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# Real-Time Monitoring and Development of a Localized OTTV Equation for Building Energy Performance

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**Abstract**

Global warming negatively impacts indoor environments, affecting human comfort. Despite global efforts, energy demand and greenhouse gas emissions continue to rise. As sustainable building designs become more critical, enhancing energy efficiency through real-time data analytics is essential. The Overall Thermal Transfer Value (OTTV) is a key metric for assessing a building's energy usage, considering factors like orientation, location, and climate. However, limited research has examined real-time data's impact on OTTV coefficients. Therefore, this research aims at developing and validating new OTTV coefficients using real-time data with the EQUEST simulation engine. The coefficients of OTTV (Equivalent Temperature Difference TDeq, Temperature Difference ΔT, and Solar Factor SF) were monitored in real-time using HOBO Temperature Data loggers and Delta Ohm Photometer for Solar Radiations. Focusing on UTM Eco-Home building, the study calculates heat gain components, including transmission through walls, windows, and radiation heat gain. The findings of the study suggest that the modified OTTV equation accurately determines a building's OTTV, enhancing energy efficiency evaluations. The novelty of the study lies in the development of a new OTTV equation for the specific climate of Johor, Malaysia, and the real-time monitoring of OTTV that helps the energy managers analyze the Thermal Transmittance of Building envelopes in real-time.

*Keywords:* Overall Thermal Transfer Value (OTTV); Energy Efficiency; Building Envelope; Hourly Heat Gain.

## 1. Introduction

Global warming is the main cause of climate change worldwide because it negatively affects the Earth's climate [1]. Similarly, since greenhouse gas emissions have steadily risen over time, energy consumption is one of the major concerns facing the world's economies and ecosystems [2]. Even though the world has made efforts to reduce the demand for energy and Green House Gas (GHG) emissions, energy demand and emissions have increased in recent decades [3]. Buildings, being the largest contributor to energy consumption, utilize approximately 40% of global energy, with as much as 60% going to building cooling and heating [4].

Since most of the energy is produced through the combustion of fossil fuels, therefore, it is one of the main producers of greenhouse gas emissions, which have a negative influence on the environment [5]. The thermal efficiency of buildings is currently governed by national regulations which refer to International Standard. For example, ASHRAE

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55 defines thermal comfort as *"that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation"* [6]. To do this, the building's envelope must be kept under control. Building envelope or building enclosure refers to the portion of the building that physically separates the interior from the outside environment. 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 [1]. 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. Thus, to lessen the air-conditioning load, the heat conduction through opaque walls and glass windows must be reduced [7]. Therefore, in 1975, the Thermal Transfer Value (OTTV) was developed as an index to measure the thermal performance of buildings with air conditioning by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) [8]. In the case of Malaysia, the OTTV was incorporated into the Malaysian Building Regulations in 2001. Since the average heat conduction from the envelope of the building is estimated by its OTTV. Therefore, it can serve as a benchmark to evaluate how different buildings perform in heat conduction [1]. Malaysia is a tropical climate country that experiences heat from the sun throughout the year due to it being situated between 2º and 7º to the North of the Equator line.

Several countries, including Pakistan, Sri Lanka, Hong Kong, Thailand, and Singapore, have created regulations for energy analysis of buildings based on OTTV specifically for their climates and types of buildings [9]. The OTTV-based building energy regulations of these countries diverge from one another due to differences in climate and geography, as well as differences in how the coefficients Equivalent Temperature Difference, Temperature Difference, and Solar Factor are calculated [9]. The location of the building and its climate have a significant impact on the values of OTTV, so coefficients and equations created in one country might not apply to another with a different climate [10]. Because of these factors, OTTV studies have been carried out globally by numerous researchers under varying climatic conditions.

A model based on the correlation between the OTTV, and the coefficient of Performance of Chillers was developed by Changnawa & Baltazar [11] for commercial buildings in Thailand. Then, this developed model was used to assess the energy usage of Thai departmental stores, hospitals, and offices. Praditsmanont & Chungpaibulpatana [12] carried out a case study on Thailand's University Hall using the OTTV method and found that applying an energy-efficient building envelope can result in greater savings and a shorter payback period than employing a lightweight, highly insulated envelope. As per the OTTV and following the regulations of the Malaysian Code on Building Energy Efficiency, Anas Zafirol & Al-Hafzan [13] developed the design guidelines for two university building halls. Nikpour et al. [14] discussed daylighting factors to reduce high-rise building energy consumption while focusing on OTTV's solar heat gain terms. In a single-landed residential building, the effectiveness of OTTV was examined by Utama et al. [15], who found that it was appropriate for non-humid environmental conditions. However, the OTTV readings did not directly correlate positively with the amount of electricity consumed by high-rise residential buildings owing to the predominance of internal load and certain integral estimation flaws.

Karim et al. [16] developed a simple and effective method for estimating how much air-conditioning is required for commercial buildings in subtropical climates such as Australia. They developed a new formula of ETTV for buildings with exterior shadings and estimated the yearly cooling energy based on ETTV in Australia's subtropical regions. By creating a correlation between Cooling Energy Requirement Ec and ETTV [17, 18], investigated the impact of parameters that affect the building energy performance. The internal loads of the building, envelope loads, operating schedules, and efficiency of cooling equipment were all considered by this correlation. To assess their efficiency in reducing the ETTV of buildings, effective parameters of ETTV were ranked relatively. Arab et al. [4] used OTTV as an evaluation tool to assess the thermal performance of high-rise buildings' envelopes in Penang State of Malaysia. In this study, distinct architectural styles of these buildings were chosen to represent various building construction eras. The west-facing façade of the chosen buildings was used to determine the OTTV value because it is thought to be a crucial orientation for receiving high solar radiation. Ismail & Zainonabidin [19] evaluated the retrofitting of a 38-story tall office building's envelope using the OTTV tool to increase its energy efficiency. To retrofit the building envelope, three variables—thermal transmittance of building materials, shading coefficient, and window-to-wall ratio—were considered. Based on the results of this study, the OTTV was reduced to 28.43 W/m2 from its initial value of 77.43. In Thailand, Tummu et al. [20] developed an OTTV-based method to assess how well the building's envelope performed, which is surrounded by bedroom space. To standardize the technique of calculating the OTTV of air-conditioned buildings, MS 1525 provided a building code of practice in Malaysia named "Energy Efficiency and Use of Renewable Energy for Non-Residential" [21].

Improvements to the method of OTTV computation have remained a point of interest for many researchers and authorities, and several modifications have also been made in the OTTV method. For example, Chan and Chow [22] and Chan and Chow [23] evaluated the OTTV calculation method for buildings integrated with green roofs and those buildings that have natural ventilation with double-skin facades. Changes in the set of Corrective Variables of the OTTV Calculation Method were made by them. In early 2000, the method of OTTV calculation was revised in Singapore, and they developed a new method that was renamed the envelope thermal transfer value (ETTV) and Roof Thermal Transfer Value (RTTV). Furthermore, another formula named the residential envelope transmittance value to assess the thermal envelope performance of residential buildings was also suggested because residential buildings consume air conditioning differently [24].

According to Kannan [25], Deringer and Busch created the first OTTV method for the Malaysian instance in 1992. Three main parts make up the OTTV, including Heat conduction from Opaque Walls, Heat Conduction from Glass Windows, and Solar Radiation Gain from Glass Windows [21]. Radiation Heat Gain from Glass Windows is essential to reduce energy usage. This is because solar heat gain through windows accounts for most of the energy required to cool the building [26]. Heat gain from windows has a significant impact on indoor thermal comfort [1]. Vighio et al. [27] conducted a study to investigate the effect of different glazing facades on the OTTV of a passive building. The passive design strategies used in the study were different façade colors, different glazing types, and the change in WWR. It was concluded that by using a combination of white façade color, Double Low E Tinted Green Glazing Type, and reduction of WWR by 10%, OTTV can be optimized up to 40%. Seghier et al. [28] focused on optimizing the thermal-daylight performance of office building envelopes in tropical climates using parametric simulations and global sensitivity analysis (GSA). It identifies key factors such as Shading Coefficient (SC1), Window-to-Wall Ratio (WWR), and Visible Transmittance (Tvis) as critical elements influencing heat gain and daylight provision.

The developed daylight prediction formula, integrated with OTTV, enables energy savings of up to 8% and serves as a practical tool for enhancing building envelope performance during the early stages of architectural design. From all the above research works, it can be concluded that many researchers have worked to optimize the OTTV using different techniques such as simulation, sensitivity analysis, and other techniques. Also, it was checked what the effect of different parameters such as window-to-wall ratio, use of different shading devices, use of different glazing types, and effect of adjacent shading of buildings is, and many researchers have developed their own new OTTV formula, equations, and the OTTV model based on Building Information Modeling. But mostly the researchers have derived these formulas and equations from the simulation of different buildings using different simulation engines. Also, the optimization of OTTV was done using passive design strategies in different simulation engines. In this context, to have a critical review, the relevant studies of OTTV-based thermal performance of the building envelope are presented in Table 1 given below. In summary, all these previous studies have been conducted on the simulation of data, but no real-time data or modeling has been carried out to determine the OTTV-based assessment. Therefore, the main objective of this study is to formulate the OTTV Equation for the Johor State of Malaysia as the measuring parameter of Building Thermal Envelope Performance from the real-time data. Also, the effect of temperature change and the change in solar radiation during the time of day from 7 am to 7 pm on the OTTV of a passive building has been analyzed.

**Table 1. Studies Related to OTTV-Based Thermal Performance of the Building Envelope**

| S. No | References | Key Findings | Use of Real-Time Data |
|---|---|---|---|
| 1 | Chua & Chou [29] | • It was examined How parameters affect the energy performance of commercial buildings.<br>• The correlation of Ec and ETTV was studied | x |
| 2 | Singhpoo et al. [30] | • The effect of temperature change on OTTV from 06:00 am to 06:00 pm was studied. | x |
| 3 | Chan & Chow [23] | • A New OTTV Equation was derived using the DOE2 Simulation Engine.<br>• Impact of OTTV Coefficients on Chiller Load was Studied. | x |
| 4 | Hui [31] | • Comparison of OTTV Standards of different countries.<br>• Improvements in the OTTV equation as per the limitations. | x |
| 5 | Chirarattananon & Taveekun [32] | • A New OTTV Equation was derived using the DOE2 Simulation Engine.<br>• Energy consumption models were developed and validated. | x |
| 6 | Yik & Wan [33] | • The evaluation of the Appropriateness of OTTV for energy performance of building envelope based on ASHRAE 90 and the advancements made in the OTTV method was done.<br>• It was concluded that OTTV does not accurately depict the true building envelope's thermal performance. | x |
| 7 | Al-Qadhi [34] | • A New OTTV Equation was derived for Saudi Arabia using Visual DOE4.0 Simulation Engine. | x |
| 8 | Devgan et al. [9] | • A new equation of OTTV was reshaped for three primary tropical areas with composite, Hot Dry, and Warm humid climates. | x |
| 9 | Chan & Chow [22] | • The Existing OTTV Calculation was revised, and correction factors were determined for estimating the OTTV of buildings integrated with green roofs. | x |
| 10 | Tummu et al. [20] | • A New OTTV Equation was derived to evaluate How well the building envelope performed when it was enclosed in the space for bedroom function. | x |
| 11 | Zhiyuan [35] | • An indicator to measure how the building envelope is performing in terms of thermal performance entitled operative envelope transfer value (OETV) was developed using a simulation engine. | x |
| 12 | Karim et al. [16] | • A new ETTV equation was developed for Australia's sub-tropical regions.<br>• Equation was verified by taking 5 commercial buildings from different cities using EQUEST simulation engine. | x |
| 13 | Lam et al. [36] | • A new OTTV equation was derived using weather data from 1980 to 1989 for 6 months (May-October) for Hong Kong.<br>• The OTTV limitations of 21 $W/m^2$ and 14 $W/m^2$ were proposed for walls and roofs based on the reference building envelope. | x |
| 14 | Natephra et al. [37] | • A comparison of OTTV and ETTV was carried out.<br>• A few recommendations and observations were made to measure the energy performance of the building envelopes of Malaysia and Singapore. | x |

| S. No | References | Key Findings | Use of Real-Time Data |
|---|---|---|---|
| 15 | Muhfizaturrahmah et al. [38] | • New OTTV Formula has been derived.<br>• Correlation of OTTV with the power consumed by Air-conditioners. | x |
| 16 | Irvandi et al. [39] | • Optimization of shading devices by calculating the horizontal shade length and slope angle for all four orientations of the building. | x |
| 17 | Pramesti et al. [40] | • OTTV Calculation of the 15-storeyed building Suara Merdeka Tower.<br>• Different alternatives for the Design of Shading Devices and Materials used in building to improve its energy consumption were suggested. | x |
| 18 | Hwang et al. [41] | • New OTTV formulation for school buildings in Taiwan.<br>• The OTTV index was limited to 20 $W/m^2$.<br>• It was recommended that for Taipei the equivalent ventilation area should be 9.5 $m^2$ and that of 14.3 $m^2$ for Kaohsiung. | x |
| 19 | Chan [42] | • New OTTV Equation for an air-conditioned building that is under the shading effect of an adjacent building.<br>• The correlation of OTTV and Annual Heat Gain was established. | x |
| 20 | Seghier et al. [43] | • To optimize the thermal performance of the building envelope by minimizing the retrofit costs, A BIM-based technique was developed.<br>• It can calculate the OTTV, and the building envelope can be optimized using BIM. | x |
| 21 | Chan et al. [44] | • For precise calculation of OTTV, the Shading device’s coefficient of Solar Radiation (β) was calculated.<br>• A computer-based application was developed for five standard types of shading devices. | √ |
| 22 | Shah et al. [45] | • How shading systems affect the opaque facades was examined in real-time.<br>• Many benefits resulted such as 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. | √ |
| 23 | Chiradeja et al. [46] | • The most energy-efficient glass for the retrofitted windows may achieve energy performance, but the installation cost may make the project less financially viable.<br>• However, the energy usage of the building can be reduced up to 16.87 percent, OTTV by 68.89 percent, IRR by 10.70 percent, and DPP by 11.83 years using the glass with the second-lowest heat transfer coefficient. | x |
| 24 | Azmi & Setiawan [47] | • The amount of sunlight that strikes the building varies on each side of the building.<br>• The best sunshade system for reducing a building's OTTV and solar radiation is an egg-crate sunshade system. | x |
| 25 | Lahji & Walaretina [48] | • Creating a façade with a low U orientation and minimal material use will increase building energy efficiency.<br>• It is efficient to reduce carbon emission trace by minimising OTTV on the façade to reduce the energy consumption of air cooling, which is the largest energy consumption in rural areas. | x |
| 26 | Vighio et al. [27] | • The study investigates the OTTV in passive design strategies such as different glazing facades to improve the energy performance of the building.<br>• The results suggested that the OTTV can be improved up to 40% by using a combination of white façade colour, Double Low E Tinted Green Glazing Type and reduction of WWR by 10% | x |
| 27 | Seghier et al. [28] | • The study employs sensitivity analysis and simulations to optimize thermal-daylight performance for office buildings in tropical regions.<br>• identifies the three main variables influencing heat gain and daylighting provision as the shading coefficient, WWR, and visible transmittance.<br>• suggests using OTTV in conjunction with a daylight prediction technique to save up to 8% on energy. | x |
| 28 | Khanh Phuong et al. [49] | • This study presents a new OTTV computation approach that can include dynamic shading control for improving the daylighting environment.<br>• Explains how the methodology will be implemented using simulation and a hypothetical case in a subtropical climate of Hanoi.<br>• Emphasizes the practical application of achieving high levels of both Daylight and thermal performance to enhance the level of energy efficiency and visual comfort. | x |
| 29 | Setiawan et al. [50] | • The study calculates the OTTV of the Administration Building at Malikussaleh University using the SNI 03-6389-2020 standard.<br>• The results showed that the OTTV of a case study building exceeds the threshold value due to its large Sunshaded openings, particularly on the east and west sides.<br>• Recommends adding horizontal shading devices, reducing the OTTV to 34 W/m², making the building energy efficient while maintaining user productivity. | x |
| 30 | Enggarsiwi et al. [51] | • This study uses OTTV calculations and simulation using the EDGE online application to assess the thermal performance of the building envelope of the UNS Tower in Surakarta.<br>• According to the results, the UNS Tower's OTTV is greater than 35W/m2, with the unshaded glass materials on the Northwest and Southeast façades exhibiting the highest OTTV values.<br>• Thermal performance is optimized through the reduction of WWR and by applying the use of double glazing with reflective film.<br>• Further research with field measurements is recommended to enhance building envelope design for energy efficiency. | x |

## 2. Methods

### 2.1. Data Collection Approach and Analysis Procedure

In this research work, a new OTTV-based assessment method has been developed using a real-time data collection approach, taking a UTM Eco House building of UTM Malaysia as a case study building. Weather exploration is a significant parameter of OTTV calculation and development because location (Latitude, Longitude, and Climate) affects the OTTV value. That's why it's of utmost importance that the weather data must be analyzed. Table 2 given below provides the details of UTM Eco-Home (Case Study Building).

**Table 2. Data of UTM Eco-Home (Case Study Building)**

| Orientation of the Building | Gross Wall Area (Sq. meter) | Fenestration Area (Sq. meter) | WWR (Window-Wall-Ratio) |
|---|---|---|---|
| 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 |

The meteorological data of the tropical climate of Johor State of Malaysia have been collected in real-time using Delta Ohm Photometer equipment for Global Solar Radiations whereas the HOBO Loggers are used for Indoor and Outdoor Air Temperature. Both the instruments were fixed within the building and to the exterior of the case-study building for data collection in real-time mode. The temperature (Interior and Exterior of the building) and Solar Radiation were observed using the above-mentioned instruments. Using real-time data for 30 days of September 2023, the temperature of the inside and outside air has been determined. The data was gathered between 7:00 a.m. and 7:00 p.m., during the sunlight hours of the building. After collecting the weather data, the regression analysis was conducted to calculate the parameters of the OTTV equation, like TDeq, ΔT, and SF. For the verification of these coefficients, the simulation of the OTTV of the building was carried out using the EQUEST Simulation Engine. The weather file of the location was downloaded from the DOE2 website. The correlation between the calculated values of OTTV from the new OTTV equation with the simulated values of OTTV was conducted. Autodesk REVIT software was used to generate the building models. First, the Revit models were exported in CAD (DWG) format to be imported to EQUEST. Because the Revit file cannot be directly imported into the EQUEST simulation engine. Then, from the AutoCAD file, the zones were created, and the file was converted into DXF format. That file was imported into the EQUEST Simulation Engine, and the simulation was carried out to calculate the total amount of heat gain through walls, windows, and solar heat gain through windows. Figure 1 interprets the step-by-step methodology adopted for this research work.

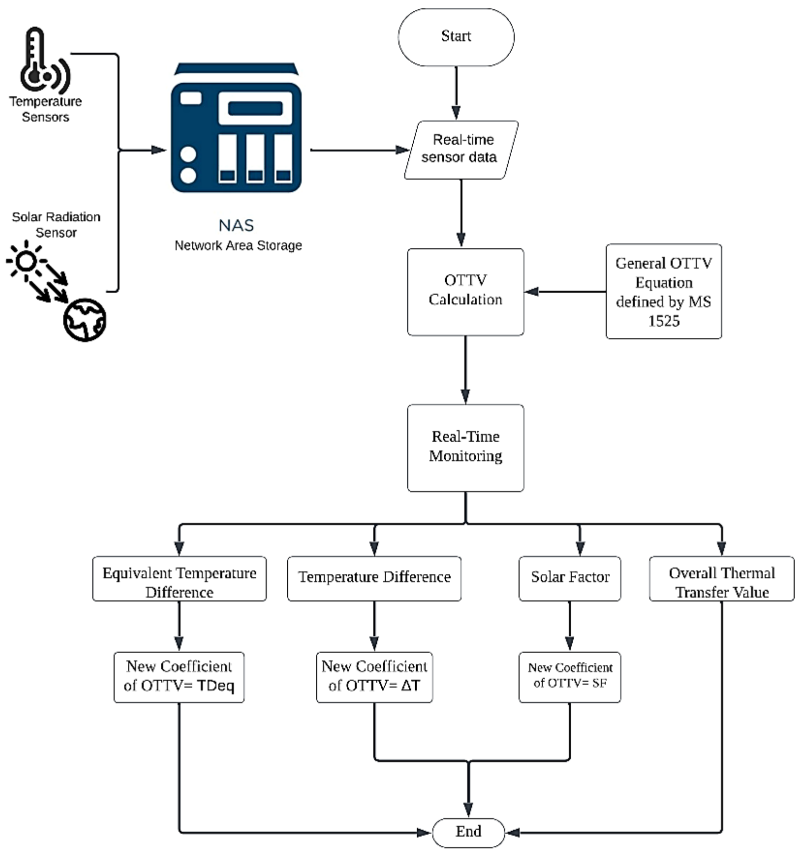


**Figure 1. Methods used to determine the OTTV Coefficients**

## 2.2. Modeling in Autodesk Revit (BIM Modeling)

For the estimation of heat gain through the building envelope, BIM modeling is utilized. Autodesk Revit is the basic tool for BIM, and it helps architects, designers, structural engineers, and MEP engineers to make 3D drawings as per the requirements. In general, there are three categories (families) of substances:

- System family, which refers to the walls, floors, ceilings, and roofs that are constructed as part of a project.
- Loadable Families / Constituents are built independently of the project using primitives (extrusions, sweeps, etc.) and then agitated into the project for use.
- Families that are in-place are created directly in a project using the same toolset as loadable components.

The drawings of the case study building (UTM Eco-Home) were collected from the concerned authority of UTM. Then these drawings were modeled in Autodesk Revit 2023. The 3D view and elevation of the building are given in the figures below (Figures 2 and 3):

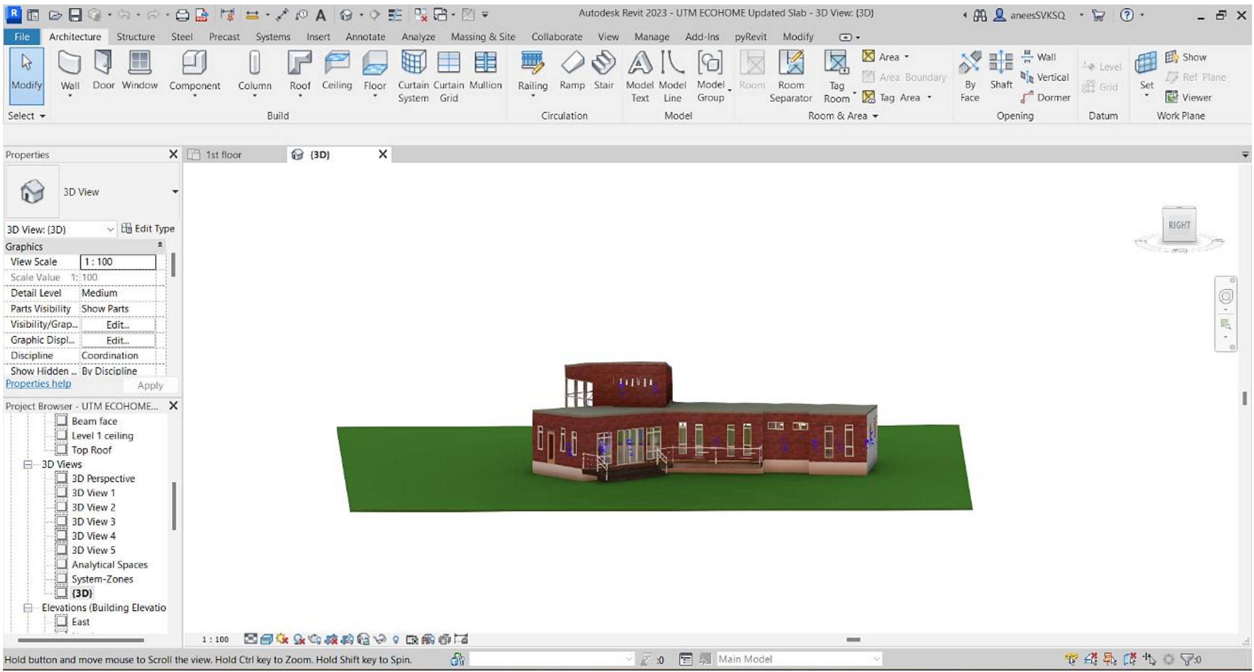


**Figure 2. 3D View of UTM Eco-Home Building in Revit**

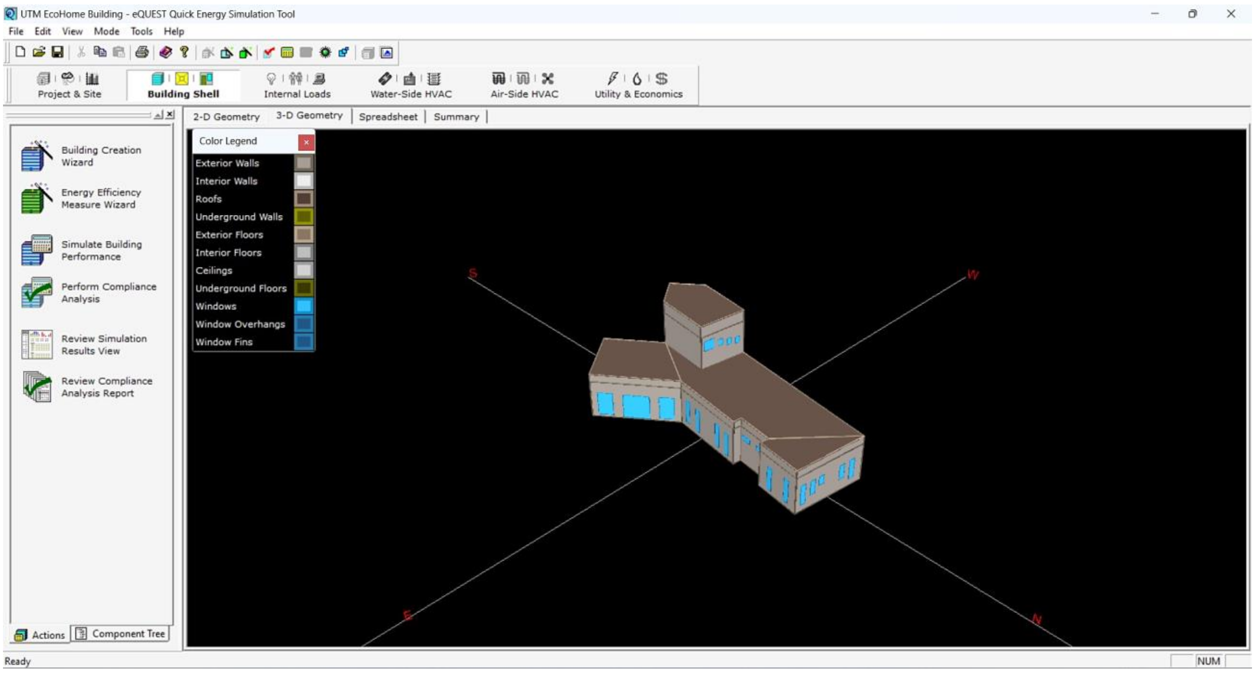


**Figure 3. EQUEST Modeling of UTM Eco-Home Building**

### 2.3. EQUEST Modeling

To simulate the existing characteristics of the case study building, eQUEST software was used. The Revit model of the existing building was used. Then, the Revit model was converted into an input file of EQUEST, and the weather file was also downloaded for the location of the case study building. Then simulations were run to calculate the Hourly Load of OTTV Components of the case study building which includes Heat-gain through Opaque walls, Heat-gain through Glass Windows, and Solar Radiations heat-gain through Glass Windows. The unit of Hourly Load was Btu/h in the output file of EQUEST, which was later converted into SI units for analysis purposes.

### 2.4. Mathematical Formulation of OTTV

Building thermal heat gain is due to three orientation-dependent basic components: (1) Conduction of heat from opaque walls, (2) Conduction of heat from glass windows, and (3) Conduction of heat due to solar radiation from glass windows. Therefore, these influencing factors have been considered in this research to develop the OTTV model. Additionally, the following assumptions were considered:

Conduction of heat gain through opaque walls is calculated by the multiplication of the thermal transmittance of the wall, the equivalent temperature difference for the wall, the absorptivity value, and (1-WWR). Similarly, the heat conduction through glass windows can be calculated by multiplying the window-to-wall ratio, the difference of temperature for the window, and the thermal transmittance of the window (U Value). The last component of OTTV is the radiation heat gain from glass windows due to the solar factors and the shading of the windows. These three are the main parts of the OTTV of a building. The heat gain through the roof of the building is not considered in this study.

The following mathematical equations for OTTV computation were created based on our considerations and assumptions. Since OTTVi is the overall thermal transfer value for every orientation of the building, the OTTV of the North-facing, South-facing, East-facing, and West-facing walls may be calculated using Equation 1. The OTTV of the whole building envelope, which is the weighted average of OTTV for the individual orientation of the building, can be calculated by the mathematical relation as shown in Equation 2.

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

$$OTTV_o = (A_{01} \times OTTV_{01} + ... + A_{0N} \times OTTV_{0N}) / (A_{01} + A_{02} + ... + A_{0N}) \quad (2)$$

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

Equations 3 to 5, respectively, have been used to determine Equivalent Temperature Difference TDeq, Temperature Difference and Solar Factor SF:

$$TDeq = (To-Ti) + Rso \times \alpha \times Id \quad (3)$$

$$\Delta T = \text{Outdoor Air Temperature} - \text{Indoor Air Temperature} \quad (4)$$

$$SF = 0.87 \times \text{Incident Solar Radiations} \quad (5)$$

The above equations are taken from the research conducted by Lam et al. (1993) [36] in his research work while calculating the OTTV parameters. The solar altitude and solar azimuth angles were determined from the 3D Sun Path Diagram for the case study building location. As the Incident Solar Radiation will be used in calculating the Solar Factor, therefore the incident angles for each orientation of the window and for each time of the day were calculated using the formula given by PTC Community of Solar Radiations:

$$\theta = a\cos(\cos(\alpha).\cos(|\gamma|).\sin(\beta) + \sin(\alpha).\cos(\beta)) \quad (6)$$

where, α is Solar Altitude Angle, β is Tilt angle (Which is $90^0$ for vertical surfaces), γ is surface solar azimuth angle ($\gamma = \phi - \psi$), ϕ is Solar Azimuth Angle, ψ is surface azimuth angle or orientations angle ($0^0$ for North, $90^0$ for East, $180^0$ for South and $270^0$ for West). In this study, we have considered the hours of operation 7 days a week, where 12 h air-conditioned and the remaining hours are free cooling so free cooling hours are not considered. The figure given below shows the methodology to monitor the OTTV in real-time.

To obtain the expected values of OTTV coefficients i.e. TDeq, ΔT, and SF, the U value of the opaque walls Uw, U value of the building Fenestration Uf, and Shading Coefficient of Glazing system SCf were calculated in time of the day during real-time monitoring using Equations 3 to 5. As the Solar Factor (SF) is orientation-dependent, therefore, the solar factor has been calculated for each orientation of the building (North, South, East, and West).

After modeling in EQUEST, the simulations were run for 47 different types of Windows glass characteristics (Taken from EQUEST Glass Library) for the verification of calculated OTTV parameters/coefficients (TDeq, ΔT, and SF). EQUEST Simulation Engine gives the values of Heat Conduction through walls, Heat Conduction through windows, and Solar Heat Gain through Glass Windows. Then using the following formula given in Equation 7, the OTTV has been calculated:

$$OTTV = \frac{\text{Total Heat gain through the building envelope}}{\text{Total operating hours of air-conditioning system} \times \text{Envelope area}} \quad (7)$$

where Total heat gain through the envelope is the sum of all three components, Total operating time is 360 hours of September month (12/7 Working Hours) and envelope area is the Total gross Area of the Building Envelope.

## 3. Results and Discussion

As previously defined the OTTV is the combination of three components Heat gain through opaque walls, heat gain through glass windows, and solar radiation heat gain from glass windows. So, there will be 3 coefficients of the OTTV equation. All the coefficients are defined below.

### 3.1. Temperature Difference

The temperature difference is outside air temperature minus inside air temperature, calculated in real-time from 7 am to 7 pm for 30 days of September 2023 with Hobo Temperature Dataloggers. From Figure 4, the peaks and valleys show that there are temperature variations from the early morning till sunset (7 am to 7 pm). There can be multiple reasons for these variations, like solar radiation and varying climatic conditions of that particular area. The temperature change ranges from -8 to 17°C, which shows a quite big range of temperature change. There are several peak values, which possibly indicate moments when outside air is much hotter than the inner spaces or cooling systems slow down. These temperature changes will affect the Overall Thermal Transfer Value. Because the OTTV involves ΔT as the coefficient of heat gain through glass windows.

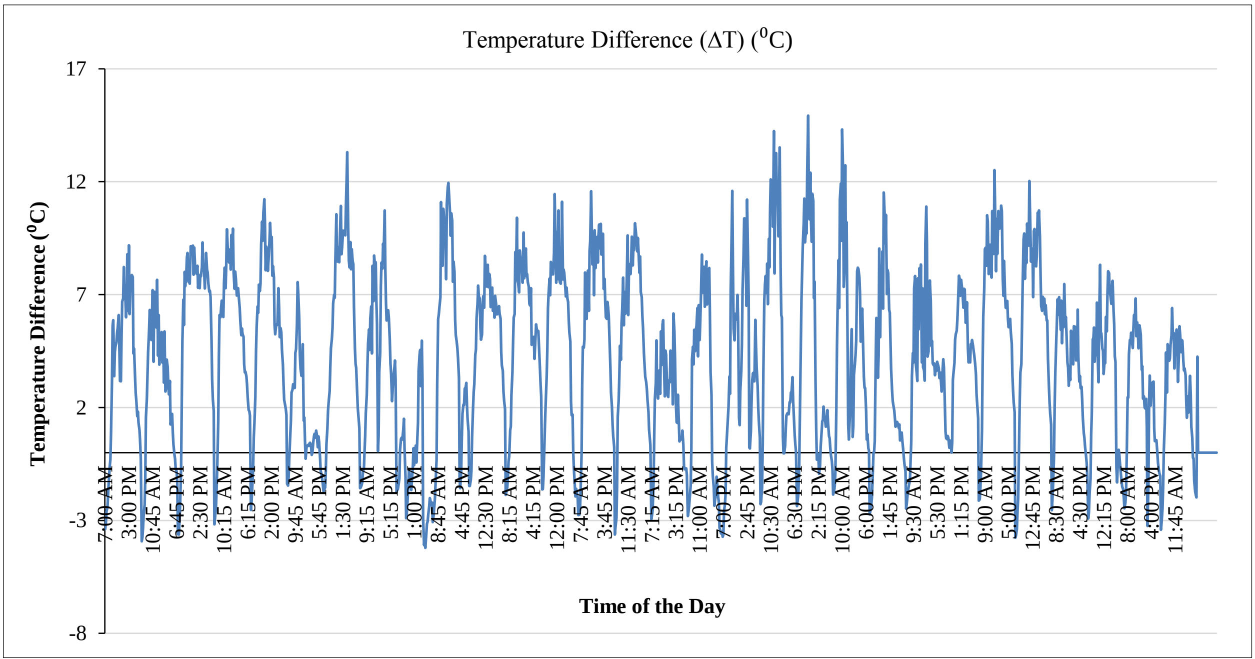


**Figure 4. Temperature Difference ($^0$C) in Real-Time**

### 3.2. Equivalent Temperature Difference (TDeq)

The Equivalent Temperature Difference is calculated from 7 am to 7 pm for 30 days of September 2023 with an interval of 15 minutes using Equation 3. As Equivalent Temperature Difference involves the Incident Solar radiation, it will be different for different orientations. Therefore, TDeq was calculated for 12 hours of the day from 7 am to 7 pm for all four orientations separately. Because in the daytime the heat transmits from the exterior to the interior of the building envelope and vice versa in the night-time. Therefore, the daytime was chosen from 7 am (Sunrise) to 7 pm (Sunset).

***TDeq for West Orientation*:** The equivalent temperature difference in real-time is shown in Figure 5. From the figure, it can be seen that there is a significant variation in TDeq for west orientation. This is dependent on incident solar radiation; therefore, during morning hours, the TDeq will be lower than that of evening hours. The variation in TDeq ranges from -20°C to 100°C, a quite big range of variation. The down troughs suggest decreasing temperature differences, with values approaching zero or even below zero, possibly at times, such as in the morning or at night when the sun is not on the west-facing surfaces. This variation greatly affects the OTTV of a building because TDeq is the coefficient of the OTTV equation.

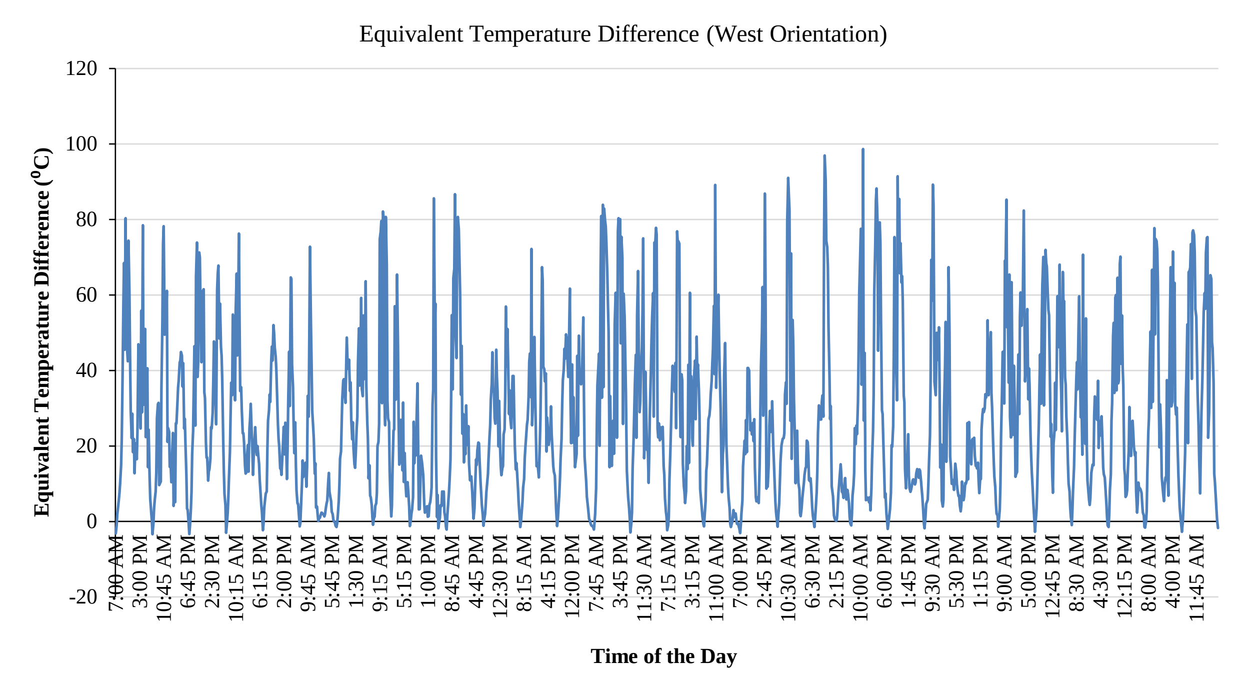


**Figure 5. Equivalent Temperature Difference (°C) in Real-Time for West Orientation**

***TDeq for East Orientation*****:** Figure 6 shows the equivalent temperature difference in real time. The TDeq varies with the time from -68.655 to 98.653°C. TDeq has higher values (Peaks) during the morning hours as compared to the evening hours due to incident solar radiation directly reaching the wall surface. The downward troughs indicate a decrease in temperature variations, with values perhaps getting close to or below zero at some periods, such as at night or in the evening when the sun is not shining on surfaces facing east. Given that TDeq is the coefficient of the OTTV equation, this variance has a significant impact on a building's OTTV.

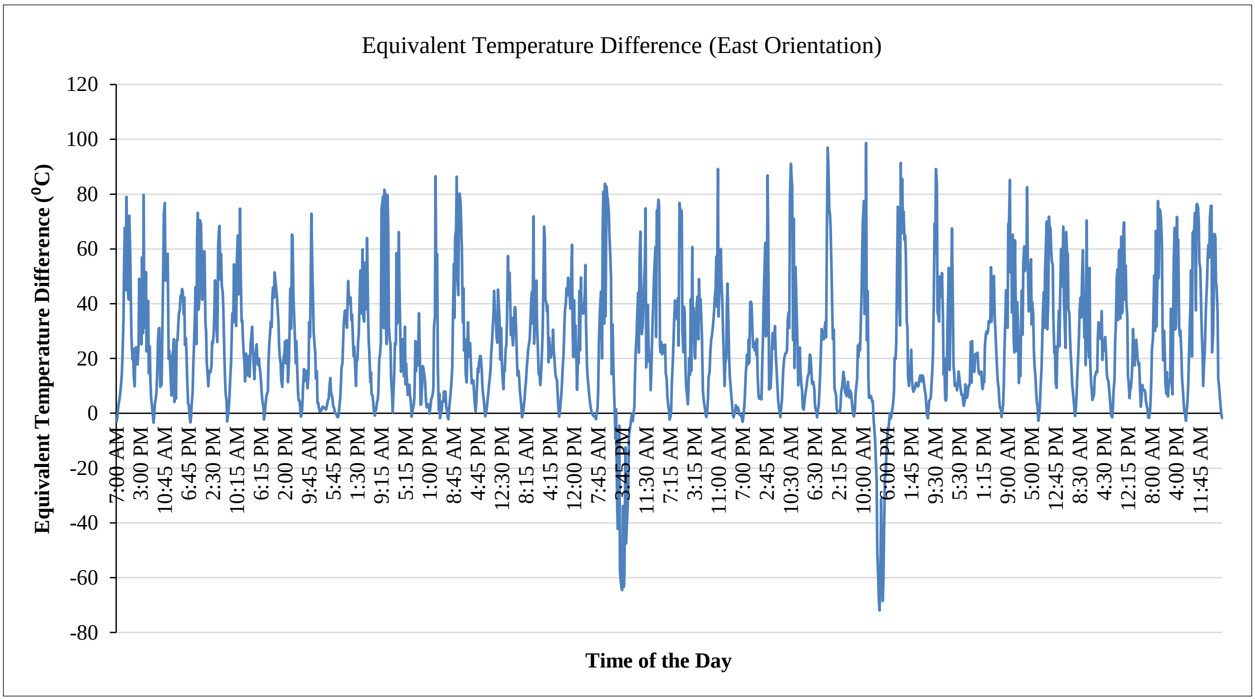


**Figure 6. Equivalent Temperature Difference (°C) in Real-Time for East Orientation**

***TDeq for South Orientation*:** The real-time values of TDeq for South Orientations are shown in Figure 7. The difference in equivalent temperature varies from -3.155 to 91.036°C. The TDeq has an irregular pattern of peaks and valleys in this orientation (South) due to the solar radiations varying with time intervals and the solar angles (Azimuth and Zenith Angle). The highest value was obtained on 19th September 2023 at 10:30 am whereas the lowest was on 1st September 2023 at 7:00 am. The variation of TDeq for south orientation confirms the effect of solar radiation on the heat gain through the opaque walls of the passive building. The downward troughs indicate a decrease in temperature variations, with values perhaps getting close to or below zero at some periods whereas the vice-versa for the upward troughs

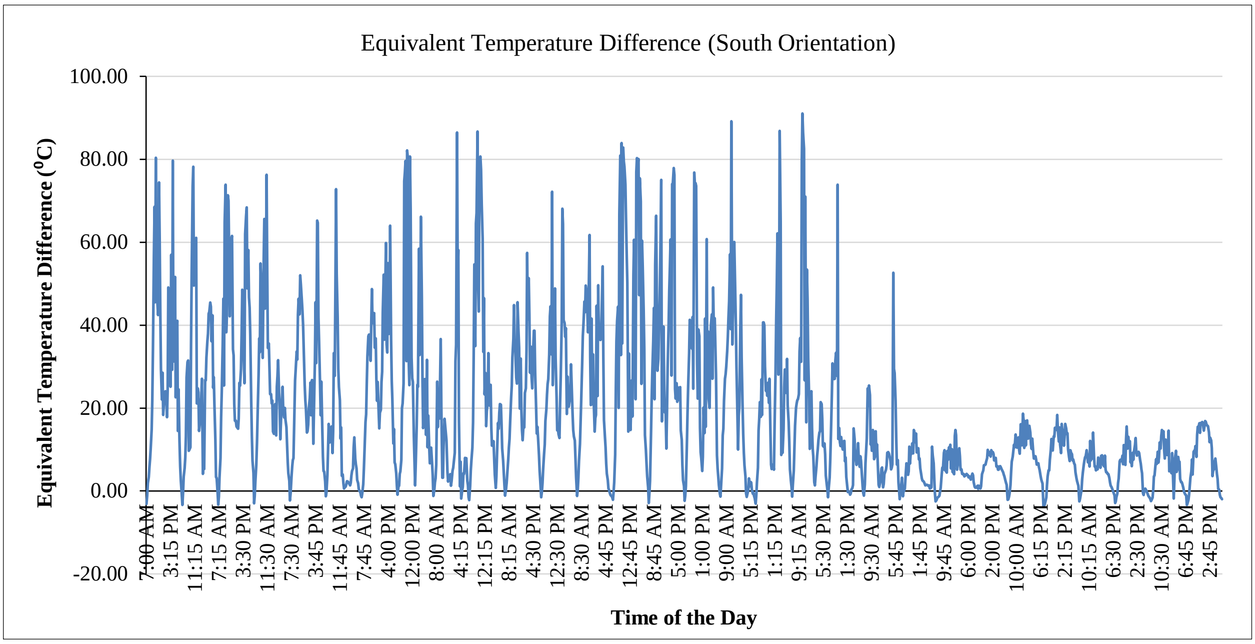


**Figure 7. Equivalent Temperature Difference ($^0$ C) in Real-Time for South Orientation**

***TDeq for North Orientation*:** Figure 8 shows the real-time values of TDeq for Norh Orientations. The difference in Equivalent Temperature varies from -3.852 to 98.67 $^0$ C. Like that of the South Orientation, the TDeq has an irregular pattern of peaks and valleys in this orientation (North) due to the solar radiations varying with time intervals and the solar angles (Azimuth and Zenith Angle). The highest value was obtained on 21$^{st}$ September 2023 at 11 am whereas the lowest was on 1$^{st}$ September 2023 at 7:00 am. The fluctuation of TDeq for North orientation confirms the effect of solar radiation on heat gain via the passive building's opaque walls. The downward troughs suggest a decrease in temperature variability, with values perhaps approaching or falling below zero at times, whilst the ascending troughs do the opposite.

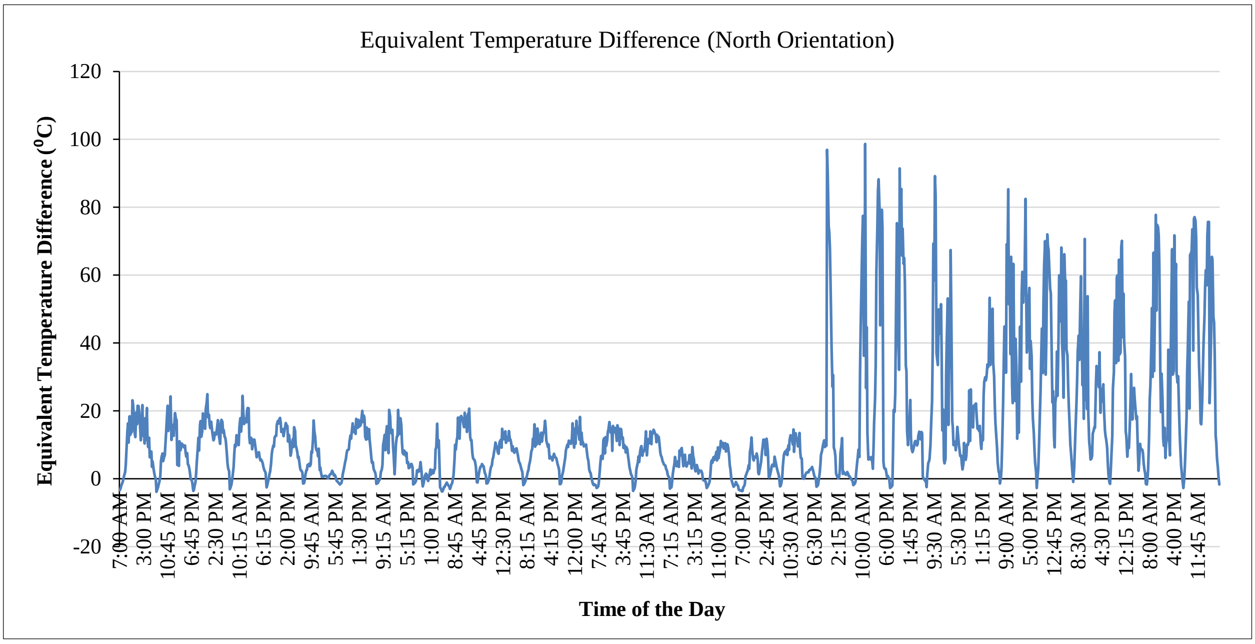


**Figure 8. Equivalent Temperature Difference ($^0$ C) in Real-Time for North Orientation**

### 3.3. Solar Factor (W/m²)

The Solar Factor is the coefficient of the third component of OTTV, which is the Solar Radiation heat gain through the glass windows. It is also orientation-dependent due to the involvement of incident solar radiation. Therefore, it is calculated for all four orientations separately from 1st September to 30th September for 12 hours from 7 am to 7 pm.

#### 3.3.1. Solar Factor (W/m²) for West Orientation

The solar factor for West Orientation is shown in Figure 9 given below in real-time. Figure 9 demonstrates that the solar factor varies significantly with the change of incident solar radiation during the day. This will consequently affect the overall thermal transfer value (OTTV) of a building. Therefore, monitoring the solar factor in real-time for that orientation is imperative. The solar factor for west orientation varies from 0.039 to 461.393 W/m². The highest value of Solar Factor is 461.393, which occurred at 11 am on 21st September 2023. Whereas the lowest value of the solar factor is 0.039 at 7 pm on 26th September 2023. This variation is important to monitor the OTTV of a passive building because in OTTV the major component is the radiation heat gain through glass windows. The Solar Factor is higher during the evening hours compared to the morning hours because the Sun is westward during the evening hours. The Solar Factor is an important parameter of the OTTV Calculation because, as per the MS1525, the solar radiation heat gain from the glass windows (the third component of the OTTV) is about 60 to 70% of the OTTV calculation. Therefore, the solar factor plays an important role in reducing the radiation heat gain component of the OTTV. Which in turn will reduce the OTTV of a building. Thus, making that building an energy-efficient building.

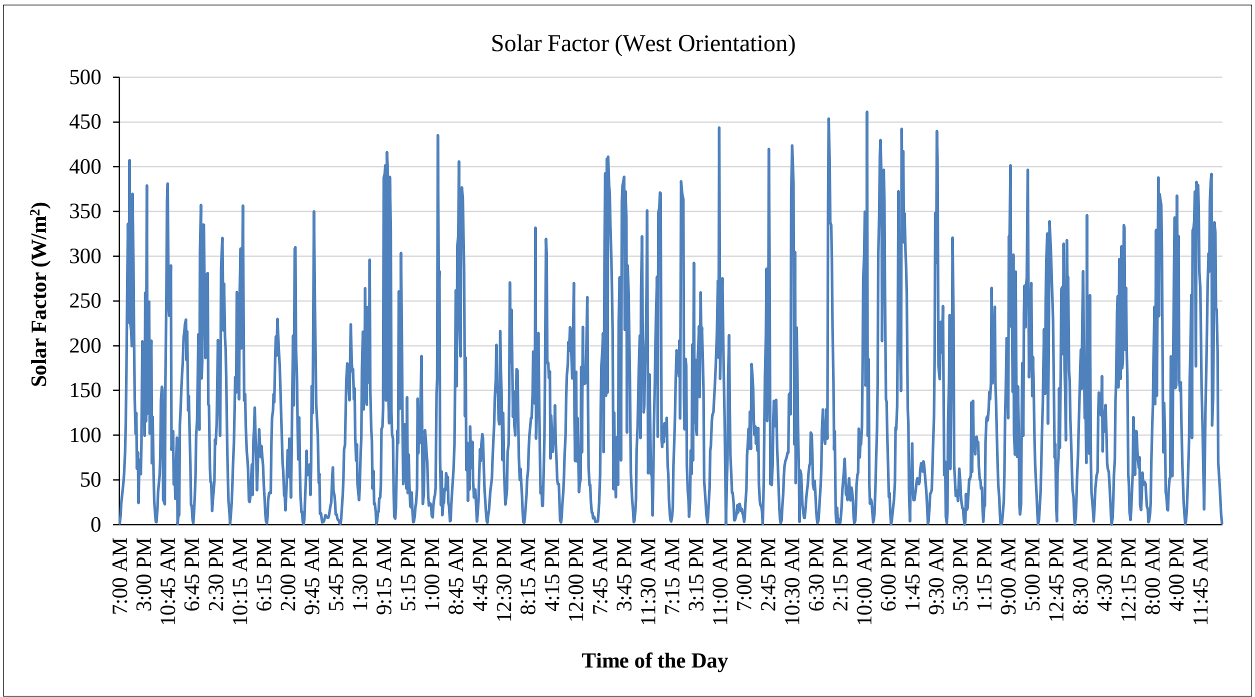


**Figure 9. Solar Factor (W/m²) in Real-Time for West Orientation**

#### 3.3.2. Solar Factor (W/m²) for North Orientation

The Solar Factor for the North Orientation in real time is presented in Figure 10. It shows that the solar factor for this orientation varies unevenly from 0 to 461.393 W/m². The highest value of Solar Factor is 461.393, which occurred at 11 am on 21st September 2023. Whereas the lowest value of the solar factor is 0.00 at 7 am on 23rd September 2023. This uneven variation in the Solar Factor for north orientation is due to the changes in solar angles (Solar Azimuth and Zenith angles), which define the position of the Sun at a particular time of the day. From Figure 10, the uneven variations of the solar factor can be seen. This is due to the angle of incidence of the sun during the day because the sun is not directed towards this orientation of the building. This fluctuation will affect the OTTV of the northward walls of the building.

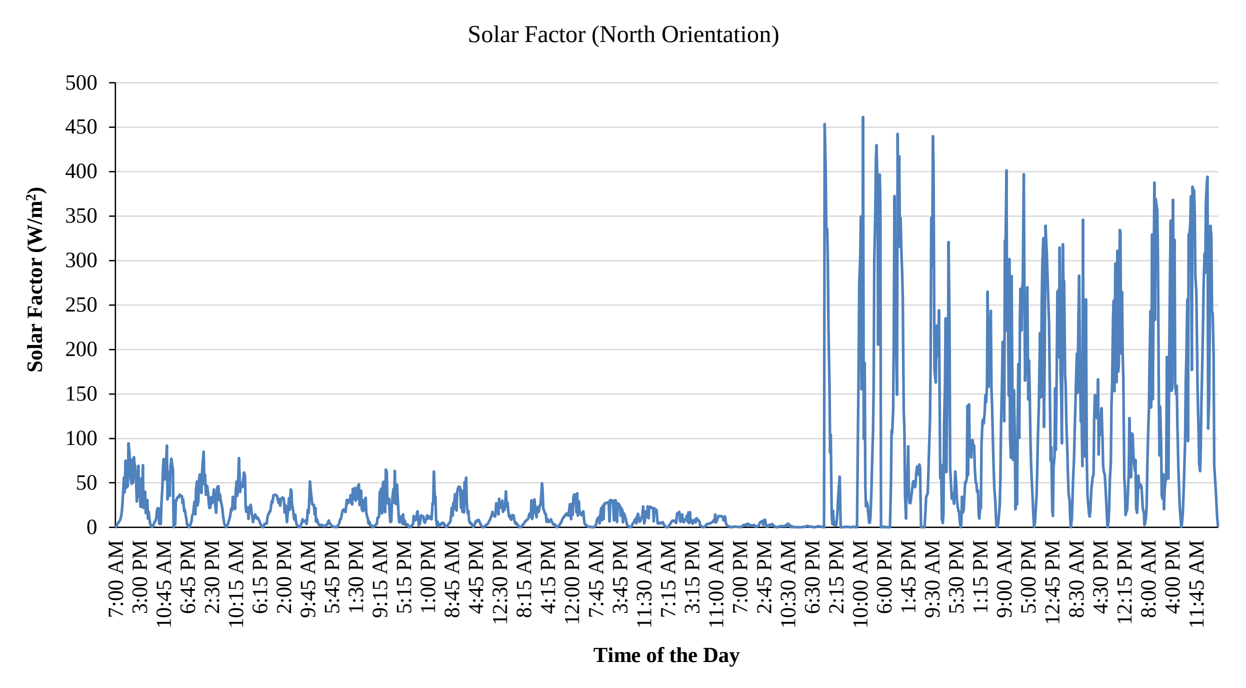


**Figure 10. Solar Factor (W/m²) in Real-Time for North Orientation**

### 3.3.3. Solar Factor (W/m²) for South Orientation

The Solar Factor for the South Orientation in real time is presented in Figure 11. The solar factor for this orientation varies unevenly from 0 to 443.624 W/m². The highest value of Solar Factor occurred at 10:45 am on 17th September 2023. The OTTV had a minimum value of 0 at 7 am on 23rd September 2023. This uneven variation in the Solar Factor for south orientation is due to the changes in solar angles (Solar Azimuth and Zenith angles) which define the position of the Sun at a particular time of the day. As this orientation is not directed towards the sun, the Solar Factor has an irregular pattern. This is the opposite to that of North orientation. This means that the solar actor is maximum during those hours on which it was minimum in North orientation graph. This variation in solar factor will affect the OTTV of the Southward walls of the building which in general will affect the total OTTV of the building envelope because the solar factor is an important component of the OTTV Calculation.

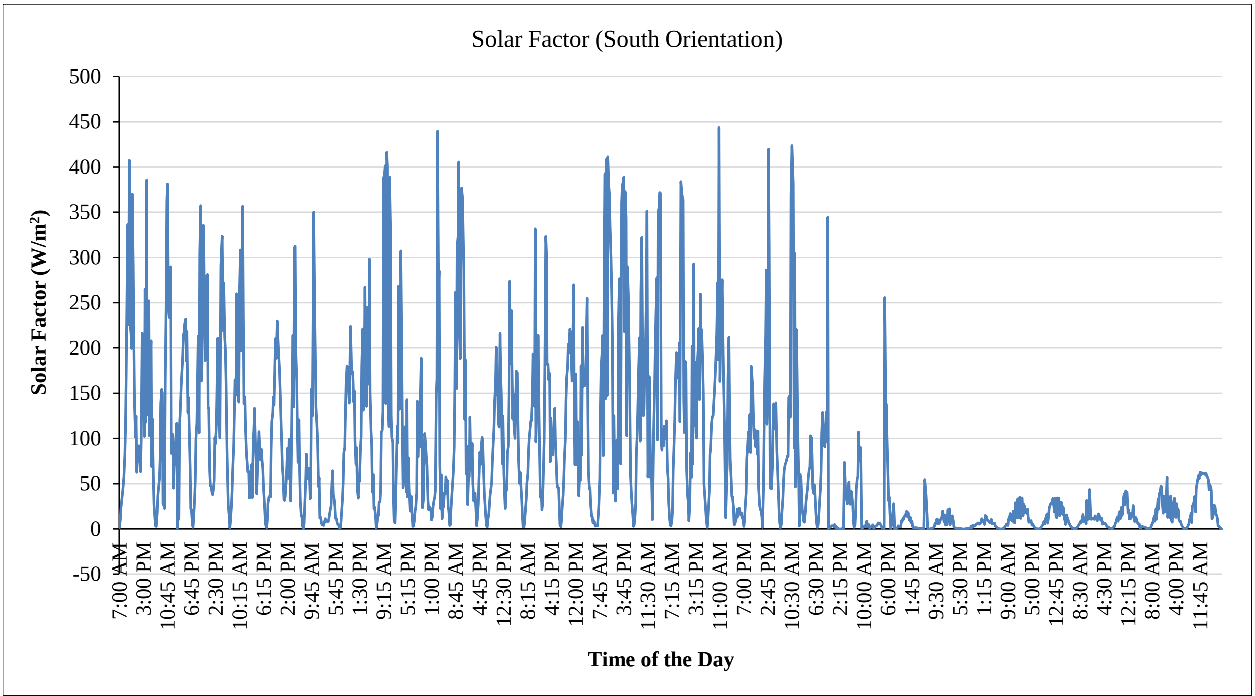


**Figure 11. Solar Factor (W/m²) in Real-Time for South Orientation**

### 3.3.4. Solar Factor (W/m$^2$) for East Orientation

The Solar Factor for the South Orientation in real time is presented in Figure 12. The solar factor for this orientation varies unevenly from -430.199 to 461.304 W/m². The highest value of Solar Factor occurred at 11 am on 21st September 2023, and the OTTV had a minimum value at 3:30 pm on 21st September 2023. This variation in the Solar Factor for east orientation is due to the changes in solar angles (Solar Azimuth and Zenith angles) which define the position of the Sun at a particular time of the day. During the early morning, the sun will be directed from Eastward therefore the solar factor will be higher during these hours, and vice versa during the evening hours. This variation will make an impactful change in the OTTV of the eastward walls of the building. The Solar Factor will have a great impact on the radiation heat gain through glass windows that are directed eastwards. Due to this, the OTTV of the building envelope will change dynamically, as the solar factor of eastwards changes.

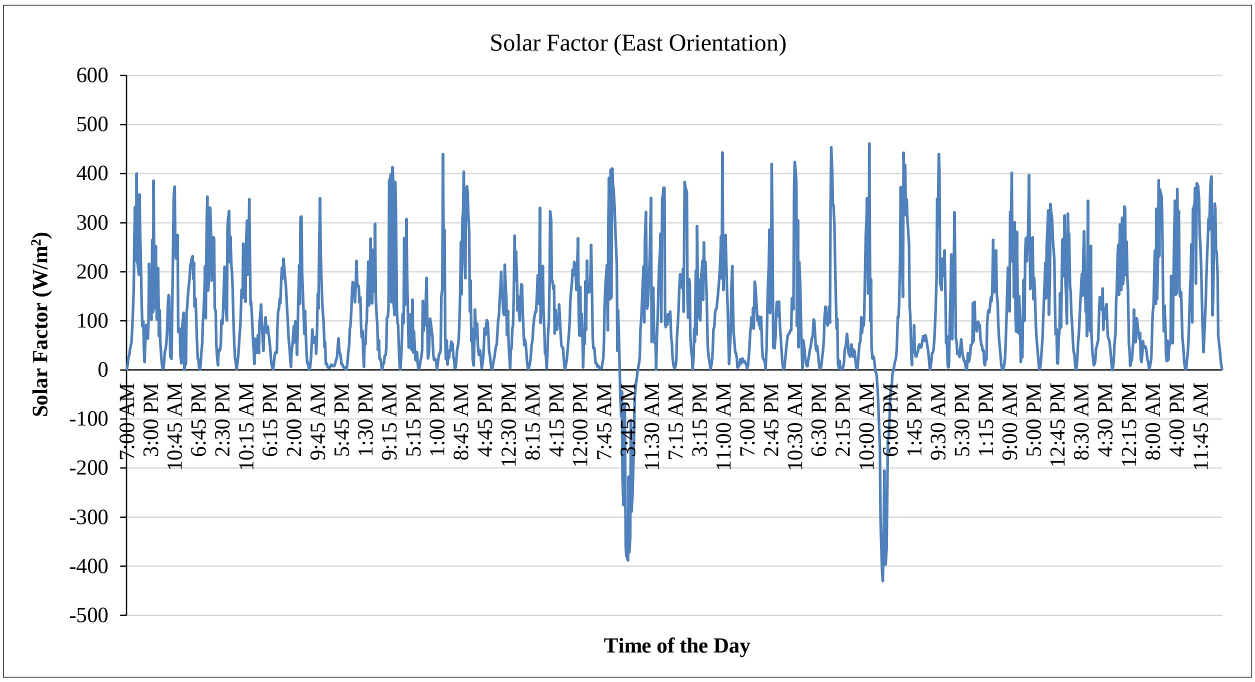


**Figure 12. Solar Factor (W/m$^2$) in Real-Time for East Orientation**

## 3.4. Real-Time Monitoring of OTTV

The real-time monitoring of OTTV is displayed in Figure 13. Due to the variations in Temperature Difference, Equivalent Temperature Difference, and Solar Factor, the OTTV Fluctuates with a wide range of values from early morning to the evening (7 am to 7 pm). This variation is important to be monitored in real-time because OTTV is the average heat gained through the building envelope. Therefore, to be within the allowable limit of the OTTV 50 W/m², defined in MS 1525 Energy Efficiency (Malaysian Standard for Energy Efficiency). Also, the thermostat of the air conditioning system can be controlled as per the values of OTTV by adding a wireless controller and IoT to the air conditioning unit to save the energy consumed by the air conditioning unit. The maximum value of OTTV is 184.572 W/m² on 2nd September 2023 at 11:45 am, and the minimum value of OTTV is -29.447 W/m² on 13th September 2023 at 06:30 pm. This negative value is due to the internal air temperature being higher than the external air temperature due to the confined space (building envelope).

Singhpoo et al. [30] conducted a similar study in which the effect of temperature difference was studied from 6 am to 6 pm for a single day. It was noticed that the OTTV was maximum at 2 pm whereas the minimum at 6 am. Compared to the results of this study, the OTTV is maximum on 2nd September 2023 at 11:45 am and minimum on 13th September at 06:30 pm. Therefore, it can be concluded that the OTTV varies with time due to variations in climatic conditions (Change in Temperature and Solar radiation) of that region. Shah et al. [45] conducted a study to check the effect of shading on opaque facades in real-time and suggested that it should be incorporated in thermal performance standards like ASHRAE 90.1 and OTTV/ETTV Methods. It was also proved that the shading systems reduced the cooling load by 34% and provided efficient facades. Therefore, it can be said that the real-time monitoring of OTTV is of great importance because it varies with changing climatic conditions and by applying different passive design techniques. This study provides the importance of the real-time monitoring of OTTV along with the effect of shading on opaque facades. Similarly, from the results of this study, it is evident that the OTTV varies with the time of the day due to the change in climatic conditions of a particular region. Therefore, this study is conducted to know the thermal performance of building envelopes in real-time and changing environments and can serve as the base for checking the dynamic impact of climate change on OTTV of passive buildings. This dynamic behaviour will help the energy managers to optimize the building envelope during the operation phase of the building, thus making it an energy-efficient building.

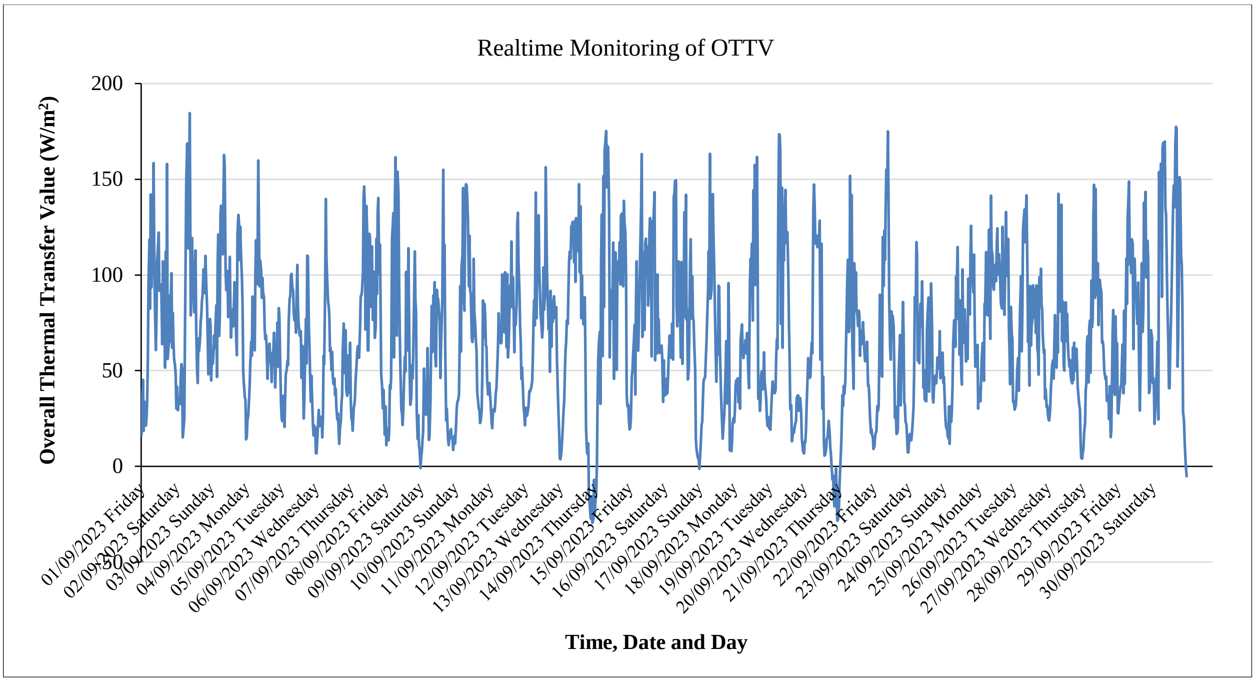


**Figure 13. Real-Time Monitoring of OTTV**

### 3.5. Formulation of OTTV Equation

Based on the basic equation and the coefficients of Overall Thermal Transfer Value (OTTV), a new OTTV equation has been developed. These coefficients of the OTTV equation were determined by the linear regression analysis. The following OTTV equations were developed for North, South, East, and West Orientations.

The general OTTV Equation:

$$TDeq\ \alpha\ (1-WWR)\ Uw + \Delta T(WWR)Uf + SF(CF)(WWR)(SCf) \tag{8}$$

***OTTV Equation for North:***

$$OTTVNorth = 11.021\ \alpha\ (1 - WWR)Uw + 4.256\ (WWR)Uf + 55.86\ (CF)(WWR)(SCf) \tag{9}$$

***OTTV Equation for South:***

$$OTTVSouth = 13.931\ \alpha\ (1 - WWR)Uw + 4.256\ (WWR)Uf + 79.897\ (CF)(WWR)(SCf) \tag{10}$$

***OTTV Equation for East:***

$$OTTVEast = 17.618\ \alpha\ (1 - WWR)Uw + 4.256\ (WWR)Uf + 106.669\ (CF)(WWR)(SCf) \tag{11}$$

***OTTV Equation for West:***

$$OTTVWest = 18.982\ \alpha\ (1 - WWR)Uw + 4.256\ (WWR)Uf + 121.066\ (CF)(WWR)(SCf) \tag{12}$$

### 3.6. Modeling of the OTTV Coefficients / Parameters

The OTTV equations derived above, are verified by using the EQUEST simulation engine. Whereby the Average Hourly Load of OTTV components (Heat conduction through walls, windows, and Heat conduction through glass windows due to solar radiation) is determined for the September month in which the real-time was collected. The case study building was modeled in Autodesk Revit 2023. Then it was exported in the format of AutoCAD to be imported into EQUEST. Where it is converted into an input file of the EQUEST Simulation Engine as well as the Weather File for that location is downloaded. The Case Study Building was imported into the EQUEST Simulation Engine along with its weather file. Hourly heat gain for wall conduction, window conduction, and window heat gains due to solar radiation have been obtained for the September month from EQUEST. The OTTV of the building was calculated with the newly developed OTTV equations. The calculated OTTV value was compared with that calculated from EQUEST by the formula given in Equation 7.

Where the overall heat gained by the building through its envelope is the sum of all three components of the OTTV equation (hourly heat conduction through walls, windows, and heat conduction through glass windows due to solar radiation), and total operating hours are the 360 hours of September 2023.

## 3.7. OTTV Calculation based on New OTTV Equation

To verify the new OTTV equation, the OTTV value of the case study building is calculated. The OTTV calculation for the case study building is presented in the table given below (Table 3):

**Table 3. OTTV Calculation based on the Newly Developed OTTV Equations**

| OTTV Calculation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | K | L |
| **OTTV Component** | **Wall Location** | **Wall Area ($m^2$)** | **Constant** | **Solar Absorption Factor (α)** | **Window to Wall Ratio (WWR)** | **1-WWR** | **Wall U-Value (Uw)** | **Glass U-Value (Uf)** | **Orientation Factor (OF)** | **Shading Coefficient** | **Wall OTTV (ie multiply all shaded cells in the same row)** |
| **Heat Conduction Through Walls** | North Wall | 25.68 | 11.021 | 0.700 | 0.201 | 0.799 | 4.320 | N/A | N/A | N/A | 684.280 |
| | South Wall | 57.01 | 13.931 | 0.700 | 0.474 | 0.526 | 4.320 | N/A | N/A | N/A | 1264.031 |
| | East Wall | 70.31 | 17.618 | 0.700 | 0.239 | 0.761 | 4.320 | N/A | N/A | N/A | 2850.950 |
| | West Wall | 55.30 | 18.982 | 0.700 | 0.592 | 0.408 | 4.320 | N/A | N/A | N/A | 1294.865 |
| | **∑ Wall Area** | ***208.30*** | **The equation for Heat Conduction Through Walls =** | | | | | **TDeq × α × ( 1 - WWR) Uw** | | ∑ | **6094.126** |
| **Heat Conduction Through Windows** | North Wall | 25.68 | 4.256 | N/A | 0.201 | N/A | N/A | 2.720 | N/A | N/A | 59.618 |
| | South Wall | 57.01 | 4.256 | N/A | 0.474 | N/A | N/A | 2.720 | N/A | N/A | 312.561 |
| | East Wall | 70.31 | 4.256 | N/A | 0.239 | N/A | N/A | 2.720 | N/A | N/A | 194.494 |
| | West Wall | 55.30 | 4.256 | N/A | 0.592 | N/A | N/A | 2.720 | N/A | N/A | 378.997 |
| | | **The equation for Heat Conduction Through Windows =** | | | | | | **4.256 × WWR × Uf** | | ∑ | **945.670** |
| **Solar Heat Gain Through Windows** | North Wall | 26 | 55.860 | N/A | 0.201 | N/A | N/A | N/A | 0.900 | 0.570 | 147.579 |
| | South Wall | 57 | 79.897 | N/A | 0.474 | N/A | N/A | N/A | 0.920 | 0.570 | 1131.246 |
| | East Wall | 70 | 106.669 | N/A | 0.239 | N/A | N/A | N/A | 1.230 | 0.570 | 1256.473 |
| | West Wall | 55 | 121.066 | N/A | 0.592 | N/A | N/A | N/A | 0.940 | 0.570 | 2123.686 |
| | | **The equation for Solar Heat Gain Through Windows =** | | | | | | **SF × WWR × OF × SC** | | ∑ | **4658.984** |
| | | | | | | | | | | **∑ Wall OTTV** | **11698.780** |
| | | | | | | | | | | **∑Wall Area** | **208.297** |
| | | | | | | | | | | OTTV | **56.164** |

## 3.8. OTTV Calculation from EQUEST Simulation Engine

EQUEST Simulation Engine gives the values of Conduction of Heat through walls and glass windows, and Radiation Heat Gain through Glass Windows. Then using the formula given in Equation 7, the OTTV has been calculated.

Where: Total heat gain through the envelope is the sum of all three components, Total operating time is 360 hours of September month (12/7 Working Hours) and envelope area is the Total gross Area of the Building Envelope. The calculation of the base case is given below:

Heat Conduction through walls = 5.993 MBTU

Heat Conduction through windows = 4.99 MBTU, and

Solar Heat Gain through Glass Windows = 3.603 MBTU

Total Heat Gain through envelope = 14.586 MBTU

Total Heat Gain through Envelope = 14.586 × 293071.070

Total Heat Gain through Envelope = 4274734.63 Watts

Total Envelope Area = 208.297 $m^2$

$$\textbf{OTTV} = \frac{4274734.63}{(360 \times 208.297)} = 57.006 \text{ W/m}^2 \quad (13)$$

Table 4 given below shows the calculated values of OTTV from the newly developed equations as well as that from EQUEST. Then Figure 14 shows the correlation of OTTV Values based on Newly developed equations and from the EQUEST.

**Table 4. OTTV Values Calculated from New Equations and Simulation**

| Sr. No | Glass Code (Taken from EQUEST Glass Library) | OTTV (Simulation) | OTTV (Equation) | SD | Pearson Correlation Coefficient |
|---|---|---|---|---|---|
| 1 | 2665 | 50.964 | 50.272 | 0.489 | |
| 2 | 2662 | 54.829 | 51.150 | 2.601 | |
| 3 | 2642 | 61.517 | 61.151 | 0.259 | |
| 4 | 2638 | 54.826 | 48.594 | 4.406 | |
| 5 | 2635 | 57.268 | 57.619 | 0.248 | |
| 6 | 2632 | 58.069 | 58.796 | 0.514 | |
| 7 | 2667 | 47.154 | 44.954 | 1.556 | |
| 8 | 2664 | 51.504 | 50.840 | 0.469 | |
| 9 | 2615 | 62.783 | 63.004 | 0.157 | |
| 10 | 2661 | 51.851 | 52.112 | 0.184 | |
| 11 | 2612 | 65.030 | 65.846 | 0.577 | |
| 12 | 2637 | 50.882 | 49.068 | 1.283 | |
| 13 | 2634 | 57.671 | 57.701 | 0.021 | |
| 14 | 2428 | 49.151 | 46.484 | 1.885 | |
| 15 | 2660 | 53.000 | 53.249 | 0.176 | |
| 16 | 2636 | 52.973 | 50.989 | 1.403 | |
| 17 | 2633 | 58.589 | 58.837 | 0.176 | |
| 18 | 2630 | 59.519 | 60.502 | 0.695 | |
| 19 | 2427 | 49.659 | 46.768 | 2.044 | |
| 20 | 2472 | 51.840 | 49.218 | 1.854 | |
| 21 | 2462 | 53.305 | 52.749 | 0.393 | |
| 22 | 2217 | 55.889 | 54.711 | 0.832 | |
| 23 | 2211 | 56.733 | 55.889 | 0.597 | |
| 24 | 2205 | 56.592 | 55.496 | 0.775 | 0.98381078 |
| 25 | 2214 | 60.786 | 61.085 | 0.212 | |
| 26 | 2208 | 61.032 | 61.477 | 0.315 | |
| 27 | 2202 | 61.302 | 61.870 | 0.402 | |
| 28 | 2471 | 52.203 | 49.501 | 1.910 | |
| 29 | 2461 | 53.329 | 53.033 | 0.209 | |
| 30 | 2216 | 56.201 | 54.995 | 0.853 | |
| 31 | 2204 | 56.885 | 56.172 | 0.504 | |
| 32 | 2634 | 49.487 | 45.659 | 2.707 | |
| 33 | 2413 | 46.505 | 41.844 | 3.296 | |
| 34 | 2470 | 53.067 | 50.652 | 1.708 | |
| 35 | 2460 | 53.911 | 53.791 | 0.085 | |
| 36 | 2213 | 61.005 | 61.761 | 0.535 | |
| 37 | 2201 | 61.501 | 62.153 | 0.461 | |
| 38 | 2001 | 66.511 | 68.824 | 1.636 | |
| 39 | 2003 | 64.495 | 66.348 | 1.310 | |
| 40 | 2000 | 66.582 | 69.190 | 1.844 | |
| 41 | 2207 | 61.239 | 61.761 | 0.369 | |
| 42 | 2200 | 61.993 | 62.911 | 0.649 | |
| 43 | 2212 | 61.536 | 62.519 | 0.695 | |
| 44 | 2203 | 57.597 | 56.930 | 0.471 | |
| 45 | 2215 | 56.960 | 56.145 | 0.576 | |
| 46 | 2209 | 57.702 | 57.322 | 0.268 | |
| 47 | 2210 | 57.006 | 56.164 | 0.596 | |

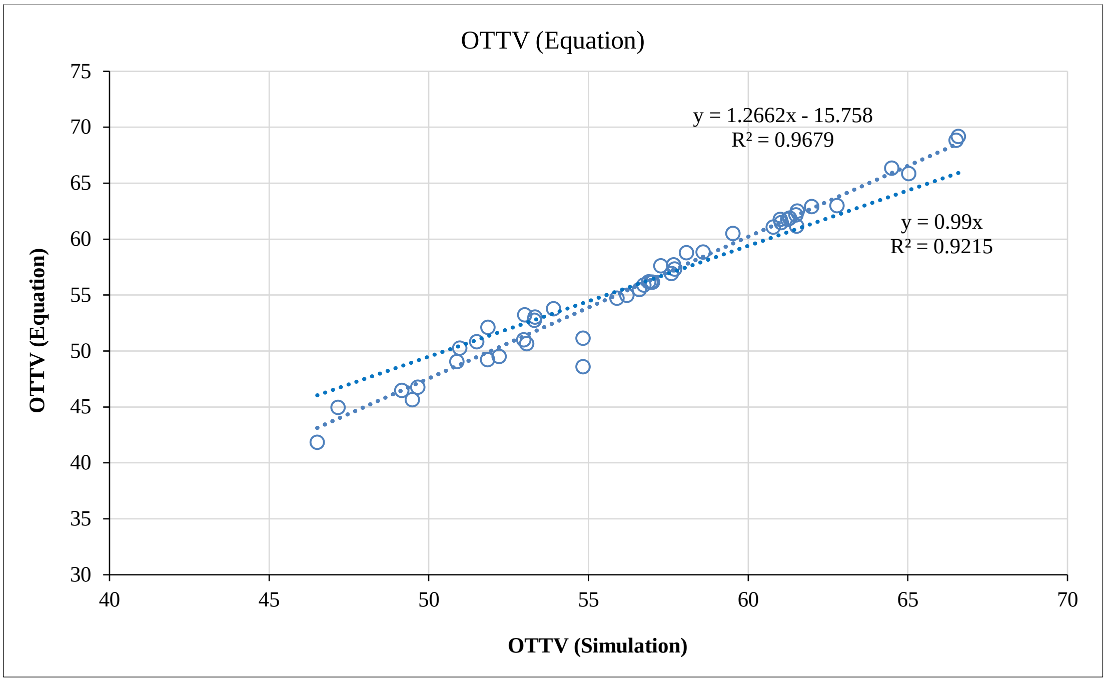


**Figure 14. Correlation of OTTV Values based on Newly Developed Equations and from EQUEST Simulation Engine**

From Figure 14, it is quite clear that the OTTV values calculated from the new equations are strongly correlated with the OTTV values obtained from the EQUEST Simulation Engine. The correlation constant ($R^2$) is 0.9679, which shows that there is a very strong and associated relation between these two values. Also, the Pearson Correlation Coefficient has been calculated, and it was found to be 0.9831, which shows the strong correlation between OTTV (Simulation) and OTTV (Equation). The intercept of OTTV (Equation) is 0.99 times that of OTTV (Simulation), which also shows a strong positive correlation. Hence, the coefficients of OTTV equations are proved to be correct.

### 3.9. Justification of Newly Developed OTTV Coefficients

The determined coefficients of the OTTV equation for the Johor State of Malaysia using Real-Time Data of September 2023 for the case study building (UTM Eco-Home Building) were validated using the EQUEST Simulation Engine. The OTTV Value of the base case building has been given in Table 3, whereas the OTTV value from the EQUEST simulation engine is also given in Section 3.8. Then the parametric runs were carried out to know the suitability of the calculated OTTV coefficients for different types of window glass conductions. As the construction characteristics of windows (type of glazing such as Single Clear, Double Clear, or Tinted glass) are altered, the OTTV will vary because the Shading Coefficient and transmissibility of glass will vary, which affects the Radiation Heat gained by windows.

The OTTV value of 47 different types of glass constructions (Taken from the EQUEST glass library; Double Clear/Tint/Reflective/Low E) has been computed by using the modified equations of OTTV as well as from the EQUEST simulation engine. Then the calculated OTTV values are plotted against the simulated OTTV values presented in Figure 14. The correlation between these two has also been examined. The accuracy of a regression model depends upon the correlation coefficient ($R^2$) of the model and the Pearson correlation coefficient. From Figure 14, $R^2$ is 0.9679, and the Pearson Correlation Coefficient is 0.9831, which shows the calculated values are highly coherent.

## 4. Conclusion

The main objective of this study was to check the effect of climate change on OTTV by monitoring it in real-time and derive the new OTTV equation using Real-Time Data with the help of sensors to simulate the varying climatic conditions of Johor, Malaysia. The OTTV equation was developed and verified using EQUEST Simulation, and it was found that the newly developed equation estimated the OTTV accurately. From the analysis, it is presumed that there is a huge impact of varying climatic conditions on the OTTV of a building due to the climate-based factors in the OTTV equation, such as TDeq, $\Delta T$, and the Solar Factor. The real-time monitoring of the coefficients of the OTTV equation clearly defines the variation in OTTV due to the change in air temperature and the solar radiations due to the changes in solar angles, which define the position of the Sun at a particular time of the day. This variation can trigger the energy managers to design the building envelope accordingly and can monitor the thermostat of the air conditioning system of the building using wireless controllers by satisfying the OTTV value in real time. For this, the maximum allowable limit of OTTV can be used as the borderline defined by MS 1525 (50 W/m²). That will further save energy and can make this building a green building. Furthermore, the calculated coefficients can be referred to as the OTTV Calculation for the September month. Likewise, the coefficients can be calculated for the whole year by using real-time data.

The present study has contributed to the body of knowledge by developing new OTTV equations for the Johor State of Malaysia using real-time data because, as per the literature available in previous studies, validation of the results using real-time data of the buildings is very limited [16]. The coefficients of the newly developed OTTV equations vary from the OTTV equation defined in MS 1525 because of the real-time data and climatic conditions of Johor. Moreover, the newly developed equation can be used to calculate the OTTV of passive buildings of Johor State and can be considered included in MS1525. The authorities administering the Building Energy Performance in Malaysia may consider this development for further evaluation and adaptation in energy performance rules and regulations. It is substantially assumed that the newly OTTV-based developed index to measure the building envelope performance will aid in the energy audit and bring new reforms to improve the energy efficiency of buildings.

### 4.1. Limitations and Future Recommendations

The scope of this study was limited to the Johor state of Malaysia. The real-time data was taken from the sensors fitted to the UTM Eco-Home building of Universiti Teknologi Malaysia Skudai, Johor. Therefore, the newly developed OTTV equations cannot be directly used in other states of Malaysia. Further studies must be conducted to compare and confirm the newly derived OTTV equations with other states in Malaysia as well as other countries with similar climates. This study considered one month of real-time data; to represent the data for a whole year, seasonal variations must be considered in future studies. Also, in this research, the OTTV equations are verified using different glazing systems (Glass Configurations). In the future, it can be verified by using different buildings having different building materials to know the effect of materials changing along with the different glazing systems to develop more comprehensive and adaptable equations.

## 5. Nomenclature

| | | | |
|---|---|---|---|
| OTTV | Overall Thermal Transfer Value ($W/m^2$) | Uw | Opaque Wall's thermal transmittance ($W/m^2$-K) |
| Uf | Thermal Transmittance of the building fenestration ($W/m^2$-K) | TDeq | Equivalent Temperature Difference ($^0$ C) |
| SC | Shading Coefficient of Glazing System | α | Absorptivity of the wall material |
| Awi | Opaque wall Area ($m^2$) | Agi | Glass Windows Area ($m^2$) |
| Rso | Outside Surface Resistance ($m^2K/W$) | Id | Incident Solar Radiations ($W/m^2$) |
| ΔT | Difference of Temperature (The outside air temperature minus inside air temperature) | | |

## 6. Declarations

### 6.1. Author Contributions

Conceptualization, A.A.V. and R.Z. ; methodology, A.A.V., F.A., and E.A.; software, A.A.V.; validation, A.A.V., R.Z., F.A., and E.A.; formal analysis, A.A.V.; investigation, R.Z.; resources, R.Z., F.A., and E.A.; data curation, A.A.V.; writing—original draft preparation, A.A.V.; writing—review and editing, A.A.V., R.Z., F.A., and E.A.; visualization, A.A.V. and R.Z.; supervision, R.Z. and F.A.; project administration, R.Z., F.A., and E.A.; funding acquisition, R.Z., F.A. All authors have read and agreed to the published version of the manuscript.

### 6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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### 6.5. Conflicts of Interest

The authors declare no conflict of interest.

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