Research Article

The Effects of Façade Design Change on the Heating and Airflow through the Building Skin of Universitas Multimedia Nusantara Tower 3

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Abstract
The design of an energy-efficient building is a complex undertaking, and these steps cannot just be performed in sequence; they are, in effect part of an iterative process that's starts with passive design. Trade-offs inevitably must be made, often because of the client's requirements and budget. Designed properly, a building with low energy and a low carbon footprint should provide greatly reduced operational costs for minimal or no increase in capital costs. The effects of design change on the completion time of Tower 3 Multimedia Nusantara University construction project is influenced by to the tower's skin. This skin is the main focus for owner in planning phase of the construction. This case is appealing to be studied further in analyzing the effects of design changes on façade which are related to heat and airflow on the building skin of Tower 3 Multimedia Nusantara University. From the discussion and recommendation, it is concluded that façade design pattern with 39% perforation as outer layer and window-wall of 13 cm thickness with 8 mm of windows give the optimum choice and the lowest operational cost.

Keywords: Heating, Airflow, Façade design, Canopy design, Building skin

1 Introduction

The design of an energy-efficient building is a complex undertaking, and these steps cannot just be performed in sequence; they are, in effect part of an iterative process that's starts with passive design. Trade-offs inevitably must be made, often because of the client's requirements and budget. Designed properly, a building with low energy and a low carbon footprint should provide greatly reduced operational costs for minimal or no increase in capital costs. In some cases, a well-executed passive design strategy can markedly reduce the costs of HVAC equipment due to the reduction in heating, cooling, ventilation, and lighting loads that can occur.

Passive design is the design of the building's heating, cooling, lighting, and ventilation systems, relying on sunlight, wind, vegetation, and other naturally occurring resources on the building site. He also said that passive design strategy has two major aspects: 1) the use of the building's location and site to reduce the building's energy profile and 2) the design of the building itself – its orientation, aspect ratio, massing, fenestration, ventilation paths, and other measures [1].

The heating, cooling, and lighting of buildings are accomplished by either adding or removing energy [2]. Energy-conscious design yields buildings that minimize the need for expensive, polluting, and nonrenewable energy. Because of the benefit to the planet earth, such design is now called sustainable, green, or low-carbon. Sustainable design includes a

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large set of issues, and the energy issues are a larger subset thereof. The solar issues are a much larger subset of the energy issues than most people realize. One reason for this is that 'solar' refers to many strategies: passive solar, active solar, photovoltaics, daylighting, and shading. Although shading is the reverse of collecting solar energy, it is one of the most important solar design strategies, because it can save large amounts of air-conditioning energy at low cost. Because heating, cooling, and lighting are major energy users, and because they are all heavily impacted by the sun, a building cannot be sustainable unless they are solar responsive.

Setiawan *et al*. (2019), mentioned that the effects of design change on the completion time of Tower 3 Multimedia Nusantara University construction project that discuss on the design discrepancies that occurred continuously and significantly on the project, is influenced by to the tower's skin [3]. This skin is the main focus for owner in planning phase of the construction. This case is appealing to be studied further in analyzing the effects of design changes on façade which are related to heat and airflow on the building skin of Tower 3 Multimedia Nusantara University.

2 Literature Review

2.1 *Exterior wall*

Exterior wall is the exterior side of a wall, that is a part of the building itself that has a function to protect the inner room from any kind of disturbance that is caused by water, air, sunlight, heat, cool, and all nature power [4]. The primary purpose of exterior wall is to separate the inner and outer environment so the environment condition in the inside can be maintained at a certain level as the main function of the building uses.

There are some systems that are used in exterior wall in construction world, one of those is curtain wall. The concept then introduced as exterior wall which is supported on every floor level by using framework. One benefit of curtain wall is that curtain wall does not bear vertical load, so it can be constructed in thin and light form. Some types of curtain wall are masonry curtain wall, and metal-window curtain wall [4].

2.2 *Exterior wall related to heating, lighting, and cooling*

Heating in a room discuss about efficient thermal protection to minimize heat loss. The main factors of heat loss are transmission, infiltration, and ventilation. For those factors, it is needed heat gain that can recover thermal loss so thermal comfort can be attained. Internal domination building has a lot of heat that is produced from human, lighting, electronic devices, or the combination of those [2]. Although some designers believe that each façade should look the same, that belief is non-sustainable, and of dubious aesthetic validity. The ideal design would have only south and north windows, and no east and west windows [5]. When that is no possible, the number of east and west windows should be minimized. The formula of heat gain in this research uses formula from SNI 03-6389-2000.

Lighting in a room generally gained from top hole (ceiling), and/or from side hole (wall). Practically, those holes have so many variants that depends on the function and the shape of existence building. Even though, building perforation for natural sun light affected on glare, so choosing transparent material for covering the hole, like windows or other materials, are important to reduce the glare itself [5]. One purpose of natural lighting is to gain visual comfort. This visual comfort can be obtained from optimization of natural lighting usage and using a precise perforation design, then the natural light can be obtained as visual working need [6], [7]. According to Standard Nasional Indonesia (SNI) 03-6575-2001, the minimum level of lighting that is recommended for classroom is 250 lux.

The relation of cooling through exterior wall refers to natural air. In natural air, there are wind and ventilation term. Wind is a moving air that happens in the atmosphere while ventilation is defined as air provision or air changes in a room. The aim of ventilation is the get fresh air (health ventilation), thermal comfort (comfort ventilation), and building interior cooling (structural ventilation) [6], [7]. To achieve those, air movement is needed. Air can move if there is a pressure different in the building and its surrounding and therefore good air circulation is needed [2].

2.3 *Exterior wall related to sound and noise*

Sound is sensation caused by vibration of one object that generate some friction with surrounding substance and pass through ears. There are two type of sound characters, desired sound like conversation and undesired sound like traffic loud or crowd [5]. Undesired sound can happen and can be heard because they have intention that cannot be tolerated by people, afflict desired sound, and have uncommon frequency that occurred all the time [6].

Noise may come either from the inside or the outside of a building. In Indonesia, most noise disturbance are caused by the sound of vehicles. To overcome those, it can be done by constructing podium or façade. Those structure can be a barrier for a building against the noise. To construct them, a specific design must be done so the building can overcome the outside noise. For the façade that facing directly to the source of noise can have some level of perforation [7]. For a building that has nature ventilation for main system, the ventilation hole is designed specifically so the airflow function still working [5].

3 Research Methodology

This research uses descriptive method which is a method to describe or explain data or observation result. Those data are then analyzed with qualitative method that refers to Miles and Huberman theory. They stated that activities in qualitative data analyzing are done in interactive and continuous process until the research is complete [8].

The research is conducted initially by studying the types of materials that are suitable for the building skin. The building skin is selected based on the operational cost, where the operational cost is calculated based on the requirement of the total energy by varying the perforation, Window to Wall Ratio, and window material.

4 Results and Discussion

4.1 *The description of the project*

This research is conducted at Tower 3 Multimedia Nusantara University project in Serpong, Tangerang. The tower is used for education and its support. The total area of the university is ± 80.000 m^2. This project consists of 2 main buildings, a podium (1 semi basement and 3 stories) and a tower from 4th floor up to 18th floor, 1 mezzanine story, and 1 roof top. The total area of the site is ± 7575 m^2 and the total area of the building is ± 45.642 m^2. The principal-project sum contract is about two hundred billion rupiahs. Setiawan *et al*. (2019), mentioned that the design changes happened in five scope of works, those are the work of façade, the work of steel for canopy podium, the work of landscape, the work of mechanical electrical, and the work of structure architecture plumbing. The total approved design changes are Rp19.894.157.361,47. (9,95% to the principal project contract) [3], [9]. This tower has double layer façade, with aluminum perforated sheets and window-wall with 13 cm of wall and 8mm of windows [10], [11].

4.2 *The work of façade*

There are two layers of façade at Tower 3 Multimedia Nusantara University, aluminum perforated sheets as outer layer and window-wall of 13 cm thickness with 8 mm of windows. These windows cover 20% of Window to Wall Ratio (WWR). Meanwhile the aluminum perforated sheets have different variation of perforation size from 32% up to 65% and have 39% of average. These perforations have objective to deliver the sunlight from outside to inner room and as a shade for decreasing heat gain to the building. The outer layer is one meter from the inner layer. These perforations form can be seen in the Figure 1.

The circular perforation form has two difference size, those are of 225 mm and 30 mm. The total volume from the work of façade is about 12,995.64 m^2. The specified amount of panels for each perforated form are show in Table 1.

Table 1: Amount of circle perforated form aluminum panel

Type of Perforation	Diameter	Total Sheets
Big Perforation	255 mm	2322 pieces
Small Perforation	30 mm	8103 pieces
TOTAL		**10425 pieces**

For the façade design pattern can be seen in the Figure 2.

This tower building is not fully covered. It can be seen in Figure 3 that west side and east side of the building have empty space for airflow to pass through. However, these west and east sides are still covered by

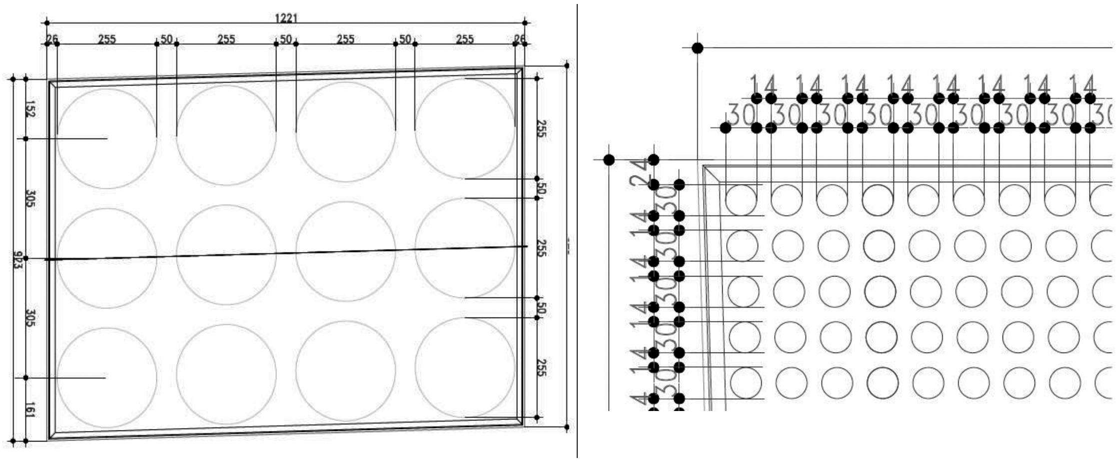

Figure 1: Circular perforated form of façade design.

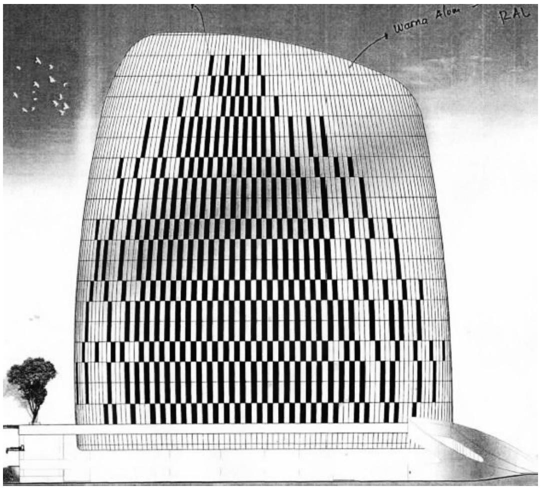

Figure 2: Façade Pattern Design.

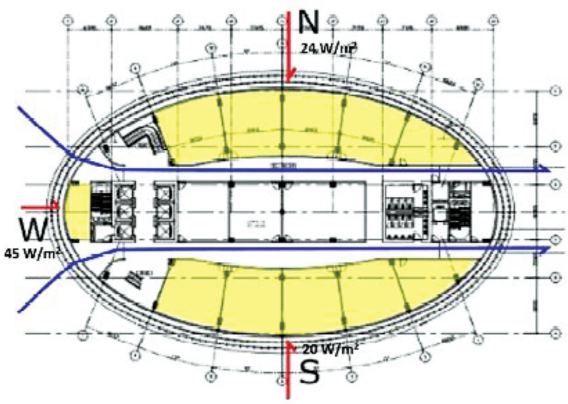

Figure 3: Heat gain direction to building façade.

aluminum perforated sheets. Using this kind of design can reduce the corridor temperature by nature ventilation so special cooling system are not needed in the area.

Façade design simulation can be used to evaluate the building performance that is related to heat gain and natural light penetration. Some modifications are also considered to optimize perforation design to get lower heat gain but sufficient for natural light penetration. The simulation is focused on the area that is using special cooling system and directly adjacent to classroom at north side and south side also a discussion room at west side. These areas have some level of heat gain that passing through façade into the room and causing cooling load to increase. At the same time there are natural light penetration that can reduce electricity and artificial lighting needs. Since the tower is not fully covered, Overall Thermal Transfer Value cannot be used as parameter to determine the façade thermal performance. Total heat gain can only be calculated from façade and cannot consider others heat gain source from electricity, number of people, ventilation, or infiltration.

The position of window to window need to be cultivated at north and south side and avoid west side [5]. From the information in the field, the building orientation fits to the theory. The number of heat gain are 23 W/m^2 from north side, 20 W/m^2 from south side and 42 W/m^2 from west side. These number are considered as low except the west side. However, if there is no outer layer of façade, the heat gain can

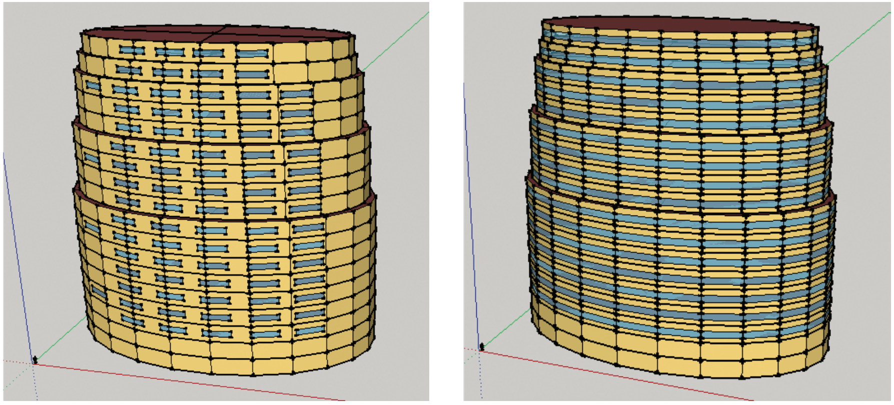

Figure 4: UMN 3 Tower Building Model with 20% WWR (left) and 40% WWR (right).

increase up to 56 W/m^2 from west side. The heat gain can be seen in Figure 3.

The lower total of heat gain from building façade that were obtained by using perforated sheet is 44.5 kW. This number is equivalent to cooling load reduction for about 12.6 ton of Refrigeration (a unit of power used in North America to describe the heat-extraction capacity of refrigeration equipment). Besides, the average of natural light availability in classroom at north and west side are considered high, which are 70% of total area. This thing describes that in some parts of classroom still need additional lighting.

In that simulation, there are some various parameter that can be changed to get a better building façade performance. Those are WWR and window-material. This performance test is conducted in every parameter and is compared to the existence design. The smallest perforation in existence design is 32% and is compared to the average perforation of 39%. The duration of lighting power is nine hours per day. The result of simulation and calculation of heat gain and natural light are shown in the Table 2.

In Table 2 above, the number of heat gain reduction is about 2 TR from building façade. Meanwhile, the total addition electricity power for lighting caused by the natural light reduction is 8.5 kW.

The existence design has WWR that is considered low, that is 20%. Therefore, it will be compared with higher WWR, that is 40%. The comparison of this tower building with 20% WWR and 40% WWR are shown in Figure 4.

The result of simulation and calculation of heat gain and natural light penetration from both designs can be seen in Table 3.

Table 2: Heat gain and natural light penetration comparison at 39% and 32% perforation

Perforation	Heat Gain (W/m^2)			Total Heat Gain (TR)	Natural Light Penetration Average $sDA_{250,70}$	Total Power for Lighting (kW)
	North	South	West			
39%	23	20	42	39	70	50.34
32%	22	19	41	37	54	58.83

Notes: W/m^2 = Watts per square meter
TR = Ton of Refrigeration
sDA = spatial Daylight Autonomy
sDA 250,70 = 54%; 54% area of floor at least has 250 Lux of natural light in 70% range of operational time of a year.
kW = kiloWatt

Table 3: Heat gain and natural light penetration comparison at 20% WWR and 40% WWR

WWR	Heat Gain (W/m^2)			Total Heat Gain (TR)	Natural Light Penetration Average $sDA_{250,70}$	Total Power for Lighting (kW)
	North	South	West			
20%	23	20	42	39	70	50.34
40%	43	36	76	72	76	43.29

The number of heat gain at 40% WWR is increase up to two times the number at 20% WWR. This number is equivalent with cooling load enhancement for 33 TR. The natural light availability also increases so the electricity power used for lighting is reduced for 7 kW.

Natural light availability always proportional with the number of heat gained from building façade. As the natural light increases, the number of heat gain also increases through the windows. The use of tint-window with low e-value and high Visible Light Transmittance (VLT) value, optimum performance can be achieved. In this part, the existence design for perforation is 39%, with 40% WWR, and 8 mm of clear window is compared to the same design with tint windows in addition. The result of simulation and calculation of heat gain and natural light from this design are shown in Table 4.

The number of heat gain is significantly decreased by using tint-windows. Heat gain that enter the room is considered low except from west side. Tint-window can reduce the total heat gain for 21 TR. By using tint-window in addition, the natural light availability in that room is decreased so the electricity power is increased for 5.5 kW.

From the air circulation aspect, when the wind blows to the building, there is air pressure that made at the building surface and some of the air pressure is deflected [12]. Those airflow changes from laminar to turbulent when it encounters sharp obstructions. And these currents are circular airflows induced by laminar airflows. In concrete material, the airflow will gradually change from laminer into turbulance because the airflow is hindered and cause swirl. Swirl airflow is caused by laminer or turbulent. as air hits the windward side of building, it compresses and creates positive pressure. At the same time, air is sucked away from the leeward side, creating negative pressure.

Meanwhile, in steel and aluminum perforated material, that wind that hit the building surface will solid-field and become positive pressure. However, at the same time, the wind will be sucked from those sides that are not hit by the wind, in this case, the perforation side. So, it become the negative pressure. These pressure areas around the building determine how air flows through the building. The difference in wind pressure makes the wind flow [2]. The illustration about airflow is shown in Figures 5 and 6.

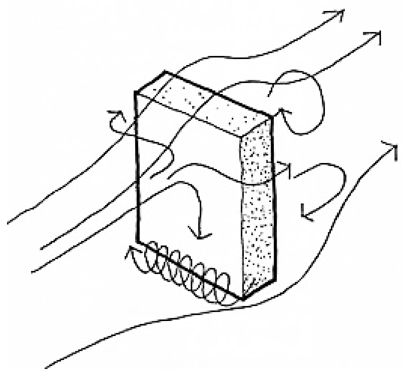

Figure 5: Air flow illustration at solid material [12].

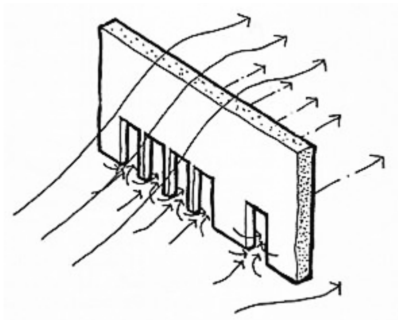

Figure 6: Air flow illustration at perforated material [12].

5 Conclusions

Performance test has been done at some parameters, those are panel perforation, WWR, and different designs of window material, and it is obtained that the percent number of panel perforation is more affecting the number of natural light penetration to the building. It is understood that the panel holds function as shading that cover the window area. Because of that, the smaller the perforation, the lesser the sun light can

Table 4: Heat gain and natural light penetration comparison from clear window and tint window

Window Material	Heat Gain (W/m^2)			Total Heat Gain (TR)	Natural Light Penetration Average $sDA_{250,70}$	Total Power for Lighting (kW)
	North	South	West			
Clear Window	43	36	76	72	76	43.29
Tint Window, VLT 70%	30	26	49	51	66	48.79

penetrate directly to the room. On the other hand, the proportion of WWR is highly affecting the number of heat gain that pass through the building façade. Using tint-windows in addition affect the heat gain and natural light. However, it also increases cost in investment. In other words, changing WWR proportion is more effective to reduce heat gain that pass through the building than adding tint-windows.

Table 5 shows all analysis of design parameter variation summary. It can be seen that the total heat gain is inversely proportional with the electricity power additional load for lighting. When the total heat gain reaches the lowest number, the number of electricity power additional load is increase, and vice versa. Beyond the total heat gain and natural light availability aspect that analyzed, existence design of building façade is equipped with natural ventilation that can drain the wind at corridor area, so it minimizes the cooling load in the building.

Completing those four variations analysis of parameters above, the calculation of annual operational cost is conducted for cooling and lighting systems that is inflicted by façade. Cooling operational cost is done by observing the number of cooling load gained from building façade. The electricity power that is needed to produce those cooling loads is calculated by multiplying with efficiency factor from cooling system. The efficiency system number that used is 0.8 kW/TR (equals to efficiency system number for chiller in common). This building are operated for 9 hours/day for 6 days/week for a year.

Lighting operational cost is calculated by observing the amount of natural light that available along the operational duration hours. Lamp is turned on when the light does not meet the condition to give illumination as needed for 250 lux (equals to required illumination in classroom from SNI) [13], [14]. The amount of electricity power for lighting each classroom can ben counted by the area of room with the assumption of Lighting Power Density (LPD) for 10 W/m^2 (according to the standard of The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) 90.1–2007 for Light-Emitting Diode (LED) type of lamp in classroom). The position of classroom each level can be seen in Figure 7.

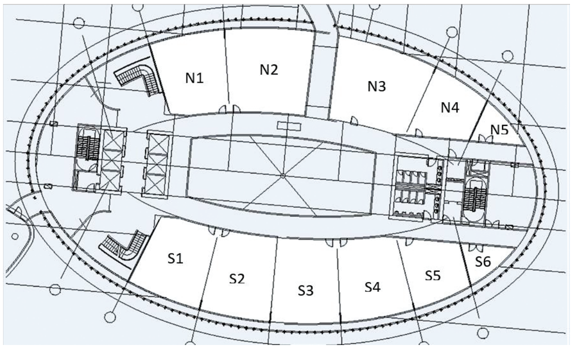

Figure 7: Position of classroom.

The use of panel perforated produce cooling load reduction from façade for 12.6 TR compared to the building without panel. This value is equivalent with 25% of façade cooling load at the building with no panel. Perforated panel also gives additional benefit that is to maintain visual comfort for occupant and reduces glare, also it can give natural ventilation to corridor area thermally. Cooling operational and annual lighting cost comparison that inflicted by façade can be seen in Table 6.

Those operational cost above came from cooling component and artificial lighting that is caused by building façade, not operational cost system in total.

It can be concluded from Table 6 that the artificial lighting requirements are proportional to the magnitude of the cooling load. In order for the

Table 5: Summary rating recapitulation analysis of parameter design variation

Perforation	Heat Gain (W/m^2)			Total Heat Gain (TR)	Natural Light Penetration Average $sDA_{250,70}$	Total Power for Lighting (kW)
	North	South	West			
39%, WWR 20%, Clear Window (existing design)	23	20	42	39	70	50.34
32%, WWR 20%, Clear Window	22	19	41	37	54	58.83
39%, WWR 40%, Clear Window	43	36	76	72	76	43.29
39%, WWR 40%, tint window VLT 70%	30	26	49	51	66	48.79

Table 6: Cooling operational and annual lighting cost comparison that inflicted by façade

Parameter Design Variation	Cooling Operational Cost (Rupiah/year)	Lighting Operational Cost (Rupiah/year)	Total Operational Cost (Rupiah/year)
39%, WWR 20%, Clear Window (existing design)	126,435,490	204,166,300	330,601,790
32%, WWR 20%, Clear Window	121,378,070	238,617,600	359,995,670
39%, WWR 40%, Clear Window	233,203,236	175,568,900	408,772,136
39%, WWR 40%, tint window VLT 70%	164,085,169	197,889,900	361,975,069

building skin to produce sufficient natural lighting, large window openings are needed, which then causes a greater cooling load. Conversely if the cooling load is made low by reducing window openings, the natural light received will also decrease resulting in increased artificial light requirements.

To get the analysis of total operational cost, details evaluation related to cooling and lighting needs to be done.

Other benefits factor from using panel as building façade allows for opening in inner wall (west side and east side) that makes the wind to flow from west side to east side and vice versa. It gives natural ventilation to the corridor area and can reduce the capacity of air conditioning system generally in the building.

The effect of noise, noise can be muted by blocking the ways of sound, one of the way is to control the opening perforation of building façade [8]. In this project, the opening of façade is minimized by changing the size and form of perforation. When it was using rectangular form, 32% of perforation number was obtained for small type perforation, 37.5% for medium type, and 64.7% for large type. These percentage was the comparison of the area of opening to the area a one whole panel. So, the average number of perforation is 39.7%. Meanwhile, using circle form of perforation, 31.6% of perforation number is obtained for small type and 50.8% for large type. So, the average number of perforation for circle form is 35.9%. The number in average decrease for almost 4%.

The percentage value of change order in the project execution phase does not affect the completion time from the master schedule [3]. However, there are some factors that changed the project completion time, that was design discrepancies of façade and canopy that required owner's decision in selecting material and the effect to the energy in general of this UMN3 tower building.

In the work of façade, the most affecting aspect are heating, lighting, and noise. Other aspect that have influence is air circulation aspect. From the result of interview with the owner of the project, it turns out that the owner gives priority in three aspects of selecting façade design, those are heating, cooling, and lighting.

From the discussion that has been done, it is concluded that:

a) Panel perforation design in UMN 3 tower, consisting of aluminum perforated sheets 39% and window-wall with 13 cm of wall and 8mm of windows is optimum with the heat gain total 39 TR that considered low and good natural light availability.

b) Using this panel perforation design provides the lowest operating costs.

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