THERMAL COMFORT ANALYSIS OF WORKING SPACE BUILDING USING OVERALL THERMAL TRANSFER VALUE (OTTV)

Study Case: Wohng Coffee in Sleman, Yogyakarta

Zahra Zakiyah[1], Noor Cholis Idham, Mahadevi Effia Arkan
[1]Jurusan Arsitektur, Universitas Islam Indonesia
[1]Surel: 21512194@students.uii.ac.id

ABSTRACT*: Thermal comfort is a fundamental consideration in architectural design, ensuring the comfort and well-being of building users. We focus on proposing design recommendations on architectural elements as a solution to the Wohng Coffee building design problem, which has an OTTV value above the SNI standard. The parameters considered in the OTTV calculation include the dimensions and materials of the facade, openings, and shadings. This research aims to evaluate the thermal comfort levels within the Wohng Coffee and provide recommendations. The methodology consists of three phases: first, conducting direct observations and measurements of the study object, applying the OTTV method for thermal analysis, and conducting simulation with OTTV calculation for the proposed design alternatives to reduce the OTTV score. The results of OTTV calculations on existing buildings show numbers below the SNI standard for OTTV thermal comfort in Indonesia, which is 39.7 Watts/m2. Three alternative solutions were proposed to reduce the OTTV value: using aerogel glazing in openings, changing the shape of horizontal shading to vertical for more effectiveness, and combining the two alternatives. After calculating, the third alternative produces a lower OTTV value and complies with the standard, which is 31.9 Watts/m2.*

Keywords: *coffee shop, design recommendation, OTTV, thermal comfort.*

INTRODUCTION

In the field of architectural design, thermal comfort is an extremely important factor that is crucial to guaranteeing the happiness and well-being of building inhabitants. The capacity to keep a building's temperature at an ideal level affects user experience and productivity in addition to creating a nice and comfortable atmosphere.

Working spaces are distinct from other commercial spaces because they are lively, busy places that serve a wide range of customers looking for more than just a cup of coffee—they also want to feel welcome and comfortable. Customers' overall experience at a working space is greatly influenced by its layout and design, with elements like lighting, seating arrangements, and temperature control all having a positive impact on their pleasure. Of them, thermal comfort stands out as a critical component that has a big influence on how patrons feel about and enjoy their time at the working space. Thermal discomfort can cause people to feel uncomfortable in public spaces and leave that public space. It does not only affect the visitors but also affects the work productivity of workers. (Gunawan et al., 2022)

Wohng Coffee Shop is one example of a coffee shop that also functions as a working space. This destination located in Sleman, Yogyakarta is always full of visitors every day. This is primarily due to the comfortable seating arrangement and facilities, the affordable and delicious food as well as drinks menu, and the ambience that supports the productivity of its visitors. However, during the midday to afternoon, the indoor space, which is dominated by glass and openings, results in an increase in temperature, which reduces the comfort of the visitors.

Indonesia has a high tendency of having discomfort as a result of the excessive thermal in the building. The maximum allowable OTTV in Indonesia is 35 W/m^2. (Paryudi et al., 2013) In specific, thermal comfort standards for the comfortable warm category according to SNI

03-6572-2001 is 25.8OC - 27.1OC with air humidity level of 50%-60% and air velocity of 0-15 - 0.25 m/second. (Zuraihan et al., 2023) Wohng Coffee, which is located in Yogyakarta has the same thermal standard.

According to this set standard, attaining ideal thermal comfort in working spaces can be a challenging task. The direction of the building, insulation, ventilation, and external environmental elements are among the variables that affect a working space's thermal climate (Soto Muñoz et al., 2022). Consequently, it is crucial to conduct a thorough evaluation of thermal comfort utilizing techniques such as the Overall Thermal Transfer Value (OTTV) in order to pinpoint problem areas and put into practice focused plans that raise employee and consumer comfort levels.

This research offers a new perspective, focusing on analyzing the opening and shading size as well as their materials using the Overall Thermal Transfer Value (OTTV) calculation approach. With a better knowledge of these variables, we want to offer suggestions that improve Wohng Coffee's thermal comfort and guarantee an ideal OTTV score. These novelties will be covered by these research questions:

1. Does the OTTV value at Wohng Coffee comply with the standard OTTV value limit in Indonesia?
2. If it does not meet the standard, what are the design changes that can reduce the OTTV score?

LITERATURE REVIEW

The Overall Thermal Transfer Value (OTTV) is a tool to measure heat transfer rate through a building's envelope, including walls, roofs, and windows. It is crucial for designing energy-efficient buildings, especially in hot climates. A number of factors, including solar absorptance, window-to-wall ratio (WWR), shading coefficient (SC), solar factor (SF), and thermal transmittance (U-value), are used to calculate OTTV in accordance with the Indonesian standard SNI 6389:2011. The total OTTV is the sum of OTTV values for each wall and the roof. Wall absorption has the least effect on OTTV, whereas the window-to-wall ratio has the biggest. For the best building performance, OTTV should be used in conjunction with other energy-saving techniques, even though it is a helpful tool for lowering heat gain. (Paryudi et al., 2013)

Several previous studies on thermal comfort analysis in commercial buildings have been conducted, such as Tarantini et al., (2017) who explains the relationship between workers' thermal comfort and productivity in production and office buildings, or research by Zhang et al., (2020) which uses experiments that take into account wind speed with its correlation to users who walk through space. Both of them are talking about thermal comfort, but they do not assess the components in the OTTV calculation such as the use of materials and the size of openings.

A study conducted by Hidayat (2022) thrived to understand thermal comfort factors and energy conservation in building design through his case study at the buildings of Universitas Mercu Buana in Jakarta, Indonesia. It aims to assess energy efficiency in the architectural design to reduce external heat loads. The findings revealed that the OTTV values for the campus buildings were within the SNI standards, ranging from 31.61 to 34.74 Watt/m^2. This case study can be used as an example for this research paper as well.

Similar example can be found as well in Wibawa & Hutama's study (2019) which aimed to optimize window openings and room comfort by analyzing OTTV (Overall Thermal Transfer Value) and sun shading, focusing on the meeting room of the UPGRIS postgraduate building, which experienced excessive heat and glare. The result showed that the OTTV value in the meeting room was found to be 52.33 watts/m^2, exceeding the SNI standard of 35 watts/m^2. The study proposed redesigning windows and shading to meet the maximum standard, After analyzing the OTTV to understand the thermal comfort, design modifications suggestions should be made. As Vijayalaxmi (2010) has done with his research. This is also supported by the research result of (Raji et al., 2017) who also emphasizes the importance of considering OTTV in the early design stages for energy efficiency. It concludes that OTTV is a crucial factor in achieving sustainability in building design.

In order to understand more about the modifications to improve the building's thermal comfort, a study that evaluated the effectiveness of different shading devices—vertical models, horizontal multiple fins, and egg crates—based on the Indonesian National Standard SNI guidelines can be used as a reference. The study emphasized the importance of appropriate shading device design in minimizing solar radiation through glass surfaces. (Zahari et al., 2023)

Other improvement references can be taken from a study that compared materials like glass wool, Vacuum Insulation Panels (VIPs), and aerogel for their impact on thermal transmittance (U-value) through experimental approach. The result showed that VIPs emerged as the superior insulation material, significantly lowering OTTV values by 22.86%-42.84% across various house types, thereby enhancing thermal comfort and aligning with SNI 03-6389 Year 2020 standards for energy-efficient building envelopes. (Haripram & Dewi, 2023)

RESEARCH METHOD

The research method employed in this study involves a systematic approach to evaluate the thermal comfort conditions within the Wohng Coffee using the Overall Thermal Transfer Value (OTTV) method. The methodology is structured into three distinct phases to ensure a comprehensive analysis.

In the first phase, direct observations and measurements will be conducted within the building. This includes gathering primary data and photographs on the dimensions and materials of the facade, openings, and shadings, crucial elements that significantly influence thermal transfer characteristics.

Following the data collection phase, the OTTV method will be applied for thermal analysis. This method incorporates the gathered data to calculate the thermal transfer characteristics of the building accurately. The OTTV calculation provides a quantitative measure of thermal comfort levels, aiding in the evaluation of existing conditions and identification of areas for improvement.

The formulation of recommendations aimed at improving the thermal comfort conditions inside the Wohng Coffee will be the study method's final stages. These recommendations will be specifically aimed at addressing elements found in the OTTV study, which will eventually lead to smaller OTTV scores.

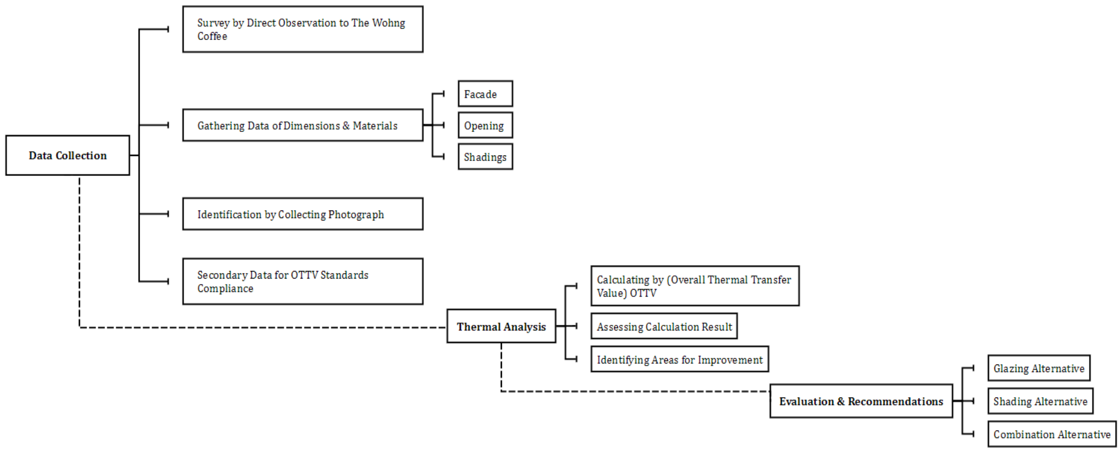

Figure 1 Method Flow Chart
Source: Author, 2024

RESULTS AND DISCUSSION

Figure 2 Building Location on Map
Source: Google Maps, 2024

Wohng Coffee is located on Jl. Degolan, Umbulmartani, Ngemplak District, Sleman Regency, Yogyakarta Special Region. This coffee shop has two floors; the first floor is for the indoor area and the second floor is for the outdoor area. The building is oriented towards the West, with a large number of openings on all three sides. The orientation of the building and the large number of openings on the first floor have the potential to cause high thermal transfer.

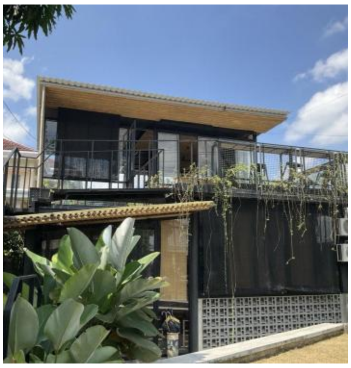

Figure 3 West Facade View of the Building
Source: Author, 2024

To determine the OTTV value of a building, it is necessary to consider the Window to Wall Ratio. The ratio of the opening area to the wall area is used to compute the Window to Wall

Ratio (WWR). According to WWR, walls are any kind of material on the facade, opaque or translucent, whereas openings are defined as translucent material on a facade. The calculation of WWR is done separately per side of the facade, where each gets a different intensity of exposure to solar heat radiation according to the angle of the sun's fall. (Latifah et al., 2022) That's why it is crucial to comprehend the size of the building facade in each orientation.

Table 1 Size of Building Walls

Orientation	Building Material	Facade Area (m)		
		Width	Height	Total
North		9	3.5	31.5
West	Concrete Wall	6.8	3.5	23.8
East		6.8	3.5	23.8
South		9	3.5	31.5

Source: Author's Direct Survey Result, 2024

Openings in this building are found on the East, North, and West sides of the building. Some openings can be opened and closed. However, the windows are more often closed so that the air from the air conditioner does not circulate in vain. The room is rectangular in shape, with part of the space to the East used as an outdoor space as well as a kitchen and a place for orders.

Figure 4 Openings at West (a), North (b), and East (c) Sides of the building.
Source: Author, 2024

Table 2 Size of Building Openings

Orientation	Opening Material	Opening Types	Amount of Opening	Opening Area (m)		
				Width	Height	Total
North		F1	6	0.7	3.3	13.86
		F2	3	0.5	2.7	4.05
		F3	2	0.6	0.85	1.02
West		F4	3	0.7	2.6	5.46
	Clear Glass (SNFL) 3 mm	F5	2	0.8	2.6	4.16
		F6	3	0.7	3.5	7.35
		F7	1	1	3.5	3.5
East		F8	3	0.7	3.5	7.35
		F9	1	1	3.5	3.5
		F10	2	0.6	0.85	1.02
		F11	3	0.6	0.85	1.53
South		-	-	-	-	-

Source: Author's Direct Survey Result, 2024

Based on the results of direct observation, detailed building material data were obtained. The building walls use concrete with SHGC 0.86 and U Value 1.13 W/m2k. The height of each floor to the ceiling is 3,5 m. The glass installed in the opening is clear glass (SNFL) with a thickness of 3 mm which has SHGC 0.63 and U Value 4.1 W/m2k. The size of each opening varies; there are 11 types and their placement and type also differ. Details of window and door sizes can be seen in the plan below.

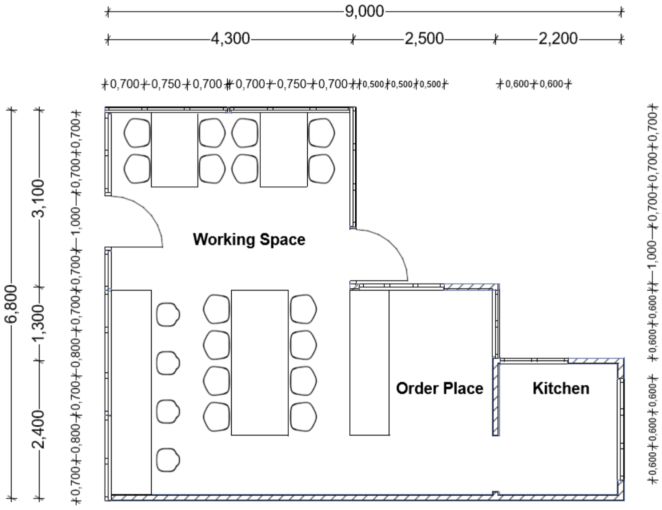

Figure 5 Schematic Floor Plan of Wohng Coffee
Source: Author, 2024

Table 3 Material Specifications

Building Material	SHGC Value	U Value
Concrete Wall	0.86	1.13 W/m2k
Clear Glass (SNFL) 3 mm	0.63	4.1 W/m2k

Source: Standard for Building Material

The shading installed in the East and West sides of the building is horizontal shading with different length each. and a width of 1 m from the glass installation on the building wall. On the west-facing facade, the shading is horizontal with a length of 80 cm and 100 cm. On the east-facing facade, the shading is also useful for shading a small outdoor terrace that also functions as a working space. The shade has a fairly large size; 3.1x4.5m.

Figure 6 Shading Shape on The East (a) and West (b) Sides of The Building
Source: Author, 2024

Table 4 Shading Size

Orientation	Horizontal Shading Length (m)	Opening Type
North	3.1	F2
West	0.8	F4 & F5
	1	F6 & F7
East	4.5	F8 & F9
South	-	-

Source: Author's Direct Survey Result, 2024

Using OTTV, some parameters were included in order to determine whether or not the OTTV score complies with the standard. By determining the type of material used in the building, the calculation of solar conduction and radiation through walls and openings can be known. Thus, the following results were obtained.

Table 5 OTTV Calculation Result

Orientation	Conduction Through Walls (Watt)	Conduction Through Openings (Watt)	Radiation Through Openings (Watt)	Total (Watt)	Total Facade Area (m2)	OTTV Value (Watt/m2)
	A	B	C	A+B+C=D	E	D/E
North	217.13	373.92	1676.44	2267.49	49.74	45.59
West	164.05	419.64	2033.21	2616.90	44.27	59.11
East	164.05	274.70	919.85	1358.60	37.20	36.52
South	217.13	-	-	217.13	31.50	6.89
Total	**762.37**	**1068.26**	**4629.50**	**6460.12**	**162.71**	**39.70**

Source: Author's OTTV Calculation Result using OTTV Calculation Sheet, 2024

Based on this calculation, the OTTV value of 39,70 W/m^2 does not comply with the standard referred to in the introduction. So improvements must be made to achieve an OTTV score that is ideal according to the standard. It can also be analyzed that the facade with the highest potential for thermal transfer from outside to inside is the North and the West side. The north-facing openings have no shading, while the west-facing openings only have small shadings. Thus, solar radiation can directly enter and cause temperature rise. (Bellia et al., 2014)

The question that arises then leads to the improvement of building performance in order to have an OTTV value that is in accordance with Indonesian standards. In the case of Wohng Coffee, considering the openings that are the dominant material in each facade orientation and also the aesthetic value of the building architecture, three alternative solutions were simulated:

1. Glazing all glass openings in each orientation using aerogel glazing,
2. Changing horizontal shading to vertical shading on the facades orientated towards the North and West, and
3. Combining the first and second alternatives, namely coating all glass openings with aerogel glazing and adding vertical shading in the North and West.

The first simulation is the addition of aerogel glazing material to the opening glass. This is a value manipulation method in the development of sustainable and energy-conscious building concepts. By combining several materials, the value which is one of the calculation components in OTTV can be reduced, which means that the ability of the material to absorb solar radiation will be reduced and will also affect the final OTTV value. (Kurniawan, 2023)(Pramesti et al., 2021) In the case of Wohng Coffee, the first alternative is to apply aerogel glazing to the openings.

Aerogel is a solid material, based on silicon, with the lowest possible density. It contains more than 95 % of air; the rest is silica ($SiO2$ – Silicon dioxide). (Valachova et al., 2018) The specification of the glazing is 4P16F, stands for 4 mm as the diameter of the aerogel particles, and the 16 mm for the aerogel filling thickness. Based on a research by Leung et al., (2020), this type of glazing has the U-Value by 2,22 W/m2K, which could reduce 32.1% heat gain and save 5.1% cooling energy consumption, thereby improving indoor visual comfort and reducing the energy use for space cooling.

If 4P16F aerogel glazing is combined with the type of opening in the existing building, a calculation is needed to determine the U-Value which will be used as an important component in the OTTV calculation simulation. To determine this, we can use the concept of thermal resistances. The U-value is the inverse of the thermal resistance (R-value). The total thermal resistance ($Rtotal$) for the combined unit is the sum of the thermal resistances of the individual layers (Yu et al., 2024). Once we have the total resistance, we can find the combined U-value as the inverse of the total resistance.

The R-value for the clear glass pane ($Rclear$) is given by:

$$R_{clear} = \frac{1}{U_{clear}} = \frac{1}{4.10 \text{ W/m2K}} \approx 0.244 \text{ m2k/W}$$

The R-value for the aerogel-filled pane ($Raerogel$) is given by:

$$R_{aerogel} = \frac{1}{U_{aerogel}} = \frac{1}{2.22 \text{ W/m2K}} \approx 0.450 \text{ m2k/W}$$

The total thermal resistance:

$$\begin{aligned} R_{total} &= R_{clear} + R_{aerogel} \\ &= 0.244 \text{ m2K/W} + 0.450 \text{ m2K/W} \\ &= 0.694 \text{ m2K/W} \end{aligned}$$

The combined U-value:

$$U_{combined} = \frac{1}{R_{total}} = \frac{1}{0.694 \text{ m2K/W}} \approx 1.44 \text{ W/m2K}$$

So, the combined U-value of the double-glazing unit is approximately 1.44 W/m2K. This value will replace the U-Value of the previous clear glass material. Then the OTTV results obtained are as follows.

Table 6 Alternative 1 OTTV Simulation Result

Orientation	Conduction Through Walls (Watt)	Conduction Through Openings (Watt)	Radiation Through Openings (Watt)	Total (Watt)	Total Facade Area (m2)	OTTV Value (Watt/m2)
	A	B	C	A+B+C=D	E	D/E
North	217.13	131.33	1676.44	2024.90	49.74	40.71
West	164.05	147.38	2033.21	1344.64	44.27	52.96
East	164.05	96.48	919.85	1180.38	37.20	31.73
South	217.13	-	-	217.13	31.50	6.89
Total	**762.37**	**375.19**	**4629.50**	**5767.06**	**162.71**	**35.44**

Source: Author's OTTV Calculation Result using OTTV Calculation Sheet, 2024

The second simulation is to change the horizontal shading to vertical shading. The consideration is to change the shading with less material but higher performance in reducing the heat transfer. In this case, the vertical shading that will be simulated has fins that are 10 cm long with a 20-degree tilt. The distance from one fin to another in one opening unit is 10 cm, forming a repetitive composition in its shape. A research done by Chan (2021) revealed that the impact of adjacent shading on the evaluation of building thermal and energy performance is very significant to reduce the heat gain through the opening. Therefore, this method is applied in the Wohng Coffee case.

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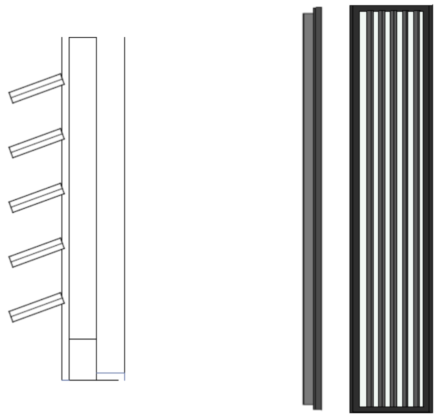

Figure 7 View on Plan (a), Side Elevation (b), and Front Elevation (c) of the Installed Vertical Shading on the Opening.
Source: Author, 2024

Shading will be simulated on the north and west facing openings, as these two orientations have the most significant heat transfer impact on Wohng Coffee. The resulting OTTV calculation simulation is as follows:

Table 7 Alternative 2 OTTV Simulation Result

Orientation	Conduction Through Walls (Watt)	Conduction Through Openings (Watt)	Radiation Through Openings (Watt)	Total (Watt)	Total Facade Area (m2)	OTTV Value (Watt/m2)
	A	B	C	A+B+C=D	E	D/E
North	217.13	373.92	1282.11	1873.16	49.74	37.66
West	164.05	419.64	1848.91	2432.59	44.27	54.95
East	164.05	274.70	919.85	1358.60	37.20	36.52
South	217.13	-	-	217.13	31.50	6.89
Total	**762.37**	**1068.26**	**4050.870**	**5881.49**	**162.71**	**36.15**

Source: Author's OTTV Calculation Result using OTTV Calculation Sheet, 2024

The third simulation combines the previous two alternatives; coating the entire opening glass with aerogel glazing and adding vertical shading in the North and West.

Table 8 Alternative 3 OTTV Simulation Result

Orientation	Conduction Through Walls (Watt)	Conduction Through Openings (Watt)	Radiation Through Openings (Watt)	Total (Watt)	Total Facade Area (m2)	OTTV Value (Watt/m2)
	A	B	C	A+B+C=D	E	D/E
North	217.13	131.33	1282.11	1630.57	49.74	32.78
West	164.05	147.38	1848.91	2160.34	44.27	48.80
East	164.05	96.48	919.85	1180.38	37.20	31.73
South	217.13	-	-	217.13	31.50	6.89
Total	**762.37**	**375.19**	**4050.87**	**5188.42**	**162.71**	**31.89**

Source: Author's OTTV Calculation Result using OTTV Calculation Sheet, 2024

To decide which alternative is most effective for reducing the OTTV score, the simulation results using OTTV calculation are presented in the following table:

Table 9 Three Alternatives OTTV Simulation Result Comparison

Type	OTTV Score (Watt/m2)
Alternative 1	35.44
Alternative 2	36.15
Alternative 3	31.89

Source: Author's OTTV Calculation Result using OTTV Calculation Sheet, 2024

Comparing the three alternatives, it can be seen that the smallest OTTV value is in the third alternative. From the initial OTTV value of 39.70 Watt/m2, the first alternative produces an OTTV value of 35.44 Watt/m2, a decrease of 10.73%. The second alternative has a value of 36.15 Watt/m2, which means only a decrease in value of 8.94%. The third alternative combines the two solutions, resulting in an OTTV value of 31.89 Watt/m2 and a decrease in value of 19.67%. This value is also in accordance with thermal standards in Indonesia which should not exceed 35 Watt/m2. Thus, thermal comfort inside Wohng Coffee can increase because the intensity of heat transfer channeled by openings can be reduced.

CONCLUSIONS

Reflecting on the standard limit of OTTV value in Indonesia which is 35 Watt/m2, the OTTV value at Wohng Coffee does not meet this standard. This is due to the large number of openings in the 3 building orientations; North, East and West. In addition, the type of glass material used along with its SHGC and U Value also affects the high OTTV value there, which is 39.70 Watt/m2.

Because it does not meet the standard, it is necessary to make some innovative design changes to the architectural elements of Wohng Coffee. This aims to reduce the OTTV value in order to create a comfortable space for its users. Three alternative simulations were carried out, resulting in the most significant percentage reduction in OTTV value in the third alternative, which was 19.67% with a final value of 31.89 Watt/m2. This third alternative has a strategy to coat all glass openings in each orientation with aerogel glazing and add vertical shading in the North and West. This proves that the integration between the use of materials and the design of architectural elements in the form of shading devices as a strategy for controlling thermal and room comfort in buildings is very important since the early stages of design.

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