

Article

Analysis of Daily Energy Demand for Cooling in Buildings with Different Comfort Categories—Case Study

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Abstract: Climate change has a potential impact on the number of hot and torrid days in the summer period. Due to the occupants' comfort needs, and because of the high heat loads during the summer period, in several European countries, the energy used for air conditioning in buildings increased. With multiple environmental monitoring systems (Testo Saveris) in two similar offices, having west and east orientation of glazing, 1920 data (internal air, mean radiant temperature) related to operative temperature were collected in order to show the differences between heat loads of rooms with similar geometry in the same building. Data were measured in a 15 min interval. The diffuse and direct solar radiation had been determined for the horizontal and vertical surfaces, using the measured hourly global radiation (Debrecen, Hungary) data for the analyzed days (summer, hot, and torrid days). The local climatic results were compared with other climatic days used in different national standards. The daily energy need for cooling for different building comfort categories was also determined in the case of the representative days. The maximum daily energy need for cooling can be even 2.3 times higher for east orientation in comparison to the west orientation of the facades.

Keywords: operative temperature; cooling load; daily energy need; solar gains



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1. Introduction

Extreme weather events, just like the summer period's hot and torrid days, are challenging the inhabitant's health and comfort. Numerous research had been performed, and plenty of scientific papers studying thermal comfort, indoor operative temperature, indoor air quality were published [1–3].

Majewsky et al. analyze the indoor environment quality in two different intelligent buildings, which are located in Poland. The authors stated that energy consumption worldwide is constantly rising. Most of the energy is used by the building sector, mainly for the daily operation of modern buildings, intelligent buildings for offices, and also for public use [4].

Increasing the airtightness of the buildings' envelope, special attention should be paid to the CO₂ concentration level in the indoor air. It was shown that the CO₂ concentration may exceed even 4000 ppm in the case of two persons performing office work if aeration of the room is not performed properly [5]. Bullová et al. have shown that the air change rate can be reduced to even 0.1–0.3 h⁻¹ in the case of refurbished buildings [6]. In the last decades, the need for thermal comfort increased considerably. Several air conditioning systems were mounted in the existing office buildings, while new office buildings are equipped with cooling systems.

Thus, the energy use for cooling in the buildings increased substantially in the last years [7,8]. Mousavi Motlagh et al. have shown that most researchers analyzed the energy use in residential and office buildings [9].

In the European Commission Report related to energy performance in buildings, the annual final energy consumption per square meter in the residential sector in Hungary was 150 kWh/m² year in 2013 [10]. Hungarian Energy and Public Utility Regulatory Authority, in the yearly report, presents the energy consumption for cooling used by air conditioning

systems in the summer period [11]. It was shown that the energy consumption for cooling increased from 271 TJ (2015) to 570 TJ (2019). Bazazzadeh et al., in their research, conclude that the cooling load will increase by 135% by 2080 in Poland [12]. The proper architectural design of buildings can mitigate the energy need for cooling. Long et al. and Reilly et al., in their research, present the thermal mass and heat storage capacity effects for the heat load of buildings [13,14].

The present paper focuses on the importance of operative temperature for different office building comfort categories and energy needs for cooling. In order to determine the operative temperature and the daily energy need for cooling in buildings, according to standards, the first step is to determine the local specific meteorological data, such as global diffuse radiation, diffuse and direct radiation on vertical surfaces, mean outdoor temperature, and so on. Duties of the Meteorological Observatory (Debrecen, Hungary, GPS coordinates: 47.53253, 21.62537) are the collection and measurement of global hourly radiation data and mean hourly outdoor temperatures.

In order to obtain an appropriate overview of the building's cooling needs, it is essential to review different standards on the topic. According to ISO-52000-1:2017, "Building: construction as a whole, including the fabric and all technical building systems, where energy may be used to condition the indoor environment" [15]. Cooling energy needs can be determined using the algorithm given by ISO 13790:2008 standard, as a room or enclosure, which is specified to be cooled to a given setpoint temperature. According to ISO standard 13790:2008, energy needs for cooling in a conditioned space have to maintain the expected temperature conditions until a given period of time. Solar heat gains are defined as heat that is provided by solar radiation, entering directly or indirectly through openings, opaque walls, and roofs, or by passive solar devices such as sunspace, transparent insulation, and solar walls [16]. The calculation methodology presented in ISO 13790:2008 standard was previously validated, and the results were published in different articles [17,18].

The aim of the present research is to discuss and analyze through a case study the effect of different building structures, size, and orientation of glazed areas on the indoor operative temperature for different comfort categories and on the daily cooling energy need in the case of hot and torrid days (selected from the 11 analyzed years).

2. Materials and Methods

In order to see the effects of the orientation of transparent surfaces, building structure, and glazing ratio on the operative temperature, measurements and simulations were simultaneously performed.

2.1. Methods for Measurements of the Operative Temperature

A multiple environmental monitoring system provided the opportunity for complex research related to building performance on different aspects, including thermal comfort, energy use, and indoor air quality.

With the expansion of wireless communication, data storage, small electronic devices, etc., will be able to transfer bigger data for increasing the building performance [19].

Firstly, it was identified a western and an eastern-orientation office in a 3-story building with heavy structure. The selected offices are located on the upper building level (similar shading) and have similar geometry. In these offices, a Testo Saveris measurement system was placed (Figure 1a,b). This measurement system can be used for monitoring building internal air and mean radiant temperature.

Very long distances can be bridged using a converter (5), which converts the radio signals of the probe or router and then transmits this measurement data to the base via an Ethernet cable. The Ethernet probes (6) can also be connected to the base using an Ethernet cable. NTC sensor measuring range of the Saveris T2/T2D is from -35 to $+50$ °C, and the accuracy is ± 0.2 °C (-25 to $+70$ °C) [20].

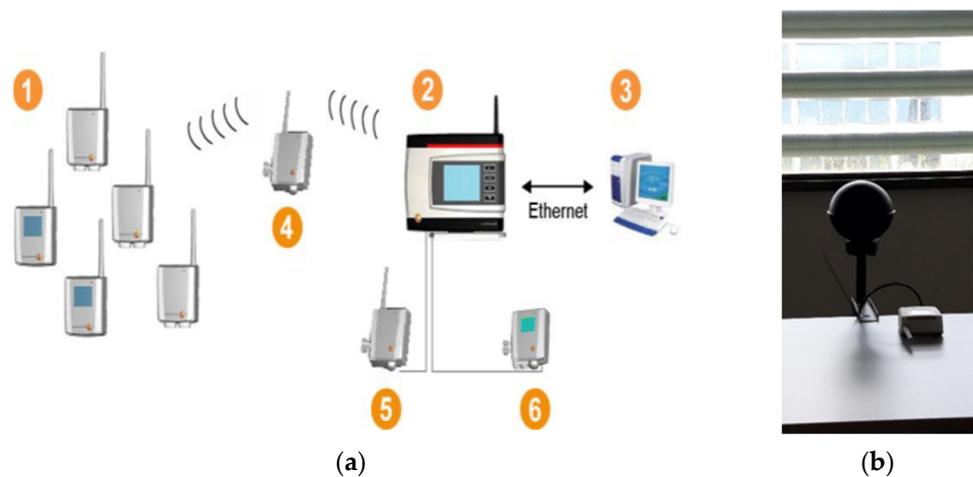


Figure 1. The Testo Saveris measurement system [20]. (a) Testo Saveris base system (b) globe sensor. With this measurement system, ambient or process data for temperature and humidity in sealed rooms and/or during transportation is measured and recorded using probes (1). These measured values are transmitted by radio to the Saveris base (2) and saved. A router (4) can be used to optimize the radio signal in the event of difficult structural conditions. The data is then called up from a computer (3) by the Saveris base and saved to a database [20].

The dimension of the analyzed offices is $7.5 \times 6 \times 4.5$ m (Figure A1 in Appendix A). The windows dimension is 1.32×5.44 m. The overall heat transfer coefficients of external building elements were $U_{wall} = 0.28$ W/m² K; $U_{window} = 1.1$ W/m² K; and $U_{flatroof} = 0.2$ W/m² K. The operative temperature was measured on the working places, which are located at 1.5 m from the window, similar for both offices (Figure 2a,b). Measurements were carried out in the summer period when no occupants were in the rooms (holiday 3 August 2018–7 August 2018). The HVAC systems were switched off.

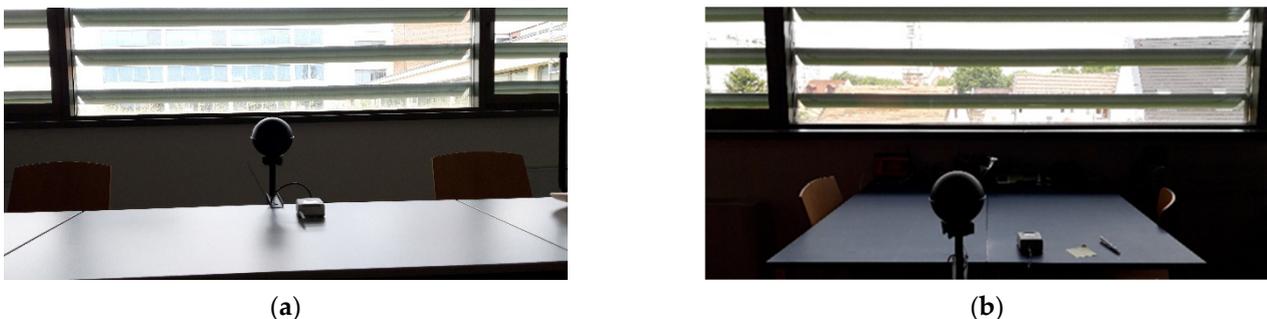


Figure 2. Measurements of the Operative temperature (a) East-orientation office; (b) west-orientation office.

2.2. Methods for Calculation of the Operative Temperature and Daily Energy Need for Cooling

The elements of a cooling system are chosen depending on the setpoint operative temperature and the maximum value of the operative temperature in a room. In order to determine the daily variation of the operative temperature, different calculation methods can be used. In the following, the method given by standard EN 13790 was used. The validation of the calculation model was performed and presented in previously published papers [17,18]. Furthermore, the day for which the calculation is performed has to be chosen carefully. This has to be a torrid day, but for energy need for a day or a whole summer period, the hot days and summer days are important as well.

The calculation method uses the RC network of the heat flows, as is shown in Figure 3 [16].

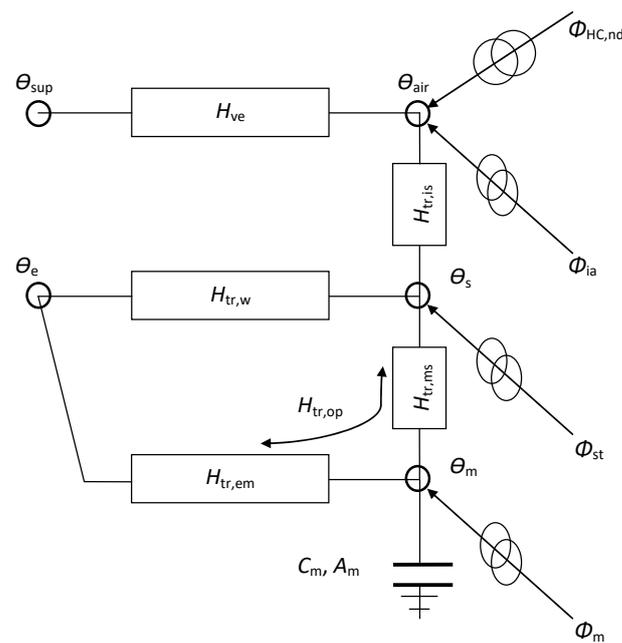


Figure 3. RC network heat flows [16].

The internal heat capacity of the building zone, C_m , (J/K), was calculated for a maximum thickness of 10 cm.

The operative temperature is obtained using Equation (1), [16]:

$$\theta_{op} = 0.3\theta_{air} + 0.7\theta_s \quad (1)$$

The cooling need is [16]:

$$\phi_{HC,nd,un} = \frac{\phi_{HC,nd10}(\theta_{air,set} - \theta_{air,0})}{(\theta_{air,10} - \theta_{air,0})} \quad (2)$$

where:

$$\phi_{HC,nd10} = 10A_f \quad (3)$$

The ASHRAE 90.1 standard presents the prototype buildings. In the standard 16 prototype buildings are presented: apartment, hospital, hotel, office (large, medium, small), restaurant, school. The room dimensions used for calculus in the present paper is a model room for each prototype building defined in the ASHRAE 90.1 standard [21].

In buildings with various functions, rooms have different dimensions. In the case of office buildings, the geometrical sizes of rooms depends on the number of persons working in the office. Usually, the dimensions of a room result from a grid. Generally, in the case of a suspended ceiling, the dimension of one element of the grid is 600×600 mm. In the following, for cooling load calculus, a room with a $4.8 \times 4.8 \times 3.0$ m dimension is taken into account.

The overall heat transfer coefficients of external building elements were $U_{wall} = 0.226$ W/m² K; $U_{window} = 1.0$ W/m² K; and $U_{flatroof} = 0.166$ W/m² K.

The room is located in the corner of the attic of a three-story building. The window has no shading, the solar energy transmittance: $g = 0.7$, and the glazed ratio is 85% (in all cases, 15% is frame). The air change rate was considered $ACH = 0.5$ h⁻¹.

The window glazed of analyzed room ratio is 85% (for example: exterior glass wall, window wall).

According to Hungarian regulation related to the energy performance of buildings [22], the building is considered light structured if the specific thermal mass is lower or equal to

400 kg/m², and the building is considered heavy structured if the specific thermal mass exceeds 400 kg/m².

Four different cases were analyzed for each window orientation.

- (a) Heavy construction, external wall with 50% window;
- (b) Light construction, external wall with 50% window;
- (c) Heavy construction, external wall with 100% window;
- (d) Light construction, external wall with 100% window.

3. Input Data for Calculation of the Operative Temperature and Daily Energy Need for Cooling

In the last decades, the heat waves are longer lasting, and their number increases. During the heatwaves, besides health problems [23], the electrical energy consumption in the building sector caused by air conditioners operation at maximum capacity raises substantially.

The local design standards for energy efficiency do not contain the input local climatic data, which are: hourly values of the external air temperature and solar radiation intensity.

Hourly global radiation data and mean outdoor temperature were provided by the local Agro-Meteorological Observatory Debrecen, Hungary [24].

In order to determine the local meteorological data, the calculation method for the selected days was presented in several articles [17,18].

According to the Hungarian Meteorological Service, those days that have a maximum temperature higher than 25 °C are called “Summer days”. If the maximum temperature value is higher or equal to 30 °C, the day is defined as a “Hot day”. “Torrid days” have the maximum daily temperature equal to or higher than 35 °C [25].

Between 2009 and 2019, 514 summer days, 247 hot days, and 21 torrid days were registered.

The daily maximum temperature of the selected summer day was 25.3 °C. The chosen hot day had a maximum daily external air temperature of 32.4 °C, while the torrid day had a maximum external air temperature of 35.6 °C.

The local climatic data for the summer, hot and torrid days are presented in Table 1 (and Figures A3–A6).

Table 1. Maximum radiation values and energy yield for hottest days [26–28].

Day	Measure Units	I _{GH}	I _{difH}	I _{difV}	I _{dirSouth}	I _{dirEast}	I _{dirWest}	I _{dirNorth}
clear sky day								
Summer day	W/m ²	927	153	76	390	676	673	169
	Wh/m ² day	8110	1338	669	2295	3091	3136	416
Hot day	W/m ²	884	146	73	377	577	689	166
	Wh/m ² day	7687	1268	634	2236	3038	3140	372
Torrid day	W/m ²	871	144	72	368	531	777	99
	Wh/m ² day	7423	1225	612	2231	2643	3148	266
different standards								
MSZ-04-140-2 Hungary	W/m ²	900	188	192	317	561	561	193
	Wh/m ² day	8156	2049	1969	1752	2695	2862	802
Urban INCD Romania	W/m ²	914	149	75	373	681	527	221
	Wh/m ² day	8327	1493	747	2210	3636	3233	862
DIN 4710 Germany	W/m ²	861	150	192	407	542	542	84
	Wh/m ² day	7479	1680	2442	2409	2597	2597	338

The clear sky days are important because the cloudiness is omitted (direct radiation values are higher than for real days, while the diffuse radiation values are lower).

Furthermore, the input meteorological data given by different national standards are included in Table 1.

Standard 04-140-2 (national Hungarian Standard) was previously in use [26]. This standard provides the solar radiation and external air temperature data for heat load calculation until 2012.

In standard [27], local meteorological data are mentioned, related to Oradea city, Romania, which is located near Debrecen, Hungary. The distance between the two cities is 60 km.

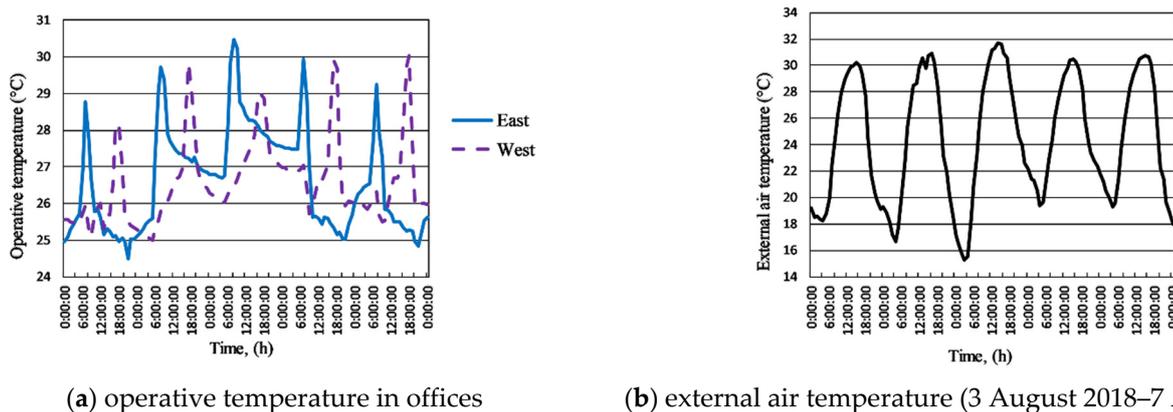
Standard [28] contains only statistic days, and real days are not included.

4. Results and Discussion

In the following, the measured and calculated operative temperatures and the determined daily energy need for cooling are presented.

4.1. Measurements of the Operative Temperature

The gathered values of the operative temperature and outdoor dry temperature are illustrated in Figure 4a,b.



(a) operative temperature in offices

(b) external air temperature (3 August 2018–7 August 2018)

Figure 4. Measured operative and external temperature.

It can be observed that the operative temperature in the offices followed the variation of the external temperature (three subsequent days increase, two subsequent days decrease). Moreover, the maximum values can be similar (second and fourth days) or different, depending on the cloudiness. As in the offices, the working hours starts at 8⁰⁰ a.m. and ends at 17⁰⁰ p.m. the west-oriented offices are advantageous from the cooling point of view. The question is: how much cooling energy can be saved renting a west-oriented office instead of an east-oriented office?

4.2. Calculation of the Operative Temperature

The results of maximum operative temperature for all analyzed cases are presented in Tables 2 and 3.

It can be observed that in Tables 2 and 3, the highest operative temperatures were obtained to east and west orientation of window for all analyzed days and windows to wall ratios.

The hourly operative temperature for south- and north-orientation glazed areas are presented in Figures A7–A14.

Table 2. Maximum operative temperature for heavy construction buildings.

Heavy Construction	50% Window				100% Window			
	South	North	East	West	South	North	East	West
Day	Maximum Operative Temperature (°C)							
Summer day	26.78	24.95	27.38	27.61	29.69	25.89	30.95	31.56
Hot day	27.58	25.71	28.19	28.48	30.56	26.87	31.82	32.62
Torrid day	27.98	26.13	28.27	28.90	31.03	27.13	31.60	33.01

Table 3. Maximum operative temperature for light construction buildings.

Light Construction	50% Window				100% Window			
	South	North	East	West	South	North	East	West
Day	Maximum Operative Temperature (°C)							
Summer day	34.85	26.99	36.43	39.36	45.96	30.59	50.33	55.59
Hot day	37.15	29.93	37.96	42.45	48.26	33.67	50.94	58.95
Torrid day	38.97	31.09	38.60	43.54	50.26	34.42	49.44	59.30

In Figures 5–8, both for the east and west orientation of the glazed area, the hourly operative temperatures are presented.

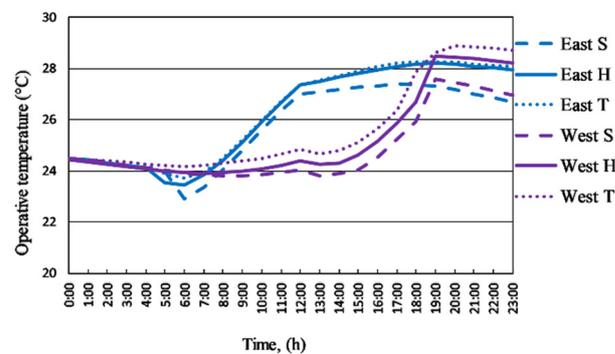


Figure 5. Heavy construction, 50% window (summer, hot, torrid day).

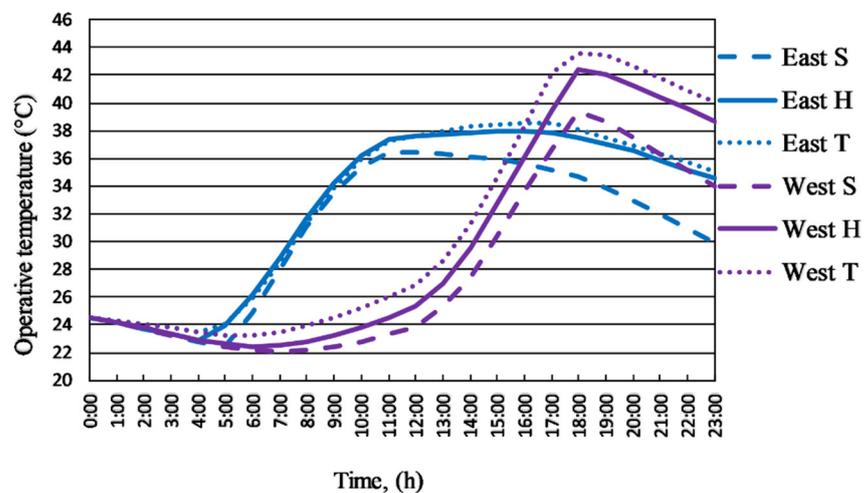


Figure 6. Light construction, 50% window (summer, hot, torrid day).

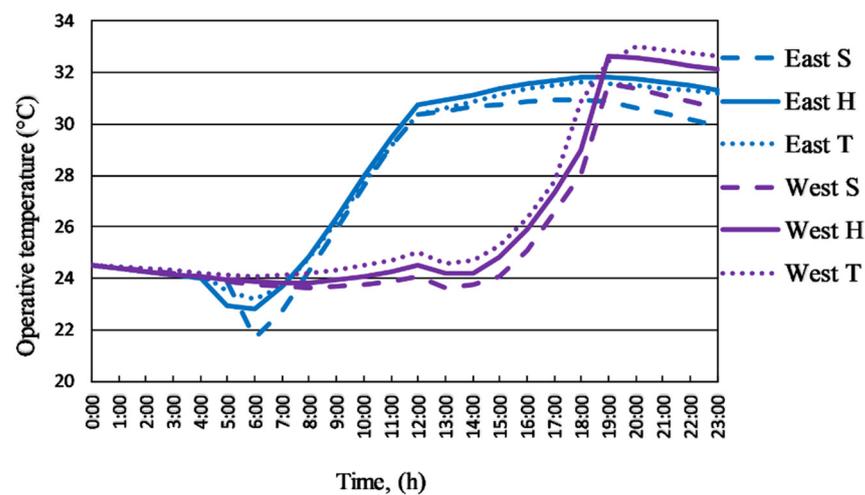


Figure 7. Heavy construction, 100% window (summer, hot, torrid day).

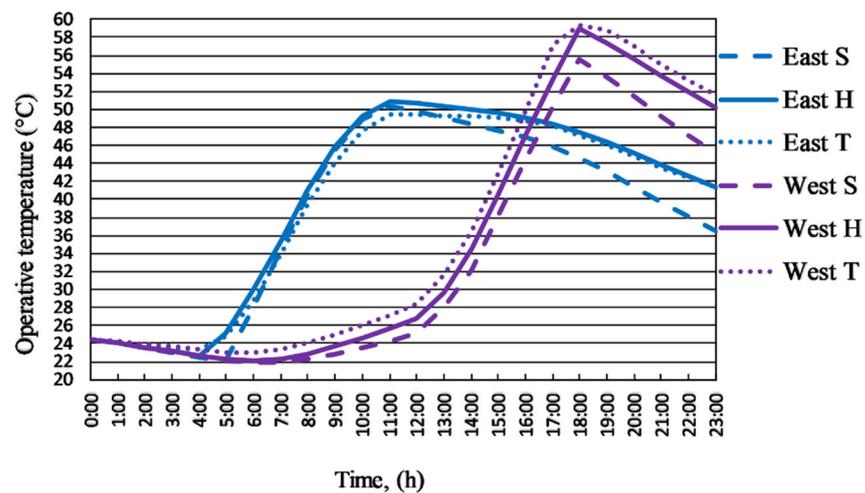


Figure 8. Light construction, 100% window (summer, hot, torrid day).

Assuming the upper limit of comfort operative temperature $26.0\text{ }^{\circ}\text{C}$, the overheating hours in the summer, hot and torrid days for east and west orientation of window can be determined based on Figures 5–8.

It can be observed that the $26\text{ }^{\circ}\text{C}$ setpoint temperature is exceeded for both orientations in each analyzed day. If there is no cooling system installed, the overheating generates thermal discomfort, which leads to health problems and a decrease in work productivity [29–31]. In the case of offices with air cooling systems, the length of overheating period determines the operation time of the cooling system, while the amplitude of overheating determines the installed cooling capacity.

4.3. Daily Energy Need for Cooling

In the Technical Report CR 1752:1998 Ventilation for buildings—Design criteria for the indoor environment, different building types, and spaces, the design criteria are defined [32].

Single/landscape office operative temperatures in summer and cooling season for different comfort categories:

- A 24.5 ± 1 ;
- B 24.5 ± 1.5 ;
- C 24.5 ± 2.5 [32].

In the following, the energy calculations were performed for the heavy and light construction using the clear sky day meteorological data, the daily energy need for cooling was determined. For each building category, the minimum and maximum acceptable operative temperatures were taken into consideration. The results are presented in Tables 4–9. Obviously, with intelligent and properly operated external shading structures, the daily energy need for cooling can be reduced substantially [33].

It can be observed that for all analyzed cases, the maximum value of daily energy demand for cooling was obtained for the east orientation of the glazed area.

Table 4. Daily energy need for cooling of analyzed room. heavy construction, summer day (Wh/day).

Heavy Construction		50% Window				100% Window			
Comfort Category	Operative Temperature	West	East	West	East	West	East	West	West
A	23.5	27,005	19,047	36,211	24,288	38,663	22,176	59,367	34,463
	25.5	7588	111	15,008	6623	20,359	2657	38,445	16,754
B	23	34,599	26,641	43,810	31,882	46,108	29,621	65,500	40,908
	26	5147	0	11,376	5036	17,715	838	34,598	15,058
C	22	49,786	41,828	59,008	47,069	60,999	44,512	80,402	55,799
	27	957	0	4800	2448	12,693	0	27,320	11,874

Table 5. Daily energy need for cooling of analyzed room. Light construction, summer day (Wh/day).

Light Construction		50% Window				100% Window			
Comfort Category	Operative Temperature	South	North	East	West	South	North	East	West
A	23.5	34,115	15,897	51,263	31,905	61,148	24,443	94,710	58,189
	25.5	24,934	6125	40,369	23,826	51,958	14,018	84,105	49,777
B	23	37,770	19,552	54,936	35,561	64,547	27,987	98,395	61,507
	26	23,414	4738	38,223	22,653	50,269	12,265	81,924	48,364
C	22	45,082	26,864	62,281	42,872	71,882	35,322	105,765	68,842
	27	20,390	2314	34,239	20,396	46,892	9099	77,561	45,795

Table 6. Daily energy need for cooling of analyzed room. Heavy construction, hot day (Wh/day).

Heavy Construction		50% Window				100% Window			
Comfort Category	Operative Temperature	South	North	East	West	South	North	East	West
A	23.5	32,218	23,730	41,973	48,066	38,688	27,756	64,523	39,640
	25.5	11,501	2900	19,944	16,497	21,051	7158	43,857	20,844
B	23	39,812	31,324	49,572	59,598	44,548	35,202	71,975	47,085
	26	9060	971	16,290	13,379	18,804	4649	40,010	19,001
C	22	55,000	46,512	64,770	82,663	56,268	50,092	86,877	61,976
	27	4457	0	9421	8107	14,595	1280	32,463	15,541

Table 7. Daily energy need for cooling of analyzed room. Light construction, hot day (Wh/day).

Light Construction		50% Window				100% Window			
Comfort Category	Operative Temperature	South	North	East	West	South	North	East	West
A	23.5	42,149	23,995	60,304	40,598	69,113	32,695	104,538	67,400
	25.5	32,373	13,661	48,711	31,305	59,623	22,214	92,951	58,418
B	23	45,805	27,651	63,976	44,253	72,781	36,363	108,223	71,068
	26	30,720	12,083	46,565	29,927	57,935	20,384	90,586	56,870
C	22	53,116	34,962	71,322	51,565	80,116	43,698	115,593	78,403
	27	27,618	9215	42,273	27,350	54,558	17,063	86,126	53,995

Table 8. Daily energy need for cooling of analyzed room. Heavy construction, torrid day (Wh/day).

Heavy Construction		50% Window				100% Window			
Comfort Category	Operative Temperature	South	North	East	West	South	North	East	West
A	23.5	36,255	28,097	43,568	34,137	48,694	31,763	63,764	44,667
	25.5	14,042	5274	20,607	11,976	27,516	9438	42,073	22,988
B	23	43,849	35,691	51,167	41,730	56,140	39,208	71,215	521,12
	26	11,237	2735	16,898	9979	24,588	6584	38,227	21,144
C	22	59,037	50,879	66,365	56,918	71,030	54,099	86,117	67,003
	27	6295	0	9634	6559	19,193	2167	30,773	17,456

Table 9. Daily energy need for cooling of analyzed room. Light construction, torrid day (Wh/day).

Light Construction		50% Window				100% Window			
Comfort Category	Operative Temperature	South	North	East	West	South	North	East	West
A	23.5	48,662	29,856	61,753	47,665	76,015	38,355	101,151	75,241
	25.5	37,221	18,069	49,415	36,359	64,827	26,573	88,787	64,134
B	23	52,318	33,512	65,426	51,321	79,682	42,022	104,836	78,909
	26	35,473	16,268	47,269	34,707	62,989	24,577	86,453	62,446
C	22	59,629	40,823	72,771	58,632	87,018	49,358	112,206	86,244
	27	32,168	12,997	42,977	31,722	59,487	20,913	82,093	59,211

5. Conclusions

The majority of comfort and energy standards do not contain external meteorological data. In the case of calculation of the operative temperature and energy need for cooling, it is essential to know the values and variation of the external air temperature and solar radiation. Therefore, meteorological data over the past 11 years were analyzed. For this period, 514 summer, 274 hot, and 21 torrid days were identified. In order to determine and investigate the daily cooling energy need, one summer day, one hot day, and one torrid day was chosen.

In the frame of a case study, the operative temperature was measured and analyzed in two similar office rooms, having east and west orientation of glazing, in a 5-day period. The results enlighten that the energy consumption for cooling and the operational costs for west-orientation offices might be advantageous.

With the use of a validated model, the operative temperature was calculated for different building structures and window dimensions. For different comfort categories, the daily energy need for cooling was determined.

The cooling energy demand was calculated in the case of the analyzed days in light and heavy construction buildings, with different sizes and orientations of windows. It was also determined the differences that occur in the case of daily energy demand under summer-hot and torrid days' radiation conditions.

The upper limit of the operative temperature in a B comfort category office is 26.0 °C. In the case of the south orientation of the glazed area, for this operative temperature, assuming 100% of the daily energy need for cooling in a summer day for a heavy structure building with 100% window, it can be observed that for hot days the daily energy need will be 106.1%, while for torrid days 138.8%. In the case of a light structure building, on a summer day is 283.8%, hot day, the daily energy need for cooling is 327%, while for a torrid day, the increase is 355.6%.

Keeping the same reference value for 100% of the daily cooling energy need but decreasing the glazed area to 50%, the daily energy need for cooling decreases to 29.1% (summer day), 51.1% (hot day), and torrid day 63.4% (torrid day) in the case of heavy structure.

For light structure, the daily cooling energy needs increase to light structures 132.2% (summer day), 173.4% (hot day), and 200.2% (torrid day).

In the glazing area north orientation, the daily energy need for cooling is substantially lower in comparison to other glazing orientations.

Analyzing the results obtained for cooling energy need (east and west orientation), it can be observed that for heavy structure, the daily operative temperature for west orientation exceeds with 1.4–2.8 K the values obtained for east orientation, while the daily energy need for cooling can be even 2.3 times higher for east orientation in comparison on the west orientation of the facades.

In the case of light construction, the operative temperature differences can be 4.7–6.7 K, while the daily energy need for cooling can be 1.69 times higher for east orientation in comparison with the west orientation of facades.

The data presented in Tables 4–9 might be useful for building renters and operators. The main point is that torrid days, hot and summer days are the most important because these days will be operating days of the cooling and ventilation systems, giving the energy consumption in a month or for a whole year.

A future research perspective is the analysis of the effect of the use of intelligent external blinds and PCMs on the cooling energy need. Furthermore, the relation between the behavior of occupants and cooling energy use has to be investigated.

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Nomenclature

H_{ve}	Heat transfer by ventilation (W/K)
θ_{air}	Air temperature node (°C)
θ_{sup}	The supply temperature (°C)
$H_{tr,w}$	Heat transfer by transmission is split into the window segment, (W/K)
$H_{tr,op}$	The thermal mass (W/K)
θ_s	(A mix of θ_{air} and mean radiant temperature) and the node representing the mass of the building zone, θ_m (°C)
C_m	Thermal capacity (J/K)
Φ_{int}	Heat flow rate given by internal heat sources (W)
Φ_{sol}	Solar heat sources (W)
Φ_{HC}	nd Energy need for cooling (W)
A_f	Is the conditioned area (m ²)
$\theta_{air,10}$	The air temperature obtained for a heating power of 10 W/m ² (°C)
$\theta_{air,0}$	Is the air temperature in free floating conditions (°C)
$\theta_{air,set}$	Air temperature (°C)
S	Summer day
H	Hot day
T	Torrid day
I_{GH}	Is the global solar radiation on horizontal surfaces (W/m ²)
I_{dirH}	Direct solar radiation on horizontal surfaces (W/m ²)
I_{difH}	Diffuse solar radiation on horizontal surfaces (W/m ²)
I_{difV}	Diffuse solar radiation on vertical surfaces (W/m ²)
$I_{dirSouth}, I_{dirEast}, I_{dirWest}, I_{dirNorth}$	Direct solar radiation on vertical surfaces (W/m ²)

Appendix A

Methods for Measurements of the Operative Temperature

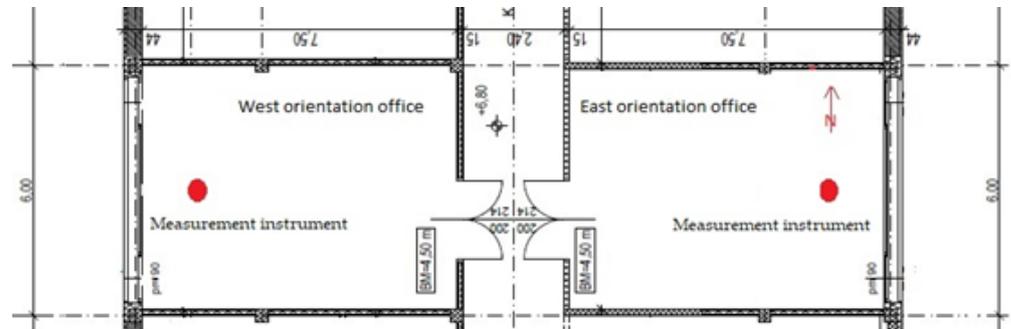


Figure A1. Plan of the offices.

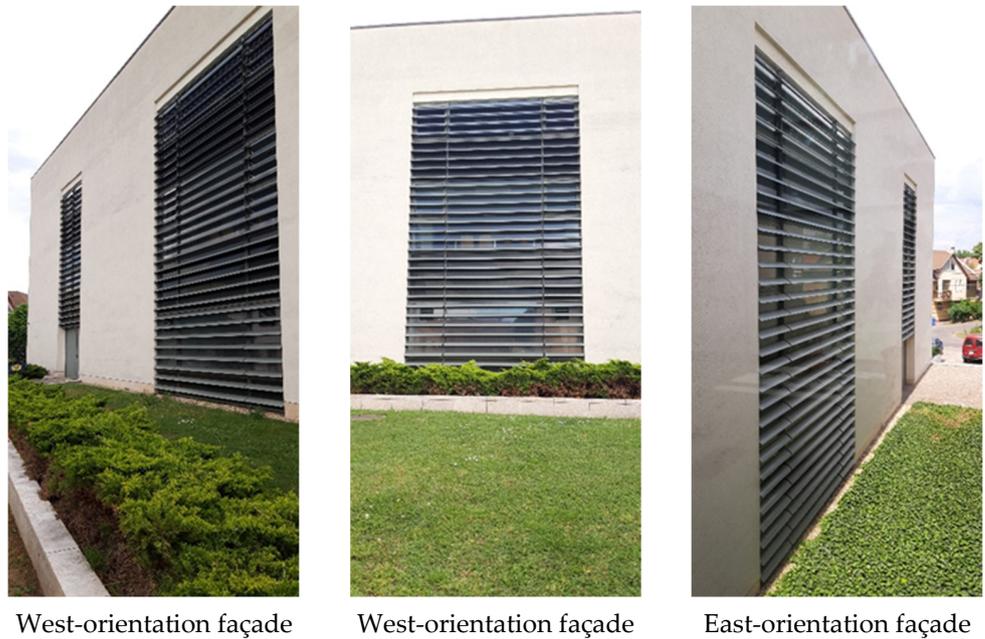


Figure A2. Façade of the building with windows oriented to east and west.

Input Data for Calculation of the Operative Temperature and daily Energy Need for Cooling

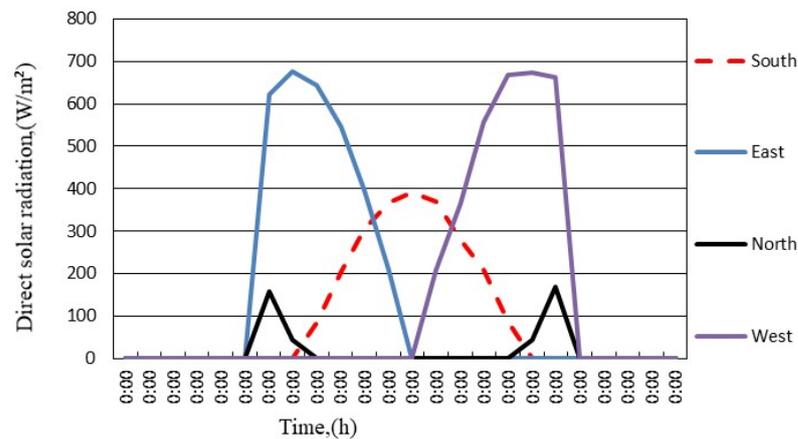


Figure A3. Direct solar radiation values, summer day.

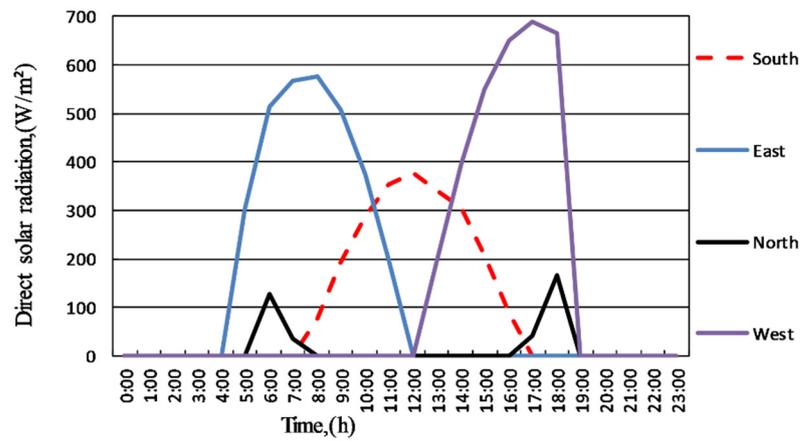


Figure A4. Direct solar radiation values, hot day.

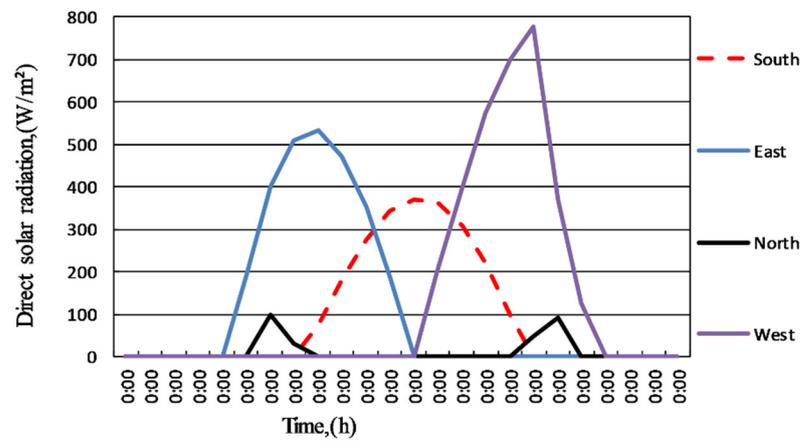


Figure A5. Direct solar radiation values, torrid day.

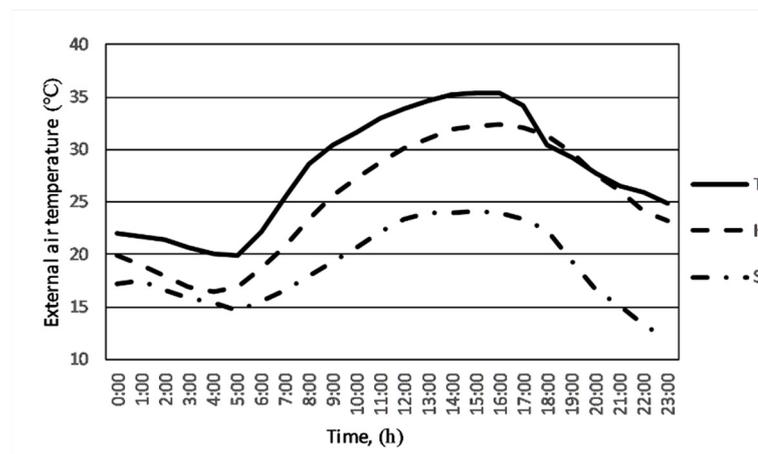


Figure A6. External air temperature, S, H, T days.

Methods for Calculation of the Operative Temperature and Energy Need for Cooling
 Calculation of the Operative Temperature

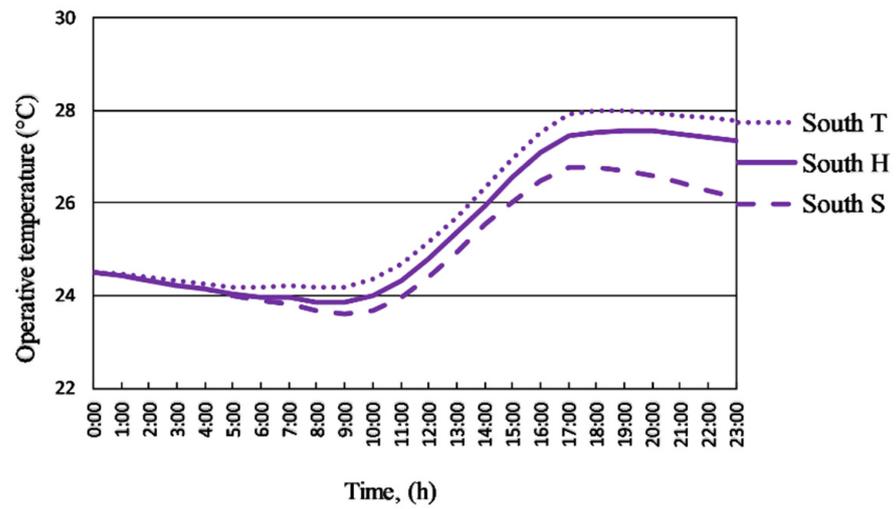


Figure A7. Heavy construction, 50% window (summer, hot, torrid day), south orientation.

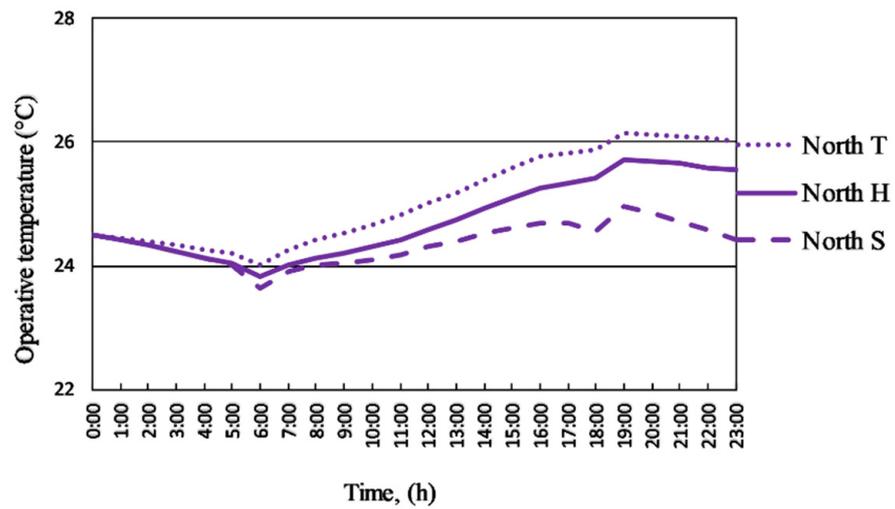


Figure A8. Heavy construction, 50% window (summer, hot, torrid day), north orientation.

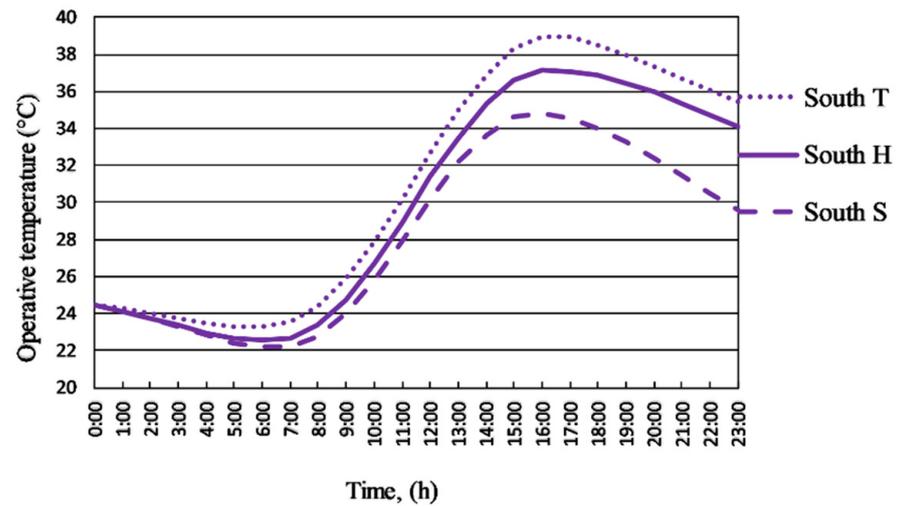


Figure A9. Light construction, 50% window (summer, hot, torrid day), south orientation.

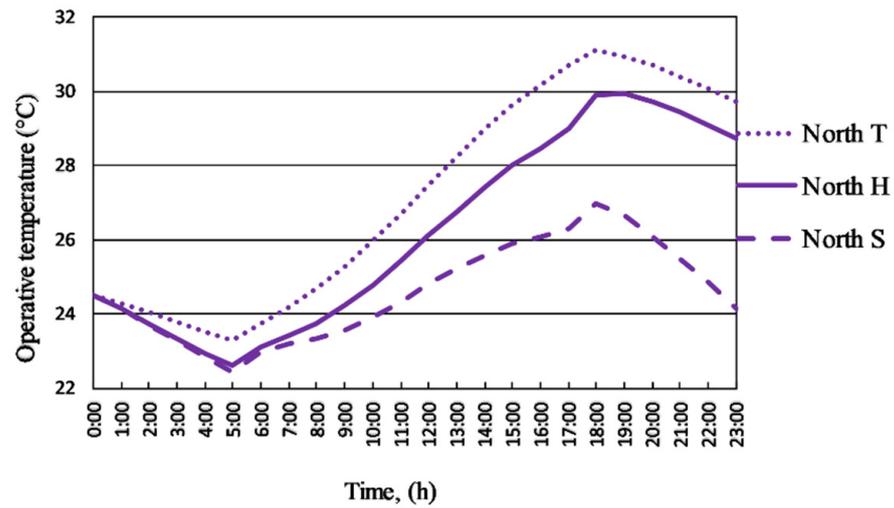


Figure A10. Light construction, 50% window (summer, hot, torrid day), north orientation.

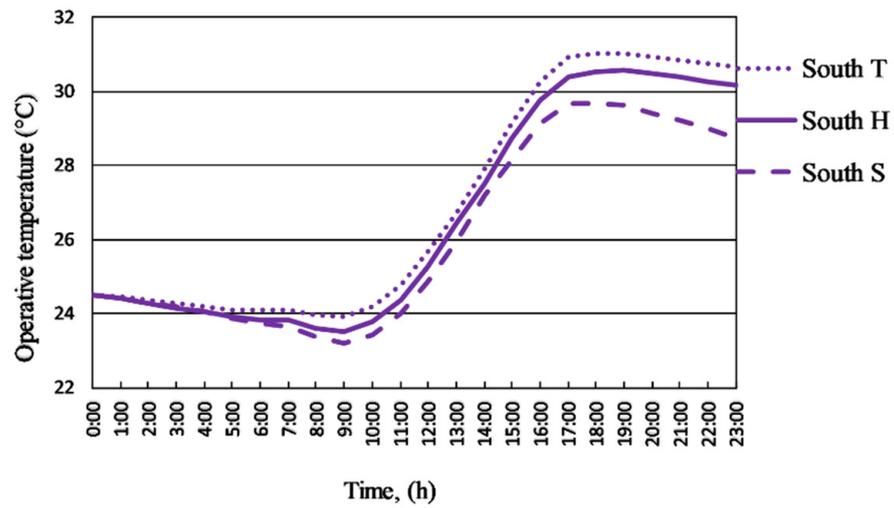


Figure A11. Heavy construction, 100% window (summer, hot, torrid day), south orientation.

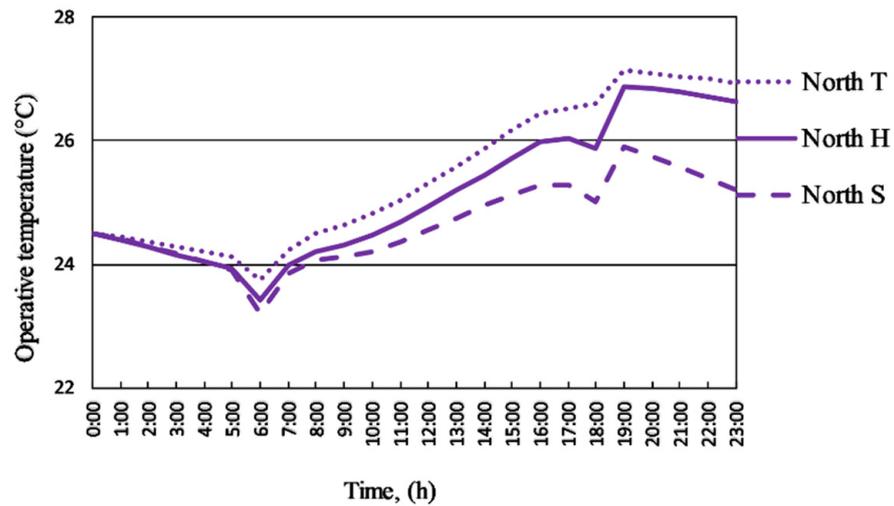


Figure A12. Heavy construction, 100% window (summer, hot, torrid day), north orientation.

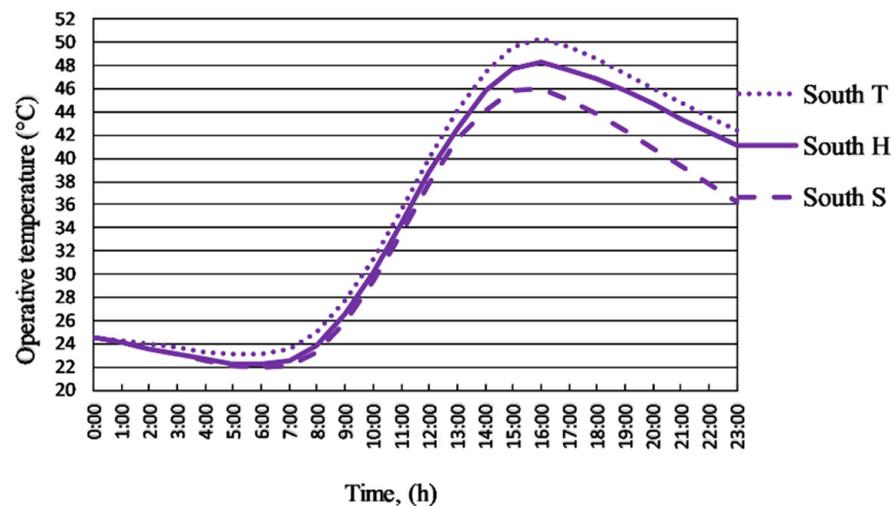


Figure A13. Light construction, 100% window (summer, hot, torrid day), south orientation.

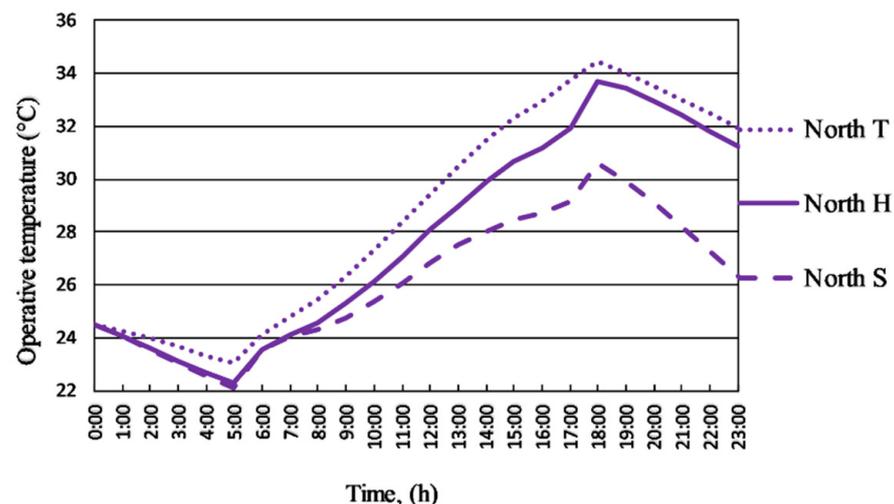


Figure A14. Light construction, 100% window (summer, hot, torrid day), north orientation.

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