
	PMV	PPD (%)	PMV	PPD (%)	PMV	PPD (%)	PMV	PPD (%)
Building	3.21	93.33	2.05	75.25	1.23	37.25	1.95	74
First floor	2.71	90	2.35	89.33				
Second floor	4.21	100	1.15	33				
Category	hot		warm		slightly warm		warm	

VI. Comparisons and Conclusions

A. Comparison with Previous Studies and International Standards

No regulations specify the thermal standards for the workplace in Syria. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 55-2010 recommend the Temperature/Humidity Ranges for Comfort for the summer period with light clothing. The ASHRAE's acceptable ranges of operative temperatures are 24.5 to 28 ℃ and 23 to 25.5 ℃ for the relative humidity levels of 30% and 60%, respectively [16]. A high relative humidity supports mold and bacterial growth and causes discomfort such as excessive perspiration and exacerbation of the effects of high temperature. A low relative humidity can cause respiratory problems. According to EN15251 [19], increased airspeed using personal ventilation systems or fans may be applied to elevate the upper comfort temperature limit when indoor operative temperatures exceed 25 ℃ in summer. Many researchers have examined the comfort of ASHRAE-55 for their countries in recent decades. Although the results of thermal temperature in different studies are different, the common point is that either they are very close to the indoor air temperature or above the limit of the required indoor temperature. Additionally, the occupants of the historical and natural ventilation buildings were more tolerant of the thermal environment than the new building occupants.

The subjective and objective results of our survey are shown in Table V. According to the results of the thermal questionnaire, the indoor air temperature values of the selected samples ranged from 26.4 to 31.7 ℃. The relative humidity values ranged from 52.7% to 96.2%. The wind speed values ranged from 0.04 to 0.97 m/s; the calculated operative temperature ranged from 28.25 to 32.23 ℃. According to the field measurement results, the indoor air temperature values ranged from 26.4 to 32.9 ℃, the relative humidity values ranged from 49.7 to 96.2%, and the wind speed values ranged from 0.04 to 0.67 m/s. The measured indoor air temperature and relative humidity compared with the ASHRAE range show that none of the studied samples were within the required limits. Based on the regression analysis in the subjective survey, the comfort band was 29.8-31.2 ℃, with a neutral thermal temperature of approximately 30.5 ℃ for building (D), and 27.63-29.3 ℃, with a neutral thermal temperature of approximately 28.625 ℃ for building (T). The comfort band in both office buildings fall in a narrow range of temperatures. The occupants showed more tolerance for hot conditions than that is specified by ASHRAE Standard 55-2010 [16]. Based on the objective results, all of the selected cases have Predicted Mean Vote (PMV) values that are outside the neutral range (-1, 0, +1). Therefore, all of these cases did not comply with ASHRAE Standard 55-2013 and were classified into the hot and slightly warm categories [17].

To investigate the thermal sensation of the building occupants and find the comfort zone, most of the previous studies were conducted in hot and humid climates. The thermal comfort zones depend on the regional climate. There is a limited amount of literature on human comfort and on historic or office buildings in moderate or eastern Mediterranean climates. Our values for neutral temperature are higher than those we found using the equations by de Dear et al, Auliciemes, Humphreys, and our previous survey in the historic residential buildings of the old city of Tartous, which were collected at the same time in summer 2016 [14], by more than 2.5 ℃, as shown in Table VI. The reason could be related to the buildings envelope and their openings oriented to the prevailing wind in summer.

TABLE V. The Subjective and Objective Results of the Indoor Parameters and Thermal Indices for the Public Buildings

	Subjective survey						Objective results				
Building	**Air temperature (℃)**	**Relative humidity (%)**	**Airspeed average (m/s)**	**OP (℃)**	**Comfort band**	**Neutral temperature (℃)**	**Air temperature (℃)**	**Relative humidity (%)**	**PMV band**	**PPD (%)**	**Category**
D	29.65- 31.7	60 - 77	0.25	32.23	29.8-31.2	30.5 ℃	28.4 - 32.9	49.7-72.4	-3.21<PMV<+3.21	93.33	Hot
T	27.6 - 31.6	52.7-84.1	0.19	31.21	27.63-29.63	28.625	27.6 - 31.6	52.7-84.1	-2.05<PMV<+2.05	75.25	Warm
G			Not surveyed				26.4 - 30.5	74.6-96.2	-1.23<PMV<+1.23	37.25	Slightly warm
P			Not surveyed				29.2 - 31	68.1-78.4	-1.95<PMV<+1.95	74	Warm
ASHRAE 55-2010		30-60%			23-25.5			30-60%	-1< PMV< +1	10%	Neutral

TABLE VI. The Comfort Band of the Old City of Tartous According to de Dear et al', Auliciemes, and Humphreys Neutral Temperature Methods, Residential Buildings Survey, and Our Survey

	Summer comfort limits for old city of Tartous based on the previous studies				This survey	This survey
	de Dear et al	**Humphreys**	**Auliciemes**	**Hassan, et al**	**Office building (T)**	**Office building(D)**
Equation	Tn = 17.8 + 0.31 Tm	Tn=11.9 + 0.534 Tm	Tn=17.6 +0.314 Tm	TSV(R) = 0.4223 OP-11.366	TSV(T) = OP- 28.625	TSV(D) = 1.425op - 43.463
Notice	Where Tartous winter Tm =12 ℃ and Tartous summer Tm =26.5 ℃			R^2= 0.782	R^2= 0.8421	R^2= 0.7934
Neutrality tem Tn (℃)	**26**	**26.1**	**25.9**	**26.42**	**28.625**	**30.5**
Comfort zone (℃)	**23.5 – 28.5**	**23.6-28.6**	**23.4- 28.4**	**24.05-28.78**	**27.63-29.63**	**29.8-31.2**

B. Conclusions and Further Work

The thermal comfort results for four public historic structures in the old city of Tartous during August 2016 were presented. Building envelope, architectural design, and materials data of the selected structures were collected, and the indoor environment parameters were measured and assessed. The sample size of the office questionnaires was approximately 80% of the total number of staff in both selected office buildings. Our results could be useful for further studies and could be used as a dataset for establishing a local thermal comfort standard. The conclusions of this study are summarized as follows:

From the results obtained in the four selected public buildings, it can be seen that most of the measured temperature and relative humidity values exceeded the acceptable operative temperature ranges based on the comfort zone diagram during summer conditions of ASHRAE Standard 55-2004. The occupants were sensitive to the humidity, particularly the occupants of building (T). The clothing adaptation was a relatively light, formal type related to the clothing of common people. The clothing insulation values in both office buildings for both genders were near the value of 0.5 Clo suggested for the summer season in the ASHRAE Standard 55-2004.

Thermal comfort indices, a comfort band, and a predicted neutral temperature were determined and compared with the international standards. The neutral temperature was approximately 30.5 ℃ for building (D), and 28.625 ℃ for building (T). By comparing the objective and subjective results, the rooms in building (T) had a PPD of 75.25%, which was operating with unanimously unacceptable indoor environment complied with the results of the thermal preference of the questionnaire of the subjective survey, where (75%) of the respondents voted between “warm and hot sensation” due to the lack of ventilation. On the other hand, the predicted dissatisfaction of building (D), with PPD of 93.33%, did not comply with the actual occupant thermal acceptability and preference results of the questionnaire. However, approximately two-thirds of the participants in building (D) accepted the overall temperature of their building. More than half of the respondents in building (D) (56.9%) voted between “neutral and slightly warm sensation”, and 41.4% voted between "warm and hot sensation”. The Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) of all four measured samples did not comply with the International Standards. That emphasized the importance of more research for finding local adapting thermal standards for naturally ventilated and historic buildings.

All the monitored public historic structures are built of sandstone and have the same building orientation. Therefore, the building envelope and the ventilation for each floor play a significant role in the thermal performance and occupant satisfaction. Each floor has a different thermal mass related to the construction periods (Crusader, Ottoman, late Ottoman and French period), which causes a different thermal behavior. In this study, the Crusader period structure is a massive sandstone structure with high relative humidity and a slight difference in the indoor air temperature and relative humidity between the nighttime and daytime and an apparent difference in values between the indoor and outdoor air temperature during the operating time. The Ottoman period rooms had a relatively stable indoor air temperature and relative humidity values, a slight difference between the nighttime and daytime, and indoor air temperature values less than the outdoor air temperature by approximately 0.5-1 ℃. The late Ottoman period and French period rooms had a noticeable difference for the indoor air temperature between night and daytime; the differences were more noticeable in the latter. Their thermal mass and their last roof facing the solar radiation cause the indoor air temperature to be higher than or approximately equal to the outdoor air temperature.

Regardless of the temperature, occupants accepted the air movement in their rooms in the two measured office buildings. The current ventilation was not providing the desired comfort conditions of the occupants in building (T), whereas half of the occupants in building (D) preferred no change in the air flow. Providing the proper cross-ventilation could enhance the occupant satisfaction and the thermal comfort in the historic buildings. According to the measurements, the rooms of building (D) and the second floor of building (T) had proper ventilation. However, an increase in the indoor wind flow values between 0.07 and 0.11 m/s in the rooms of the first floor of building (T) and in the public multifunctional gallery (G) was needed.

Preservation of the built heritage is an essential task for both societal and community well-being. Special considerations need to be taken when suggesting the appropriate usage function of heritage buildings. Improvements considering the building envelope and value are helpful to adapt the indoor environment for the occupants and to increase productivity during the operating hours. Further studies related to the adaptive reuse and thermal performance of historic buildings are recommended. A computer simulation for the selected buildings could help in validating the thermal results, and year-round studies could give a comprehensive image of the thermal performance and needs. Future thermal studies should be carried out in other historic sites on the Syrian coast to collect a dataset as a base to define the current situation, determine proper key strategies, and find a way to improve the indoor environment of these historic buildings.

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