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A RELATIVE MEASUREMENT AND MONITORING OF OTTV OF GLASS FACADE PASSIVE BUILDING IN TROPICAL CLIMATE

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Abstract. Efficient and productive buildings are vital to sustainable cities, significantly contributing to Sustainable Development Goals (SDGs) 3, 7, 11, and 12. Urban areas are responsible for 80% of global energy consumption, with buildings accounting for 40%. Achieving a healthy and comfortable indoor thermal envelope depends on various factors including building function, location, layout design, openings, and materials. The building facade, particularly glass facades, is a significant contributor to both energy performance and occupant comfort. Despite their importance, few studies focus on real-time measurement and monitoring of the Overall Thermal Transfer Value (OTTV) of passive buildings, especially with glass facades. Glass allows natural light and heat exchange, impacting the overall energy performance and quality of indoor environments. This study investigates the real-time impact of temperature variations on the OTTV of glass facade passive buildings from 8 am to 5 pm, focusing on Malaysia's tropical climate. The study's findings revealed that the OTTV varies from 42.642 W/m^2 at 11:30 am to 80.341 W/m^2 at 10:30 am. The study contributes to the body of knowledge by providing valuable insights regarding the dynamic thermal behaviour of the passive building envelope. Specifically, it demonstrates how OTTV varies with changing climatic conditions such as temperature fluctuations and solar radiation.

Keywords: sustainable development goals, overall thermal transfer value, building envelope, energy efficiency, facade materials.

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1. Introduction

A political agreement was signed during the meeting of the United Nations Sustainable Development held at its Headquarters in New York in September 2015. The majority of the nations worldwide have acknowledged and embraced the framework established by the 2030 Agenda. This framework consisted of 17 Sustainable Development Goals (SDGs) (United Nations, 2015).

According to the 7th Development Goal of this framework (SDG-7), clean and affordable energy is required. In other words, by 2030, it will be necessary to provide conservation of energy and reduce CO_2 emissions (United Nations, 2015). The recent spike in energy consumption and CO_2 emissions is concerning. Many people think that this increase is due to the growing trend of urban population (Zakari et al., 2022). Sustainability has been the driving force of Energy, which means that when as the economy grows, the energy demand grows parallelly (Fankhauser & Jotzo, 2018). This means that the economic growth will be pulled back in turn if the energy is restrained. Therefore, sustainable development and increase in energy efficiency have a bidirectional relationship (Sadorsky, 2010).

The socio-economic growth can be quickened by Energy efficiency (EE) which supports sustainable development, because it is obligatory for the current corporate environment to achieve competitive benefit, given the global challenge of developing sustainable economies through decarbonization (Caiado et al., 2017). Energy efficiency is a goal of policy and a way to cut emissions of carbon dioxide (CO_2) (Vehmas et al., 2018). Efficient and productive buildings are integral to sustainable cities, offering substantial contributions in response to SDGs. It is believed that sustainable construction of green buildings (GBs), facilitated by Green Building Rating Tools (GBRTs) is the solution for energy reduction (Wen et al., 2020). As a result, it's not unexpected that energy-efficient buildings contribute to initiatives related to the environment and energy. Studying how buildings with low energy consumption (energy-efficient) relate to the Sustainable Development Goals is therefore significant since these buildings have the potential to make a big difference in sustainability. On top of that, energy-efficient buildings are addressed in SDGs 11 and 13, which demand "rapid action to battle changes in the climate and its repercussions" and "sustainable, safe, buoyant, and comprehensive settlements of human beings and the cities" (Di Foggia, 2018).

Most of the energy is produced by the combustion of fossil fuels, due to which it contributes to greenhouse gas emissions, which negatively affect the natural environment (Economic Planning Unit, 2020). Therefore, to lessen the adversative impact of this on the environment and reduce the energy consumption of the buildings, many actions have been taken by several countries globally by using different technologies that support renewable energy and the energy efficiency of buildings (Mirrahimi et al., 2016). Because energy-efficient buildings are considered as among the crucial triggers in achieving the regional and global sustainable development goals (Wen et al., 2020). The building envelope is fundamental for the energy efficiency of the building. Consequently, a thorough assessment of heat gain through the enclosure is crucial for significant energy savings while taking the thermal comfort of occupants into account (Djamila et al., 2018). The Overall Thermal Transfer Value (OTTV) is considered an indicator to estimate the thermal performance of the buildings since the OTTV represents the average heat gain via the building envelope (Chan & Chow, 2013; Pramesti et al., 2021). Therefore, in tropical climates, the building's façade must be optimised to get the full advantage of passive cooling strategies and efficient integration with active cooling systems, because the building façade acts as a crucial part of designing a sustainable building (Ghassan et al., 2021). The thermal load in commercial buildings is determined by the building's construction, which includes the construction materials used, glazing characteristics, orientation of the building, shape of the building, solar insulation, climatic conditions, and location. Therefore, to lessen the air-conditioning load, the heat conduction through opaque walls and glass windows must be reduced (Karim et al., 2019).

Therefore, to analyse the performance of building envelopes based on OTTV, several studies have been conducted globally. Such as in 2004, A model based on the correlation between the Overall Thermal Transfer Value, and the Coefficient of Performance of Chillers was developed by Chirarattananon and Taveekun (2004) for commercial buildings in Thailand. Then, this developed model was used to assess the energy usage of Thai departmental stores, hospitals, and offices. In a single-landed residential building, the effectiveness of OTTV was examined by Utama et al. (2011), who found that it was appropriate for non-humid environmental conditions. Due to internal load dominance and a few intrinsic measurement errors, the OTTV values did not, however, directly correlate favorably with the amount of electricity consumed by high-rise residential buildings. Using the OTTV method, Praditsmanont and Chungpaibulpatana (2008) conducted a case study in a Thai university hall and discovered that utilising an energy-efficient building envelope can yield higher savings and a shorter payback period than utilising a lightweight, highly insulated envelope. Two university building halls' design criteria were developed by Anas Zafirol and Al-Hafzan (2010) based on the OTTV and its adherence to the Malaysian Building Energy Efficiency Code's guidelines. Nikpour et al. (2011) talked about daylighting elements to lower the energy usage of high-rise buildings, concentrating on the solar heat gain in terms of OTTV. The envelope thermal performance of high-rise buildings in Penang, Malaysia, was assessed using OTTV by Arab et al. (2023) as a tool for assessment. To account for various building construction periods, a variety of architectural styles and high-rise buildings were chosen for this study. As it is believed to be an essential orientation for receiving high solar radiation, the west-facing façade of the selected buildings was utilised to calculate the OTTV value. Singhpoo et al. (2015) studied the effect of temperature change on OTTV values from 6 am to 6 pm by keeping an indoor set point temperature of 25 °C. Using the OTTV tool, Amin Ismail and Zainonabidin (2016) assessed the envelope retrofitting of a 38-story high-rise office building to improve the building's energy efficiency. Three variables were taken into consideration for the envelope retrofitting: WWR, Shading Coefficient (SC), and U-value. This analysis indicates that OTTV can be reduced from 77.43 W/m^2 at initialization to 28.43 W/m^2. Sozer (2010) underlined the significance of using passive building design techniques, even for large-scale hotel buildings in Turkey, with an emphasis on energy efficiency. It was concluded that in comparison to most traditional Turkish hotels, the proposed building uses 40% less energy overall for heating and cooling loads. To optimize the shading devices for multistory buildings in the tropical climate of Jakarta, Indonesia research was conducted by Irvandi et al. (2021), for all four orientations of the buildings. In this study, the shade element length for different orientations was proposed. The influence of OTTV on building energy efficiency was evaluated by Muhfizaturrahmah et al. (2021). Furthermore, the discussion included how OTTV was calculated using measurements of the façade and how this corresponded to the amount of power used by those air conditioners. Pramesti et al. (2021) conducted a study on OTTV calculation of 15 storeyed glass facade building (Suara Merdeka Tower) in Indonesia. Different alternatives for the design of shading devices and materials used in buildings to improve their energy consumption were suggested. Shah et al. (2023) examined the effect of shading systems on the opaque facades of the building and many benefits resulted such as a reduction in conduction of heat gain, cooling load of the building, carbon emission over the building life cycle, and the local climatic temperature along the building façade. In Northern and Southern Taiwan, thermal comfort, natural ventilation, and cooling load, of the school buildings were simulated by Hwang et al. (2021) to discuss the potential parameters of building envelope design. It was suggested that the equivalent ventilation area for Taipei should be 9.5 m^2 and 14.3 m^2 for Kaohsiung (Two cities of Taiwan). It was concluded that these equivalent ventilation areas possess no risk of overheating during the ventilation season.

All the above studies were conducted on OTTV-based building energy efficiency to achieve the SDGs. However, the real-time effect of temperature change on the OTTV of glass building facade has gotten very little attention. Therefore, to meet the SDGs for affordable and clean energy, climate action, and sustainable cities and communities, this paper will examine the relative measurement and monitoring of OTTV of glass facade passive buildings in a tropical climate. Our goal is to address the particular difficulties presented by tropical climates while contributing to worldwide endeavours toward sustainable development.

2. Methodology

This section defines the methodology adopted to conduct this research work, which includes the methods, instruments, and tools used to achieve the objective of the study.

2.1. Data collection and analysis procedure

In this research work, the real-time monitoring of OTTV of UTM Eco house building has been done to know the effect of temperature change on the OTTV of a passive design building. Because the location (Latitude, Longitude, and Climate) influences the OTTV value, weather analysis is a crucial parameter for OTTV development and determination because the OTTV parameters rely on the location's climatic data. Using Delta Ohm Photometer equipment for solar radiations, meteorological data for Johor state, Malaysia, which has a tropical climate, have been gathered in real-time. Conversely, the HOBO Loggers are employed for measuring both indoor and outdoor air temperatures. The case study building's outside and inside were equipped with fixed devices to enable real-time data collecting. With the use of the aforementioned sensors, the temperature both inside and outside the building as well as solar radiation were measured. The indoor and outdoor temperatures were determined in real-time from 8 am to 5 pm (working hours of the university building) on 28th August 2023. After collecting the weather data, the data was analysed by calculating the equivalent temperature difference and the temperature difference, the two coefficients of the OTTV Equation from 8 am to 5 pm. The details of the case study building are shown in Table 1, whereas the step-by-step methodology used in this study can be interpreted from Figure 1.

Table 1. Data of case study building (UTM Eco house building)

Orientation	Gross Wall Area (m^2)	Fenestration Area (m^2)	WWR
North	25.682	5.15	0.200
South	57.005	27	0.473
East	70.313	16.801	0.238
West	55.297	32.739	0.592

Figure 1. Flow chart of research methodology

2.2. OTTV calculation

A heat transfer value is the amount of heat that enters a building by the change in the surrounding environment and solar radiation.

Building thermal heat gain is the result of three orientation-dependent main components: (1) conduction of heat from opaque walls, (2) conduction of heat from glass windows, and (3) radiation heat gain through glass windows. Conduction of heat gain through opaque walls can be calculated by multiplying the thermal transmittance of the wall (U-Value), equivalent temperature difference for the wall, absorptivity value, and (1-window to wall ratio). Similarly, the heat conduction by the window can be calculated by multiplying the window-to-wall ratio, window temperature difference, and thermal transmittance of the window (U-Value of the fenestration). Finally, the last component of OTTV is the radiation heat gain from glass windows due to the solar factors and the shading of the windows.

So, when the heat from these three portions is averaged by area, the overall heat transfer value is calculated (see Figure 2). The overall heat transfer value of the exterior walls on either side ($OTTV_i$) can be calculated by the following equations:

$$OTTV_i = (A_w \times U_w \times TDeq) + (A_f \times U_f \times \Delta T) + (A_f \times SF \times SC) / A_i, \quad (1)$$

$$OTTV_i = TDeq\alpha(1-WWR)U_w + \Delta T(WWR)U_f + SF(CF)(WWR)(SC_f). \quad (2)$$

Additionally, the following equation is used to determine OTTV, which is the average of the total heat transfer of the outer walls on each side ($OTTV_0$):

$$OTTV_0 = (A_{01} \times OTTV_{01} + \ldots + A_{0N} \times OTTV_{0N}) / (A_{01} + A_{02} + \ldots + A_{0N}), \quad (3)$$

where $OTTV_0$ is the weighted average $OTTV$ (W/m^2), A_{01} … A_{0N} are the distinct areas of the external wall (m^2), SF is the solar factor (W/m^2), $TDeq$ is the equivalent temperature difference (K), U_f is the thermal transmittance of glass windows (W/m^2·K), CF is the correction factor for solar heat gain through fenestration, SC_f shading coefficient of glazing system, ΔT is difference in temperature of windows from outside and inside of the buildings (K), and WWR is the window-to-wall ratio.

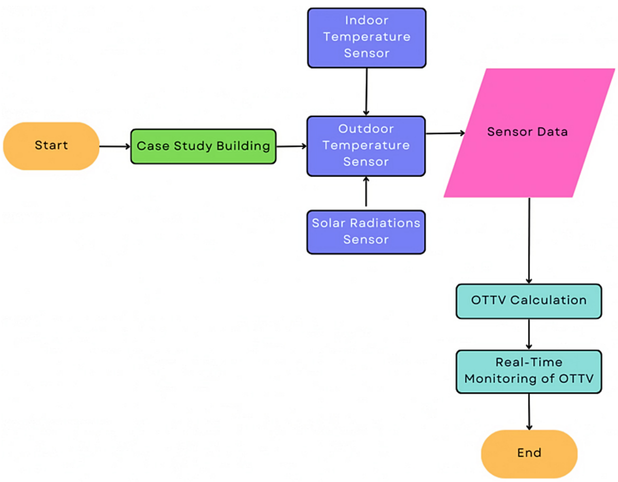

Figure 2. Flow chart of sensor real-time calculation of OTTV

2.3. Equivalent temperature difference

The temperature difference between the exterior and interior of a building, referred to as the equivalent temperature difference, encompasses the absorption of solar radiation by walls. This parameter is determined by considering factors such as the duration of solar radiation absorption, the coefficient for solar radiation absorption, and the orientation and inclination of the walls (Singhpoo et al., 2015). The equivalent temperature difference is calculated by the equation which was developed and used by Lam (1993):

$$TDeq = (To - Ti) + R_{so} \times \alpha \times Id, \quad (4)$$

where: $TDeq$ – Equivalent temperature difference; To – outside temperature (°C); Ti – inside temperature (°C); R_{so} – outside surface resistance (m^{2}K/W); α – absorptance of the surface for solar radiations (dimensionless); Id – incidence solar radiations (W/m^2).

2.4. Temperature difference

The temperature difference means the outdoor air temperature minus the indoor air temperature of the case study building. The temperature difference between the exterior and interior air temperatures of the building's air-conditioned section was used to compute the amount of heat conduction via glass windows in real-time. The temperature difference was calculated from 8 am to 5 pm from the case study building via HOBO Temperature Sensors:

$$\Delta T = Outside\ Air\ Temperature - Inside\ Air\ Temperature. \quad (5)$$

2.5. Glass as facade material

The widespread adoption of glass as a load-bearing material in construction represents a relatively recent innovation compared to traditional and established solutions like timber, steel, concrete, or masonry. On the other hand, in modern world buildings, glass has been widely used in windows and facades for many reasons such as thermal, energy, light, and beauty (aesthetics) (Bedon et al., 2018).

Glass, a versatile and typically transparent solid, is gaining traction as a favoured construction material for contemporary buildings. Additionally, it features prominently in the built environment as a non-load-bearing component. Traditionally, it is produced by heating a blend of raw materials in a furnace until they reach the transition temperature. Subsequently, the molten glass from the melting tank is floated through tin and slowly annealed to reach room temperature (Bedon et al., 2018).

Glass is a complex material whose properties vary depending on its chemical composition. For instance, soda lime glass, commonly used for windows, contains about 72% silica, while borosilicate glass, with approximately 80% silica, offers better resistance to temperature shock. Borosilicate glass is often used in laboratory glassware rather than in building construction. Other types of glass, such as lead oxide glass, alumina-silicate glass, and fused quartz glass, have unique characteristics due to their specific chemical compositions (Bedon et al., 2018). The utilization of technological glass enhances spatial qualities and light transmission, while also playing a pivotal role in energy conservation, addressing a crucial architectural challenge of our time (Naqash et al., 2021). A specific variety of glass is produced to improve its performance in terms of acoustics, light transmission, and energy efficiency (measured by U and R values) (Naqash et al., 2021; Schittich et al., 2006). Lower U-values in glass indicate superior insulation capabilities, while higher R-values signify enhanced thermal resistance. These values are influenced by factors such as the thickness of the glass panes, the type of insulation material, and the lamination process employed. The vast array of available glass glazing options allows for nearly limitless combinations of colour, thickness, and opacity. Nevertheless, the two most commonly used thicknesses in commercial construction are 6 mm monolithic glass and 25 mm insulating glass (Naqash et al., 2021).

Single skin facades consist of single layer whereas, Double skin facades consist of two layers of facade separated by a space. Building configurations incorporating this design vary in terms of the depth of the space, materials utilized for each facade layer, the ratio of windows to walls, the structure of the air space, and the shading materials employed within the space (Hamza, 2008). Single-pane absorptive glazing finds extensive application in commercial buildings, while double glazing is typically employed to enhance both acoustic and thermal insulation. By carefully selecting the appropriate glazing type for buildings, it is possible to substantially reduce the space cooling load caused by external factors, as well as electricity consumption in the air-conditioning system (Chan et al., 2009).

3. Results

This section discusses the results obtained from the data analysis using the above-mentioned equations and methods.

3.1. Equivalent temperature difference

As discussed earlier in Section 2.3, the equivalent temperature difference depends upon the solar radiation. Therefore, it will be separately calculated for all four orientations of the building (North, South, East, and West). Because the incident angle of the wall will be different for different orientations. The equivalent temperature difference for different orientations from 8 am to 5 pm is shown in Table 2 below.

As the equivalent temperature difference is based on solar radiation, therefore it varies with the variation in solar radiation during the time of the day. It is the coefficient of the first component of OTTV, i.e., heat conduction through opaque walls. *TDeq* is calculated for all four orientations, therefore, the OTTV was calculated for all four orientations separately and then averaged over the whole area of the building to check the effect of change in equivalent temperature difference on the OTTV of a passive building.

Table 2. Equivalent temperature difference values

Time	*TDeq* (North) (^{0}C)	*TDeq* (South) (^{0}C)	*TDeq* (East) (^{0}C)	*TDeq* (West) (^{0}C)
8:00 am	2.065	4.982	4.932	4.982
8:15 am	3.742	7.660	7.592	7.660
8:30 am	5.053	11.489	11.373	11.489
8:45 am	7.803	14.751	14.622	14.751
9:00 am	6.235	9.614	9.548	9.614
9:15 am	9.035	17.161	16.993	17.161
9:30 am	10.155	16.193	16.058	16.193
9:45 am	8.059	13.945	13.801	13.945
10:00 am	10.783	15.704	15.570	15.704
10:15 am	8.116	10.906	10.820	10.906
10:30 am	11.660	14.668	14.561	14.668
10:45 am	9.101	12.879	12.719	12.879
11:00 am	5.252	5.910	5.876	5.910
11:15 am	3.030	3.115	3.109	3.115
11:30 am	0.188	0.139	0.110	0.139
11:45 am	0.241	0.506	0.472	0.506
12:00 pm	0.506	0.687	0.651	0.687
12:15 pm	1.032	1.285	1.197	1.285
12:30 pm	1.378	1.508	1.407	1.508
12:45 pm	1.895	1.972	1.770	1.972
1:00 pm	2.056	2.067	1.704	2.067
1:15 pm	2.137	2.151	2.151	1.733
1:30 pm	2.983	3.154	3.154	2.723
1:45 pm	3.945	4.470	4.470	4.074
2:00 pm	4.386	5.331	5.331	5.007
2:15 pm	5.036	6.318	6.318	6.069
2:30 pm	6.989	9.306	9.306	9.017
2:45 pm	6.710	9.436	9.436	9.197
3:00 pm	6.329	9.623	9.623	9.406
3:15 pm	7.993	12.812	12.812	12.562
3:30 pm	7.708	12.339	12.339	12.143
3:45 pm	7.643	11.618	11.618	11.476
4:00 pm	3.947	5.436	5.436	5.390
4:15 pm	2.809	4.460	4.460	4.416
4:30 pm	3.109	4.322	4.322	4.293
4:45 pm	3.079	4.121	4.121	4.098
5:00 pm	3.190	4.083	4.083	4.064

From Figure 3 and Table 2 it is observed that the maximum value of equivalent temperature difference was 16.193 obtained at 09:30 am for South and West Orientations. Whereas the lowest value of equivalent temperature difference was 0.110 obtained at 11:30 am for East orientation. Therefore, the OTTV for the above-mentioned times i.e. 9:30 am is highest due to the highest equivalent temperature difference and the lowest at 11:30 am due to the same reason of least *TDeq*.

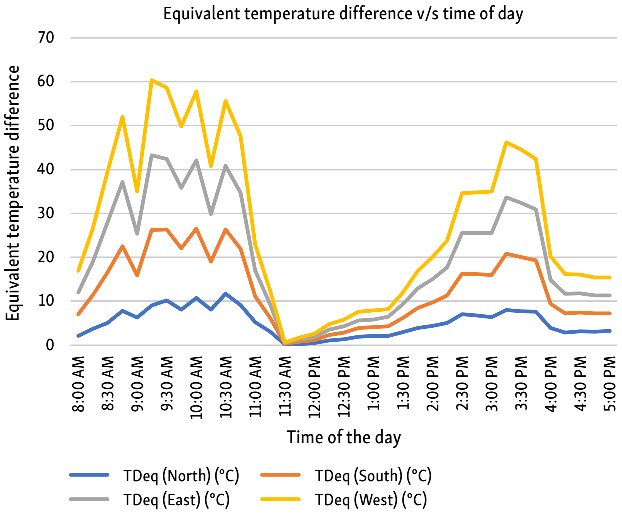

Figure 3. Equivalent temperature difference for all four orientations in real-time

3.2. Temperature difference

Temperature difference means outside air temperature minus inside air temperature. As it is not orientation-dependent, so it is calculated generally for all orientations. The temperature difference for different times of the day from 8 am to 5 pm is shown in Table 3 below. This temperature difference plays an important role in the calculation of OTTV because it can be considered as the coefficient of the second component of OTTV, i.e., heat conduction through glass windows. The case study building is a passive building with having high window-to-wall ratio therefore if the temperature differs then the OTTV will also differ accordingly.

Table 3. Temperature difference values

Time	Temperature Difference (°C)
08:00	1.475
08:15	2.943
08:30	3.721
08:45	6.337
09:00	5.502
09:15	7.215
09:30	8.747
09:45	6.617
10:00	9.503
10:15	7.338
10:30	10.75
10:45	7.841
11:00	5.006
11:15	2.993
11:30	0.355
11:45	0.074
12:00	0.357
12:15	0.732
12:30	1.117
12:45	1.517
13:00	1.606
13:15	1.612
13:30	2.17
13:45	2.905
14:00	3.28
14:15	3.991
14:30	5.543
14:45	5.329
15:00	4.919
15:15	6.195
15:30	6.169
15:45	6.443
16:00	3.533
16:15	2.38
16:30	2.812
16:45	2.836
17:00	2.99

End of Table 3

It is evident from Figure 4 and Table 3 that, the maximum value of temperature difference was 10.75 obtained at 10:30 am, and the minimum value was 0.074 at 11:45 am. Though the highest temperature difference was observed at 10:30 am, the OTTV was not the highest at that time because the solar radiation was comparatively lower, and correspondingly the *TDeq* will also lower.

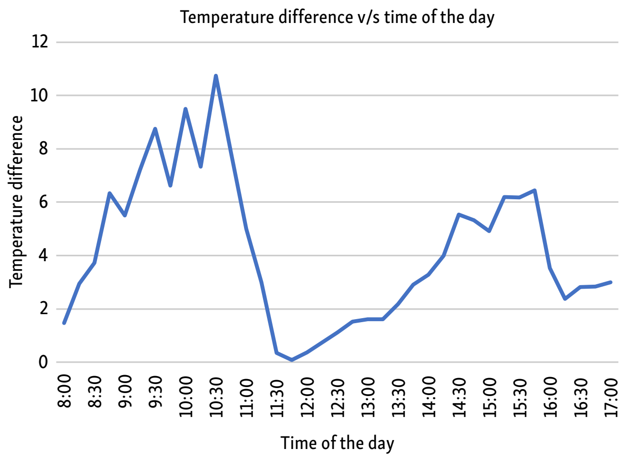

Figure 4. Temperature difference in real-time

3.3. Overall thermal transfer value

OTTV is considered the index for measuring the thermal transfer performance of the building envelope of a passive building. OTTV is composed of 3 parts: heat gain through opaque walls, heat gain through glass windows, and radiation heat gain through glass windows. The coefficients of OTTV are climate-dependent, therefore the OTTV is calculated based on the real-time data of the case study building's location (Tables 4–7).

Table 4. OTTV calculation for South Wall

Date and Day	Time	Outdoor Temperature *To* (°C)	Indoor Temperature *Ti* (°C)	Temperature Difference (*ΔT*) (°C)	*Id* Incident Solar Radiations	$TDeq = (To - Ti) + R_{so} \times \alpha \times Id$	*WWR*	Wall conduction $TDeq\alpha(1 - WWR)Uw$	Area × OTTV	Window Conduction $\Delta T(WWR)U_f$	Area × OTTV	Window Solar Heat Gain $SF(CF)(WWR)SC_f$	Area × OTTV	∑Area × OTTV
28/08/2023 Monday	8:00 am	27.785	26.310	1.475	21.639	4.982	0.473	7.939	452.521	1.898	108.168	48.120	2742.840	3303.528
	8:15 am	29.131	26.188	2.943	29.110	7.660	0.473	12.208	695.845	3.786	215.822	48.120	2742.840	3654.507
	8:30 am	29.252	25.531	3.721	47.933	11.489	0.473	18.309	1043.593	4.787	272.876	48.120	2742.840	4059.308
	8:45 am	31.601	25.264	6.337	51.922	14.751	0.473	23.508	1339.953	8.153	464.717	48.120	2742.840	4547.509
	9:00 am	30.329	24.827	5.502	25.374	9.614	0.473	15.321	873.305	7.079	403.483	48.120	2742.840	4019.628
	9:15 am	31.825	24.610	7.215	61.378	17.161	0.473	27.349	1558.890	9.283	529.104	48.120	2742.840	4830.834
	9:30 am	33.429	24.682	8.747	45.946	16.193	0.473	25.805	1470.905	11.254	641.452	48.120	2742.840	4855.196
	9:45 am	31.203	24.586	6.617	45.218	13.945	0.473	22.223	1266.693	8.513	485.251	48.120	2742.840	4494.783
	10:00 am	34.089	24.586	9.503	38.266	15.704	0.473	25.027	1426.519	12.226	696.892	48.120	2742.840	4866.251
	10:15 am	32.020	24.682	7.338	22.021	10.906	0.473	17.381	990.718	9.441	538.124	48.120	2742.840	4271.682
	10:30 am	35.505	24.755	10.750	24.180	14.668	0.473	23.376	1332.451	13.831	788.340	48.120	2742.840	4863.630
	10:45 am	32.765	24.924	7.841	31.092	12.879	0.473	20.525	1169.941	10.088	575.011	48.120	2742.840	4487.792
	11:00 am	29.906	24.900	5.006	5.581	5.910	0.473	9.419	536.889	6.441	367.110	48.120	2742.840	3646.839
	11:15 am	27.796	24.803	2.993	0.752	3.115	0.473	4.964	282.949	3.851	219.488	48.120	2742.840	3245.277
	11:30 am	24.351	24.706	–0.355	3.046	0.139	0.473	0.221	12.596	–0.457	–26.034	48.120	2742.840	2729.403
	11:45 am	24.418	24.344	0.074	2.665	0.506	0.473	0.806	45.947	0.095	5.427	48.120	2742.840	2794.213
	12:00 pm	24.629	24.272	0.357	2.036	0.687	0.473	1.095	62.392	0.459	26.180	48.120	2742.840	2831.412
	12:15 pm	24.883	24.151	0.732	3.412	1.285	0.473	2.048	116.726	0.942	53.680	48.120	2742.840	2913.246
	12:30 pm	25.099	23.982	1.117	2.411	1.508	0.473	2.403	136.953	1.437	81.914	48.120	2742.840	2961.707
	12:45 pm	25.427	23.910	1.517	2.808	1.972	0.473	3.143	179.143	1.952	111.248	48.120	2742.840	3033.230
	1:00 pm	25.588	23.982	1.606	2.843	2.067	0.473	3.294	187.735	2.066	117.774	48.120	2742.840	3048.349
	1:15 pm	25.498	23.886	1.612	3.324	2.151	0.473	3.427	195.363	2.074	118.214	48.120	2742.840	3056.417
	1:30 pm	26.152	23.982	2.170	6.071	3.154	0.473	5.026	286.483	2.792	159.135	48.120	2742.840	3188.457
	1:45 pm	26.695	23.790	2.905	9.656	4.470	0.473	7.123	406.025	3.737	213.035	48.120	2742.840	3361.900
	2:00 pm	27.094	23.814	3.280	12.656	5.331	0.473	8.496	484.248	4.220	240.535	48.120	2742.840	3467.623
	2:15 pm	27.901	23.910	3.991	14.358	6.318	0.473	10.068	573.893	5.135	292.676	48.120	2742.840	3609.408
	2:30 pm	29.670	24.127	5.543	23.223	9.306	0.473	14.831	845.359	7.131	406.490	48.120	2742.840	3994.689
	2:45 pm	29.746	24.417	5.329	25.344	9.436	0.473	15.038	857.151	6.856	390.796	48.120	2742.840	3990.787
	3:00 pm	29.408	24.489	4.919	29.026	9.623	0.473	15.335	874.102	6.329	360.730	48.120	2742.840	3977.671
	3:15 pm	30.877	24.682	6.195	40.830	12.812	0.473	20.417	1163.773	7.970	454.304	48.120	2742.840	4360.916
	3:30 pm	30.900	24.731	6.169	38.074	12.339	0.473	19.664	1120.836	7.937	452.397	48.120	2742.840	4316.072
	3:45 pm	31.222	24.779	6.443	31.934	11.618	0.473	18.515	1055.339	8.289	472.490	48.120	2742.840	4270.669
	4:00 pm	28.215	24.682	3.533	11.744	5.436	0.473	8.663	493.807	4.545	259.089	48.120	2742.840	3495.736
	4:15 pm	26.772	24.392	2.380	12.838	4.460	0.473	7.108	405.177	3.062	174.535	48.120	2742.840	3322.551
	4:30 pm	27.132	24.320	2.812	9.321	4.322	0.473	6.888	392.639	3.618	206.215	48.120	2742.840	3341.693
	4:45 pm	27.035	24.199	2.836	7.931	4.121	0.473	6.568	374.359	3.649	207.975	48.120	2742.840	3325.174
	5:00 pm	27.021	24.031	2.990	6.744	4.083	0.473	6.507	370.876	3.847	219.268	48.120	2742.840	3332.984

Table 5. OTTV calculation for North Wall

Date and Day	Time	Outdoor Temperature To (°C)	Indoor Temperature Ti (°C)	Temperature Difference (ΔT) (°C)	Id Incident Solar Radiations	$TDeq = (To - Ti) + R_{so} \times \alpha \times Id$	WWR	Wall conduction $TDeq\alpha(1 - WWR)Uw$	Area × OTTV	Window Conduction $\Delta T(WWR)U_f$	Area × OTTV	Window Solar Heat Gain $SF(CF)(WWR)SC_f$	Area × OTTV	∑Area × OTTV
28/08/2023 Monday	8:00 am	27.785	26.310	1.475	3.641	2.065	0.2	4.996	128.304	0.802	20.607	19.904	511.185	660.096
	8:15 am	29.131	26.188	2.943	4.933	3.742	0.2	9.054	232.517	1.601	41.117	19.904	511.185	784.819
	8:30 am	29.252	25.531	3.721	8.222	5.053	0.2	12.225	313.961	2.024	51.986	19.904	511.185	877.132
	8:45 am	31.601	25.264	6.337	9.048	7.803	0.2	18.878	484.813	3.447	88.534	19.904	511.185	1084.533
	9:00 am	30.329	24.827	5.502	4.522	6.235	0.2	15.083	387.363	2.993	76.868	19.904	511.185	975.416
	9:15 am	31.825	24.610	7.215	11.23	9.035	0.2	21.858	561.348	3.925	100.801	19.904	511.185	1173.333
	9:30 am	33.429	24.682	8.747	8.691	10.155	0.2	24.568	630.950	4.758	122.204	19.904	511.185	1264.339
	9:45 am	31.203	24.586	6.617	8.901	8.059	0.2	19.497	500.727	3.600	92.446	19.904	511.185	1104.358
	10:00 am	34.089	24.586	9.503	7.898	10.783	0.2	26.086	669.938	5.170	132.766	19.904	511.185	1313.889
	10:15 am	32.020	24.682	7.338	4.800	8.116	0.2	19.634	504.236	3.992	102.519	19.904	511.185	1117.940
	10:30 am	35.505	24.755	10.750	5.616	11.660	0.2	28.208	724.436	5.848	150.188	19.904	511.185	1385.809
	10:45 am	32.765	24.924	7.841	7.773	9.101	0.2	22.016	565.421	4.266	109.547	19.904	511.185	1186.152
	11:00 am	29.906	24.900	5.006	1.520	5.252	0.2	12.706	326.328	2.723	69.939	19.904	511.185	907.451
	11:15 am	27.796	24.803	2.993	0.226	3.030	0.2	7.329	188.231	1.628	41.815	19.904	511.185	741.231
	11:30 am	24.351	24.706	–0.355	1.028	–0.188	0.2	–0.456	–11.710	–0.193	–4.960	19.904	511.185	494.515
	11:45 am	24.418	24.344	0.074	1.027	0.241	0.2	0.582	14.943	0.040	1.034	19.904	511.185	527.161
	12:00 pm	24.629	24.272	0.357	0.918	0.506	0.2	1.224	31.427	0.194	4.988	19.904	511.185	547.599
	12:15 pm	24.883	24.151	0.732	1.849	1.032	0.2	2.496	64.094	0.398	10.227	19.904	511.185	585.506
	12:30 pm	25.099	23.982	1.117	1.611	1.378	0.2	3.334	85.617	0.608	15.606	19.904	511.185	612.407
	12:45 pm	25.427	23.910	1.517	2.335	1.895	0.2	4.585	117.756	0.825	21.194	19.904	511.185	650.135
	1:00 pm	25.588	23.982	1.606	2.777	2.056	0.2	4.974	127.739	0.874	22.437	19.904	511.185	661.361
	1:15 pm	25.498	23.886	1.612	3.239	2.137	0.2	5.169	132.761	0.877	22.521	19.904	511.185	666.467
	1:30 pm	26.152	23.982	2.170	5.019	2.983	0.2	7.217	185.356	1.180	30.317	19.904	511.185	726.858
	1:45 pm	26.695	23.790	2.905	6.416	3.945	0.2	9.543	245.080	1.580	40.586	19.904	511.185	796.851
	2:00 pm	27.094	23.814	3.280	6.824	4.386	0.2	10.610	272.488	1.784	45.825	19.904	511.185	829.498
	2:15 pm	27.901	23.910	3.991	6.449	5.036	0.2	12.183	312.889	2.171	55.758	19.904	511.185	879.833
	2:30 pm	29.670	24.127	5.543	8.921	6.989	0.2	16.907	434.203	3.015	77.441	19.904	511.185	1022.830
	2:45 pm	29.746	24.417	5.329	8.520	6.710	0.2	16.232	416.867	2.899	74.452	19.904	511.185	1002.504
	3:00 pm	29.408	24.489	4.919	8.702	6.329	0.2	15.311	393.225	2.676	68.723	19.904	511.185	973.133
	3:15 pm	30.877	24.682	6.195	11.094	7.993	0.2	19.336	496.592	3.370	86.550	19.904	511.185	1094.327
	3:30 pm	30.900	24.731	6.169	9.499	7.708	0.2	18.648	478.919	3.356	86.187	19.904	511.185	1076.291
	3:45 pm	31.222	24.779	6.443	7.405	7.643	0.2	18.490	474.862	3.505	90.015	19.904	511.185	1076.062
	4:00 pm	28.215	24.682	3.533	2.556	3.947	0.2	9.549	245.239	1.922	49.360	19.904	511.185	805.783
	4:15 pm	26.772	24.392	2.380	2.645	2.809	0.2	6.795	174.503	1.295	33.251	19.904	511.185	718.939
	4:30 pm	27.132	24.320	2.812	1.833	3.109	0.2	7.521	193.165	1.530	39.286	19.904	511.185	743.636
	4:45 pm	27.035	24.199	2.836	1.499	3.079	0.2	7.448	191.290	1.543	39.622	19.904	511.185	742.096
	5:00 pm	27.021	24.031	2.990	1.233	3.190	0.2	7.717	198.181	1.627	41.773	19.904	511.185	751.139

Table 6. OTTV calculation for East Wall

Date and Day	Time	Outdoor Temperature *To* (°C)	Indoor Temperature *Ti* (°C)	Temperature Difference (*ΔT*) (°C)	*Id* Incident Solar Radiations	$TDeq = (To - Ti) + R_{so} \times \alpha \times Id$	*WWR*	Wall conduction $TDeq\alpha(1 - WWR)Uw$	Area × OTTV	Window Conduction $\Delta T(WWR)U_f$	Area × OTTV	Window Solar Heat Gain $SF(CF)(WWR)SC_f$	Area × OTTV	∑Area × OTTV
28/08/2023 Monday	8:00 am	27.785	26.310	1.475	21.330	4.932	0.238	11.364	799.024	0.955	67.139	32.371	2276.115	3142.278
	8:15 am	29.131	26.188	2.943	28.689	7.592	0.238	17.494	1230.069	1.905	133.959	32.371	2276.115	3640.143
	8:30 am	29.252	25.531	3.721	47.222	11.373	0.238	26.207	1842.720	2.409	169.372	32.371	2276.115	4288.207
	8:45 am	31.601	25.264	6.337	51.127	14.622	0.238	33.694	2369.103	4.102	288.446	32.371	2276.115	4933.665
	9:00 am	30.329	24.827	5.502	24.968	9.548	0.238	22.001	1546.979	3.562	250.439	32.371	2276.115	4073.533
	9:15 am	31.825	24.610	7.215	60.340	16.993	0.238	39.157	2753.241	4.671	328.411	32.371	2276.115	5357.768
	9:30 am	33.429	24.682	8.747	45.116	16.058	0.238	37.002	2601.745	5.662	398.144	32.371	2276.115	5276.005
	9:45 am	31.203	24.586	6.617	44.332	13.801	0.238	31.801	2236.050	4.284	301.191	32.371	2276.115	4813.357
	10:00 am	34.089	24.586	9.503	37.441	15.570	0.238	35.878	2522.715	6.152	432.556	32.371	2276.115	5231.387
	10:15 am	32.020	24.682	7.338	21.490	10.820	0.238	24.933	1753.148	4.750	334.010	32.371	2276.115	4363.274
	10:30 am	35.505	24.755	10.750	23.518	14.561	0.238	33.553	2359.210	6.959	489.317	32.371	2276.115	5124.642
	10:45 am	32.765	24.924	7.841	30.103	12.719	0.238	29.309	2060.771	5.076	356.905	32.371	2276.115	4693.791
	11:00 am	29.906	24.900	5.006	5.370	5.876	0.238	13.540	952.061	3.241	227.862	32.371	2276.115	3456.038
	11:15 am	27.796	24.803	2.993	0.717	3.109	0.238	7.165	503.761	1.938	136.235	32.371	2276.115	2916.111
	11:30 am	24.351	24.706	–0.355	2.867	0.110	0.238	0.253	17.770	–0.230	–16.159	32.371	2276.115	2277.726
	11:45 am	24.418	24.344	0.074	2.458	0.472	0.238	1.088	76.530	0.048	3.368	32.371	2276.115	2356.014
	12:00 pm	24.629	24.272	0.357	1.816	0.651	0.238	1.501	105.524	0.231	16.250	32.371	2276.115	2397.889
	12:15 pm	24.883	24.151	0.732	2.867	1.197	0.238	2.757	193.875	0.474	33.319	32.371	2276.115	2503.310
	12:30 pm	25.099	23.982	1.117	1.792	1.407	0.238	3.243	228.038	0.723	50.843	32.371	2276.115	2554.997
	12:45 pm	25.427	23.910	1.517	1.559	1.770	0.238	4.078	286.715	0.982	69.051	32.371	2276.115	2631.881
	1:00 pm	25.588	23.982	1.606	0.606	1.704	0.238	3.927	276.116	1.040	73.102	32.371	2276.115	2625.333
	1:15 pm	25.498	23.886	1.612	3.324	2.151	0.238	4.956	348.455	1.044	73.375	32.371	2276.115	2697.946
	1:30 pm	26.152	23.982	2.170	6.071	3.154	0.238	7.267	510.980	1.405	98.774	32.371	2276.115	2885.869
	1:45 pm	26.695	23.790	2.905	9.656	4.470	0.238	10.300	724.200	1.881	132.229	32.371	2276.115	3132.545
	2:00 pm	27.094	23.814	3.280	12.656	5.331	0.238	12.284	863.720	2.123	149.298	32.371	2276.115	3289.134
	2:15 pm	27.901	23.910	3.991	14.358	6.318	0.238	14.558	1023.613	2.584	181.662	32.371	2276.115	3481.390
	2:30 pm	29.670	24.127	5.543	23.223	9.306	0.238	21.444	1507.809	3.588	252.305	32.371	2276.115	4036.230
	2:45 pm	29.746	24.417	5.329	25.344	9.436	0.238	21.743	1528.842	3.450	242.564	32.371	2276.115	4047.522
	3:00 pm	29.408	24.489	4.919	29.026	9.623	0.238	22.173	1559.076	3.184	223.902	32.371	2276.115	4059.093
	3:15 pm	30.877	24.682	6.195	40.830	12.812	0.238	29.521	2075.741	4.010	281.983	32.371	2276.115	4633.840
	3:30 pm	30.900	24.731	6.169	38.074	12.339	0.238	28.432	1999.158	3.994	280.799	32.371	2276.115	4556.073
	3:45 pm	31.222	24.779	6.443	31.934	11.618	0.238	26.771	1882.337	4.171	293.271	32.371	2276.115	4451.723
	4:00 pm	28.215	24.682	3.533	11.744	5.436	0.238	12.526	880.771	2.287	160.814	32.371	2276.115	3317.700
	4:15 pm	26.772	24.392	2.380	12.838	4.460	0.238	10.278	722.687	1.541	108.332	32.371	2276.115	3107.134
	4:30 pm	27.132	24.320	2.812	9.321	4.322	0.238	9.960	700.323	1.820	127.996	32.371	2276.115	3104.434
	4:45 pm	27.035	24.199	2.836	7.931	4.121	0.238	9.496	667.719	1.836	129.089	32.371	2276.115	3072.923
	5:00 pm	27.021	24.031	2.990	6.744	4.083	0.238	9.408	661.506	1.936	136.098	32.371	2276.115	3073.720

Table 7. OTTV calculation for West Wall

Date and Day	Time	Outdoor Temperature *To* (°C)	Indoor Temperature *Ti* (°C)	Temperature Difference (ΔT) (°C)	*Id* Incident Solar Radiations	$TDeq = (To - Ti) + R_{so} \times \alpha \times Id$	*WWR*	Wall conduction $TDeq\alpha(1 - WWR)Uw$	Area × OTTV	Window Conduction $\Delta T(WWR)U_f$	Area × OTTV	Window Solar Heat Gain $SF(CF)(WWR)SC_f$	Area × OTTV	∑Area × OTTV
28/08/2023 Monday	8:00 am	27.785	26.310	1.475	21.639	4.982	0.592	6.146	339.871	2.375	131.336	61.536	3402.732	3873.939
	8:15 am	29.131	26.188	2.943	29.110	7.660	0.592	9.451	522.624	4.739	262.049	61.536	3402.732	4187.404
	8:30 am	29.252	25.531	3.721	47.933	11.489	0.592	14.174	783.804	5.992	331.323	61.536	3402.732	4517.859
	8:45 am	31.601	25.264	6.337	51.922	14.751	0.592	18.200	1006.389	10.204	564.256	61.536	3402.732	4973.376
	9:00 am	30.329	24.827	5.502	25.374	9.614	0.592	11.862	655.907	8.860	489.906	61.536	3402.732	4548.545
	9:15 am	31.825	24.610	7.215	61.378	17.161	0.592	21.173	1170.825	11.618	642.434	61.536	3402.732	5215.990
	9:30 am	33.429	24.682	8.747	45.946	16.193	0.592	19.978	1104.742	14.085	778.845	61.536	3402.732	5286.319
	9:45 am	31.203	24.586	6.617	45.218	13.945	0.592	17.205	951.366	10.655	589.187	61.536	3402.732	4943.285
	10:00 am	34.089	24.586	9.503	38.266	15.704	0.592	19.375	1071.405	15.302	846.161	61.536	3402.732	5320.298
	10:15 am	32.020	24.682	7.338	22.021	10.906	0.592	13.456	744.091	11.816	653.386	61.536	3402.732	4800.209
	10:30 am	35.505	24.755	10.750	24.180	14.668	0.592	18.098	1000.754	17.310	957.195	61.536	3402.732	5360.681
	10:45 am	32.765	24.924	7.841	31.092	12.879	0.592	15.891	878.699	12.626	698.174	61.536	3402.732	4979.605
	11:00 am	29.906	24.900	5.006	5.581	5.910	0.592	7.292	403.238	8.061	445.741	61.536	3402.732	4251.711
	11:15 am	27.796	24.803	2.993	0.752	3.115	0.592	3.843	212.512	4.819	266.501	61.536	3402.732	3881.745
	11:30 am	24.351	24.706	–0.355	3.046	0.139	0.592	0.171	9.461	–0.572	–31.610	61.536	3402.732	3380.583
	11:45 am	24.418	24.344	0.074	2.665	0.506	0.592	0.624	34.509	0.119	6.589	61.536	3402.732	3443.830
	12:00 pm	24.629	24.272	0.357	2.036	0.687	0.592	0.847	46.861	0.575	31.788	61.536	3402.732	3481.380
	12:15 pm	24.883	24.151	0.732	3.412	1.285	0.592	1.585	87.669	1.179	65.178	61.536	3402.732	3555.579
	12:30 pm	25.099	23.982	1.117	2.411	1.508	0.592	1.860	102.860	1.799	99.459	61.536	3402.732	3605.051
	12:45 pm	25.427	23.910	1.517	2.808	1.972	0.592	2.433	134.547	2.443	135.076	61.536	3402.732	3672.355
	1:00 pm	25.588	23.982	1.606	2.843	2.067	0.592	2.550	141.001	2.586	143.001	61.536	3402.732	3686.733
	1:15 pm	25.498	23.886	1.612	0.745	1.733	0.592	2.138	118.213	2.596	143.535	61.536	3402.732	3664.480
	1:30 pm	26.152	23.982	2.170	3.410	2.723	0.592	3.359	185.750	3.494	193.220	61.536	3402.732	3781.702
	1:45 pm	26.695	23.790	2.905	7.212	4.074	0.592	5.026	277.927	4.678	258.665	61.536	3402.732	3939.324
	2:00 pm	27.094	23.814	3.280	10.655	5.007	0.592	6.177	341.574	5.282	292.056	61.536	3402.732	4036.362
	2:15 pm	27.901	23.910	3.991	12.825	6.069	0.592	7.488	414.080	6.426	355.364	61.536	3402.732	4172.176
	2:30 pm	29.670	24.127	5.543	21.437	9.017	0.592	11.125	615.175	8.926	493.557	61.536	3402.732	4511.464
	2:45 pm	29.746	24.417	5.329	23.866	9.197	0.592	11.347	627.433	8.581	474.502	61.536	3402.732	4504.667
	3:00 pm	29.408	24.489	4.919	27.688	9.406	0.592	11.605	641.715	7.921	437.995	61.536	3402.732	4482.442
	3:15 pm	30.877	24.682	6.195	39.291	12.562	0.592	15.499	857.049	9.975	551.612	61.536	3402.732	4811.392
	3:30 pm	30.900	24.731	6.169	36.867	12.143	0.592	14.982	828.480	9.934	549.297	61.536	3402.732	4780.508
	3:45 pm	31.222	24.779	6.443	31.061	11.476	0.592	14.160	782.984	10.375	573.694	61.536	3402.732	4759.409
	4:00 pm	28.215	24.682	3.533	11.462	5.390	0.592	6.651	367.763	5.689	314.583	61.536	3402.732	4085.078
	4:15 pm	26.772	24.392	2.380	12.562	4.416	0.592	5.448	301.262	3.832	211.919	61.536	3402.732	3915.913
	4:30 pm	27.132	24.320	2.812	9.138	4.293	0.592	5.297	292.881	4.528	250.385	61.536	3402.732	3945.997
	4:45 pm	27.035	24.199	2.836	7.788	4.098	0.592	5.056	279.585	4.567	252.522	61.536	3402.732	3934.838
	5:00 pm	27.021	24.031	2.990	6.630	4.064	0.592	5.015	277.293	4.815	266.234	61.536	3402.732	3946.259

Table 8. OTTV calculation for total building envelope

Date and Day	Time	WEST	EAST	SOUTH	NORTH	Total Building Envelope OTTV	
		∑Area × OTTV	∑Area × OTTV	∑Area × OTTV	∑Area × OTTV	∑Area × OTTV	OTTV
28/08/2023 Monday	8:00 am	3873.939	3142.278	3303.528	660.096	10979.840	52.712
	8:15 am	4187.404	3640.143	3654.507	784.819	12266.873	58.891
	8:30 am	4517.859	4288.207	4059.308	877.132	13742.506	65.976
	8:45 am	4973.376	4933.665	4547.509	1084.533	15539.083	74.601
	9:00 am	4548.545	4073.533	4019.628	975.416	13617.122	65.374
	9:15 am	5215.990	5357.768	4830.834	1173.333	16577.926	79.588
	9:30 am	5286.319	5276.005	4855.196	1264.339	16681.860	80.087
	9:45 am	4943.285	4813.357	4494.783	1104.358	15355.782	73.721
	10:00 am	5320.298	5231.387	4866.251	1313.889	16731.825	80.327
	10:15 am	4800.209	4363.274	4271.682	1117.940	14553.104	69.867
	10:30 am	5360.681	5124.642	4863.630	1385.809	16734.763	80.341
	10:45 am	4979.605	4693.791	4487.792	1186.152	15347.341	73.680
	11:00 am	4251.711	3456.038	3646.839	907.451	12262.039	58.868
	11:15 am	3881.745	2916.111	3245.277	741.231	10784.364	51.774
	11:30 am	3380.583	2277.726	2729.403	494.515	8882.226	42.642
	11:45 am	3443.830	2356.014	2794.213	527.161	9121.218	43.789
	12:00 pm	3481.380	2397.889	2831.412	547.599	9258.281	44.447
	12:15 pm	3555.579	2503.310	2913.246	585.506	9557.640	45.885
	12:30 pm	3605.051	2554.997	2961.707	612.407	9734.162	46.732
	12:45 pm	3672.355	2631.881	3033.230	650.135	9987.600	47.949
	1:00 pm	3686.733	2625.333	3048.349	661.361	10021.777	48.113
	1:15 pm	3664.480	2697.946	3056.417	666.467	10085.309	48.418
	1:30 pm	3781.702	2885.869	3188.457	726.858	10582.886	50.807
	1:45 pm	3939.324	3132.545	3361.900	796.851	11230.619	53.916
	2:00 pm	4036.362	3289.134	3467.623	829.498	11622.615	55.798
	2:15 pm	4172.176	3481.390	3609.408	879.833	12142.807	58.296
	2:30 pm	4511.464	4036.230	3994.689	1022.830	13565.212	65.124
	2:45 pm	4504.667	4047.522	3990.787	1002.504	13545.479	65.030
	3:00 pm	4482.442	4059.093	3977.671	973.133	13492.340	64.775
	3:15 pm	4811.392	4633.840	4360.916	1094.327	14900.475	71.535
	3:30 pm	4780.508	4556.073	4316.072	1076.291	14728.945	70.711
	3:45 pm	4759.409	4451.723	4270.669	1076.062	14557.864	69.890
	4:00 pm	4085.078	3317.700	3495.736	805.783	11704.297	56.190
	4:15 pm	3915.913	3107.134	3322.551	718.939	11064.538	53.119
	4:30 pm	3945.997	3104.434	3341.693	743.636	11135.761	53.461
	4:45 pm	3934.838	3072.923	3325.174	742.096	11075.031	53.169
	5:00 pm	3946.259	3073.720	3332.984	751.139	11104.101	53.309

Table 8 and Figure 5 show the real-time values of OTTV of the case study building from 8 am to 5 pm.

From Table 8, it was found that the maximum value of OTTV was 80.341 W/m^2 at 10:30 am, and the minimum OTTV was 42.642 W/m^2 at 11:30 am. From Figure 5, it can be seen that the OTTV varies with the change in temperature throughout the time of the day. The pattern of OTTV shows that on that time of day, the thermal load was maximum during the morning time around 10:30 am whereas after getting its peak value it gradually decreased during the midday. In the afternoon, again the OTTV rises peaking around 3 pm due to higher solar radiations. The OTTV was affected by the fluctuations in temperature as well as the solar radiations during the time of the day. With this continuous monitoring of OTTV, the building design can be optimized to make it energy efficient building. Which in other words can help to achieve the 7th sustainable development goal (Affordable and Clean Energy).

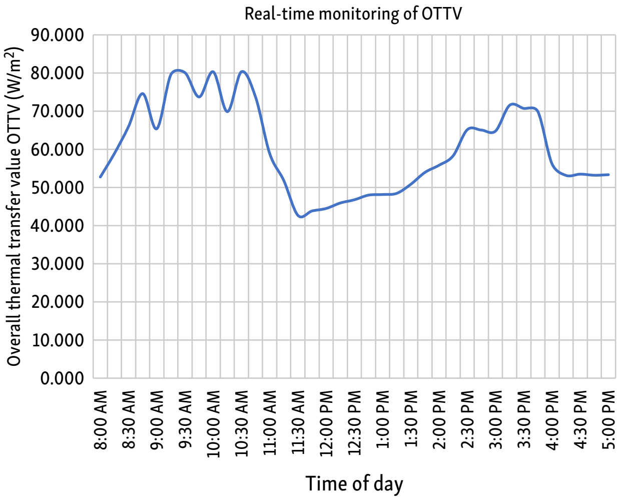

Figure 5. Real-time values of OTTV of case study building

4. Conclusions

Based on the findings of this research work, it is concluded that the OTTV varies with the temperature variation, and it is directly proportional to the change in temperature which is aligned with the conclusion of Singhpoo et al. (2015). Efficient and productive buildings are integral to sustainable cities, offering substantial contributions in response to SDGs. OTTV plays a vital role in the thermal transfer performance of passive buildings because OTTV is heat gain through the building envelope. For a green building, it is necessary to monitor the Value of OTTV in real-time, because normally the OTTV is calculated in the design stage or steady-state conditions. So, this study was undertaken to investigate the influence of temperature variation on OTTV from 8 am to 5 pm. As a result, the maximum value of OTTV was 80.341 W/m^2 at 10:30 am, and the minimum OTTV was 42.642 W/m^2 at 11:30 am. This study offers valuable insights into the dynamic thermal behaviour of the passive building envelope under variable climatic conditions. Real-time analysis and visualization of OTTV therefore provide a better way of understanding on how climatic factors affect heat gains and thereby inform better design, operation and even retrofitting of energy efficient buildings. As cities endeavour to become more sustainable, incorporation of real time OTTV in the building management system will improve the energy performance of the building and the occupant's comfort thereby supporting the overall objective of lesser energy usage as well as the reduction in carbon emission.

5. Limitations and future recommendations

The study was limited to the effect of temperature change and the change in solar radiations for one day only on the overall thermal transfer value of the UTM Eco-home building. Further study can be conducted to check the effect of climate change (temperature fluctuations and change in solar radiations) for a longer period. However, the effect was checked for the first two coefficients of OTTV (equivalent temperature difference and temperature difference) and the third coefficient, solar factor (SF), remained constant. Future research can explore the effect of temperature change and solar radiation by calculating all three variables of OTTV (equivalent temperature difference, temperature difference, and solar factor). This research was limited to a passive design approach, providing a basis for future research that may integrate these findings with active systems, such as dynamic optimization for minimal HVAC demand, latent heat storage, and heat recovery. Furthermore, this research was conducted on a single building; future studies could expand the scope to include multiple surrounding buildings.

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