Chapter

Adaptive Thermal Comfort of an Office for Energy Consumption-Famagusta Case

Halil Zafer Alibaba

Abstract

The aim of this study was to determine how much thermal comfort can be obtained through heat/energy transfers between the office/external air and the transparent/opaque surfaces of an office by combining different transparent and opaque wall surface ratios with different window opening percentages using dynamic thermal simulations. It found that the optimum window-to-wall ratio (WWR) for energy conservation is 40%, with a 20% window opening ratio. The 80% and 90% thermal comfort ranges of the adaptive thermal comfort methodology are found in May, October, September, and the yearly average, while June and August are only in the range of 80% acceptability. The office constantly loses heat through air flow with any glass size on its external facade and any window opening ratio. Moreover, all sizes of opaque and transparent internal surfaces transferred heat from outside by conduction, while the opaque wall similarly always transferred energy to heat up the office air internally and outside air externally through convection. The external glass also heats the office air by convection, except in the months of January, November, and December.

Keywords: passive heating and cooling, transparency ratio of the skin, adaptive thermal comfort, conduction, convection

1. Introduction

Natural ventilation has great potential for cooling buildings with a passive strategy because it improves user comfort and indoor air quality, while simultaneously reducing electricity usage demand [1–5]. Thermal comfort has a great impact on the well-being and performance of users, as well as the energy requirements of buildings [6]. Moreover, in developed countries, people spend 90% of their time indoors, which requires securing their well-being and a healthy environment [7].

Reducing active cooling requires passive solutions; therefore, utilizing glass on external walls has a great impact on thermal situations through its influence on energy demand for the cooling and heating of buildings [8].

An adaptive approach to thermal comfort relies on outdoor air temperature and the individuals' thermal environment [9]. Adaptive comfort limits are similar for hot-humid and hot-dry climates with a 0.6 coefficient value. Additionally, air movement is important for a hot-humid climate, while indoor relative humidity (RH) is important for a hot-dry climate [10]. In hot-humid climate environments, relative humidity is not significant when it is below 70%, but is really significant when higher than 70% with increasing air temperature [11].

Sustainable approaches for energy efficient buildings are very important to architects and engineers for the provision of comfortable and health-conscious buildings [12]. In addition to these, adaptive thermal comfort can be used to design energy efficient (low-energy) naturally ventilated buildings around the world [13].

The aim of this study was to determine the minimum, maximum, and yearly averages of naturally ventilated office performance, as well as the impact of the wall-to-window ratio on thermal comfort due to solar gain, heat loss, resultant temperature, relative humidity, and external air temperature. Moreover, the analysis focuses on the office's performance in relation to the winter and summer season (based on each month), heat transfer (conduction), and energy transfer (convection) for opaque and glass walls (internally and externally). In identifying the naturally ventilated office performance (minimum, maximum, and yearly) and the seasonal performance of the office (based on conduction-convection), this article hopes to fill in existing gaps in the literature for hot-humid climatic conditions.

2. Literature review

Heat transfer through the opaque walls of buildings is important for energy saving and thermal comfort issues. Cities in Turkey such as Ankara, Erzurum, Istanbul, and Izmir with different climates were analyzed using the TS825 standard (Turkish standard on thermal insulation requirements for buildings) [14]. It was found that 15-cm- and 25-cm-thick sandwich panels created a decrease of 65% and 80% heat loss and gain respectively during the worst winter and summer conditions. The optimal heat loss and gain ratios under different climatic conditions were determined using sandwich wall insulation. Heat transfer for different building orientations was found to be longer in the summer period due to solar radiation [15]. Radiative heat transfer was higher during daytime than the evening in summer, with no significant changes during the spring, autumn, and winter periods [16].

In the subtropical climate of China, out of eight free-running dormitories, 1829 returned questionnaires with subjective scales indicated that 15.9–28.2°C were acceptable temperatures, where 23.2°C was the preferred temperature and 22.1°C was the neutral temperature based on students' thermal perception and preferences. Moreover, the students' air movement sensation was 53% satisfied with the indoor air humidity when thermal sensation was neutral [17]. In Tuxtla Gutiérrez-México, 496 data points were collected from 27 educational buildings in the warm season. In air-conditioned mode, 48.1% of users felt comfortable, 44% felt cold, and 7.9% felt warmth. However, in naturally ventilated mode, 59.7% felt comfortable, 11% felt cold, and 29.3% felt warmth. Most of those who felt cold can have their thermal satisfaction improved by adapting rooms to slightly higher temperatures [18]. In the hot-humid part of China, naturally ventilated buildings have a thermal neutrality of 25.4°C, 23.5°C for 90% acceptability, and 27.4°C for the 80% acceptability range. In naturally ventilated buildings in China with a hot-humid climate, the Predicted Mean Vote (PMV) model can be used with a 0.822 expectancy factor [19].

In two Indian cities, Chennai with a humid climate and Hyderabad with a composite climate, the mean room temperature was 28.8°C for naturally ventilated mode but 26.2°C for air-conditioned mode with 45% and 48% relative humidity ratios, respectively [20].

Naturally ventilated buildings in hot-humid climate conditions should have a minimum of 0.65 m/s indoor air speed for thermal comfort [10]. In north-east Brazil, 90% acceptability of thermal comfort for a naturally ventilated building needs from 24 to 27°C room temperature with 0.4 m/s air movement, while from 27 to 29°C needs a minimum of 0.41–0.81 m/s air velocity, and a room temperature from 29 to 31°C needs a minimum of >0.81 m/s air velocity [21].

Tianjin is a city in China where 80% adaptive comfort acceptability ranges between room temperatures of 21°C and 27.3°C [22].

The national code for India has a narrow thermal comfort range that is between 21 and 26°C for all naturally ventilated building types and seasons. A questionnaire with 2610 responses found that the comfort ranges were 30.6°C with 0.30 clo dress and 0.62 m/s preferred air velocity for the summer season, and 25.2°C with 0.80 clo dress and 0.27 m/s preferred air velocity for the winter season [23].

A survey conducted in Spain found that 23.6°C is the observable average operative temperature in (free-running and air-conditioned) buildings. Moreover, it is very clear that an adaptive comfort model is suitable for hybrid buildings [24]. In India, the ideal comfort temperature was determined to be 27.3°C, while the actual preferred temperature is 24.5°C. Half of all the fans in offices start working after 31°C, with no fan needed up to 22.5°C [25].

3. Methodology

3.1 Adaptive thermal comfort method

Dynamic thermal simulations for this article were generated using the thermal analysis software EDSL Tas version 9.4.4 [26], which was simulated for Famagusta with hot and humid climatic conditions. The location of Famagusta can be seen in **Figure 1**. ASHRAE 55-2017 [28] standard for adaptive thermal comfort for 80% and 90% can

Figure 1.
Location of Famagusta on the map [27].

be observed in **Figure 2**. Heat transfer (conduction) and energy transfer (convection) opportunities were analyzed for the internal and external surfaces of both opaque and transparent surfaces in an office. Moreover, the office environment was that of a regular office (3 m by 5 m), including standard construction materials with one inlet and outlet function. The three-dimension (3D) and plan of the case study building can be seen in **Figure 3**. Furthermore, the weather file for Famagusta was also used for the simulations, as shown in **Figure 4**. Transparent surfaces on opaque walls and window opening percentages ranged from 10 to 100% each. A typical section of the case study building can be seen in **Figure 5** along with its yearly performances. In this chapter, all of the simulations used 0.5 ach of infiltration and 0 W/m^2 (lighting gain, occupancy/equipment gain) with 0.01 (CO_2)/hr/m^2 pollutant generations.

The opaque and transparent components of the case-study building are detailed in **Tables 1** and **2**. ASHRAE 55-2017 [28] was used to generate the acceptable thermal comfort conditions, shown in **Table 3** (80% and 90%), of a naturally ventilated office environment with minimum, maximum, and average yearly performances for solar gain (W), infiltration gain-heat lost (W), resultant temperature (°C), relative humidity (%), and external temperature (°C).

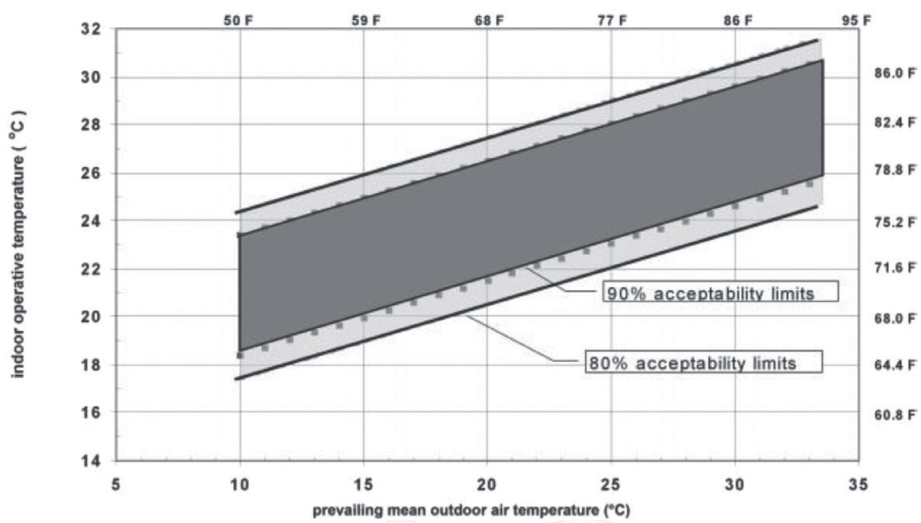


Figure 2.
ASHRAE 55-2017 standard on acceptable limits for the resultant temperature of a naturally ventilated building with met: 1.0–1.3 and 0.5–1.0 clo when the prevailing mean outdoor temperature is greater than 10°C and less than 33.5°C [28].

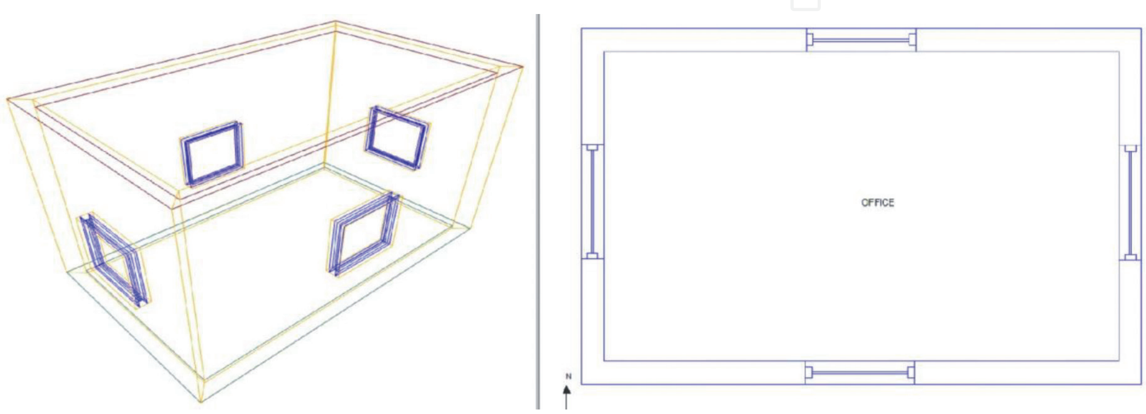
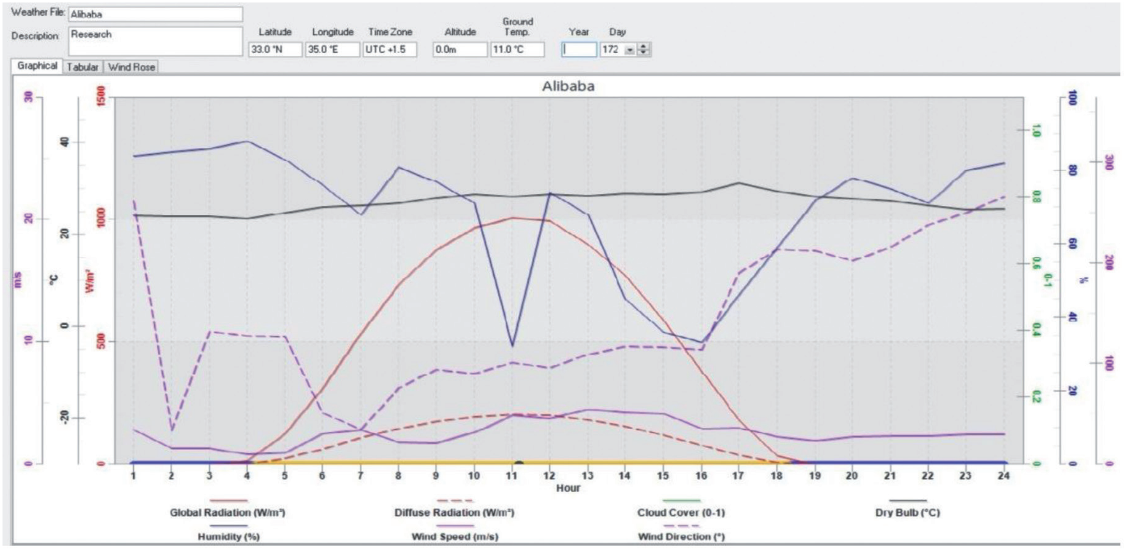
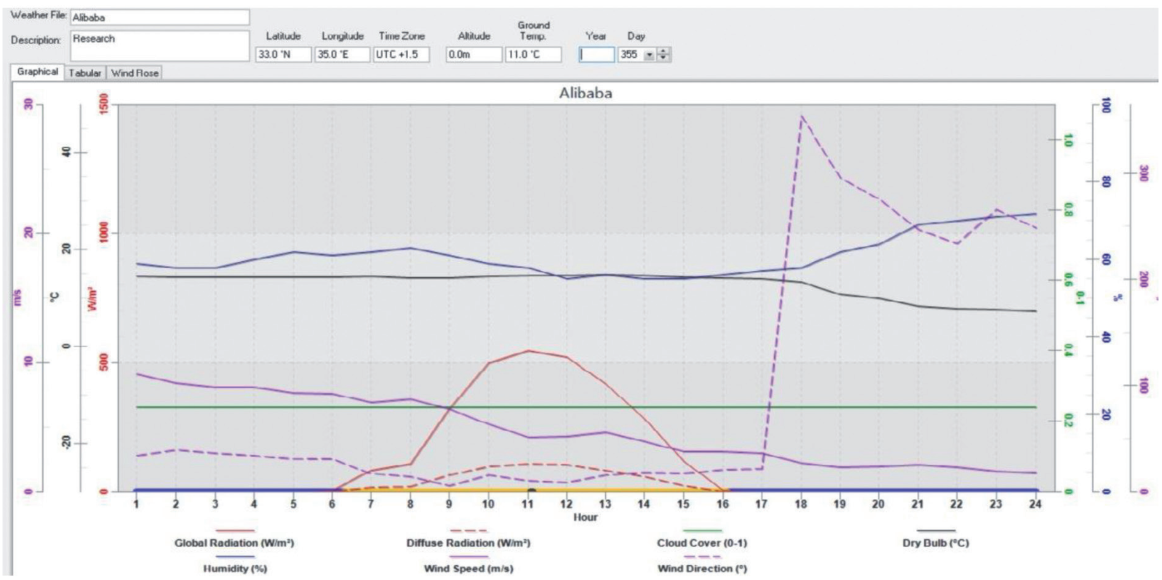


Figure 3.
The case study building.



(a)



(b)

Figure 4.
Examples from the Famagusta weather file of (a) day 172 for 21st June representing the summer period and (b) day 355 for 21st December representing the winter period.

Solar gain, heat lost, resultant temperature, relative humidity, and external temperature are the parameters analyzed in this article as the minimum, maximum, and yearly averages for the different window openings and sizes. Seasonal conduction and convection performances of the studied office are based on monthly analysis, taken in conjunction with opaque/glass surface performances for internal/external surfaces. Global solar radiation (W/m^2), diffuse solar radiation (W/m^2), cloud cover (0–1), dry bulb temperature (°C), relative humidity (%), wind speed (m/s), and wind direction (°) are parameters used in the weather file of Famagusta for simulations as seen in **Figure 4**.

3.2 Inter-model validation of the article

An inter-model validation model for annual heat loss is used in this article because its numerical results are compared with previous results in the literature. Badeche and

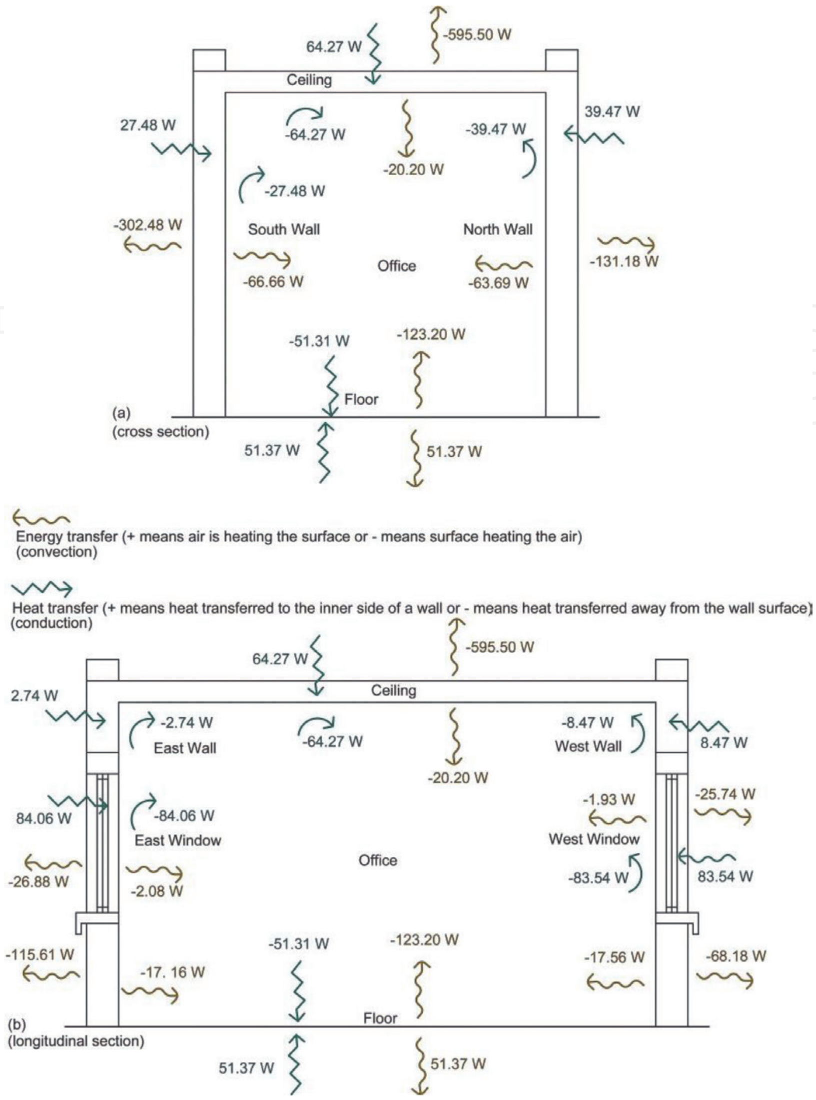


Figure 5.
Yearly average heat and energy transfer performance (for all window opening percentages with all window sizes) of the simulated office.

Plastered solid brick wall	External/ internal solar reflectance	External/ internal emissivity	Conductivity (W/m °C)	Convection coefficient (W/m^2 °C)	Vapor diffusion factor	Density (kg/m^3)	Specific heat (J/kg/°C)
12-mm plaster (inside)	0.600	0.900	0.3	0.0	11.000	960.0	837.0
200-mm solid brick wall	0.350	0.900	0.317	0.0	14.800	1040.0	1050.0
12-mm cement-based plaster	0.600	0.900	0.3	0.0	11.000	960.0	837.0

Flow direction	Internal R value (m^2·°C/W)	External R value (m^2·°C/W)	Internal U value (W/m^2·°C)	External U value (W/m^2·°C)
Horizontal	0.971	0.881	1.03	1.135
Upward	0.911	0.851	1.098	1.175
Downward	1.051	0.921	0.952	1.086

Table 1.
Solid wall properties of the case study building.

Clear 6-12-6 double glazing low E	**Dimensionless parameters**							**Convection coefficient (W/m^2 °C)**	**Specific heat (J/kg·°C)**
	Solar transmittance	**External solar reflectance**	**Internal solar reflectance**	**External emissivity**	**Internal emissivity**	**Conductivity (W/m·°C)**	**Vapor diffusion factor**		
6-mm clear glass	0.630	0.200	0.150	0.120	0.845	1.0	99,999.000	0.0	0.0
12-mm air	0.000	0.000	0.000	0.000	0.000	0.0	1.000	2.08	0.0
6-mm clear glass	0.780	0.070	0.070	0.845	0.845	1.0	99,999.000	0.0	0.0
R value (m^2·°C/W): 0.555							U value (W/m^2·°C): 1.803		

Light		**Solar energy (EN410)**				**Pilkington shading coefficients**		
Transmittance	**Reflectance**	**Direct transmittance**	**Direct reflectance**	**Direct absorptance**	**Total transmittance (G value)**	**Short wavelength**	**Long wavelength**	**Total**
0.760	0.120	0.498	0.193	0.308	0.616	0.573	0.136	0.709

Table 2.
Glass properties of the case study building.

<table>
<tr><th rowspan="2">Months</th><th rowspan="2" colspan="2">Remarks</th><th colspan="2">Yearly averages</th><th colspan="2">Thermally comfortable months (ranges)</th><th rowspan="2">Never thermally comfortable months</th></tr>
<tr><th>External temperature (°C)</th><th>Resultant temperature (°C)</th><th>90% acceptable months</th><th>80% acceptable months</th></tr>
<tr><td>January</td><td rowspan="4" colspan="2">Cool period (below 80–90% ranges)</td><td>10.93</td><td>12.28</td><td rowspan="4" colspan="2">×</td><td rowspan="4">√</td></tr>
<tr><td>February</td><td>12.77</td><td>14.27</td></tr>
<tr><td>March</td><td>14</td><td>16</td></tr>
<tr><td>April</td><td>16.23</td><td>18.51</td></tr>
<tr><td>May</td><td rowspan="6">Warm period</td><td>Within 80–90% ranges</td><td>21.36</td><td>23.86</td><td colspan="2">√</td><td rowspan="2">×</td></tr>
<tr><td>June</td><td>Only in 80% range</td><td>26.03</td><td>28.98</td><td>×</td><td>√</td></tr>
<tr><td>July</td><td>Hot (above 80–90% ranges)</td><td>28.35</td><td>31.21</td><td colspan="2">×</td><td>√</td></tr>
<tr><td>August</td><td>Only in 80% range</td><td>28.43</td><td>30.85</td><td>×</td><td>√</td><td rowspan="3">×</td></tr>
<tr><td>September</td><td rowspan="2">Within 80–90% ranges</td><td>25.70</td><td>27.81</td><td rowspan="2" colspan="2">√</td></tr>
<tr><td>October</td><td>22.83</td><td>24.60</td></tr>
<tr><td>November</td><td rowspan="2" colspan="2">Cool period (below 80–90% ranges)</td><td>17.91</td><td>19.11</td><td rowspan="2" colspan="2">×</td><td rowspan="2">√</td></tr>
<tr><td>December</td><td>13.65</td><td>14.86</td></tr>
<tr><td colspan="2">Averages of the whole year</td><td>Within 80–90% ranges</td><td>19.89</td><td>21.91</td><td colspan="2">√</td><td>×</td></tr>
</table>

Table 3.
The acceptable, cool, and hot months for the simulated office.

Bouchahm [29] identify the optimum window-to-wall ratio (WWR) as 40–50% for energy saving in the Mediterranean climate. Goia [30] found that a WWR between 30–40% is needed for energy saving. Moreover, in this article, the optimum window-to-wall ratio (WWR) is 40% with a 20% window opening for heat loss, thus confirming harmony between the results (10% up or down for different studies), as shown in **Table 2**.

3.3 Findings and discussions

The resultant temperature (operative temperature-°C) is analyzed using ASHRAE 55-2017 [28] to determine when the naturally ventilated office is within acceptable ranges. The averages for May, September, October, and the yearly average are in the range of 80% and 90% acceptability. In addition to these, June and August are only in the 80% acceptability range. Therefore, January, February, March, April, November, and December are considered cool months by virtue of being below the acceptable ranges; but only July is considered hot because it is above the acceptable ranges, as can be seen in **Table 3**.

The yearly average solar gain (for all glass sizes and window opening percentages) of the office is 674.30 W, which also occurs when half of the skin is made of glass with a fully open window. When the glass size on the external skin is changed from 10 to 20%, solar gain increased by 113%. When the glass size on the external skin changed from 20 to 30%, solar gain experienced a 48% increase. When the glass size on the external skin changed from 30 to 40%, solar gain increased by 25%. When the glass size on the external skin changed from 40 to 50%, solar gain increased by 21%. When the glass size on the external skin changed from 50 to 60%, solar gain increased by 20%. When the glass size on the external skin changed from 60 to 70%, solar gain increased by 12%. When the glass size on the external skin changed from 70 to 80%, solar gain increased by 13%. When the glass size on the external skin changed from 80 to 90%, solar gain experienced an 8% increase. When the glass size on the external skin changed from 90 to 100% (full opening), solar gain increased by 8.5%. When the glass size on the external skin changed from 10 to 100%, there was a 763.16% increase in solar gain. Conversely, window opening percentages never affected solar gain, as shown in **Table 4**.

The yearly average infiltration ventilation gain (heat gained or lost by air flow) in the office for all glass sizes and window opening percentages reported a heat loss of 311.49 watts. Regardless of the glass size on the external skin or window opening percentage, the office is always losing heat during hot and humid climatic conditions. When the window opening percentage was set between 10 and 100% (from smallest to largest), the office lost 100% heat when the glass size on the external skin was 10%, 43.24% when the glass size on the skin was 20%, 37.80% when the glass size on the skin was 30%, 30.58% when the glass size on the skin was 40%, 33.78% when the glass size on the skin was 50%, 23.67% when the glass size on the skin was 60%, 28% when the glass size on the skin was 70%, 27.35% when the glass size on the skin was 80%, 38.10% when the glass size on the skin was 90%, and 40.84% when the glass size on the skin was 100%. A maximum of 100% heat loss occurred when the glass size was only 10% with all ratios of window openings, while the minimum of 23.67% heat loss occurred when the glass size was 60% of the external skin with all window opening ratios. However, when the window was 10% opened with all sizes of glass on the external facade (from smallest to largest), the office lost 762% of its heat; when the window was 20% opened with all sizes of glass on the facade, the office lost 622% heat; when the window was 30% opened with all sizes of glass on the facade, the office lost 506% heat; when the window was 40%, 70% and 80% opened with all sizes of glass on the facade, the office lost ~485% heat; when the window was half open with all sizes of glass on the façade, the office lost 458% of its heat; when the window was 60% open with all sizes of glass on the facade, the office lost 473% heat; when the window was 90% open with all sizes of glass on the façade, the office lost 516% heat; and when the window was fully open with all sizes of glass on the facade, the office lost 507% of its heat. The maximum 762% heat loss occurred when the window was always 10% opened with all sizes of glass on the external skin and the minimum 458% heat loss occurred when the window was always opened halfway with all sizes of glass on the external skin, as shown in **Table 4**.

In the hot and humid climatic conditions of Famagusta, the yearly average external environmental temperature of 19.89°C is close to the monthly average of 17.91°C in November. The yearly average resultant temperature (for all external glass skin sizes and window opening percentages) for the simulated office was 21.91°C, which is also very closely achieved when the glass skin is 40% of the opaque skin with a 20% window opening ratio, half of the skin is glass with 40% and 50% window opening

Parameters		Performances	Yearly averages (with all window sizes and openings)
Solar gain	Min.	75.19 W (December-Min.) + 133.04 W (yearly Avrg.) 10–90% window opening with 10% glass on skin	674.30 W
	Max.	1721.18 W (June-Max.) + 1148.66 W (yearly Avrg.) 10–20%, 40%, 60–100% window opening with fully glazed skin	
Heat loss (W)	Min.	−950.23 W (June-Min.) + −607.70 W (yearly Avrg.) Fully opened window with fully glazed skin	−311.49 W (−238 W for optimum WWR because of optimum heat loss when glass size is 40% and window opening is 20%)
	Max.	−24.51 W (January-Max.) + −50.06 W (yearly Avrg.) 10% window opening with 10% glass on skin	
For yearly-based energy reduction (energy saving) optimum WWR is 40–50% according to Badeche and Bouchahm [29]. Moreover, in this article, the optimum WWR is 40% with 20% window opening for heat loss (energy saving).			
Resultant temp. (°C)	Min.	11.47°C (January-Min.) + 20.73°C (yearly Avrg.) Fully open window with 10% glass on skin	21.91°C
	Max.	32.61°C (July-Max.) + 22.94°C (yearly Avrg.) 10% open window with fully glazed skin	
RH for office (%)	Min.	59.02% (June-Min.) + 64.45% (yearly Avrg.) 10% open window with 10% glass on skin	67.56%
	Max.	77.42% (February-Max.) + 68.63% (yearly Avrg.) Fully opened window with fully glazed skin	
Ext. temp. (°C)	Min.	10.93°C (Min.) January (Avrg.)	19.89°C Whole year (Avrg.)
	Max.	28.43°C (Max.) August (Avrg.)	

Table 4.
Performance of the office space in terms of solar gain, heat loss-gain, resultant temperature, relative humidity, and external temperature.

percentages, and 60% of the skin is glass with 80–100% window opening percentages. When the windows are between 10 and 100% opened (increasing the opening ratio), the resultant temperature decreased by 2.58% when the skin is 10% glass, 3.09% when the skin has a 20, 30, 90, and 100% glass facade, 2.75% when the skin has 40% glass, 2.46% when the external skin is half constructed of glass, 3.14% when the skin has 60% glass, and 3.24% when the external skin is 70 and 80% glass on the facade, as shown in **Table 4**. However, when the window was 10% and 80% open with all sizes of glass on the external skin (from smallest to largest), the resultant temperature increased by 7.8%. When the window was 20% open, the resultant temperature increased by 7.63% with all sizes of glass on the external skin (from smallest to largest); when the window was 30% open with all sizes of glass on the external skin (from smallest to largest), the resultant temperature increased by 7.59%; when the window was 40% open with all sizes of glass on the external skin (from smallest to largest), the resultant temperature increased by 8.04%; when the window was 50% open with all sizes of glass on the external skin (from smallest to largest), the resultant temperature increased by 7.73%; when the window was 60% open with all sizes of glass on the external skin (from smallest to largest), the resultant temperature increased by 8.08%; when the window was 70% open with all sizes of glass on the external skin (from smallest to largest), the resultant temperature increased by 7.94%; when the window was 90% open with all sizes of glass on the external skin (starts from smallest to largest), the resultant temperature increased by 7.63%; and when the window was 100% open with all sizes of glass on the external skin (from smallest to largest), the resultant temperature increased by 7.28%, as shown in **Table 4**.

The yearly average relative humidity of the office is 67.56% for all glass sizes on the external skin with all window opening ratios. Moreover, the yearly average relative humidity (aforesaid) is also observed in the office when the glass skin is 10% of the external skin with a 60% to fully open window, when the glass skin is 20% of the external skin with a 40–80% open window, when the glass skin is 30% of the skin with a half open window, when the glass is 40% of the skin with a 20–40% open window, when half of the skin is glass with a 40% open window, when glass is 60–80% of the external skin with a 30–40% open window, and when the glass is 90%and 100% (fully glazed external skin) with a 30% open window. When the window is opened at all ratios (10% to fully opened, starting from smallest to largest), relative humidity increased by 5% when the external skin is 10, 50, and 60% glass, 5.74% when the external skin is 20% glass, 5.96% when the external skin is 30% glass, 5.39% when the external skin is 40% glass, 4.77% when the external skin is 70% glass, 4.52% when the external skin is 80% glass, 4.3% when the external skin is 90% glass, and 4% when the external skin is fully constructed of glass. However, when the external skin has 10–100% glass on the facade (from smallest to largest), relative humidity increases by 2.31% when the window is 10% open, 2.84% when the window is 20% open, 2.5% when the window is 30% open, 2.18% when the window is 40% open, 2% when the window is half open, 1.8% when the window is 60% open, 1.65% when the window is 70% open, 1.5% when the window is 80% open, 1.69% when the window is 90% open, and 1.34% when the window is fully open, as shown in **Table 4**.

Heat is always being transferred away from the internal surface of the opaque wall of the simulated office in all seasons. The minimum heat transfer from the internal surface of the opaque wall for all glass sizes on the external skin and all window opening percentages is in June, during the summer period, at −48.64 W, while the maximum heat transfer is during the winter season in December at −21.26 W. The heat of an opaque wall is always being transferred from the outside surface toward the inside surface in all seasons. The minimum heat transfer from the outside surface of the opaque wall to its inside surface is during the winter season in February at 16.96 W, while the maximum heat transfer is during the summer season in September at 41.31 W. Heat is always being transferred away from the internal surface of the glass wall in the simulated office during all seasons. The minimum heat transfer from the internal surface of a glass surface occurred during the summer season in June at −116.40 W, with the maximum heat transfer during the winter season in November at −58.17 W. The heat on a glass surface is always being transferred from the outside surface toward the inside surface of the glass during all seasons. The minimum heat transfer from the outside surface of the glass to the inside surface is during the winter season in November at 58.17 W, while the maximum heat transfer from the outside to the inside surface of the glass surface is during the summer season in June at 116.40 W, as shown in **Table 5** and **Figure 5**.

The internal surface of an opaque wall in the simulated office always transfers energy to heat the office air during all seasons. The minimum energy transfer from the internal surface of the opaque wall into the office air is in June at −79.07 W during the summer season, while the maximum energy transfer from the internal surface of the opaque wall into the office air is during the winter season in November at −29.12 W. The external opaque wall is always transferring energy to the external air during all seasons. The minimum energy transfer from the external opaque wall into the external air is during the summer season in June at −313.09 W, while the maximum energy transfer from the external opaque wall into the external air is during the winter season in November at −89.89 W. The internal glass surface in the simulated office is always transferring energy to heat the office air during all seasons, except in January, November, and December because energy transfer in the these three months flows from the external air to the internal surface of the glass to heat it. The minimum energy transfer from the internal surface of the glass surface is during the summer season in July at −5.21 W, while the maximum energy transfer from the internal surface of the glass into the office to heat the office air is in October during the summer season at −1.33 W; however, the internal surface of the glass is heated by the office air in January at 1.86 W, in November at 0.69 W, and in December at 0.77, all during the winter season. The external surface of a glass in the simulated office is always transferring energy to heat the office during all seasons, except in January, November, and

		All window sizes with all window openings (10–100%)							
		Heat transfer (conduction)				**Energy transfer (convection)**			
		Opaque (W)		**Glass (W)**		**Opaque (W)**		**Glass (W)**	
		Internal	**External**	**Internal**	**External**	**Internal**	**External**	**Internal**	**External**
Winter season	January	−23.53	27.34	−65	65	−31.19	−94.42	*1.86*	*12.40*
	February	−24.19	**16.96**	−62.05	62.05	−37.41	−160.27	−1.58	−17.38
	March	−30.69	29.25	−84.96	84.96	−52.05	−179.32	−1.74	−20.76
	April	−36.44	29.89	−93.31	93.31	−58.83	−212.97	−2.57	−33.67
Summer season	May	−37.81	27.64	−94.60	94.60	−63.12	−251.98	−4.33	−50.91
	June	**−48.64**	39.69	**−116.40**	*116.40*	**−79.07**	**−313.09**	−4.95	−62.66
	July	−42.08	40.32	−107.46	107.46	−74.97	−307.81	**−5.21**	**−62.92**
	August	−36.42	38.71	−91.38	91.38	−58.59	−253.09	−3.51	−48.36
	September	−35.41	*41.31*	−91.41	91.45	−54.60	−194.54	−2.10	−28.36
	October	−29.28	37.62	−77.47	77.47	−44.76	−167.09	*−1.33*	−15.37
Winter season	November	−21.40	28.33	*−58.17*	**58.17**	*−29.12*	*−89.89*	0.69	6.20
	December	*−21.26*	28.34	−62.02	62.02	−32.06	−96.16	0.77	8.64

Table 5.
Monthly heat and energy transfer performance of the simulated office.

December because in these three months, the energy transfer is from the external air to the external surface of the glass in order to heat the external glass surface using the external air temperature, as shown in **Table 5** and **Figure 5**.

The yearly average heat and energy transfer performances are individually shown including as bold for minimum performances in **Figure 5** for the East, West, South, and North walls.

4. Conclusion

The yearly average solar gain is 674.30 W when the glass size is from 10 to 100% (full) on the external wall with different window opening percentages, although solar gain increased by 763.16% when the glass size on the external skin was suddenly changed from 10% to full (100%) glass. Moreover, the maximum solar gain was observed as 113% when the glass size on the external wall changed from 10 to 20%, while the minimum solar gain was 8% when the glass size on the external wall changed from 80 to 90%.

Office environments with the smallest to largest glass size or the smallest to largest window opening percentage always lose heat; moreover, a 311.49 W heat loss was observed as the yearly average for the above conditions. In addition to this, the window opening percentage never affects the solar gain, as shown in **Table 3**.

The maximum heat loss of 100% occurred when the glass size is only 10% for all window opening ratios, while the minimum 23.67% heat loss occurred when the glass size is 60% of the external skin for all window opening ratios. However, the maximum heat loss of 762% occurred when the window is always 10% opened for all glass sizes on the external skin, and the minimum 458% heat loss occurred when the window is always half opened for all glass sizes on the external skin.

The yearly average resultant temperature for the simulated office is 21.91°C for all glass sizes on the external skin, with all window opening percentages. Furthermore, the yearly average resultant temperature is also achieved when the external skin has 40% glass with a 20% window opening ratio, half of the external skin is constructed of glass with 40 and 50% window opening ratios, and the external skin has 60% glass with an 80% to full window opening ratio.

The yearly average relative humidity of the simulated office is 67.56% for all glass sizes on the external skin with all window opening percentages. In addition to this, the yearly average relative humidity is also achieved when the external skin has 10% glass with a 60% to full opening, the external skin has 20% glass with a 40–80% window opening ratio, the external skin has 30% glass with a 50% window opening ratio, the external skin has 40% glass with a 20–40% window opening ratio, half of the external skin is constructed of glass with a 40% window opening, the external skin has 60–80% glass with a 30–40% window opening, and the external skin is 90% to full glass with a 30% window opening ratio.

During all seasons, heat is always transferred away from the opaque and transparent internal surfaces of the simulated office. Moreover, heat is also transferred from the outside of the opaque walls and transparent surfaces toward both internal surfaces.

Office air is heated by energy transferred from the internal surfaces of the simulated office's opaque and transparent walls during all seasons of the year. The external opaque wall is always transferring energy toward the external air, while the internal surfaces of the transparent surfaces transfer energy to heat up the office air except in

January, November, and December, because the energy transfer in these three months flows from the external air to the internal surface.

Architects, users, and engineers should be careful because in a hot and humid climate like Famagusta, adaptive thermal comfort within buildings is of great importance. Furthermore, July was found to be extremely hot, while January, February, March, April, November, and December were extremely cold, indicating that building users should pay attention to the cost of utilizing mechanical devices in these times of the year.

Conflict of interest

The author declares no conflict of interest.

Author details

Halil Zafer Alibaba
Department of Architecture, Faculty of Architecture, Eastern Mediterranean University, Famagusta, North Cyprus, Turkey

*Address all correspondence to: halil.alibaba@emu.edu.tr

References

[1] Sacht H, Lukiantchuki MA. Windows size and the performance of natural ventilation. Procedia Engineering. 2017;**196**:972-979. DOI: 10.1016/j.proeng.2017.08.038

[2] Wang H, (Yan) Chen Q. Modeling of the impact of different window types on single-sided natural ventilation. Energy Procedia. 2015;**78**:1549-1555. DOI: 10.1016/j.egypro.2015.11.201

[3] Hamdani M, Bekkouche SMA, Benouaz T, Belarbi R, Cherier MK. The study natural ventilation by using buildings windows: Case study in a hot dry climate, Ghardaïa, Algeria. Energy Procedia. 2017;**139**:475-480. DOI: 10.1016/j.egypro.2017.11.240

[4] Yang X, Zhong K, Kang Y, Tao T. Numerical investigation on the airflow characteristics and thermal comfort in buoyancy-driven natural ventilation rooms. Energy and Buildings. 2015;**109**:255-266. DOI: 10.1016/j.enbuild.2015.09.071

[5] Wang J, Wang S, Zhang T, Battaglia F. Assessment of single-sided natural ventilation driven by buoyancy forces through variable window configurations. Energy and Buildings. 2017;**139**:762-779. DOI: 10.1016/j.enbuild.2017.01.070

[6] Alfano FR'A, Olesen BW, Palella BI, Riccio G. Thermal comfort: Design and assessment for energy saving. Energy and Buildings. 2014;**81**:326-336. DOI: 10.1016/j.enbuild.2014.06.033

[7] Frontczak M, Wargocki P. Literature survey on how different factors influence human comfort in indoor environments. Building and Environment. 2011;**46**:922-937. DOI: 10.1016/j.buildenv.2010.10.021

[8] Kisilewicz T. Passive control of indoor climate conditions in low energy buildings. Energy Procedia. 2015;**78**:49-54. DOI: 10.1016/j.egypro.2015.11.113

[9] Halawa E, van Hoof J. The adaptive approach to thermal comfort: A critical overview. Energy and Buildings. 2012;**51**:101-110. DOI: 10.1016/j.enbuild.2012.04.011

[10] Toe DHC, Kubota T. Development of an adaptive thermal comfort equation for naturally ventilated buildings in hot-humid climates using ASHRAE RP-884 database. Frontiers of Architectural Research. 2013;**2**:278-291. DOI: 10.1016/j.foar.2013.06.003

[11] Jin L, Zhang Y, Zhang Z. Human responses to high humidity in elevated temperatures for people in hot-humid climates. Building and Environment. 2017;**114**:257-266. DOI: 10.1016/j.buildenv.2016.12.028

[12] Nguyen AT, Singh MK, Reiter S. An adaptive thermal comfort model for hot humid South-East Asia. Building and Environment. 2012;**56**:291-300. DOI: 10.1016/j.buildenv.2012.03.021

[13] Vellei M, Herrera M, Fosas D, Natarajan S. The influence of relative humidity on adaptive thermal comfort. Building and Environment. 2017;**124**:171-185. DOI: 10.1016/j.buildenv.2017.08.005

[14] TS 825. Thermal insulation requirements for buildings. 2013

[15] Pekdogan T, Basaran T. Thermal performance of different exterior wall structures based on wall orientation. Applied Thermal Engineering. 2017;**112**:15-24. DOI: 10.1016/j.applthermaleng.2016.10.068

[16] Yang W, Zhu X, Liu J. Annual experimental research on convective heat transfer coefficient of exterior surface of building external wall. Energy and Buildings. 2017;**155**:207-214. DOI: 10.1016/j.enbuild.2017.08.075

[17] Li B, Tan M, Liu H, Ma X, Zhang W. Occupant's perception and preference of thermal environment in free-running buildings in China. Indoor and Built Environment. 2010;**19**:405-412. DOI: 10.1177/1420326X10377545

[18] López-Pérez LA, Flores-Prieto JJ, Ríos-Rojas C. Adaptive thermal comfort model for educational buildings in a hot-humid climate. Building and Environment. 2019;**150**:181-194. DOI: 10.1016/j.buildenv.2018.12.011

[19] Zhang Y, Wang J, Chen H, Zhang J, Meng Q. Thermal comfort in naturally ventilated buildings in hot-humid area of China. Building and Environment. 2010;**45**:2562-2570. DOI: 10.1016/j.buildenv.2010.05.024

[20] Indraganti M, Ooka R, Rijal HB, Brager GS. Adaptive model of thermal comfort for offices in hot and humid climates of India. Building and Environment. 2014;**74**:39-53. DOI: 10.1016/j.buildenv.2014.01.002

[21] Cândido C, de Dear R, Lamberts R. Combined thermal acceptability and air movement assessments in a hot humid climate. Building and Environment. 2011;**46**:379-385. DOI: 10.1016/j.buildenv.2010.07.032

[22] Song Y, Sun Y, Luo S, Hou J, Kim J, Parkinson T, et al. Indoor environment and adaptive thermal comfort models in residential buildings in Tianjin, China. Procedia Engineering. 2017;**205**:1627-1634. DOI: 10.1016/j.proeng.2017.10.310

[23] Kumar S, Singh MK, Loftness V, Mathur J, Mathur S. Thermal comfort assessment and characteristics of occupant's behavior in naturally ventilated buildings in composite climate of India. Energy for Sustainable Development. 2016;**33**:108-121. DOI: 10.1016/j.esd.2016.06.002

[24] Barbadilla-Martín E, Lissén JMS, Martín JG, Aparicio-Ruiz P, Brotas L. Field study on adaptive thermal comfort in mixed mode office buildings in southwestern area of Spain. Building and Environment. 2017;**123**:163-175. DOI: 10.1016/j.buildenv.2017.06.042

[25] Singh MK, Ooka R, Rijal HB, Takasu M. Adaptive thermal comfort in the offices of North-East India in autumn season. Building and Environment. 2017;**124**:14-30. DOI: 10.1016/j.buildenv.2017.07.037

[26] EDSL Tas. Software Package for the Thermal Analysis of Buildings. Available from: http://www.edsl.net/main/support/documentation.aspx [Accessed: 10 April 2021]

[27] Location of Famagusta on a Map [Internet]. 2021. Available from: https://www.weather-forecast.com/locations/Famagusta/forecasts/latest [Accessed: 01 October 2021]

[28] The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ANSI/ASHRAE Standard 55-2017. In: ASHRAE Standard-Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigeration and Air-Conditioning Engineers. Atlanta, GA, USA: ASHRAE; 2017

[29] Badeche M, Bouchahm Y. Design optimization criteria for windows providing low energy demand in office buildings in Algeria. Environmental and Sustainability Indicators. 2020;**6**:1-10, 100024. DOI: 10.1016/j.indic.2020.100024

[30] Goia F. Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential. Solar Energy. 2016;**132**:467-492. DOI: 10.1016/j.solener.2016.03.031