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Effects of Heat Transfer through the Walls of a Catholic Church in Semarang Indonesia Simulated with Psi-Therm Software and OTTV

L.M.F. Purwanto[1], **Karsten Tichelmann**[2]

[1]Architecture Doctoral Program of Soegijapranata Catholic University, Semarang 50234, Central Java, Indonesia
[2]Department of Architecture, Structural development & building physics, Technische Universität Darmstadt, Darmstadt 64287, Hessen, Germany
*Corresponding Author: lmf_purwanto@unika.ac.id

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Abstract Verifying the effects of heat transfer towards the rise of temperature in certain spaces which impact air control and conditioning. Climate change affect the rise of environmental temperatures, with the humid and tropical Indonesia not exempt from its effects. Many church buildings in Semarang, Indonesia, of which were previously partial to natural ventilation, have now opted to rely on Air Conditioning in order to cool their indoor temperatures. As a result, electrical consumption is now at an all-time-high, with the absence of proper adjustments needed to anticipate heat transfer from the outdoors from entering these buildings. Aside from skyrocketing expenses spent on electrical bills, the rise in energy consumption is also partial to uncontrollable energy waste. This research aims to provide a guide in designing the walls of church buildings, in order to reduce massive electrical consumption. Methods used in this research are calculations done through the software *Psi-Therm* as well as making considerations regarding *Overall Thermal Transfer Value* (OTTV) in order to provide the big picture of controllable thermal conductivity through church wall design. Research results entail a design model of heat transfer flow obstruction which will be beneficial for future church designs

Keyword Heat transfer, Psi-Therm, wall design, OTTV

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1. Introduction

Construction developments and renovations of the archdiocese church building in Semarang has shown significant developments as of late. Current considerations related to the development and renovation of the church building, however, are only limited to its architectural design developments, church building expansion, and church rooms additions. Thoughts regarding its building performance' improvements by considering building physics remain subsidiary. The results are the rise of profligate energy consumption, all done for the means of comfort. [1] Data obtained from The Roman Catholic Archdiocese of Semarang reveal a drastic rise in every parish's operational cost due to the use of Air Conditioning in both post-renovated and currently still-in-development church buildings. The effects of world's climate change in regards to environment temperature rise prove discernable in the tropical, humid climate of Indonesia, with the country's high temperature and high humidity levels that last all-year-long. [2] This results in the way Church buildings require thermal comfort in order to allow concentration and focus to transpire during services. The use of air conditioning is deemed the feasible solution, however changes are still yet to be made when it comes to building design, particularly toward walls that serve as direct borders to the outdoors. [3] The use of air conditioning, if not properly planned out, may result in overindulgence of electrical consumption. [4] The internal impact of this reckless electrical use lies in how operational funding costs are ultimately provided by the collective, due to the lack of subsidy provided by the government. Meanwhile externally, the rise of electrical consumption has become a global issue, one which focus is set on reducing the use of fossil fuel (oil and coal), a resource still prominently used in Indonesia. [2] On the other hand, the additions. Thoughts regarding its building performance improvements by considering building physics remain subsidiary. The results are the rise of profligate energy consumption, all done for the means of comfort. [1] Data obtained from The Roman Catholic Archdiocese of Semarang reveal a drastic rise in every parish's operational cost due to the use of Air Conditioning in both post-renovated and currently still-in-development church buildings. The effects of world's climate change in regards to environment temperature rise prove discernable in the tropical, humid climate of Indonesia, with the country's high temperature and high humidity levels that last all-year-long. [2] This results in the way Church buildings require thermal comfort in order to allow concentration and focus to transpire during services. The use of air conditioning is deemed the feasible solution, however changes are still yet to be made when it comes to building design, particularly toward walls that serve as direct borders to the outdoors. [3] The use of air conditioning, if not properly planned out, may result in overindulgence of electrical consumption. [4] The internal impact of this reckless electrical use lies in how operational funding costs are ultimately provided by the collective, due to the lack of subsidy provided by the government. Meanwhile externally, the rise of electrical consumption has become a global issue, one which focus is set on reducing the use of fossil fuel (oil and coal), a resource still prominently used in Indonesia. [2] On the other hand, the most prominent electrical consumption falls under the use of air conditioning within buildings, which make up to about 30%-40% of the total electrical requirements of a structure. [5]

A building's walls serve a significant role as a barrier between the outdoors to the exterior of the building. Façade wall design is determinant to fulfilling the Thermal Performance of a structure. In this research, a software called Psi-Therm— which helped calculate heat transfer along the building walls and thermal bridge which occurred upon the materials chosen for the building construction — was used. This software was able to measure and optimize the design in order to obtain a lower heat loss value as well as obviate surface condensation.[6]. In this research, building performance control will be conducted by using *Overall Thermal Transfer Value* (OTTV) as the means of energy efficiency improvement within a structure [7]. OTTV measures the level of heat collected through a structure's façade [8].

2. Literature Review

Approach used to calculate heat transfer is the *Psi-Therm* program. This calculation is based on the application of U_{value} formula on every calculate section of the building, as seen below:[9]

$$U_{value} = \left(\frac{1}{\alpha_d} + \Sigma\frac{1}{\Lambda} + \frac{1}{\alpha_l}\right)^{-1} \quad [\ \mathrm{W/m^2K}\ ] \tag{1}$$

α_d = outdoor surface resistance
α_l = indoor surface resistance
Λ = total resistance of all materials

Within elements of a building which constitute multiple layers, each layer's resistance is therefore defined as reciprocal. Since thermal conductivity factor significantly defines heat flow in every aspect, therefore surface conductivity value L can be explained mathematically through the equation:[9]

$$L = \frac{\lambda}{d} \tag{2}$$

d = thickness (m)
λ = conductivity (W/mK)

If temperature differentiation is provided, heat flow can be calculated by simply multiplying conductivity value which is related to temperature difference.

$$q = L\ .\delta T \tag{3}$$

L = surface conductivity value

δT = Temperature difference

With the assumption that the heat flow is constant, a formula as documented in DIN EN ISO10211: 2008-04 is therefore applied, as seen below:

$$q = \frac{(\theta - \theta_s)}{R_s} \tag{4}$$

q = Heat flow
θ = the inside or outside temperature
θ_s = the temperature of the interior or exterior surface
R_s =The interior or exterior heat transfer resistance.

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3. Materials and Methods

The main object of this research is *Yesus Maria Yosef Plamongan Indah* Catholic Church, picked specifically because this Church is currently assembling a masterplan to establish an independent parish (see figure 1). Preparations entail reassembling the Church building structure and establishing a masterplan to serve as a guide for future Church developments. This Church building is then documented and its walls calculated by using the *Psi-Therm* 7 software. Results of this simulation is then followed by the use of OTTV calculation to establish the existing value. Modelling is then done to acquire the most ideal OTTV value, so that the amount of heat that enters the building can be reduced [10].

Figure 1. Yesus Maria Yosef Plamongan Indah Catholic Church

4. Results and Discussion

Based on temperature measurements done to both inner and outer walls of The *Yesus Maria Yosef Plamongan Indah* Catholic Church, by using Lutron THM-934S, 2 channeled- digital thermometers as research objects, the results are as seen in figure 2. These measurements may prove very beneficial for coming up with a design for the structure, since they may help solve energy efficiency issues and improve protection designs, preventing outer-climate conditions from affecting the indoor temperatures.[11]

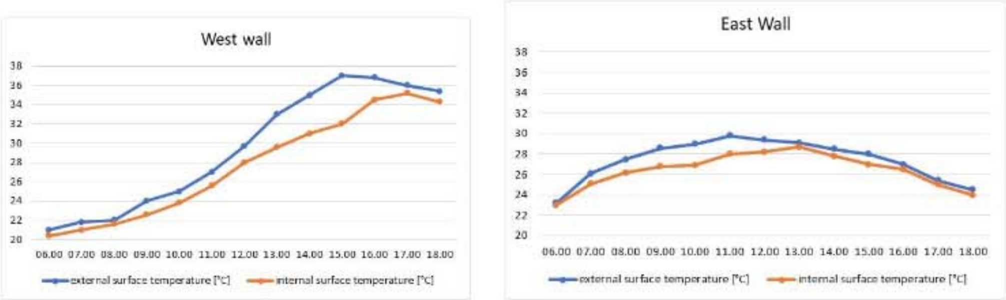

Figure 2. Internal & external Surface temperature of the East and West walls

According to these measurements, the minimum external surface temperature of the east wall is 23,2 °C at 06.00 am, and the maximum external surface temperature is 29,8 °C which occurs at 12.00 pm, while the minimum internal surface temperature of the east wall is 23 °C at 06.00 am and its maximum internal surface temperature is 28,7 °C at 1.00 pm. As for the west wall, the value of the minimum external surface temperature is 21 °C at 06.00 am and the maximum external surface temperature is 37 °C at 3.00 pm, while the minimum internal surface is 20,4 °C at 06.00 am and the maximum internal surface temperature is 35,2 °C at 5.00 pm.

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Upon deciding objects of which heat transfer is going to be observed by using the *Psi-Therm* software, two different surfaces are chosen: a windowed and windowless walls, each of which reside on the east and the west sides of the building respectively. (see figure 3).

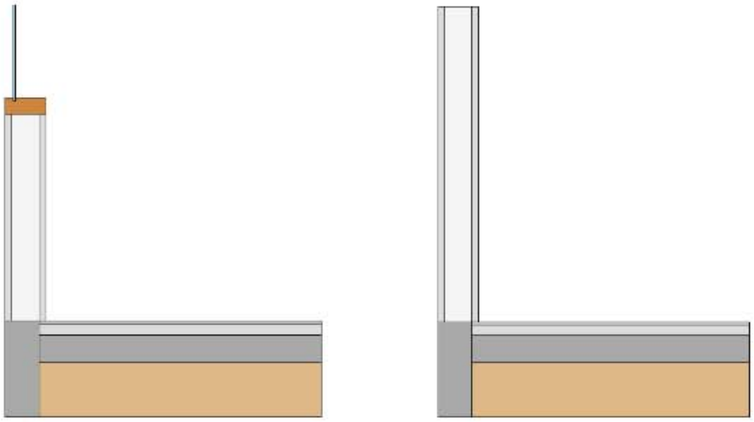
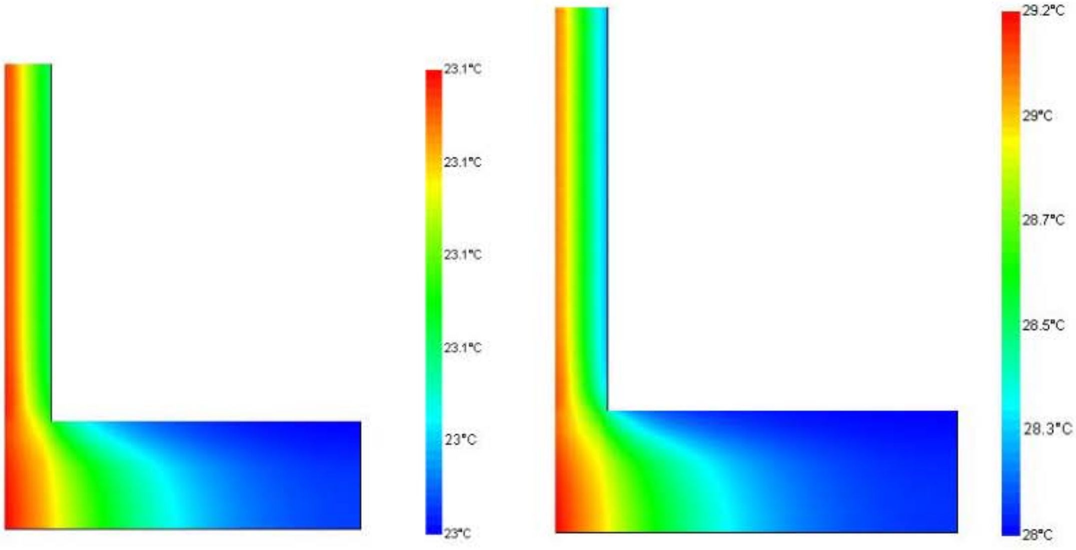


Figure 3. Observation Objects in Detail

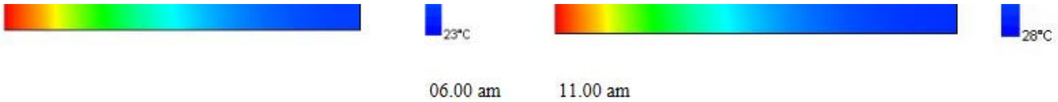
Using these two models, calculations are done by inserting each material's Thermal Resistance value in order to obtain a U_{value}. Upon these brick walls, external Surface temperatures on their minimum and maximum degrees are measured, which result in 23,2°C at 06.00 am and 29,8°C at 11.00 am. These data are then inserted to the *Psi Therm 7* software to calculate heat transfer and the chances of thermal Bridge occurring.[12] Calculation results are as seen in figure 4. Calculation results show that at 06.00 am, there is not a great difference between heat transfer values that occur on each external and internal surface temperatures, however at 11.00 pm it can be seen that the heat distribution on the external Surface is spread out more evenly and there occurs a heat storage which is then released at its peak at 1.00 pm.



06.00 am 11.00 am

Figure 4. Calculations of the East wall

Calculations done of the west wall show a heat shift which occurs when the external Surface temperature reaches its peak at 3.00 pm, this results in heat being distributed within the structure, consequentially rising the heat level throughout the space (see figure 5). However, since the west side consists of a considerably smaller area compared to the north and the south sides, the impact of heat level rise is not too significant inside the structure.[13]



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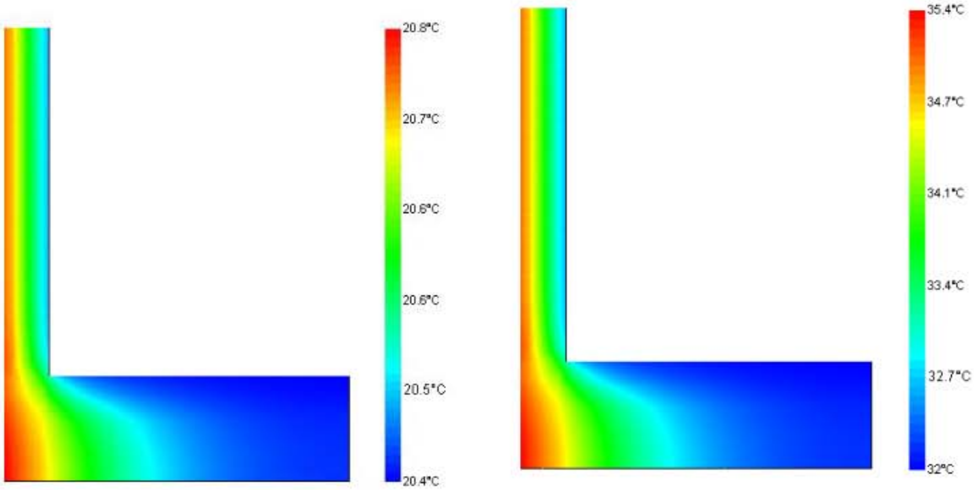
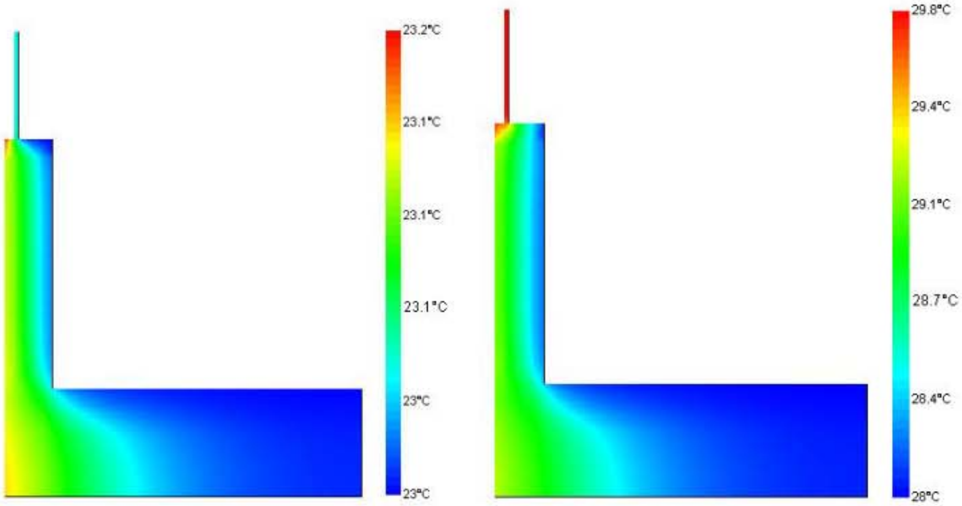


06.00 am 3.00 pm

Figure 5. Calculations of the West wall

On the west side of the wall there is a glass window (see figure 6), heat transfer is significantly dominant upon the glass surface, of which transfers heat expeditiously despite the glass in question being Dark Gray in color, with an R_{value} of 0,172 m^2K/W. Although this is a better choice compared to clear glass which possesses a mere R_{value} of 0,169 m^2K/W, heat transfer still abundantly occurs upon glass surfaces regardless, therefore shading needs to be done on the east side of the building. [14]



06.00 am 11.00 am

Figure 6. Calculations of the West Side of the wall

On the west side, heat transfer upon the glass surface becomes more dominant (see figure 7). The west side ought to be redesigned to utilize glass windows at its lowest capacity possible. The use of sun shading on the west side often does not guarantee the optimal minimization of heat entering the building. [15]

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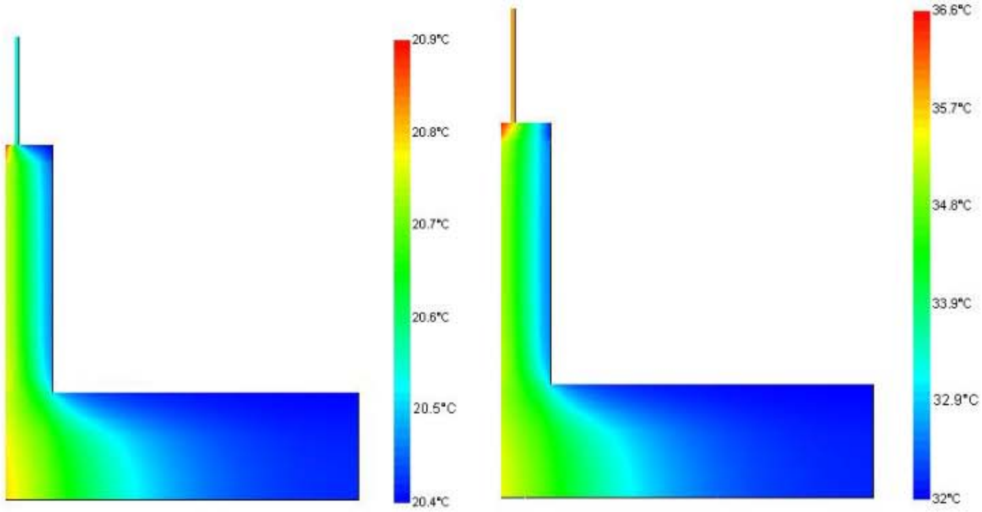

06.00 am 3.00 pm

Figure 7. Calculations of the West wall

The North and South walls were measured in correlation to the orbit of the sun. In the city of Semarang, which is located along the coordinates 6°58′S 110°25′E, the sun positioned itself on the South in December and North in June. The sun's angle of incline on both the North and South sides in correlation to the way it hit the walls resulted in small-valued angles of incline, which have already been repelled by the roof, rendering them insignificant in regards to the walls' heat transfer. Thus, the North and South sides of the walls were not taken into account in this research due to their miniscule contribution to the building's heat transfer calculations.

The modelling done on *Yesus Maria Yosef* Catholic Church building shows that Thermal Bridge does not occur because the door jambs of said building is made out of *Bengkirai* wood (see fig.3), which possesses the U_{value} of 2,174W/m^{2}K , significantly lower than the U_{value} of brick walls which is 2,850 W/m^{2}K. [17] To add, if Thermal Resistance were to be calculated, both materials amount to the R_{Wall} value of = 0,180 m^{2}K/W and R_{Frame} value of = 1,09 m^{2}K/W, which, when summed up using parallel resistance calculation, results in an R_{total} of = 0,154 m^{2}K/W, thus declining Thermal Resistance by 27%. The use of a glass window further declines Thermal Resistance of the surface to 43%. Therefore the west wall must come up with a design that minimizes the use of glass windows.[16,18]. Thermal Bridge is a phenomenon which occurs when different materials are used in a single building's façade. In the observed building, the façade was made out of a combination of brick walls and wooden frames. The wooden frame could function as a thermal bridge, however, due to wooden materials' good thermal isolation values in general, the thermal bridge became insignificant.

OTTV calculation done upon these two detailed models of the building above uses the approach as seen below:[11]

$$\boldsymbol{OTTV = \frac{(A_w \times U \times \Delta T_s)+(A_g \times U \times \Delta T)+(A_g \times I \times \theta)}{.}} \quad (5)$$

OTTV= OTTV as per ASHRAE.
① A_w= area of wall + area of glass in m^2
U = Transmittance value in W/m^2 K
ΔT_s= T_s–T_i=(T_o+ Ix a/ f_o) –T_i.
To = Outside air temperature in K
I = radiation intensity in W/ m^2.
a = absorbance of the surface.
f_o = Surface conductance outside in W/ m^2 K
T_i = inside air temperature in K
A_g= Area of glass in m^2.
ΔT = Difference between internal and external air temperature.
θ= solar gain factor of window glass.

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θ= solar gain factor of window glass.

Calculation results of observed objects are as displayed in table 1, 2 and 3 below:

Tabel 1: Wall and Door Conduction of *Yesus Maria Yosef* Catholic Church

Orientation	Construction	Area	TD_{eq}	U_{value}	α	Wall & Door Conduction
North	Wall	176,050	10	2,850	0,30	1505,2280
East	Wall	38,032	10	2,850	0,30	325,1736
South	Wall	176,050	10	2,850	0,30	1505,2280
West	Wall	48,330	10	2,850	0,30	413,2215
North	Door	15,750	15	2,174	0,88	451,9746
East	Door	9,000	15	2,174	0,88	258,2712
South	Door	15,750	15	2,174	0,88	451,9746
West	Door	4,670	15	2,174	0,88	134,0141
					Total	5045,0850

Calculations done on Wall and Door Conduction show that the North and South sides of the walls hold the highest values due to them being broader in length compared to the East and West sides. The wall and door of the West wall are in direct adjacent to a rice field, however, the door and window are both relatively small in size, resulting in most of sun radiation intensity being blocked by the brick wall. [19] The smaller Wall and Door Conduction values of the west side in comparison to the rest of the walls is beneficial for the OTTV value as a whole.

Table 2: Glass Conduction of *Yesus Maria Yosef* Catholic Church

Orientation	Construction	Area	ΔT	U_{value}	Glass Conduction
North	Window	28,200	5	5,8	817,800
East	Window	6,968	5	5,8	202,072
South	Window	28,200	5	5,8	817,800
West	Window	1,000	5	5,8	29,000
				Total	1866,672

To determine the U_{value} and Shading Coefficient (SC) of the glass, WINDOW 7.7 software— a software developed by *Lawrence Berkeley National Laboratory— is used*. This software is needed in order to calculate the total window thermal performance indices (i.e. U-values, solar heat gain coefficients, shading coefficients, and visible transmittances. [20]

Table 3: Glass Radiation of *Yesus Maria Yosef* Catholic Church

Orientation	Construction	Area	SC	SF	Glass Radiation
North	Window	28,200	0,59	143	2379,234
East	Window	6,968	0,59	155	637,2236
South	Window	28,200	0,59	98	1630,524
West	Window	1,000	0,59	167	98,530
				Total	4745,512

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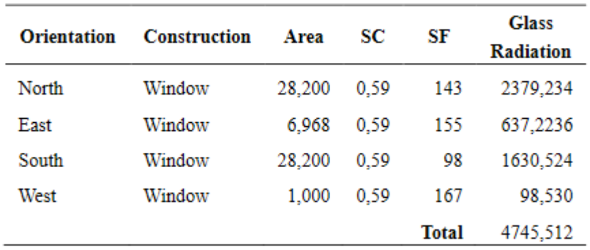

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On the West side of the wall, minimum use of a glass window proves beneficial for the final OTTV result for it is able to decrease the high Glass Radiation value caused by its Solar Factor (SF) multiplier being higher compared to the SFs of the North, East, and South walls. [10] *Yesus Maria Yosef* Church building's west side consist of mostly walls, hence minimizing the final OTTV value.

OTTV calculations done result in the North wall being 23,43 W/m^2, East wall being 26,33 W/m^2, South wall being 20,35 W/m^2 and West wall being 12,50 W/m^2 in values. The total OTTV value of *Yesus Maria Yosef* Catholic Church building is 21,272 W/m^2, which is still smaller than Indonesian regulations which require a minimum value of 35 W/m^2. Minimizing OTTV value will result in energy efficiency in the forms of energy cost reduction, improved occupant comfort and improved building operating performance. [21][22]

The results of this research were beneficial for *Yesus Maria Yosef* Church and may be beneficial for other church buildings in the future as well. Church planning oftentimes merely focus on spatial layouts and building facades, whilst the discourse on building physics gets ignored, as well as building acoustics; lack of acoustics planning would result in the need to add a sound system, which would typically be costly. Barring natural lighting considerations would also consequently lead to the installation of artificial lighting, which leads to massive energy consumption. Hence, thermal calculations as done in this research should be done, so that outdoor influences (in this case, high air temperatures in tropical climates) would not pose as a thermal burden which impacts energy consumption.

However, in current times, energy efficiency considerations are not yet a prioritized. A small church in an archdiocese can spend around Rp 6.000.000,- or 425 US$ (a hefty value, in comparison to the money collected from the congregation, which amount to Rp 1.500.000,- or 106US$ per week). Meanwhile, a big church building can spend a budget 3-4 times bigger than a small church does (Data was collected from the Annual Report of the Archdiocese of Semarang). These values are large for Indonesian standards, let alone for the Archdiocese of Semarang, which is situated in a small city. This research was specifically aimed to calculate heat transfer which occurred as well as OTTV calculations to serve as guidance for future church building planning in regards to energy efficiency, along with improving a building's quality. Based on research results, *Yesus Maria Yosef* Church proved to be an example of a good church building when energy efficiency was taken into account, moreover, it also showed adequate thermal calculations.

5. Conclusions

Yesus Maria Yosef Church building consists of East and West walls surfaces which are smaller in comparison to those of the North and South sides. This serves as a benefit on its own, attenuating efforts in design adjustments if it were to be done to the East and West walls while prohibiting high heat contribution from entering the building. Reduction of OTTV to under 35 W/m^2 must be done especially on the West wall due to its high Solar Factor value. The utilization of glass windows on both West and East sides must be reduced by design in order to minimize heat transfer from the outdoors to the building's interior.

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