Doctoral Dissertation

The Effect of L-Shaped Mini-Louvers for Building Facades on Indoor Environment and Cost in Hot and Humid Areas

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Preface

This is the exploration about the dark side of the designs, the function of the shadow in Architecture in dealing with the energy consumption in buildings.

This is the part of the journey of seeking the balance between dark and light.

勝利を得る者は、これらのものを受け継ぐであろう。わたしは彼の神となり、彼はわたしの子となる。
ヨハネの黙示録 21:7

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Abstract

The problem of cooling energy consumption growth occurs globally, but much worse in hot regions which have driving factors such as population and economic growth, technological advances, and climate changes. Indonesia is one of the area which show significant increase of cooling energy demands. It is a tropical country which needs cooling energy all year round. Indonesia is the fourth most populous country in the world with more than half of the population live in the city. Indonesia has positive economic growth rate accompanied by increasing of gross national income per capita. Indonesia used 36% of primary energy in Southeast Asia, the largest energy consumption country in that region.

Focusing on Jakarta, Indonesia's capital city, proposed shading devices were simulated using Rhinoceros and Grasshopper with EnergyPlus to show their performance for providing shadow, to improve daylight and reduce cooling energy consumption. The shading design is inspired by traditional Japanese koshi, but using modern L-shaped aluminum profiles as mini-louvers. The L-shaped mini-louvers design is simple, using ready and widely available raw materials. The construction is easy, requires no specific technical skills. The L-shaped mini-louvers can be placed at the outdoor surface of glass window or attached on the window frame. Since it is from aluminum, the L-shaped mini-louvers is lightweight and need no maintenance.

The environmental benefit is obtained from improving daylight condition and saving the cooling energy used. Using a simple box building, several simulations were executed. Attaching L-shaped mini-louvers at the window in one side of the wall can lead the Useful Daylight Illuminance (UDI) to be more than 90. Even when there were four windows in every side of the walls, a combination strategy by modifying window size and attaching L-shaped mini-louvers can optimize the UDI to be 100. Residential and open-office setting were used for simulating annual cooling energy consumption. The star-rated air conditioning unit, which complies with the official government's law was used for monetizing the cooling energy consumption to calculate the annual electric saving. The comparison between electric saving and application cost shows the simple payback period of the simulated sun shadings. The application cost includes price of the sun shading construction, and attachment elements. L-shaped mini-louvers attachment in the exterior surface of the window cut around 7%-12% while placing them on the window frame reduce 9%-18% of cooling energy consumptions in average of all orientations for residential. Using 15 mm × 15 mm L-shaped mini-louvers on the window frame for office can cut 17%-29% of cooling energy consumption in average of all orientation. Moreover, placing the 15 mm × 15 mm L-shaped mini-louvers in the east and west can meet the simple payback period less than a year in both residential and office.

Keywords: daylight, cooling energy, simulation, L-shaped mini-louvers, simple payback period

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Chapter 1 – Introduction

1. 1. Cooling energy

In the past, energy for cooling was only a small part of global energy consumptions. Recently, cooling energy use increase significantly. According to the International Energy Agency (IEA) in their reports (2017), there were five factors that drive the growth of cooling energy[1]. Wealth was the first factor. People wanted to achieve indoor comfort condition by using mechanical air-conditioning devices. Rising incomes made people able to afford the use of air-conditioning unit. The price of air-conditioning machines became cheaper too, make them more accessible to the people. Many countries, especially in the emerging economic countries, had a high population growth, which was the second factor. The population increased in developing countries which have warmer temperature. The needs of cooling energy in the warmer area were higher than in the cooler locations. Moreover, there were area where cooling energy was needed all year round since they had a relatively high average temperature. The IEA also highlighted the movement of people in the same country from colder to warmer area. Other than occasional movement of the people during specific period of cold weather, there was urbanization, a more permanent movement of the people from rural to the urban area. The United Nations specifically noted that urbanization is a global phenomenon[2], which happened all over the world. Cities already faced the problem of urban heat island. It made the urban area usually had higher temperatures than the rural[3]. Higher temperature required more cooling energy. The condition was worsen by the third factor, the climate. Climate change happened and had impact globally. Gore (2006)[4] presented the earth condition in his book An Inconvenient Truth. He predicted the condition in the near future in the world as climate change effects, including the use of energy, notably the possibilities of significantly higher cooling energy as a result of higher temperature. In 2017, Gore published "An Inconvenient Sequel" as a proof of his prediction in his previous book[5]. He highlighted the effort that have been done and urged people to act more to deal with the climate change. He made several notes related to the cooling energy in buildings.

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[1] The International Energy Agency (2017). Space Cooling Energy Insight Brief. Retrieved from https://www.iea.org/publications/freepublications/publication/SpaceCoolingEnergyEfficiencyInsightsBrief.pdf. Accessed October 6, 2019

[2] https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html. Accessed October 6, 2019

[3] https://www.smithsonianmag.com/science-nature/city-hotter-countryside-urban-heat-island-science-180951985/. Accessed October 6, 2019

[4] Gore A (2006) An inconvenient truth: The planetary emergency of global warming and what we can do about it. Rodale

[5] Gore A (2017) An inconvenient sequel: Truth to power. Rodale

Climate change drove global temperature continue to rise and increased average and peak temperature during extreme weather period. There were more extreme temperature frequency as an effect of urban heat island phenomena and climate change. According to the IEA (2018)[6] projections, the average of cooling degree days increased. More cooling degree days mean more cooling energy is needed to keep the comfort zone in the indoor area to support people activities. Other than trends in economic and environmental, there was another trend in building lifestyle. The fourth factor, building designs, gave higher impact on cooling energy consumption. The choice of building materials, for example less new buildings utilize heavy materials such as brick, shifting to lighter materials with less thermal mass, increased cooling energy. The change of space-use design, for example porches and courtyards and less passive cooling design also drove higher cooling energy consumption. Building aesthetic, such as full glass façade and hidden air conditioning lead to higher cooling energy. Last factor that lead higher cooling energy consumption was electronic appliances. Growth in electronic tools, devices, and office machinery inside buildings produced heat as a by-product.

According to the IEA (2018) final energy use in the world in buildings and appliances increased by 21% reaching 120 EJ from the year 2000 and 2017[7]. In the same report, the IEA specifically noted that space cooling has large portion of energy demands and residential buildings utilized energy three times higher than the energy spent by end-uses in non-residential buildings in 2017. The expansion of air conditioning units use pushed the energy used for space cooling, make it increased almost two times since 2000[8]. According to the IEA (2018), cooling energy consumption was the fastest growing energy end-use in buildings, globally increased from 3.6 EJ in 2000 to 7 EJ in 2017. World energy use growth in buildings had been largely pushed by the six major emerging economy countries: Brazil, China, India, Indonesia, Mexico, and South Africa (the IEA, 2018). The IEA (2018) noted that these six countries account for one-third of world primary energy demand, equivalent to the energy demand of all Europe and the United States[9]. In Southeast Asia itself, the energy use increased by 60% in the past 15 years[10]. Electricity defined the biggest portion of the growth in final consumption, as increasing incomes in this area turns into higher ownership of

[6] The International Energy Agency (2018) The Future of cooling. p58
[7] The International Energy Agency (2018) Market Report Series Energy Efficiency 2018: Analysis and Outlook to 2040. p81. Retrieved from https://doi.org/10.1787/9789264024304-en
[8] The International Energy Agency (2018) Market Report Series Energy Efficiency 2018: Analysis and Outlook to 2040. p82. Retrieved from https://doi.org/10.1787/9789264024304-en
[9] The International Energy Agency (2018) Market Report Series Energy Efficiency 2018: Analysis and Outlook to 2040. P138. Retrieved from https://doi.org/10.1787/9789264024304-en
[10] The International Energy Agency (2019) Southeast Asia Energy Outlook 2019. p1

electronic devices and growing demand of cooling. Two thirds of increasing Southeast Asia's electricity demand occured from the residential and services sectors, because of the increasing urban middle class[11]. The IEA (2019) reported less than 10% household in Indonesia using air conditioning in comparison with around 80% household in wealthier countries with less challenging climate. However, the IEA (2019) also noted that the use of air conditioning become higher because of the rise of income and urbanization. Higher income made air conditioning units more affordable. Since temperatures tend to be higher in urban area, the demand for cooling would be emphasized by urbanization. There was an ongoing significant change of the use of electrical air-conditioning units.

Building designs, orientation, and the use of shading are strategies for dealing with hot condition to keep the buildings cool. However, recently, the use of air-conditioning device increased all over the world. The use of air-conditioning system was relatively new, since the invention of electrical air-condition at the beginning of the 20th century. The use of air-conditioning itself began in the 1950's in the United States. Then it spread all over the world. On the other hand, the mechanical air-conditioning devices production grew. It made the air-conditioning devices widely available. The electrical air-conditioning units were vary in size and price, from the small, even a portable ones to the large and permanent, from the simple to more complicated and complex system. The use of air-conditioning devices were also varied, from mobile vehicle to static buildings. In buildings, the air-conditioning was used from small rooms to large building complexes and even to the city scale. The vast majority of the use of mechanical air-conditioning taok place in urban area, both in the developed and developing countries.

The data from the IEA[12] of mechanical air-conditioning showed the steady sales of air-conditioning. By the end of 2016, approximately 1.6 billion air-conditioning were in use with roughly 11,675 giga watts of capacity. The data are shown in the table 1.1. The cooling output in the end of 2016 was more than double in comparison with only 4,000 giga watts in 1990 (figure 1.1). More than half air-conditioning used were in residential. The increasing use of air-conditioning units in residential drive up the total stock of units and global cooling capacity.

[11] The International Energy Agency (2019) Southeast Asia Energy Outlook 2019. p12
[12] The International Energy Agency (2018) The Future of cooling. p16

Table 1. 1. Air-conditioning units and cooling capacity by country/region by the end of 2016. Source: The Future of Cooling p19.

	Installed stock						Annual sales					
	Million units			GW output capacity			Million units			GW output capacity		
	Res	Com	Total	Res	Com	Total	Res	Com	Total	Res	Com	Total
United States	241	132	374	2295	2430	4726	16	8	24	314	129	443
European Union	43	53	97	192	654	847	9	3	12	34	41	75
Japan	116	33	148	407	352	759	9	2	11	47	14	61
Korea	30	29	59	129	220	348	2	2	4	19	15	34
Mexico	7	9	16	40	65	105	1	1	2	5	6	10
China	432	138	569	2092	807	2899	41	12	53	305	81	386
India	14	13	27	77	72	149	3	2	4	14	12	25
Indonesia	7	5	12	32	27	59	1	1	2	5	4	9
Brazil	14	14	27	59	68	127	1	0.3	1	5	1.4	6
South Africa	1	1	3	6	15	22	0.1	0.1	0.3	0.9	1.1	2.1
Middle East	30	18	47	147	153	299	4	2	6	29	16	45
World	1093	529	1622	6181	5491	11673	94	40	135	848	359	1207

Notes: Res = residential; Com = commercial; the data on air-conditioning capacity and units shown in this reports, unless otherwise noted, include residential and commercial systems, including packaged and split units, chillers and other large space-cooling

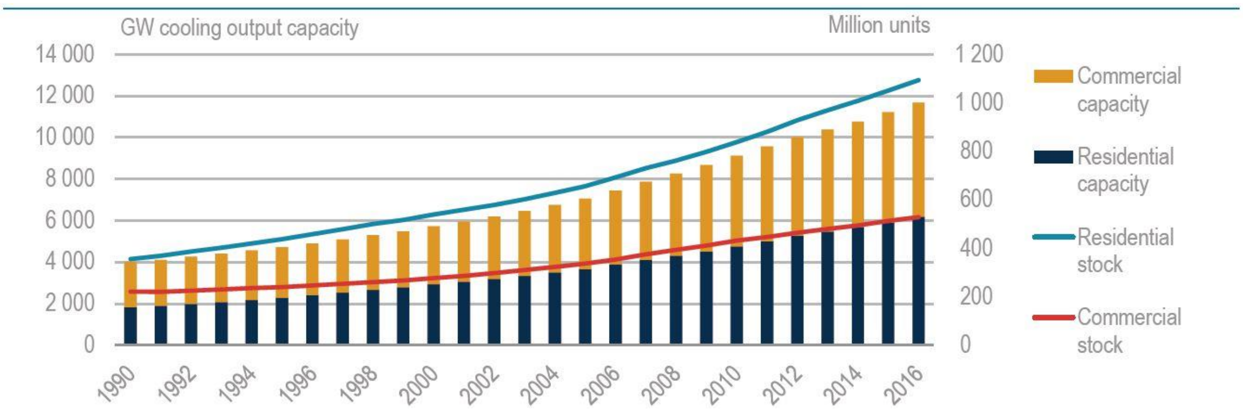

Figure 1. 1. Worldwide stock and capacity of air-conditioning by sector. Source: The Future of Cooling p20.

The available stock of and the sales of air-conditioning in different countries were varied. The IEA noted that the difference is a results of climate, population, and prosperity. Even the amount of installed air-conditioning in the United States was highest at around 50%

of the world, the sales was declining. Reversed condition occured in other countries, especially in Asian countries. The highest sales of the air-conditioning in 2016 happened in China. The detailed situation can be seen in figure 1.2. In this report the IEA specifically noted that the trend of using mechanical air-conditioning continues to grow rapidly in other markets, notably in India, Indonesia, and Middle East.

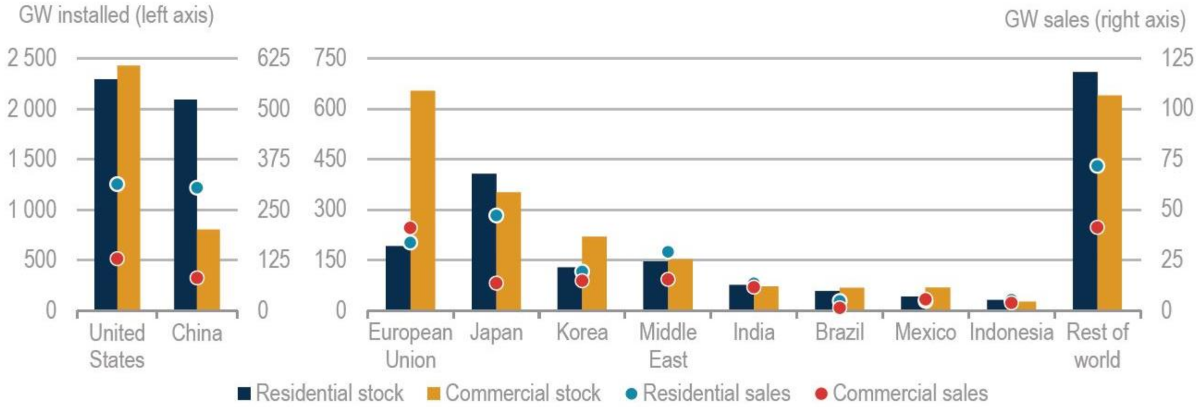

Figure 1. 2. Aggregate of the air-conditioning cooling output capacity and sales by country/ region in 2016.

Source: The Future of Cooling p20.

Figure 1.3 shows the air-conditioning sales per capita in every country by the end of 2016. Japan, the United States, Korea and China had significantly higher air-conditioning unit sales per capita. The highest sales for household air-conditioning units was still hold by these countries and regions: China, the United States, Japan, and the European Union. Residential in China still lead the total unit sales of air-conditioning in comparison with other countries in the world in 2016. However, the IEA noted that the number of air-conditioning selling rates were rising, especially of those emerging economic countries in Asia.

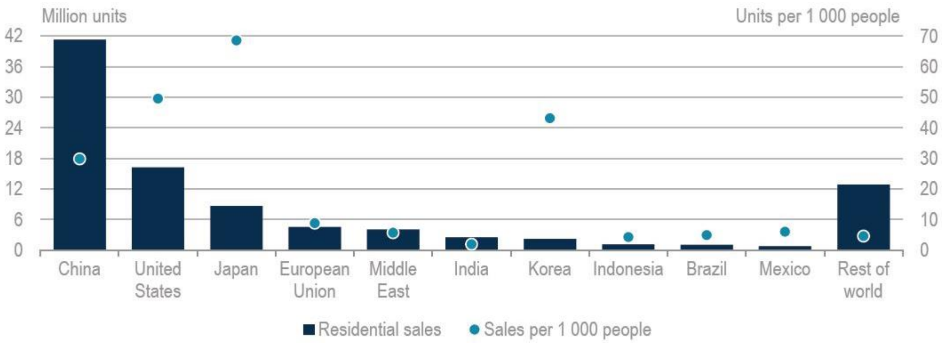

Figure 1. 3. Sales of residential air-conditioning units by country/ region in 2016.

Source: The Future of Cooling p21.

Of the 1.6 billion air-conditioning in use in all the countries, nearly 70% of them were used in residential. Household ownership of air-conditioning varied from around 4% in India, over 90% in Japan and the United States and close to 100% in a few middle eastern countries. Most of the type of the air-conditioning was split systems, individual mini-split or multi-split air-conditioning (figure 1.4). The IEA noted that the central ductless systems use decreased as the use of split systems for small housing, such as apartments grown. Chillers were used almost entirely for large central systems, commercial buildings and district cooling.

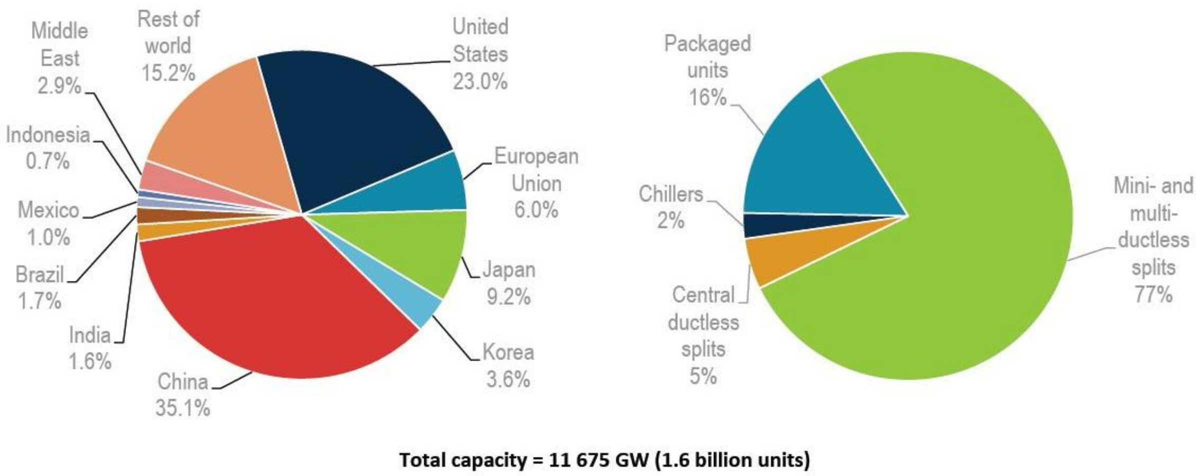

Figure 1. 4. Stock if air-conditioning by country/ region and type by the end of 2016. Source: The Future of Cooling p21

Space cooling was the fastest-growing energy used in buildings, both in developing and developed countries. In developing countries, especially in hot and humid area, with the emerging economies, the demand of space cooling significantly increased. In the developed countries, it also increased following the growth of consumer demand of thermal comfort. The final energy used for space cooling in residential and commercial buildings grew more than three times from around 600 terawatt hours (TWh) to 2020 TWh between 1990 to 2016 (figure 1.5). During the same period, cooling energy was up from around 2.5% to become more 6% of total final energy.

Figure 1. 5. World energy consumption for space cooling in buildings.

Source: The Future of Cooling p23.

There were differences of the level and trend of space cooling energy used in diferent countries accross the world. The IEA noted the differences mainly as a result from different need of cooling, level and pace of economic growth. The United States was the world largest cooling energy market, with its 328 million people utilized more cooling energy than 4.4 billion people in all Africa, South America, the Middle East and Asia - excluding China (table 1.2).

Table 1. 2. World final energy consumption for space cooling in buildings by country/ region.

Source: The Future of Cooling p24.

	TWh				% of total building final energy use in 2016
	1990	2000	2010	2016	
United States	339	448	588	616	10.60
European Union	63	100	149	152	1.20
Japan	48	100	119	107	9.50
Korea	4	17	34	41	8.50
Mexico	7	16	23	37	9.80
China	7	45	243	450	9.30
India	6	22	49	91	3.40
Indonesia	2	6	14	25	3.00
Brazil	10	19	26	32	7.70
South Africa	4	6	6	8	2.80
Middle East	26	49	97	129	9.30
World	608	976	1602	2021	5.90

The use of cooling energy in the United States already stable as an effect of the market saturation, improvement in air-conditioning technology, population growth, migration, and rising indoor temperatures. However, enormous disparities of access to space cooling, as seen in per-capita levels of energy consumption occured in other countries and regions. The condition can be seen in figure 1.6. The consumption of energy per capita in Africa was only 35 kWh, eventhough they had hot places. In comparison, the cooling energy consumption was higher in countries with relatively mild climate, for example more than 800 kWh in Japan and Korea, and 1880 kWh in the United States. Even in Europe, the consumption of space cooling energy per-capita was higher than people in Africa, Brazil, and Indonesia, which had much hotter temperature and higher cooling demands.

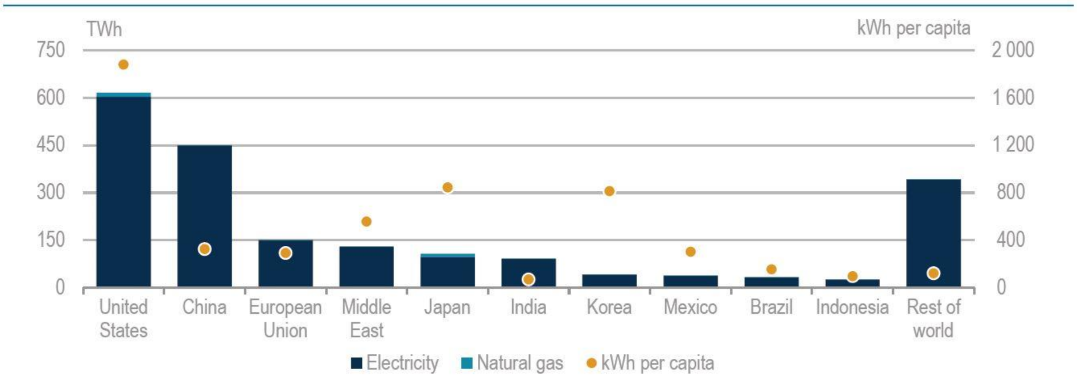

Figure 1. 6. Final energy use for space cooling in buildings by fuel by the end of 2016. Source: The Future of Cooling p25.

Figure 1.7 shows the final energy consumption for space cooling in the year 1990 and 2016. The highest energy for cooling was in the United States in 2016. China had the largest and fastest increase cooling energy consumption since 1990. However, the demand of cooling energy in other emerging economy countries, such as China, India, and Indonesia, were also rapid and significantly higher. In general, cooling energy demand was increasing during the period all over the world.

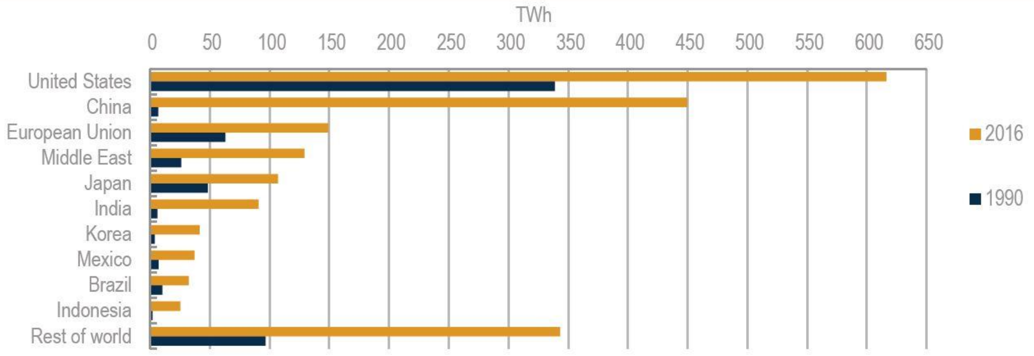

Figure 1. 7. Final energy consumption for space cooling by fuel and country/ region. Source: The Future of Cooling p25.

Since 1990, space cooling had been one of the largest portion to the growing electricity use in buildings. Space cooling for buildings also accounted for a large portion of increased electricity demand today. In the emerging economic countries, the amount of increased electricity demand for space cooling in building was larger than all end-use sectors combined (figure 1.8).

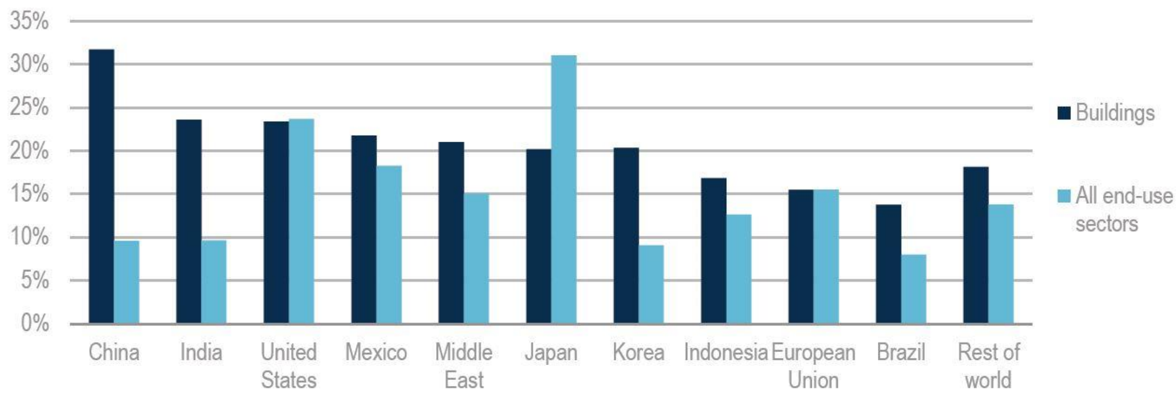

Figure 1. 8. Share of cooling energy in the increased of electricity demand by country/ region in 1990 and 2016.

Source: The Future of Cooling p26.

Space cooling also took a big portion of electricity peak demand (figure 1.9). This condition pushed the power system to work further. This condition happened due to the climate condition. For example, cooling represented around 74% of peak electricity demand in Philadelphia, the United States during a particular hot days in July 2011. Even in France, area where the use of air-conditioning was less than the United States, electrical power used was up to 10% (around 4000 megawatts) in comparison to the normal summer condition. Same condition occured in China during summer heatwave in 2017. In area which have cooling needs all year round, such as Singapore, the cooling energy contribute 50% or more.

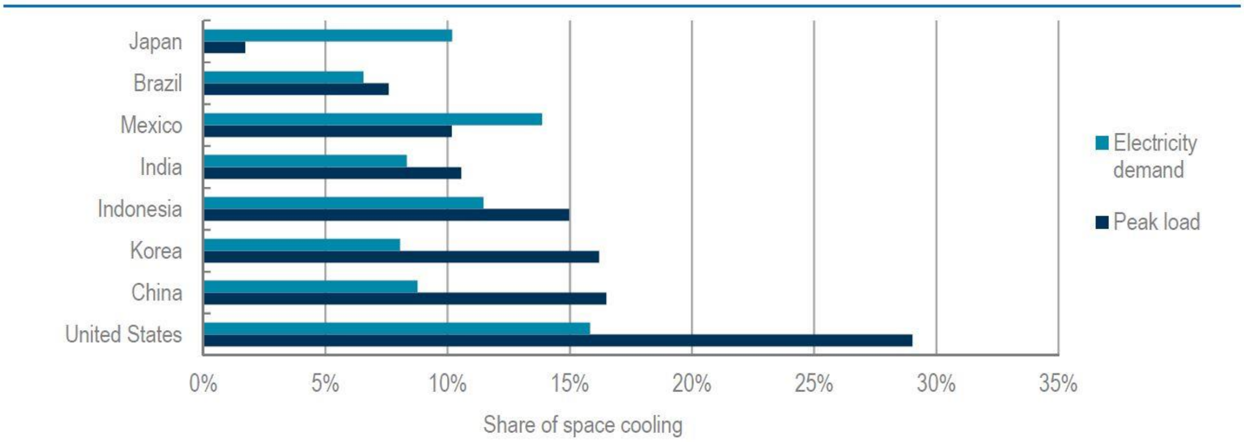

Figure 1. 9. Share of cooling energy in the peak load and total electricity demand by country/ region in 2016.

Source: The Future of Cooling p27.

The share of cooling energy in the peak load Indonesia was around 15% in 2016 according the aforementioned data. Moreover, Indonesia had all five driving factors for higher cooling demands: increasing wealth, population and urbanization, climate condition, building design changes, and the growth of electronic appliances use. These were the reason of selecting specific location for this research. Using shading device to reduce cooling energy would be most beneficial for hot and humid area, even though it could be still usefull for area with milder climate and environmental condition. According to the IEA projections in 2050, the share of cooling energy in electricity load would be more than 40% in Indonesia. Jakarta, the capital city of Indonesia, represents other cities which deal with similar condition, not only in Indonesia but also in other countries, especially those located in hot-humid areas.

The IEA (2018) highlighted that indoor cooling has a big portion of building energy demand and needs policy consideration to make energy consumption more efficient[13]. They predicted that cooling energy consumption will increase significantly by 150% globally and 300 – 600% in developing country in 2050. The IEA (2018) stated that in hot climates, low-cost technologies, such as reflective roofs and walls, exterior shades and low-e window

[13] The International Energy Agency (2018) Market Report Series Energy Efficiency 2018: Analysis and Outlook to 2040. p81. Retrieved from https://doi.org/10.1787/9789264024304-en Accesed October 7, 2019.

coatings and film can cut cooling energy consumption[14]. The IEA (2018) suggested that national and local government to establish and enforce energy codes for new buildings using affordable technological solutions. The codes should be adapted to local situations and market barriers. The IEA (2018) noted that energy inefficient building materials, such as single, clear, glazed windows should be avoided, and existing materials replaced or upgraded with window attachments[15]. Fundamental technologies for cooling energy efficiency were insulation, shading, windows, and efficient air conditioners (the IEA, 2018). The policy for building energy retrofit included obligations, disclosure, incentives, or financing programs enable on existing buildings[16]. Exterior shading was one of building envelope technologies that could be used for new constructions or old building retrofit. Available product, cost, climate, and energy price at the local level had to be examined to meet the balance between envelopes and equipment needed to apply the designs[17]. According to IEA's cost and performance goals for building envelope technologies 2020-2030, windows attachments, such as exterior solar shades, could be applied mainly for existing windows since they could decrease solar heat gain while still had daylight feature to prevent increasing in lighting energy. The target cost of windows attachment was USD 70/ m^2[18]. Exterior shading was cost effective and becoming more prominent[19]. Many investment of space air conditioning was assigned to develop building envelopes for decreasing heating and cooling energy load[20].

Climate, with its two main factors: air temperature and humidity, was the basic driver of cooling demand. Base on the cooling degree days, the location around the equator, including tropics and parts of sub-tropics area needed the highest cooling energy among other territories. Cooling degree days were calculated using standard dry bulb temperature of 18°C (figure 1.11). However, when the humidity was also accounted, the temperature feels higher whenever the humidity increases. Indonesia had a relative high air temperature and humidity all year round. The average number of cooling degree days in Indonesia was approximately 3,300. However, considering the humidity, the number of cooling degree days was around 10% higher on average. Cooling degree days moved over time with the weather, not only across the season but also from one year to another. Increasing of cooling degree days in one

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[14] The International Energy Agency (2013) Technology roadmap: energy efficient building envelopes. p5
[15] The International Energy Agency (2013) Technology roadmap: energy efficient building envelopes. p6
[16] The International Energy Agency (2017). Space Cooling Energy Insight Brief. Retrieved from https://www.iea.org/publications/freepublications/publication/SpaceCoolingEnergyEfficiencyInsightsBrief.pdf
[17] The International Energy Agency (2013) Technology roadmap: energy efficient building envelopes. p9
[18] The International Energy Agency (2013) Technology roadmap: energy efficient building envelopes. p25
[19] The International Energy Agency (2013) Technology roadmap: energy efficient building envelopes. p48
[20] The International Energy Agency (2018) Market Report Series Energy Efficiency 2018: Analysis and Outlook to 2040. p85. Retrieved from https://doi.org/10.1787/9789264024304-en. Accesed September 20, 2019.

area could make permanent change to actual cooling load. In France, a series of heat wave made people bought air-conditioning. After that period, people in that area continued using air-conditioning during the cooling period, even though there was no heat wave and they used to utilize fans and no air-conditioning. Rising average temperature would drive the cooling degree days up. The IEA estimates that an increase of 1°C of global average temperature would make additional 25% of cooling degree days across the world.

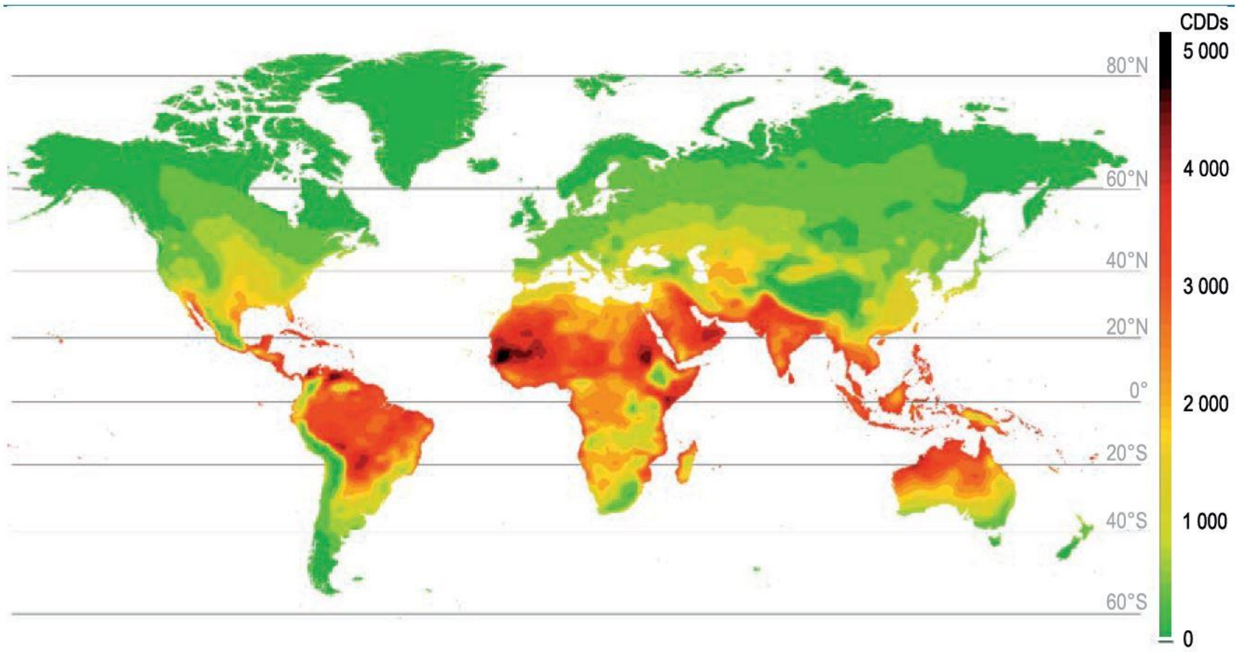

Figure 1. 10. Cooling degree days across the world, mean annual average from 2007 – 2017. Source: The future of cooling p34.

Area which had high population and density would have to deal with the highest increase of cooling degree days. The IEA predicted that the actual cooling degree days in 2050 will increase around one-quarter. Moreover, the IEA noted not only the significances of the population but also growth of income as well as urbanization would lead to the increase of cooling degree days in several area, a lot higher than other territories (table 1.3). Economic growth, which was the second considerable factor for driving cooling demand up, was relatively high in Indonesia. In the year 2016, there were 3390 of cooling degree days in Indonesia with its 261 million populations. In the 2050 outlook, the IEA predicted there would be 661 more of cooling degree days and the population would be up to 332 million in Indonesia.

Table 1. 3. Outlook for cooling degree days by country/ region in the baseline scenario. Source: The future of cooling p37.

	2016		2050		
	CDDs	Million persons	CDDs	Million persons	Change in CDDs over 2016
United States	764	328	973	392	27.4%
European Union	292	511	343	505	17.5%
Japan	909	127	1040	108	14.4%
Korea	762	51	844	51	10.7%
Mexico	868	123	1188	156	36.8%
China	1051	1384	1169	1351	11.3%
India	3084	1327	3486	1705	13.0%
Indonesia	3390	261	4051	322	19.5%
Brazil	1846	210	2314	238	25.4%
South Africa	714	55	746	66	4.6%
Middle East	2337	232	2516	354	7.6%
World	1905	7422	2388	9714	25.4%

Notes: CDDs shown here are calculated on the basis of a temperature of 18°C; historical population distributions were used to calculate the weighted CDDs in 2016 and expected population growth rates (without taking into account potential shifts in population distribution from the migration patterns) were used to calculate future trends.

Economic growth made people able to meet the demand of cooling needs. In rich countries, the demand for cooling could easily be met by utilizing mechanical air-conditioning units. In Singapore for example, Happel, et. al. research showed that around 98.8% of private apartments had air-conditioning which was on for most of the time the apartment is occupied[21]. Singapore is one of the hottest and most humid country in the world. Different condition happened in India. With relatively high temperature and humidity, only 4% of residential in India had air-conditioning. The economic condition as well as electricity access became barriers for people to obtain air-conditioning. With the growth of economic, the access to electricity became wider, and the affordability became higher too. This condition made the use of air-conditioning in several area increased significantly. As the income became higher, people started using air-conditioning and continued to do so. Larger

[21] Gabriel Happle, Erik Wilhelm, Jimeno A Fonseca, Arno Schlueter (2017) Determining air-conditioning usage patterns in Singapore from distributed, portable sensors. Energy Procedia 122. P 313-318

income contributed to higher cooling demand, not only air-conditioning energy consumptions but also other electronic devices. The rise of the use of televisions, computers, printers and other electronic appliances which emitting heat when the equipment was used or even during stand-by period, drove the cooling energy inside buildings further. According the IEA analysis, the relationship between average per-capita income and air-conditioning was strong. They specifically noted the air-conditioning ownership was rising very significant in the countries which has extreme condition of more than 3000 cooling degree days, such as Brazil, India, and Indonesia. Other than economic factor, the price of the air-conditioning, and the cost of electricity, the IEA added the possibilities of sociocultural preferences factor which made high air-conditioning ownership in Ukraine, parts of Japan and the United States. Mechanical air-conditioning units were seen as a status or economic symbol – like owning a car – made people buying air-conditioning devices to use them extensively even there was no need or even when no one occupied the space. The IEA assumed an outlook of the average annual rates of growth of the countries which have high cooling demand. Indonesia was relatively high at 4.5%, significantly higher than the average of the world in 3.1% (table 1.4)

Table 1. 4. Assumed average annual rates of growth in real GDP by country/ region. Source: The future of cooling p37.

Compound average annual growth rates (%)	2000 - 16	2016 - 30	2030 - 50	2016 - 50
United States	1.8%	2.0%	1.9%	2.0%
European Union	1.4%	1.7%	1.4%	1.5%
Japan	0.7%	0.7%	0.7%	70.0%
Korea	3.9%	2.7%	1.3%	1.9%
Mexico	2.1%	3.3%	2.5%	2.8%
China	9.2%	5.4%	2.5%	3.7%
India	7.3%	7.2%	4.5%	5.6%
Indonesia	5.4%	5.4%	3.3%	4.2%
Brazil	2.4%	2.5%	2.7%	2.6%
South Africa	2.9%	2.6%	2.7%	2.6%
Middle East	4.3%	3.7%	3.0%	3.3%
World	3.6%	3.7%	2.7%	3.1%

Rather than only having steadily economic growth, Indonesia also had population growth and urbanization. These demographic factors were also linked to the cooling demand. The IEA published world energy outlook in 2017 to predict the demographic conditions in countries with high cooling needs (table 1.5). Urbanization increased the cooling demand for several reasons. First, the temperature in the urban tend to be higher than in the rural area as the effect of urban heat island. Second, cooling was less concerned in the rural lifestyles perspectives. Third, more machineries were used in the cities, which emit heat in operation or stand-by period. Fourth, buildings and hard surfaces in the cities could absorb heat and release it during the night, made the temperature higher. The IEA (2013) also signified the less reflective cities than rural area and soak more sun's heat. Zielinski (2014) noted the local climate and surrounding area, which affect the convection transfers heat[22]. Salamenca et.al. (2014) showed that air-conditioning can raise more than 1°C of temperature during the night in some cities[23].

Table 1. 5. Demographic assumptions by country/ region.
Source: The future of cooling p40.

	Average annual growth rate			Population (million)		Urbanization rate	
	2000 - 16	2016 - 30	2030 - 50	2016	2050	2016	2050
United States	0.8%	0.7%	0.4%	328	392	81.9%	87.5%
European Union	0.3%	0.1%	-0.1%	511	505	75.0%	83.0%
Japan	0.0%	-0.4%	-0.6%	127	108	93.9%	97.7%
Korea	0.5%	0.3%	-0.2%	51	51	82.6%	87.6%
Mexico	1.2%	1.0%	0.5%	123	156	79.5%	86.4%
China	0.5%	0.2%	-0.2%	1384	1351	56.9%	76.0%
India	1.5%	1.0%	0.6%	1327	1705	33.2%	50.3%
Indonesia	1.3%	0.9%	0.4%	261	322	54.4%	70.9%
Brazil	1.1%	0.6%	0.2%	210	238	85.9%	91.0%
South Africa	1.4%	0.6%	0.4%	5	66	65.3%	77.4%
Middle East	2.3%	1.6%	1.0%	232	354	70.3%	78.7%
World	1.2%	1.0%	0.7%	7422	9714	54.4%	66.1%

The energy efficiency of air-conditioning units was one of the possible ways to deal with high cooling demand. Enhancing the efficiency of the air-conditioning units reduced not only the consumption of cooling energy but also the peak electricity demand. In Indonesia, the Energy Efficiency Ratio (EER) of currently used air-conditioning units was still low

[22] Sarah Zielinski. Why the city is (usually) hotter than the countryside. https://www.smithsonianmag.com/science-nature/city-hotter-countryside-urban-heat-island-science-180951985/. Accesed November 20, 2019.
[23] F Salamanca, M Georgescu, A mahalov, M Moustaoui, M. Wang. (2014) Anthropogenic heating of the urban environment due to air conditioning. Journal of Geophysical Research: Atmospheres/ Vol 119 Issue 10. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2013JD021225. Accesed November 10, 2019.

(figure 1.12). The effectiveness of the implementations of EER standard was influenced by the policy of the government.

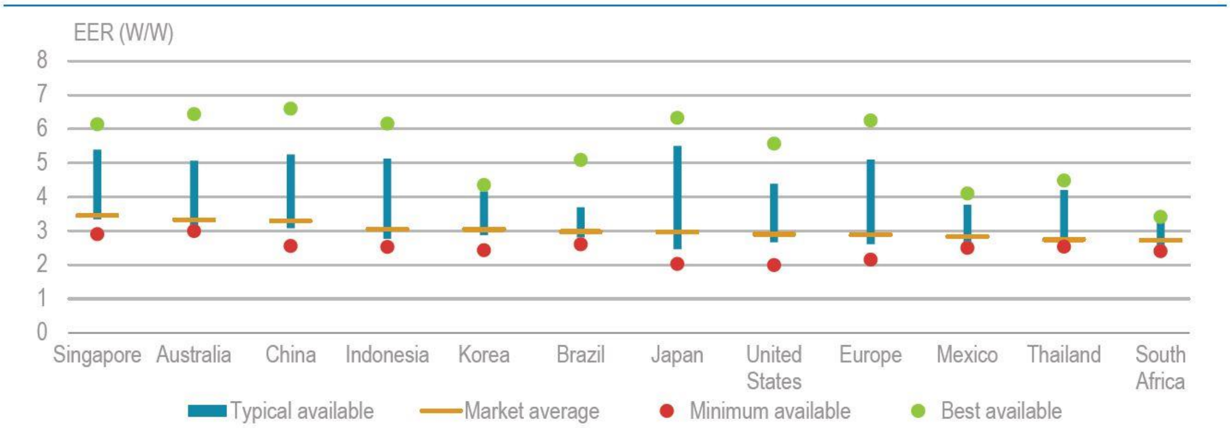

Figure 1. 11. Energy Efficiency Ratio of available residential air-conditioning in selected countries/ regions in 2018.

Source: The future of cooling p44.

The government of Indonesia published the regulations from the Ministry of Energy and Mineral Resources number 57 in 2017 about the Minimum Energy Performance Standards for single split wall mounted air-condition units with maximum cooling capacity of 27,000 BTU/ hour both inverter and non-inverter types[24]. This type of air-conditioning was commonly used in residential. The regulation divides the air-conditioning into four-stars categories based on the EER. One star, which was the lowest rated has EER from equal to 8.53 to 9.01. Two stars had EER from equal to 9.01 to 9.96. Three stars had EER from equal to 9.96 to 10.41. Four stars, which was the highest rating, had EER value from 10.41 and above. To effectively apply this regulations, the government put expiration date of air-conditioning units that has less EER value. All the air-conditioning units which had EER less than 8.53 could not be installed after July 31, 2018. All the air-conditioning units which had EER less than 9.01 can only be installed from August 1, 2018 to July 31, 2020. All the air-conditioning units installed after August 1, 2020 must have EER value at least 9.96. However, currently used air-conditioning units were not affected.

The government of Indonesia issued the regulations since the residential sectors account for a large portion of cooling demand. The trend showed that the use of air-conditioning units in residential sector continue to increase, in many hot and humid countries,

[24] The minimum energy performance standards and energy saving label for air-conditioning (2017) http://jdih.esdm.go.id/peraturan/Permen%20ESDM%20Nomor%2057%20Tahun%202017.pdf. Accessed October 19, 2019

rising incomes make them more affordable and in a warmer climate makes them indispensable. This condition lead to the increase of the use of electricity too. The IEA projected that the global energy for space cooling increased threefold from 2020 TWh in 2016 to 6200 TWh in 2050, with almost 70% of the increase comes from residential sector (figure 1.13).

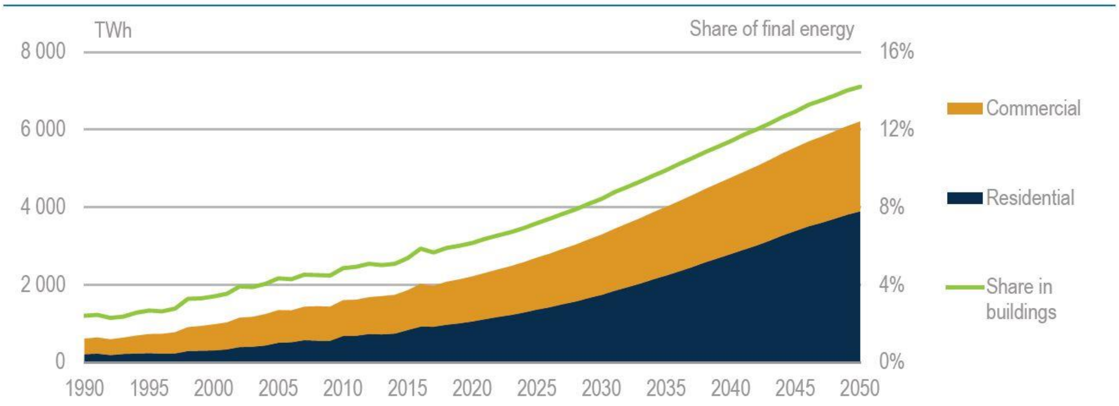

Figure 1. 12. World energy use for space cooling by subsector in the baseline scenario. Source: The future of cooling p61.

The increase of global energy use of space cooling came from emerging economic countries, with only combination of three countries: India, China, and Indonesia contributes half of it. Indonesia had near 13-fold increase from the year 2016 to 2050 (figure 1.14).

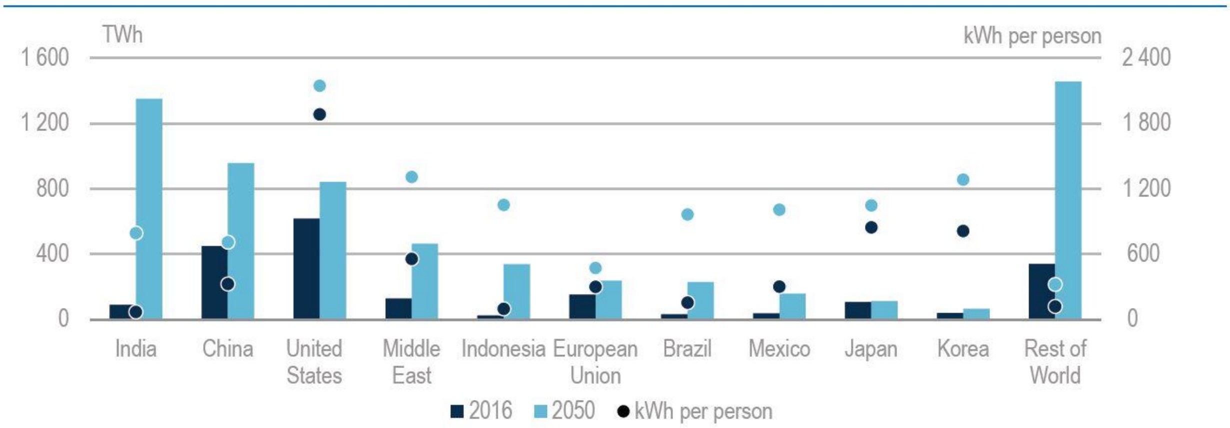

Figure 1. 13. Energy use for space cooling by country/ region in the baseline scenario. Source: The future of cooling p62.

The increase of energy use in space cooling had big effect on the electricity system. The share of electricity for cooling in total electricity demand steeply increased. This condition would occur in all hot regions, and more extreme in countries with growing economic and large populations (figure 1.15). In Indonesia, almost 40% of total electricity demand came from electricity for cooling. This condition was predicted as an effect of sharply increasing use of air-conditioning.

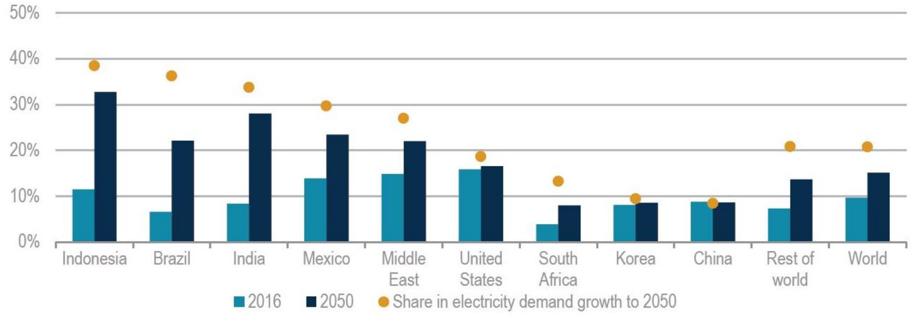

Figure 1. 14. Share of space cooling in total electricity demand and in the growth in electricity demand by country/ region in the baseline scenario.
Source: The future of cooling p63.

The increase of electricity for cooling also impacted the peak electricity demand too. This become critical since there was a limitation in electricity system. The increase was varied in each countries according to climatic condition, electricity demand, and consumer behavior (figure 1.16). In Indonesia, there would be a jump of contribution of the space cooling in electricity peak from around 15% in 2016 to more than 40% in 2050.

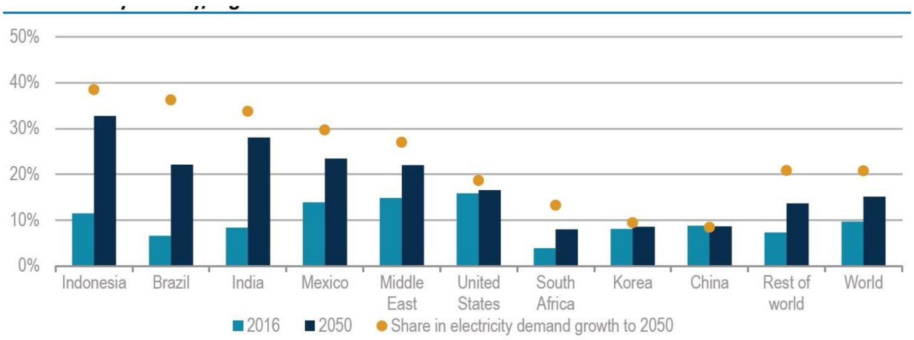

Figure 1. 15. Share of space cooling in peak electricity load by country/ region in the baseline scenario.
Source: The future of cooling p64.

The historical data, current trends, and future predictions of the demand of cooling energy in the worlds showed enormous change. The tremendous increase of the cooling demand was happening. The cooling energy demand was higher in several area, notably the area which geographically lay around equator area.

While it is inevitable, several country have to deal significantly larger challenges due to the other factors which drive the cooling demand even higher, such as: economic and population growth which is worsen by the climate change. The IEA noted six emerging countries which have all these challenges: Brazil, China, India, Mexico, South Africa, and Indonesia. Indonesia, with its location in the equator line was the selected country for this research (Figure 1.16). Jakarta, its capital city was the specific chosen location to do the simulation of sun shading devices in this dissertation.

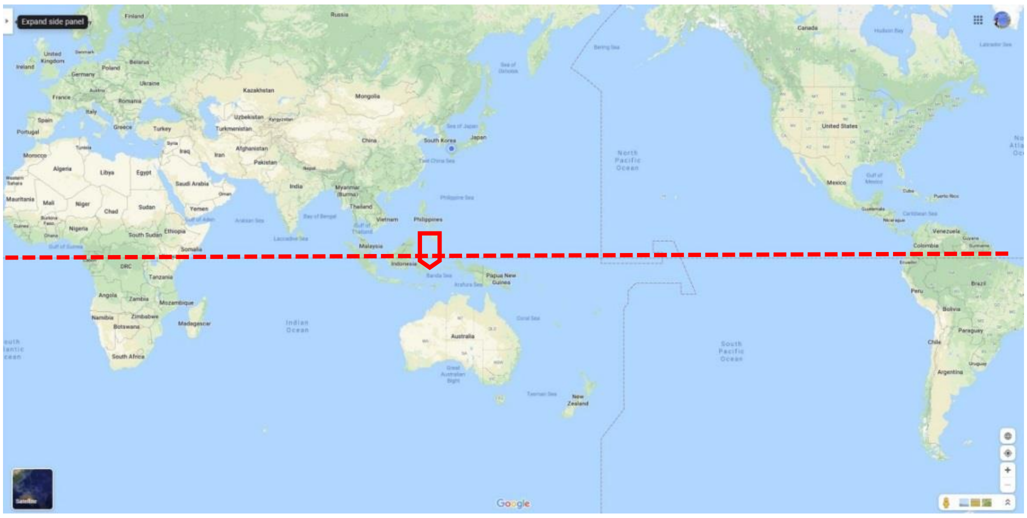

Figure 1. 16. Location of Indonesia, the chosen country in this study.
Source: maps.google.com, pin location and equator line are marked by the author.

Indonesia is a large archipelago country, consisting five main islands and more than 13,461 smaller islands, expands from 6° 04' 30" north latitude to 11° 00' 36" south latitude, between 94° 58' 21" and 141° 01' 10" east longitude. Indonesia, the world's fifteenth largest country, has 1,916,862.2 km² total areas. Indonesia was the fourth most populous nation in the world which more than 50% of the population lives in Java islands[25]. Indonesia was the largest economy country in Southeast Asia, the tenth largest in the world in terms of purchasing power parity (the World Bank, 2019). Indonesia had average economic growth rate consistently above 5% since the year 2010, accompanied by increasing of gross national

[25] Statistik Indonesia 2019, bi-lingual edition. Retrieved from https://www.bps.go.id/publication/2019/07/04/daac1ba18cae1e90706ee58a/statistik-indonesia-2019.html Accesed October 7, 2019.

income per capita from USD 823 in the year 2000 to USD 3932 in 2018[26]. The IEA special report on Indonesia's energy efficiency (2017a) showed that Indonesia used 36% of primary energy in Southeast Asia, which made it the largest energy consumption country in that region. Indonesia's GDP growth multiplied twice from 2000 to 2015 and electric consumption increased 150%[27] (the IEA 2017a). According to World Bank (2018), Indonesia had 267 million people, of whom 55% of the population lived in the cities. It increased from 48% of the city population ten years before[28]. However, based on 2017 data people in Indonesia consumed only 900 kWh electricity, just a quarter of world average annual electric consumptions (3200 kWh). On the other hand, economic growth in Indonesia remained strong and positive. IEA projection in 2030, Indonesia's electric consumption would reach 491 TW h. The residential sector accounted for the largest portion of electricity in Indonesia by using 41.5% of electric consumption in 2012. Industry took 34.6% of electric consumption while commercial sector consumes the rest 24%[29]. Electricity consumption in the residential sector grew around 159% from 2010 to 2017 (the IEA, 2020). The residential sector accounted for the largest portion of total final consumption of energy in 2017 by using 41%, higher than industry which used 33% and commercial and public services' 25% of total final energy consumption (figure 1.17).

[26] Indonesia overview. Retrieved from https://www.worldbank.org/en/country/indonesia/overview#1. Accesed October 7, 2019.

[27] The International Energy Agency. (2017a). Energy Efficiency 2017: Laporan Khusus Efisiensi Energi di Indonesia. p5. Retrieved from https://www.iea.org/publications/freepublications/publication/EnergyEfficicency2017IndonesiaFocusBahasaIndonesia.pdf Accessed October 6, 2019

[28] Urban population: Indonesia. Retrieved from https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=ID&view=chart Accesed October 7, 2019.

[29] The International Energy Agency (2015) Indonesia 2015: Energy policies beyond IEA countries. p99

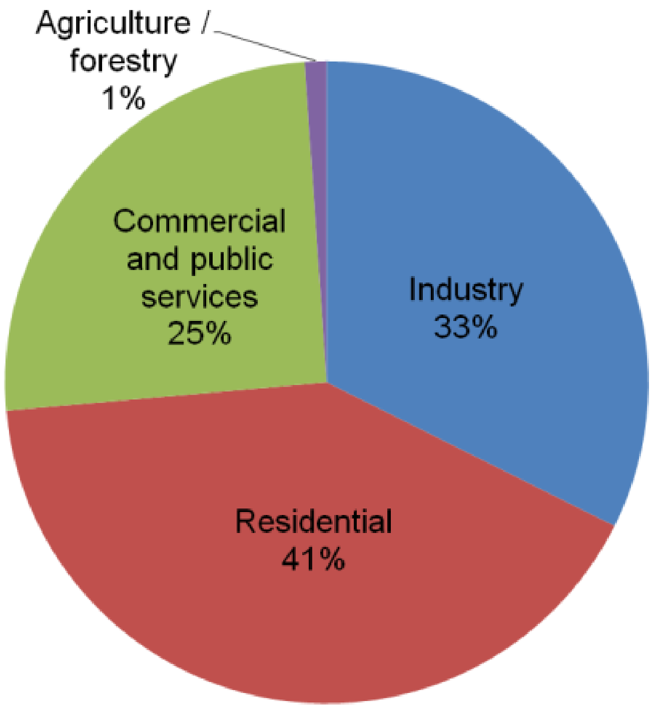

Figure 1. 17. Total final energy consumption in Indonesia by sector in 2017.
Source: the International Energy Agency (2020); visualized and photographed by the author

Jakarta is the capital city of the Republic of Indonesia. It was one of the most populous city with the high density in the world. Even Jakarta was the smallest among other provinces in Indonesia, by only covering 6,392 km², there were 10,846 million people in Jakarta in 2018[30]. Jakarta had a low altitude, with an average of 7 meters above sea level. Jakarta is in tropical area, at 6°12' and 106°48'[31], on the northwest coast of Java island (Figure 1.18). Java Island itself was one of the world's most populous island. According to the Koppen climate classification system, Jakarta has a tropical monsoon climate. The temperature in Jakarta is relatively high all year round. The average of real temperatures in Jakarta from 2009 to 2013 were presented in table 1.6[32]. The humidity in Jakarta was also relatively high. The average of real humidity in Jakarta from 2009 to 2013 were presented in table 1.7[33]. Jakarta has the wet season from October to May. Less than 100 mm of rainfall only occurs in June to September.

[30] https://jakarta.bps.go.id/dynamictable/2020/03/04/414/3-1-4-registrasi-penduduk-menurut-jenis-kelamin-rasio-jenis-kelamin-dan-kabupaten-kota-administrasi-di-provinsi-dki-jakarta-2018.html. Accessed October 6, 2019
[31] https://jakarta.go.id/ Accessed October 6, 2019
[32] https://jakarta.bps.go.id/statictable/2015/04/20/57/suhu-udara-jakarta-menurut-bulan-2009-2013.html Accessed October 6, 2019
[33] https://jakarta.bps.go.id/statictable/2015/04/20/56/kelembaban-udara-rata-rata-jakarta-menurut-bulan-2009-2013.html Accessed October 6, 2019

Figure 1. 18. Location of Jakarta.

Source: : https://www.big.go.id/assets/download/2017/NKRI-2017/Peta_NKRI_Skala_5000000_03102017.jpg. Jakarta is marked by the author

Table 1. 6. Monthly average temperature in Jakarta from 2009 to 2013.

Source: jakarta.bps.go.id

Month	Average Temperature (ºC)				
	2009	2010	2011	2012	2013
January	27.1	27.3	27.3	27.3	26,9
February	27.2	27.2	27.4	27.9	27,9
March	28.3	28.4	27.9	28	28,8
April	28.9	29.2	28.6	28.1	28,7
May	28.5	28.9	28.8	28.3	28,7
June	28.9	28.0	28.7	28.4	27,3
July	28.7	27.8	28.3	27.9	27,3
August	29.0	28.2	28.8	28.1	28,6
September	29.4	27.4	29	28.5	29,0
October	29.4	27.6	29.2	29.1	29,4
November	28.4	28.0	28.9	28.1	28,5
December	28.5	27.5	28.9	28	27,7

Table 1. 7. Monthly average humidity in Jakarta from 2009 to 2013.

Source: jakarta.bps.go.id

Month	Average Relative Humidity (%)				
	2009	2010	2011	2012	2013
January	81	82	79	79	84
February	81	80	79	80	80
March	76	80	76	79	76
April	76	76	75	80	79
May	77	78	76	79	78
June	75	80	73	76	80
July	68	79	74	64	80
August	69	77	69	66	72
September	68	81	68	67	73
Oktober	70	79	72	70	72
November	75	78	74	71	76
December	77	78	76	76	79

The combination of high temperature and high humidity made the people perceptions of the heat condition was higher. Jakarta had a warm-humid climate which was considered as the most difficult one to design for[34]. The warm-humid climates were around the equator area where the sun path was near the zenith with very strong radiation and high humidity. The best thing to do was ensuring the interior condition was not much hotter than the exterior. The opening in the west and east should be avoided or whenever it happens, it must be carefully designed and protected.

The weather data from the simulation were downloaded directly from OneBuilding.org. There were no significant difference between the real data provided by the government of Indonesia website with the downloaded weather data from OneBuilding.org. Onebuilding is a website which provides weather data in many places around the world. Onebuilding had a good reputation for providing weather data for simulation, which were usually used by researchers to simulate specific location-based examination of designs, ranging from architectural to mechanical engineering purposes. The exact location for residential simulation was at Jakarta observatory[35]. The Jakarta observatory was located

[34] Steven V Szokolay (2004) Introduction to Architectural Science: the basis of sustainable design. Architectural Press. p68.
[35] The Onebuilding. (n.d.). Jakarta Indonesia TMY3. Retrieved from http://climate.onebuilding.org/WMO_Region_5_Southwest_Pacific/IDN_Indonesia/JW_Jawa/IDN_JW_Jakarta.Obs.967450_TMYx.zip Accessed October 3, 2019

around the middle of the Jakarta city. Similar with the real recorded data in Jakarta from 2009 to 2013, the average temperature in the weather files were ranging from a minimum 26.87°C in January to a maximum of 29.1°C in October. The annual average temperature was 28.23°C. The weather files showed the average total radiation per hour of all orientation was 296.91 Wh/m². The west direction suffered the highest annual total solar radiation of 948.34 k Wh/m². The south orientation get the lowest annual total solar radiation of 525.02 kWh/m². This means that cutting the total solar radiation in the west façade will have greater impact than other orientations. However, the northwest, east and northeast orientation also suffered a relatively high total solar radiation, from both direct and diffuse. The total direct and diffuse solar radiation for one year can be seen in figure 1.19.

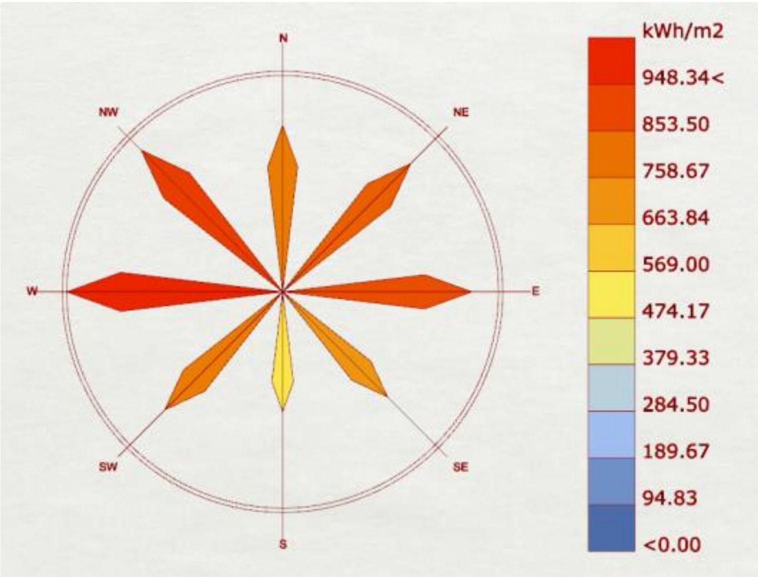

Figure 1. 19. Total solar radiation in Jakarta.
Source: The weather data were provided by onebuilding.org, extracted from the weather file for simulation. Visualized and photographed by the author using LadyBug

There was a simple known strategy to reduce the excessive solar radiation in architecture by providing shadow. Shadow can be very useful for reducing solar radiation by filtering and blocking both light and heat which may lead to cooling energy consumption reduction. There were only small number of researches in shadow, in comparison with researches in light. This dissertation would contribute on shadow researches, especially related to the architecture, in terms of the environmental and economical benefits.

1. 2. The role of shadows in architecture

Shadow was often a forgotten aspect in architecture since western perspectives considers shadows as a negative part of light. Charles Moore in the foreword of Tanizaki's *In Praise of Shadows*[36] stated that in the west, light is the most powerful ally. Moore noted that many explorations about light through research and design, for example Louis Kahn's and Renzo Piano's design, but there were very limited of researches on shadows in comparison with researches in lighting in Architecture. Kahn noted that shadow was natural part of the light and use it extensively in his design, from the façade, main room, to the less important space, such as the back side of ground level in Richards Medical Research Laboratories, the University of Pennsylvania (figure 1.20). Renzo Piano carefully used shadow to balance the natural day lighting, notably in his museum design (figure 1.21). However, Moore showed a different perspective of darkness and light between western and Japanese cultures and proposed that this point of view might change western's life. The negativity of shadows was also argued by Roberto Casati[37]. Casati stated that too much light can be harmful. He gave the excessive light from the sun as an example. On the other hand, he noted that shadow was a form of darkness which was usually seen as something that covered or hide. However, during lunar eclipse, rather than hide, shadow revealed the true form of the moon. The moon did not shine but a dark, large rock, hanging in the sky. Casati underlined that the shadow in Architecture-especially shadow space revealed the relation among shadows, human activities, and culture.

[36] Tanizaki, J. (1977). *In Praise of Shadows*. New Haven, CT: Leete's Island Books.
[37] Casati, R. (2004). *Shadows: Unlocking Their Secrets, from Plato to Our Time*. New York: Vintage Books.

Figure 1. 20. Ground floor, Richards Medical Research Laboratory by Louis Kahn.
Source: photographed by the author

Figure 1. 21. Main hall, The Chicago Insitute of Arts by Renzo Piano.
Source: photographed by the author

Ruskin[38] mentioned shadow as a "positive shade" that was important and eminent for architects, even more than painters which extensively used shadow in their paintings. Ruskin stated that a building was great when it had big strong volumes and deep of shadows blended with its surfaces. He noted examples of European buildings, especially in its façade (figure 1.22). The depth of the shadow easily made the structure, as well as the ornaments of the building shows up. Moreover, he suggested that young architects learn about thinking of shadows. He argued that the shadow could be benefit for architecture designs. Reed[39] noted that shadow was far from negating, but coming to intensify a building. The use of the shadows could be found not only in western architecture but also in other several examples from different culture.

Figure 1. 22. The facade of Basilica di San Giovanni in Laterano.

Source: photographed by the author

[38] John Ruskin (n.d) *The Seven Lamps of Architecture. Createspace independent publishing platform 2018*

[39] Arden Reed. *Signifying Shadows in VIA 11: Architecture and Shadow*. (1990). Philadelphia, PA: Graduate School of Fine Arts, University of Pennsylvania. p.12

Shadows could be used for defining a space since the concept of shadow was spatial. Casati said that shadows were (dark) areas. He cited Thales' concept about a triangular space of shadow. Thales put a post on the ground. Then, there was a triangle space shaped by the post, the shadow on the ground, and an invisible line that links the top of the shadow with the top of the post. The concept of shadow space could be seen in Karen Hillier and Thomas Woodfin[40] photographs in Chiapas, Mexico. They found that shadows help to define the spatial zone on a building by simply dividing the outside with the inside of homes and buildings. The doors, windows, and passageways were filters. They acted as a mark on the entrance to go through between light and the shadow in the atmosphere. Another example about the use of shadows came from Alison and Peter Smithson's project[41]. They started using climate-conscious, climate responsive architecture in the mid 1950-s. They were guided by the cyclic nature of shadows – day movement, seasonal pattern – and made climate responsive architecture more articulate in their project. Their understanding of the language potential of the shadow cycle became clearer when they studies the Damascus Gate in Jerusalem. In this project, they found that shadows did not only create a vagueness of the building shape but also became contextual and more alive. Shadows created a living space that was used for its occupants to do their activities. For example, there were wall-encircling-hole-buildings that were used as an extended space for the Muslims to do the Friday prayer. Another architect that extensively use shadows in his designs was Sri Lankan architects, Anjalendran[42]. He used extended roof to provide shadow and also for rain screen, as a response to Sri Lankan climate condition.

In a different climate than most of western countries, the Japanese embraced shadows to blend with their culture. Tanizaki gave many example of the use of dimly-lit atmosphere related with Japanese culture, from heater, toilets, lamps, jade, cuisine, lacquer ware, theater, and architecture in his essay In Praise of Shadows[43]. The beauty of Japanese rooms was based on variation of shadows, heavy shadows versus light shadows. In the Japanese culture, a traditional heater did not only bring heat but also dim light to create an area for family gatherings around the fire. The dim-light area was formed by the red glow from the coal fire. It could be seen at the *Irori*, Japanese hearth space in traditional houses (figure 1.23). Next, a traditional Japanese toilet was different with modern toilet which usually was well lit and had

[40] Karen Hillier and Thomas Woodfin. *Suite: Luna de Miel in VIA 11: Architecture and Shadow*. (1990). Philadelphia, PA: Graduate School of Fine Arts, University of Pennsylvania. p.124
[41] Alison and Peter Smithson. *Working with Shadow: Damascus Gate, Jerusalem in VIA 11: Architecture and Shadow.* (1990). Philadelphia, PA: Graduate School of Fine Arts, University of Pennsylvania. p.76
[42] Robson, David G. (2009) *Anjalendran: Architect of Sri Lanka.* North Clarendon, VT: Tuttle Pub.
[43] Tanizaki, J. (1977). *In Praise of Shadows*. New Haven, CT: Leete's Island Books.

glossy looks. Japanese toilets had a degree of matte finish brought by the material around the room: wood. It made Japanese traditional toilet darker and had more spatial depth. Tanizaki mentioned another Japanese novelist, Natsume Soseki, who considered the morning routine at traditional Japanese toilets as "a physiological delight" brought by the space. However, he critiqued the Japanese theater, Kabuki and Nô, which used modern lamps. The excessive flood lamps drove away the condition of dim lit from traditional lighting. Dynamic light and shadow strength from dim lighting provide spatial gradation which were lost by applying modern lighting. There was a degree about intimacy and proportion between the stage and performance that was lost because of the modern system.

Figure 1. 23. The irori is a traditional hearth space where the family gather and relax. Source: https://www.trekearth.com/gallery/Asia/Japan/Chubu/Gifu/Shirakawago/photo1574768.htm

Before giving an example about architecture, Tanizaki stated that he was not an architect nor had the expertise on it; nevertheless, he succeeded in identifying Japanese building typology. From a noble to ordinary house, massive roof of tile or thatch was the main focal with deep shadow under its eaves. Even in the bright midday, a shaded space covered all beneath the eaves and made entrance, doors, walls, and columns invisible.

Kurokawa[44] distinguished shadows in western from Japanese architecture by the construction itself. Western architects tend to block the sun but the Japanese used posts and beams to create spaces which do not sharply blocked out the sunlight. There was an intermediate space, which was a unique characteristic of Japanese Architecture. This fundamental philosophy, symbiosis, culture of greys, *ma* (interval), vagueness, and ambiguity, were used by Kurokawa in his design. Ando[45] also examined the shadow issues in architecture. In his perspective, one important thing that diminished from modern Japanese culture was a sense of the depth and richness of darkness.

Like in other places in the world, shadow played significant role in Indonesia too. One of the most known terms of shadow in Indonesia is *wayang*. *Wayang* is a shadow puppet theater that was recognized by the UNESCO, inscribed in 2008, as world's intangible cultural heritage of humanity[46]. The word *wayang* was derived from *bayangan* which literally means shadow. Sunarto cited Holt's note that the terms *wayang* was found in 907 AD King Balitung inscription[47]. *Wayang* Theater represented Javanese people in the daily life. At first, the *wayang* show was popular in Java but later, the use of *wayang* spread to other areas in Indonesia too. *Wayang* was obtained from tree's shadow in the ground. Trees, as the source of shadow, was similar with Laugier`s roof shelter in primitive hut. Laugier in An Essay on Architecture showed the importance of shadow for protecting human from sunlight[48]. Shadow was one of the important features of his model of a primitive hut, the very first architecture in human history. The shaded area for human activities was one of important aspect of architecture.

There were three essential features of traditional architecture which were related to shadow in Indonesia. The raised pile foundation was the first feature. Raised pile foundations were commonly found in Indonesian traditional architecture[49]. This feature had many benefits in tropical climate. The main space of the building was lifted and protected from rain water and mud during the rainy season. During the hot condition, hot air rise to the roof and cooler air entered from gap in the floor. This gap also allowed smoke from small fire under the building to drive away mosquitos. Dirt and small garbage could also be cleared through the

[44] Kisho Kurokawa. *Shadows, Symbiosis, and A Culture of Wood in VIA 11: Architecture and Shadow*. (1990). Philadelphia, PA: Graduate School of Fine Arts, University of Pennsylvania. p.26

[45] Tadao Ando. *Light, Shadow and Form: The Koshino House. in VIA 11: Architecture and Shadow*. (1990). Philadelphia, PA: Graduate School of Fine Arts, University of Pennsylvania. p.52 .

[46] https://ich.unesco.org/en/RL/wayang-puppet-theatre-00063. Accessed October 15, 2019

[47] Sunarto. (1989). Wayang Kulit Purwa Gaya Yogyakarta. Jakarta: Balai Pustaka.

[48] Laugier, MA (1755) *An Essay on Architecture*. London: T. Osbourne and Shipton.

[49] Waterson, Roxanna. (1998) Common Features: Raised Pile Foundations. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.12). Singapore: Archipelago Press

same floor gaps. In Kalimantan, notably taller pile foundations were used for providing additional protection of the house during tribal warfare. In Nias, the raised pile foundation was used as bracing structure to counter the earthquake that occured in this location. However, all the raised pile foundations formed shaded spaces underneath the building that were protected from the sunlight. In Java, as depicted in Borobudur temple carvings, people engage their daily activities in the shaded area under the floor. More shadow was provided from the roof. The second feature was extended pitched roof. Most of Indonesian traditional architecture buildings had extended roof features, which brought shadows not only in the interior space but also in-between interior and exterior area. The roof shape was a legacy from Austronesian. However, parts of Papua, Halmahera, and east Timor were not from Austronesian and the difference was seen architecturally. From sixteen types of Indonesian traditional architecture[50], only Dani's tribe traditional buildings had no extended roof features. However, the use of shadow could be found in all Indonesian traditional architecture and had many meanings, not only functional but also philosophical. Third feature was post and beam structures. Rather than sharply blocking the light, there were in-between spaces of dark and light. Kurokawa highlighted post and beam structures as features of Japan and Southeast Asia architecture[51]. However, the roof, which shaded the area underneath it, dominated the whole buildings form in Indonesian Architecture[52]. One example of these three architectural features related to shadows can be seen in Batak tribe traditional house (figure 1.24).

[50] Davison, Julian. (1998) Traditional Architecture. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.8-9). Singapore: Archipelago Press

[51] Kisho Kurokawa. *Shadows, Symbiosis, and A Culture of Wood in VIA 11: Architecture and Shadow*. (1990). Philadelphia, PA: Graduate School of Fine Arts, University of Pennsylvania. p.27

[52] Gaudenz Domenig (1998) Structures without nails. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.13). Singapore: Archipelago Press

Figure 1. 24. The palace of Rajas of Simalungun (top) and Toraja rice barns (bottom). Image source: Indonesian Heritage (1998) p.14, edited by the author

Davison showed general vertical hierarchy of buildings which represent head, body, and legs[53]. Roof symbolized head, which was the space for gods and ancestors. Buildings middle part symbolized body, the space that were shaded and protected, used for accommodating people activities. Legs, the foundations of the buildings, represented the underworld. These symbolic and philosophical view of shadow was different with western perspectives but commonly found in the east. Waterson gave an example of symbolic meaning of the extended roof[54]. In Toraja house Tongkonan, one of Indonesian traditional architecture families, a longer extension of the roof represented the higher power and status

[53] Davison, Julian. (1998) The House as A Ritually Ordered Space. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.18). Singapore: Archipelago Press

[54] Waterson, Roxanna. (1998) Common Features: Extended Roof Ridges. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.14). Singapore: Archipelago Press

of the owner. A longer and larger roof formed bigger shadow. The shadow had meaning to define the space function, as well as distinguish profane and sacred space. In Indonesian traditional architecture, the sacred space was not the area which has abundant light. In contrast with western perspectives, the most sacred area was the darkest place in a building. Miksic noted that the dark sacred space in Indonesian temple was similar with Indian temple[55]. The temple was made from stone, and almost completely separated from outdoor. More common buildings did not use stone but wood. However, the idea of dark and light space were brought to common buildings too. The most dark space was the most sacred and private area.

Indonesian architecture was developed from tribal traditional architecture until the arrival of Europeans in the 16th century. Sumalyo noted that in the 17th to 19th centuries, Indonesian traditional architecture was influenced by western, mainly as a result of the Netherlands colonization[56]. However, western buildings were not suitable with local condition. Later, even architects from the Netherlands, such as W. Lemei, Thomas Karsten, and Henri Maclaine Pont concerned about tropical architecture and used shadow as part of their modern designs to adapt with the local condition[57]. Karsten used roof expansion for solar shading as well as other climate responsive design features, such as opening for cross ventilation and hip roof for rain water. Lemei used shadings to cover openings in European style building for the governor's office in Surabaya (figure 1.25). Sukada highlighted the indigenous design explorations of young revolutionary architects for finding the feasible solutions for climate conditions[58]. Moreover, Sukada noted of two perspectives from 1984 national seminar by Indonesian Institute of Architects of a national architecture identity[59]. The first view showed that national identity should use traditional forms as a reference. The second perspective proposed a new cultural image, which considers western architectural values. Later, Indonesian architecture gradually adapted modern-western architecture to meet local conditions and needs.

[55] Miksic, John. (1998) Sources of Early Indonesian Stone Architecture. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.54). Singapore: Archipelago Press

[56] Saliya, Yuswadi. (1998) Architecture of the 17th to 19th centuries. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.105). Singapore: Archipelago Press

[57] Sumalyo, Yulianto. (1998) Attempted synthesis: Dutch architects in the indies. In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.122-123). Singapore: Archipelago Press

[58] Sukada, Budi A. (1998) The Emergence of a new Indies Style In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.121). Singapore: Archipelago Press

[59] Sukada, Budi A. (1998) Regionalism and Identity in Contemporary Architecture In Gunawan Tjahjono (ed), Indonesian Heritage Volume 6: Architecture (pp.133). Singapore: Archipelago Press

Figure 1. 25. The governor's office in Surabaya, designed by W. Lemei. Image source: Indonesian Heritage (1998) p. 122, edited by the author.

The use of shadow as one of important features of architecture was researched by Purwestri and Widyarta. They studied Universitas Indonesia administrative buildings, Said Naum mosque, and Sendangsono shrine which extensively used shadows. In those buildings, shadow was used by the architect to make dark and light effect which support human activities and has philosophical meaning. Sutedjo highlighted the meaning of shadow as front line protection of tropical buildings against excessive sun effect[60]. Economically, he noted the expensiveness of cooling system so the building protection system against heat must work all the time. A paper was presented to show the perspective of using shadow for an identity of Indonesian architecture in Indonesia national seminar, focusing on contextualizing Indonesian architecture[61]. The paper showed the possibilities of exploring the use of shadow in Indonesian architecture based on but not limited to the design, history, and technology point of view. Shadow already became parts of Indonesian culture which also affecting traditional architecture in Indonesia. The paper specifically highlighted the possibilities of utilizing shadow to respond to the excessive sunlight. Reducing the harmful effect of sun light would help reducing indoor temperature since relatively high temperature happenned all year round in Indonesia, as well as other tropical countries.

Research topic in shadow had a long history in the world, including in architecture. However, the number of researches about shadow were smaller in comparison with research

[60] Sutedjo, Suwondo Bismo. (1996). Konsepsi Arsitektur Indonesia in Eddy Supriyatna Marizar (ed) Upaya Membangun Citra Arsitektur, Interior, dan Seni Rupa Indonesia. Jakarta: Djambatan. Pp.45-62

[61] Suryandono, Alexander Rani. Wihardyanto, Dimas. Bayangan sebagai bagian dari identitas arsitektur nusantara. Prosiding seminar arsitektur nusantara IPLBI 2018.

about lighting in architecture. It happened because shadow was seen as negative part of lighting in western perspective. Lighting was needed in the west to support people activities. Nonetheless, several areas, especially countries around the equator needed shadow for balancing the light. In the tropical region, excessive sunlight was harmful. People had to protect themselves from harmful effects of the light, such as heats and glares. Shading and filtering the enormous amount of lights were two possible solutions. On the other hand, shadow and light also had philosophical and symbolism aspects in several countries, such as Indonesia.

Shadow had also a long history in Indonesian culture, including architecture. Indonesian traditional architecture used shadow, from design process to the operational period of the buildings. The symbolism and philosophical meaning of shadow were important and always be considered in the design process. Shadow, as well as building form, defined spaces. In the building operational phase, shaded spaces were used for human activities. Modernism that was brought by the Netherlands and European colonization affected Indonesian architecture. Western perspective of lighting negated the use shadow following the culture and environmental condition in the west. However, some architects, even Dutch architects, concerned about climate responsive design while they were in tropical countries. The use of roof expansion and solar shading devices were two example of the use of shadow in architecture as responses to the local environment.

Regarding the climate responsive design in architecture, shadow could be explored from engineering aspect too. This research explored the possibilities of shadow as one of alternatives to deal with sustainability issues. Sustainability became one of the main focus of many researches including architectural research. Green buildings were one of the solutions provided by architecture. Kwok and Grondzik (2011) in Green Studio Handbook emphasized Brundtland arguments in an essay that in the common future, while sustainability made no negative impact to the environment for meeting the needs of the people, green buildings was considered as a step toward sustainability. Green buildings had efficiency in terms of energy, water, resource while addressing on-site or off-site impacts. Green design was a process which positively support sustainability[62].

Life-cycle was one approaches to measure the benefits of green design, includes in buildings. According to Tshudy in the United States Green Building council (1996), there

[62] Alison Kwok, Grondzik (2011) Green Studio Handbook 2nd edition. Routledge. p4

were six basic principles and objectives of the green buildings from a life-cycle approach[63]. The first principle was minimizing materials and energy consumptions in the buildings life cycle. The second principle was minimizing pollution and waste throughout the building life cycle. Third principle was the protection of natural environment. The fourth principle was creating a safe, comfortable, and healthy environment. The fifth principle was ensuring the function of the buildings to follow the proposed objectives. The last principle was balancing the environmental with economic performance. Tsudhy also noted that applying the principles of green buildings would bring benefits such as the reduction of the buildings life cycle costs, risk and liability. Green buildings offered enhancement of energy efficiency, lighting, comfort, and healthier built environment which could boost user productivity. Green buildings application would raise stakeholder understanding and awareness of environment. In architecture, green buildings could bring opportunities for new products, and designs.

Woolley, et.al. (2001) in Green Building Handbook volume 1 noted four principles of green buildings[64]. The reduction of building energy in during operational period was the first principle. The second principle was minimizing external waste and environmental damage. The third principle was the reduction of embedded energy and resource consumption. The fourth principle was minimizing the indoor pollution to support healthy environments.

Kats (2003) agreed with Kwok, Grondzik, and Tshudy that green buildings could bring many benefits considering energy and water savings, waste reduction, improve buildings environmental quality, higher occupant productivity, reducing of employee health cost, lower operations and maintenance cost[65]. Kats showed four factors related to the design of green buildings which have positive correlation with improved productivity. These four factors were: ventilation control, temperature control, lighting control, and day lighting[66]. The United States Green Building Council noted that in the United States, the use of overhangs could reduce light and solar heat gain, they also reduced the day light inside the building. The overhangs should be designed carefully including the all year-round effects[67]. According to the United States Department of Energy (1996) passive solar buildings used 47 percent lower energy consumption than conventional new buildings and 60 percent less than older

[63] Tshudy, James A. (1996) Section C: Materials and specifications in US Green Building Council. Sustainable building technical manual. Public technology, Inc.
[64] Woolley. The Green Building Handbook vol 1 p6
[65] Gregory H. Kats. Green building costs and financial benefits. Massachusetts technology collaborative. Massachusetts. 2003. Pp3
[66] Gregory H. Kats. Green building costs and financial benefits. Massachusetts technology collaborative. Massachusetts. 2003. Pp7
[67] US Green Building Council. Sustainable building technical manual. Public technology, Inc. 1996. Part IV Section A-3

buildings[68]. Following the previous research on green buildings and considering the context, this research focused on cooling energy reduction by passive design using sun shading devices while also considering economic benefits.

Passive cooling should be taken into consideration when buildings were designed, built, or renovated since the way buildings were designed, constructed, and used had huge impacts on the need of energy. Once the building was constructed, the amount of active cooling energy was locked in[69]. The most basic of keeping the building cool was solar responsive building orientation and building passive designs, including the use of shading[70]. Fixed shading devices, which were designed into a building, would shade windows throughout the solar cycle[71].

Rather than using internal building elements, external shades were the most effective because they stop solar gain before the sun hits the building[72]. Szokolay (2004) showed that external shading devices were the most effective strategy to control solar heat input. However, Szokolay noted that the effect of external sun shading such devices on wind (thus ventilation) and on day lighting and views must be kept in mind[73]. Eicker (2009) emphasized the importance of external shading by putting the sun protection through shading devices on the outside of the facade[74]. Some researches focused on improving opening in the buildings, such as replacing single glass pane with higher performance double or triple glass, and adding more layers to shelter the building from single to double façade. Other researches highlighted the improvement of glass properties, considering the use of low-e glass rather than traditional glass. Several other researches explored the possibilities of using external shading devices, from overhangs, window fins to louvers. The external shading devices were varied too from static, simple passive design to more complex, dynamic mechanical devices.

There were three basic external shading devices, which were the most effective building element to control the solar heat gain (figure 1.26). The first one was vertical devices, such as vertical louvers or projecting fins. This type of devices was characterized by horizontal shadow angles and provide shading mask in sectorial shape. The horizontal shadow angle was between 90° and - 90° since the angles outside these range means that the

[68] US Green Building Council. Sustainable building technical manual. Public technology, Inc. 1996. Part IV Section A-1
[69] The International Energy Agency (2018) The Future of cooling. p78
[70] The International Energy Agency (2018) The Future of cooling. p15
[71] US Green Building Council. Sustainable building technical manual. Public technology, Inc. 1996. Chapter 11 Renewable Energy
[72] Charles Eley Associates. Passive solar design strategies: guideleines for home building. Passive solar industries council NREL. Rochester, NY. Pp36
[73] Steven Szokolay. 2004. Introduction to architectural science the basis of sustainable design. Architectural press. Burlington, MA. Pp65
[74] Ursula Eicker. 2009. Low energy cooling for sustainable buildings. John wiley and sons ltd pp21

sun was behind the buildings. The vertical shading devices could be symmetrical, providing same left and right performance or asymmetrical. The vertical shading devices were most effective when the sun was towards one side of the window directions. Horizontal shading devices, such as projecting eaves, horizontal canopy or awning, and horizontal louvers or slats, were the second types of external sun shading. The vertical shadow angles characterized the horizontal shading devices which provided a segmental shape shadow mask. The horizontal shading devices were most effective when the sun was at near-opposite the window direction. The last type was the combination between vertical and horizontal shading devices: egg-crate shape shading devices. The shading mask was complex and characterized by multiple angles, following the size and depth of the devices.

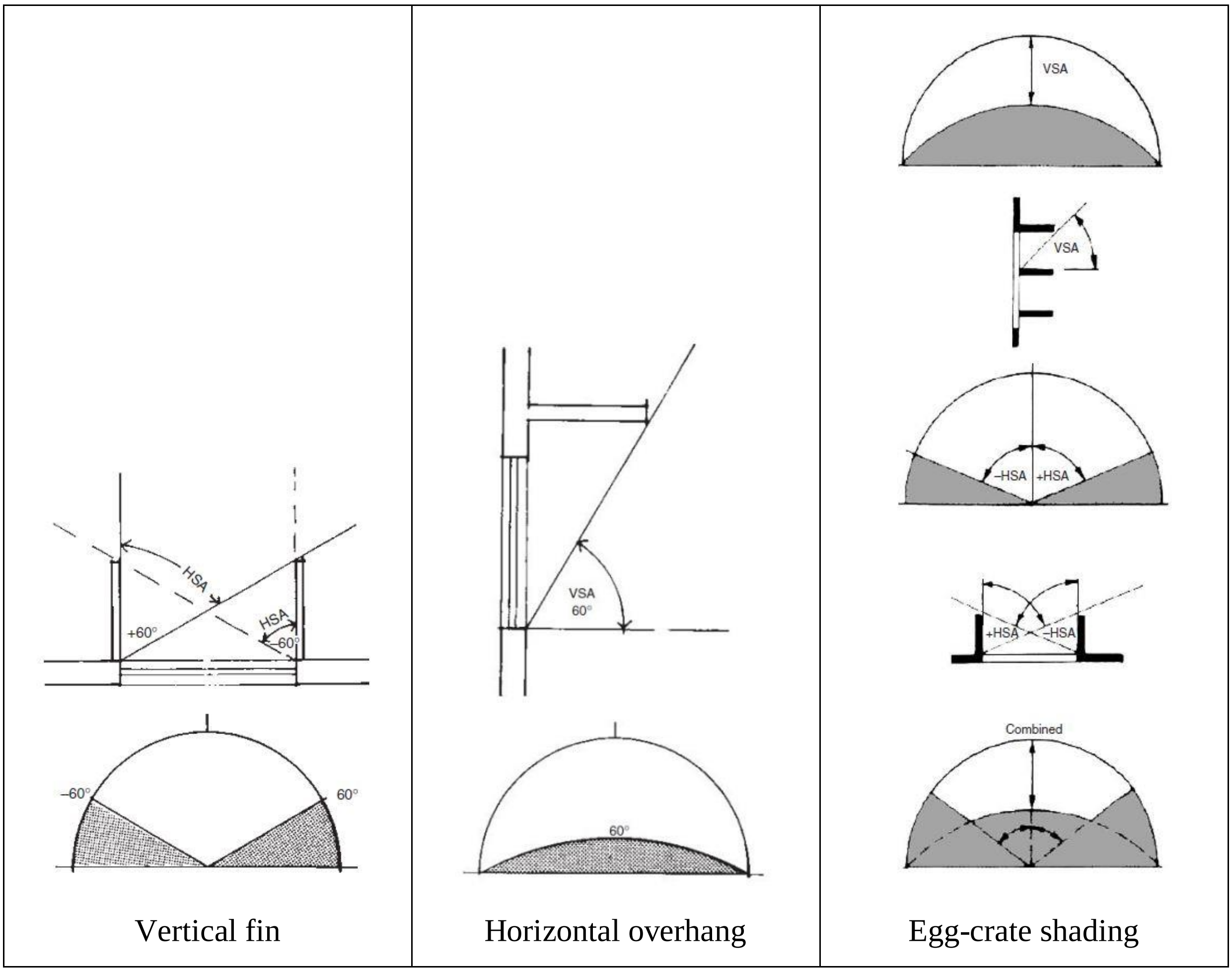

Figure 1. 26. Three basic types of sun shading devices.

Source: Introduction to architectural science the basis of sustainable design p35-37.

There were several researches related to the theory of external shading devices. Evola et.al. (2017) simulated several shading devices in the hall and room in an existing office building in the west and south orientation[75]. The south oriented building for their research was located in Catania, Italy. They emphasized that external shading devices work better than internal shading. There was around 47.7% difference of cooling demand between internal venetian blind with external roller blind in the west façade for hall and the office. In the south-facing glazed façade, external roller blind cut approximately 60.6% of cooling demand higher than those of internal venetian blind. Lai et.al. (2017) showed that different design of grid shading for double glazing window had different effects in energy saving[76]. They simulated several grid base on the width to depth ratio and height to depth ratio in double glazing window for eight cities in China and eight cities in the United States. Lower width to depth ratio and higher height to depth ratio made the total building load lower.

There were traditional architectural elements which sheltering the buildings from excessive sunlight. The Japanese *koshi* was one of the examples of the traditional building elements, which protect the buildings from unwanted external condition, including abundant sun light.

1. 3. An introduction to Japanese *koshi*

According to the simulation, the solar radiation from May to August in Kyoto and Ehime, which use *koshi* in buildings have similarities with the solar radiation with Jakarta. Utilizing weather data from OneBuilding, the average solar radiation in Kyoto and Matsuyama (a city close to Ehime) during the period of summer is 234.08 Wh/m² and 257.82 Wh/m² respectively. There is a possibility to use architectural features in traditional buildings which could reduce the excessive heat during the summer. Architectural features in traditional buildings were the results of thousand years of researches by the ancestors. The inspiration for the proposed design in this study came from *koshi* that utilized small size of sun shading which was attached close to the window's exterior surface. The proposed designs used aluminum with L-shaped profiles which had small size and could be placed close to the window, mimicking the idea of Japanese *koshi*.

Japanese *koshi* was the inspiration for designing mini-louvers. There are similarities in size and shape of Japanese *koshi* and several shading devices, such as Venetian blinds and Persian slats. The difference is the placement of the aforementioned devices in buildings. Unlike blinds or slats, which are usually placed inside the buildings, Japanese *koshi* is placed

[75] Evola, G., Gullo, B., Marletta L., (2017). The role of shading devices to improve thermal and visual comfort in existing glazed buildings. *Energy Procedia 134.* 346 - 355

[76] Lai, K., Wang, W., Giles, H. (2017). Solar shading performance of window with constant and dynamic shading function in different climate zones. *Solar Energy 147.* 113 - 125

at the outside of the buildings. *Koshi* is placed outdoor, with a relative close or without gap with the outdoor surface of the windows or the doors, different with double façade system which are usually leaves a relatively wide gap between façade. *Koshi* placement is similar to overhangs or louvers, but a lot smaller in terms of the members' size.

There are several exterior elements of a traditional Japanese house. One of visually notable elements is *koshi-mado* (格子窓**)**, literally translated as latticed window[77]. Figure 1.27 shows traditional elements of Japanese architecture, *koshi* is marked by the number 6.

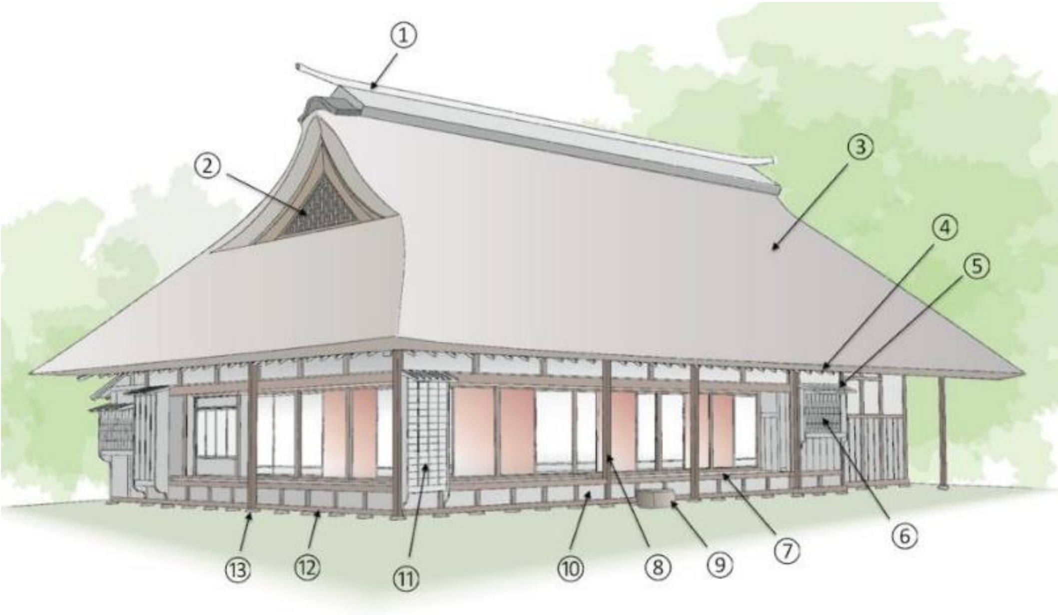

Figure 1. 27. The exterior elements of a traditional Japanese house.
Source: https://manabi-japan.jp/en/art-design/20200401_20235/

Traditional *koshi* or the latticework in the window is made from thin strips of woods. *Koshi* with parallel strips members is called *renji*. *Renji* provides additional security to the house while still allows air and light to pass through. This type of *koshi* are also used for doors. There is another local, specific name for *koshi*, for example the lattice windows in the plastered second story house in *Kyo-machiya* which is called *mushiko-kabe.*

Traditional Japanese houses in *Kyo-Machiya*, (*machiya* literally means townhouse) Kyoto usually have *koshi*. These buildings are protected by law as one of the most culturally significant and valuable architecture in Kyoto. *Machiya* (町屋/町家) houses, which

[77] https://manabi-japan.jp/en/art-design/20200401_20235/ Accessed October 7, 2019

accommodate two functions as residential and commercial, in Kyoto can be single to three storey buildings which are built long, narrow and close to the street[78]. The buildings are made from natural materials, such as wood, earth materials, topped with baked tile roof. Indoor garden are usually present to bring natural elements and seasonal changes into the interior area. Other notable elements in Machiya are *mushikomado*, *inuyarai* and *degoushi or koshi*. Second storey wall in *machiya* is made from earthwork which consists of *Mushikomado* (虫籠窓), a plastered window embedded in façade. The vertical shape of *mushikomado* resembles the traditional Japanese insect cage. *Inuyarai* (犬 矢 来) is curved bamboo barrier, mainly used for preventing the dogs urinate the wall. It also serves for protection against splashing rain water, and people leaning against the wall. *Degoushi* (出格子) or *koshi* (格子) is basically means latticework or grille, with its various forms and names[79]. *Koshi* is commonly used as fence, door, or parts of windows. However, *koshi*, which is attached in windows, was established after the Onin civil war in Kyoto[80].

The classic traditional *koshi* has six basic types (figure 1.28). They are *senbon koshi*, *men koshi*, *kogaeshi koshi*, *oyako koshi*, *kiriko koshi*, and *ara koshi*[81]. *Senbon koshi* literally means thousand strips. The name comes from the latticework arrangement which consists of many small stripes. This type of *koshi* is usually used for residential. The size and gaps among stripes are varied from one house to others. However, in the same *koshi*, the members' size are identical. Same rule is also applied to the gaps' size. Rather than using small strips, *men koshi* utilizes wide planks with small gap among them. This type of *koshi* provides the most filters from the outside and vice versa. Since it provides more covering, this type of *koshi* is usually used not only as building elements but also as fence. It gives more security in comparison with other type of *koshi*. *Kogaeshi koshi* have identical size of the gap and strips. The size is usually larger than *senbon koshi* but smaller than *men koshi*. *Oyako koshi*, means parent and child, have combination of wide planks (parents) and small strips (children). *Kiriko koshi* have 2 to 4 top strips cut at a recurrent interval for allowing more light to come into the buildings. This type of *koshi* is usually used for fabric shop, for example kimono store. More opening from the cut strips of *koshi* lets extra natural light from the outside to support the activity inside buildings. *Ara koshi* utilizes similar size with *kogaeshi koshi* but

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78 Kyoto center for community collaboration. Machiya revival in Kyoto. 2009. Mitsumura Suiko Shoin publication. Kyoto, Japan. p10

79 http://www.aisf.or.jp/~jaanus/deta/k/koushi2.htm Accessed September 6, 2019

80 Exterior Koshi. http://www.hachise.com/kyomachiya/features/exteriorKoshi.html. Accesed October 1, 2019

81 Japan Architecture: Koshi Latticework. https://www.japan-architecture.org/latticework/. Accesed October 1, 2019

thicker wood. This type of *koshi* is sturdy and hard to be removed. This type of *koshi* is usually painted with reddish color paint finishes called Bengara.

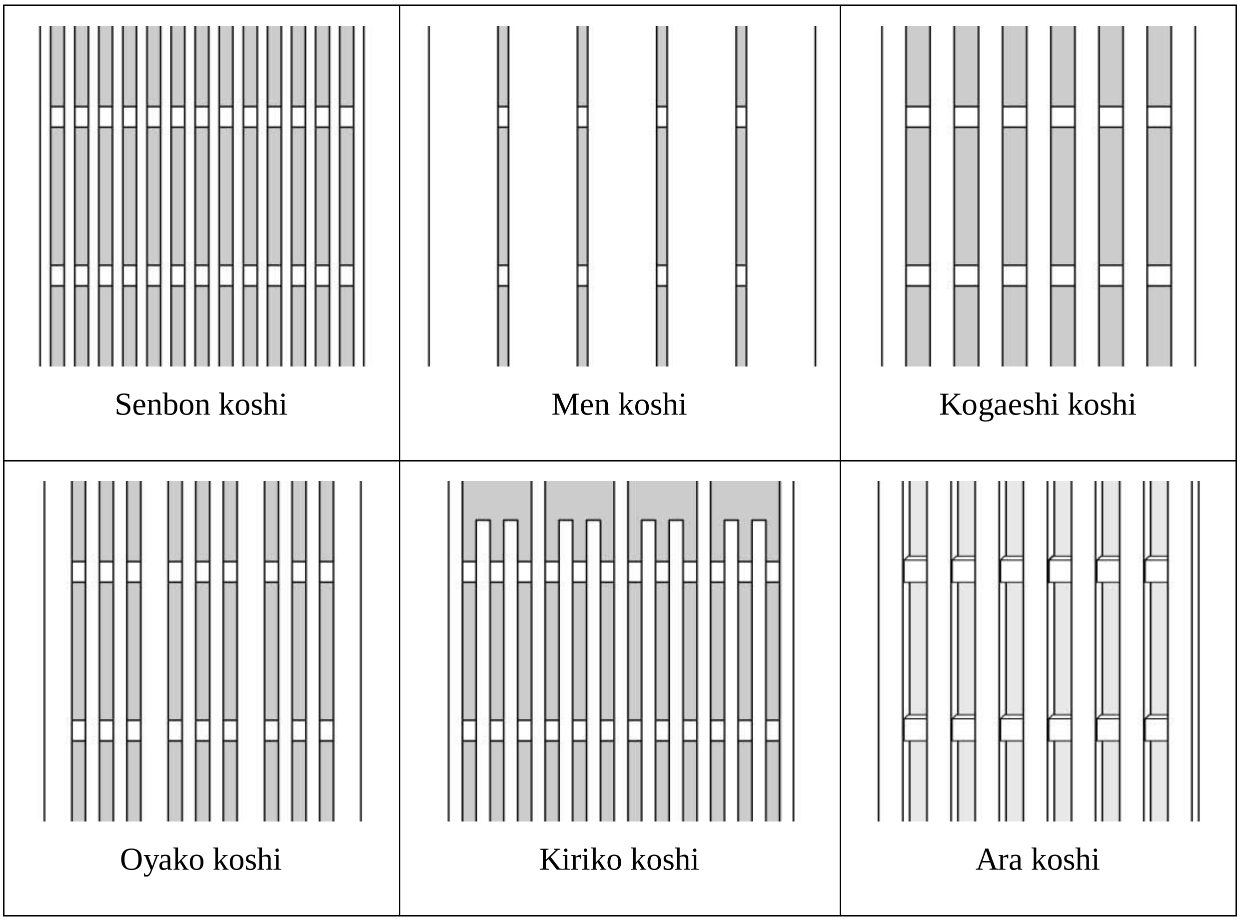


Figure 1. 28. Several types of koshi.

Source: https://www.japan-architecture.org/latticework/

Koshi has many roles. First, it serves as an identity of the shop, for example in Kyoto, *itoya-koshi* is an identity for thread stop while *ochaya-koshi* is used for tea shop. Second, *koshi* provides extra security to the buildings. Third, *Koshi* can be used for placing or attaching building identity, informations or seasonal ornaments (figure 1.29). Fourth, *koshi* acts as filtering screen. *Koshi* can protect the privacy without fully blocking the view from outside to the inside of the building and vice versa. People can view the activities inside the building, especially for checking the crowd inside the shop. When *koshi* is placed without glass, it can filter the excessive sound, reducing the unwanted noise from the outside of the buildings. Without additional layers covering *koshi*, it can also filter wind, reducing the speed of the wind to be a more comfortable level of speed inside the buildings. *Koshi* can reduce the excessive sunlight to the buildings. There is also a possibilities of using *koshi* to reduce not only natural light inside the buildings but also heat that comes with it.

Figure 1. 29. Informations of the buildings and seasonal ornaments were attached to koshi. Source: photographed by the author

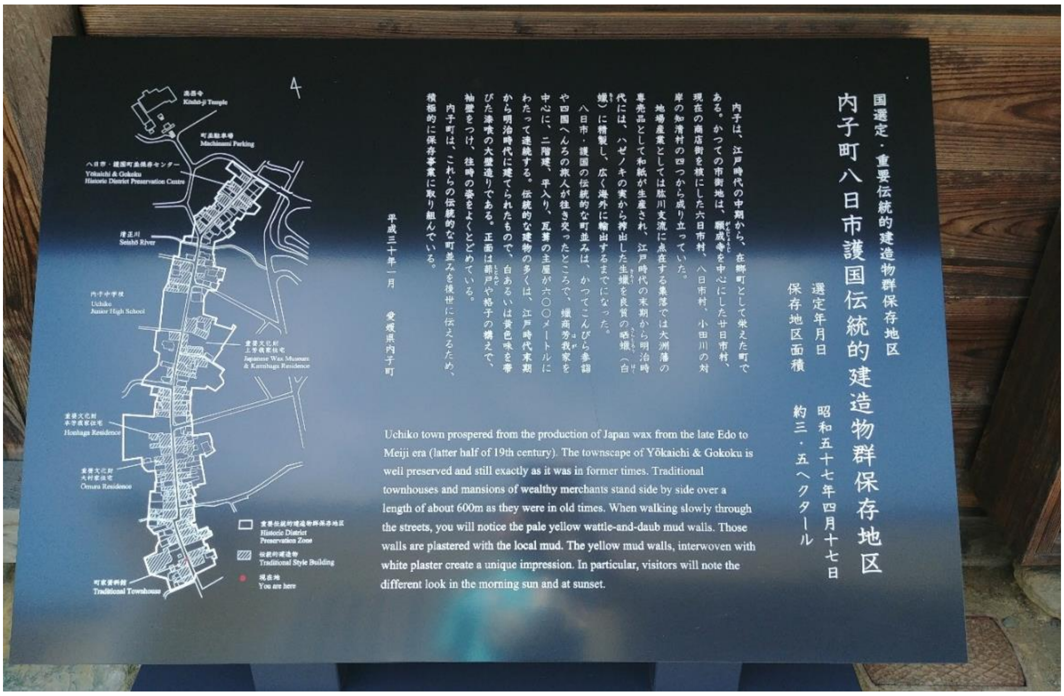


Figure 1. 30. The map of Uchiko Town, Ehime, Japan.

Source: photographed by the author

Figure 1. 31. Koshi in Uchiko, Ehime.

Source: photographed by the author

There is another area in Uchiko town, Ehime which has many traditional buildings (figure 1.30). These buildings are preserved by the government. All of the preserved houses and buildings in this village have *koshi*, for example one building in figure 1.31 which specifically has information about *koshi*. These building elements let the sunlight enter the building and keep maintaining privacy. *Koshi* can be placed close to outdoor surface of window (figure 1.32) or have a distance with the window by putting it at the window frame (figure 1.33). It can be a freestanding element without glass or paper layer which not only allows light to come through but also the wind and sound (figure 1.34). *Koshi* becomes one of the building element which easily recognized as Japanese style, which is placed not only for traditional houses but also modern buildings with a wide variety of building functions, from housing, office, to commercial functions. The orientation of *koshi* is also varied from vertical to horizontal (figure 1.35). It is used not only all over the Japan but in other countries as well.

Figure 1. 32. Koshi is attached at the door frame.

Source: photographed by the author

Figure 1. 33. Koshi is attached in the window frame.

Source: photographed by the author

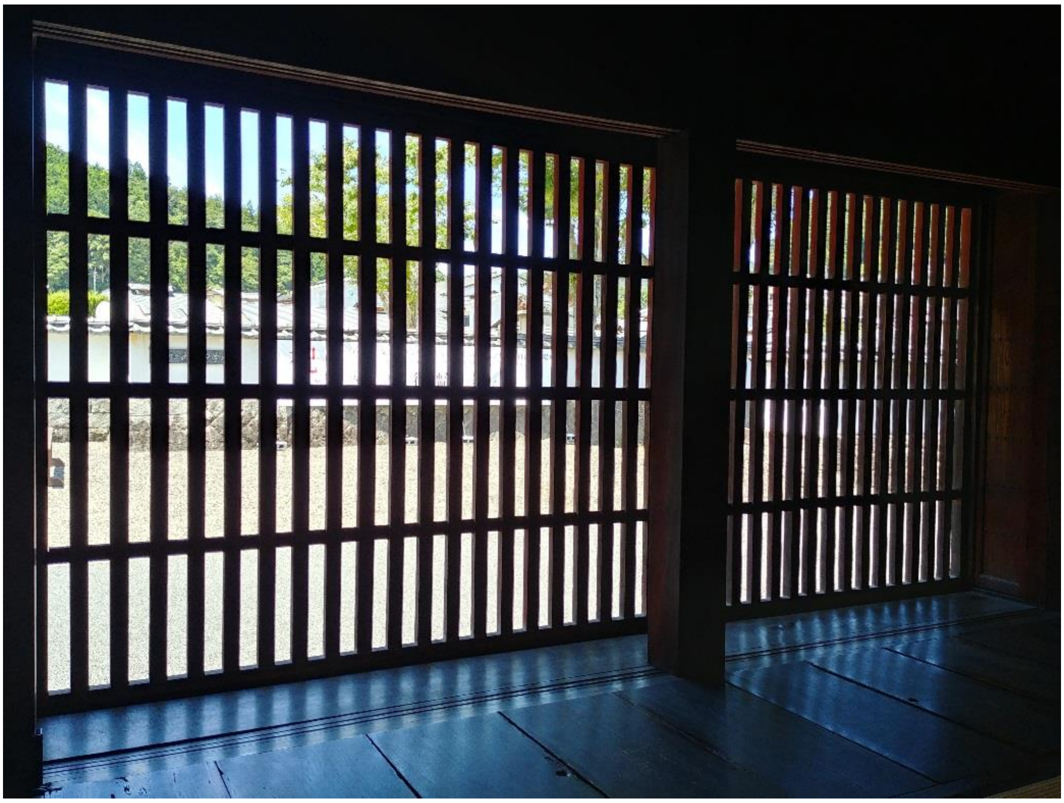


Figure 1. 34. Koshi as a freestanding building element.

Source: photographed by the author

Figure 1. 35. Horizontal koshi in a commercial building in Kitakyushu, Japan.
Source: photographed by the author

One example of the use of *koshi* outside Japan is in a museum in Chicago, the United States. The Frank Lloyd Wright collections of Japanese printing become permanent exhibition in The Chicago Institute of Arts. Japanese *koshi* stands as interior partition which also serves as an identity to the room (figure 1.36). Frank Lloyd Wright is one of notable western architects that worked and lived in Japan. One of his notable design in Japan was the Imperial Hotel in Tokyo. Frank Lloyd Wright specifically noted the simplicity, modularity, and emphasis on geometric structure in Japanese traditional building elements as their similarity with his admiration in art and architecture. After visiting Japan in 1905, he brought a large number of Japanese prints which also contain photographs as well as information about Japanese architecture. These prints as well as photographs were exhibited inside the room which are marked by the presence of Japanese *koshi*.

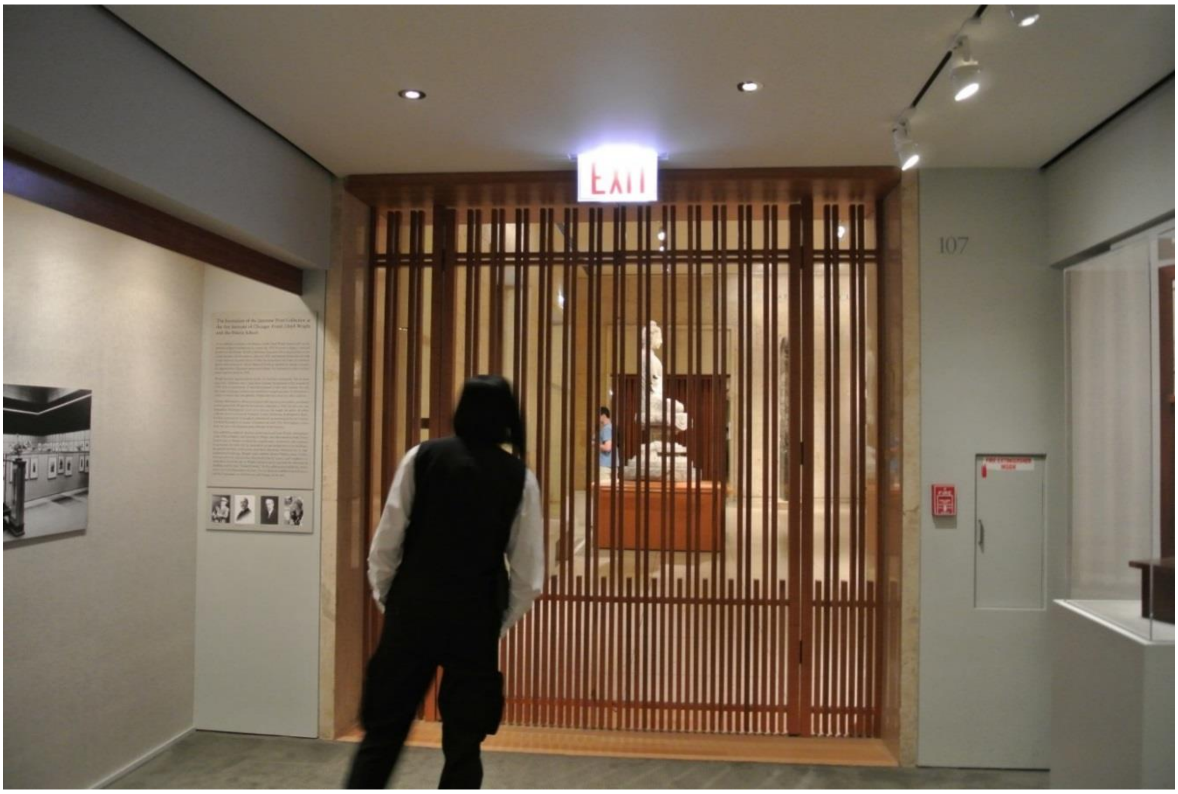


Figure 1. 36. Japanese koshi in the interior of the Institute of Arts in Chicago, the United States.

Source: photographed by the author

Koshi are usually made from wood strips or planks. However, more varied materials can be found today, not only wood but also other materials such as vinyl and metal. Aluminum is a metal material that is widely used for many applications in buildings, from decoration to structural purposes. Stacey and Bayliss (2015) examined the durability of aluminum by inspecting twelve case studies and executing three non-destructive tests of the aluminum finishes[82]. They concluded that the life span of aluminum windows should be at least 80 years. A 41 years old polyester powder coated aluminum window were still in service in 2014 while the guarantee offered by the company in 1973 was only 10 years. The oldest, 26 years old PVDF coated aluminum showed a similar condition to the first inspection in 1988. They noted that aluminum which are used in the interior have an infinite life expectancy. They added that aluminum which are used outdoor and exposed with weather condition, such as sun and rain have more than 120 years of life expectancy. They also noted that aluminum is more durable when the surface was washed by rain water. Skejic, et.al. (2015) studied the use of aluminum in modern structures, ranging from bridges to buildings.

[82] Michael Stacey and Chris Bayliss. Materials Today: Proceedings 2 (2015) p5088-5905

They showed many advantages of aluminum over other building materials, such as lightweight, easy workability, tough even at low temperatures, low maintenance cost, high durability and recyclability. However, they noted that the stability and fire resistance of the aluminum was not studied in their paper. They also mentioned that the main barrier of wider use of aluminum was its relatively high price. In the Wonder metals website, they mentioned four benefits of the aluminum louvers[83]. First, the aluminum louvers was flexible. It was versatile enough to be shaped according to the user. Second, the aluminum louvers was durable. Aluminum was one of the sturdiest materials and light weight, which could be used for a long time. Third, the aluminum was recycle able. The new aluminum needed a lot of energy to create from raw materials. However, it could be recycled without losing its material properties. Forth, the aluminum had an aesthetic value. The weather and climate condition could not impair the look of an aluminum since it did not rust and had resistance to a corrosion. It could also be coated and colored to follow and match with the designer intention.

Based on the proposed sun shading design, which was inspired by Japanese *koshi*, the L-shaped aluminum profiles were chosen to replace the small strips wood. L-shapes aluminum profiles had all the benefits of aluminum. There were several benefits of choosing L-shaped aluminum profiles as mini-louvers. First, it was widely available. L-shaped aluminum profiles were widely available in building material stores in most of the cities, not only in Jakarta, Indonesia - the selected location for this study but also other cities as well. It also available in online store, not only local but also international web market which could sell their products worldwide. There were many sizes available to from as small as 9 mm to 50 mm. The legs of L-shaped profiles could be asymmetric or both had same size. Second, the price was relatively low in Jakarta. For the selected size of 15 mm x 15 mm with 0.08 mm thickness, the silver color cost around IDR 4,000 (around USD 0.26 – April 2020 currency exchange rates) per meter. Third, the proposed design was very simple and easy to construct. It required no specific construction working skills. The louvers could be attached at the exterior surface of the glass window by applying double-sided tape. The L-shaped mini-louvers could also be put in the window frame using screw or nail, according to the window frame materials.

[83] http://wondermetals.com/benefits-of-aluminum-louvers/ Accessed October 6, 2019

1. 4. Research problem

Cooling energy reduction was the main problem in this research. This research focused in designing a simple sun shading device as solar protection that reduce heat gain entering a building using available materials, require minimum skill for constructing, and low maintenance. The proposed design was examined to provide a possible solution for cooling energy reduction while considering not only environmental benefit, from cooling energy reduction to day light optimization but also from economic point of view, by checking the simple payback period. Jakarta, Indonesia was the chosen location for this research as an example for other area which may have similar problem.

1. 5. Research purpose

The purpose of this research was examining the proposed design of L-shaped mini-louvers both environmental, such as cooling energy reduction and day light optimization and economic benefits, such as construction price and simple payback period. Based on this research result, the proposed sun shading design could be used as one of the possible simple solution to obtain environmental benefit by reducing the cooling energy consumption while considering economic benefit for buildings in Jakarta. The proposed L-shaped mini-louvers sun shading device could be used for different building types, from residential, office, to other building functions. The L-shaped mini-louvers could also be installed in new constructions, as well as applied to retrofit old buildings. There was a possibilities to put the L-shaped mini-louvers to single detached houses to multi story, high-rise buildings.

1. 6. Research novelty

There were some researches related to sun shading devices. Palmero-Marrero and Oliveira (2010) researched louvers for cooling energy reduction using computer software simulation[84]. They noted that energy saving for cooling by applying louvers as sun shading devices were significantly higher in cities with high solar radiation such as Cairo, Lisbon, and Madrid, in comparison with London. Invidiata and Ghisi (2016) researched life-cycle energy and cost analysis of window shading to improve indoor thermal condition[85]. They noted that the initial cost, includes the cost of the shading, cost of shading transportation, and cost of shading assembly and installation, the maintenance cost, and the cost of deconstructing the

[84] Palmero-Marrero Ana I, Oliveira Armando C 2010. Effect of louver shading devices on building energy requirements. Applied Energy 87 pp 2040-2049
[85] Invidiata Andrea, Ghisi Enedir 2016. Journal of cleaner production 133/ pp 1371 - 1383

shading have larger role in terms of economic. Zomorodian and Tahsildoost (2019) accessed the effectiveness of predicting day light availability and visual comfort in classroom[86]. They found a positive correlation between the simulation results and overall occupant satisfaction of useful daylight index. However, they noted the limitation of their research, only for a classroom in Texas, US and suggested more studies to improve the annual climate-based day lighting metric understanding. Hariyadi et.al. (2017) simulated office buildings in Jakarta using external shading device to reduce around 6% of annual thermal energy in office buildings[87].

Some architects and studio used filtering panel as shading and visual aesthetic elements to give identity to the building. There were several case studies vary from small, residential buildings to large hotels and museums, and from new constructions to old building retrofitting. M.H. de Young Museum in San Francisco building by Herzog and de Meuron was known for its copper façade panel (figure 1.37)[88]. According to the architects, the idea of copper perforated panel came from the shadow of trees. The perforated panel filtered sun light blended the museum with surrounding natural environment, which was one of the most consideration of the architects (figure 1.38).

Figure 1. 37. Exterior view of de Young Museum by Herzog and de Meuron. Source: herzogdemeuron.com

[86] Zomorodian Zahra S, Tahsildoost Mohammad 2019. Assessing the effectiveness of dynamic metrics in predicting daylight availability and visual comfort in classrooms. Renewable Energy 134. Pp 669-680

[87] Hariyadi A, Fukuda H, and Ma Q 2017 The effectiveness of the parametric 'Sudare' blind as external shading for energy efficiency and visibility quality in Jakarta *Architectural Design and Management* 13 (5) pp 384-403

[88] https://www.herzogdemeuron.com/index/projects/complete-works/151-175/173-de-young-museum.html Accessed October 12, 2019

Figure 1. 38. Interior view of the perforated copper panel detail.
Source: herzogdemeuron.com

RARE architecture designed a façade to restore and refurbish Edwardian town hall, an existing grade II listed building[89]. They cut holes through aluminum panel which envelope the old building with book pattern. The laser-cut aluminum perforated panel filtered the light to the interior area (figure 1.39). The screen filter also protected the privacy of the interior from unwanted view from the outside. Aesthetic and functional for filtering, the panel also covered the radiator and air-conditioning that currently used in the hotel.

[89] https://www.designhotels.com/hotels/united-kingdom/london/townhall-hotel-apartments/architecture Accessed October 13, 2019

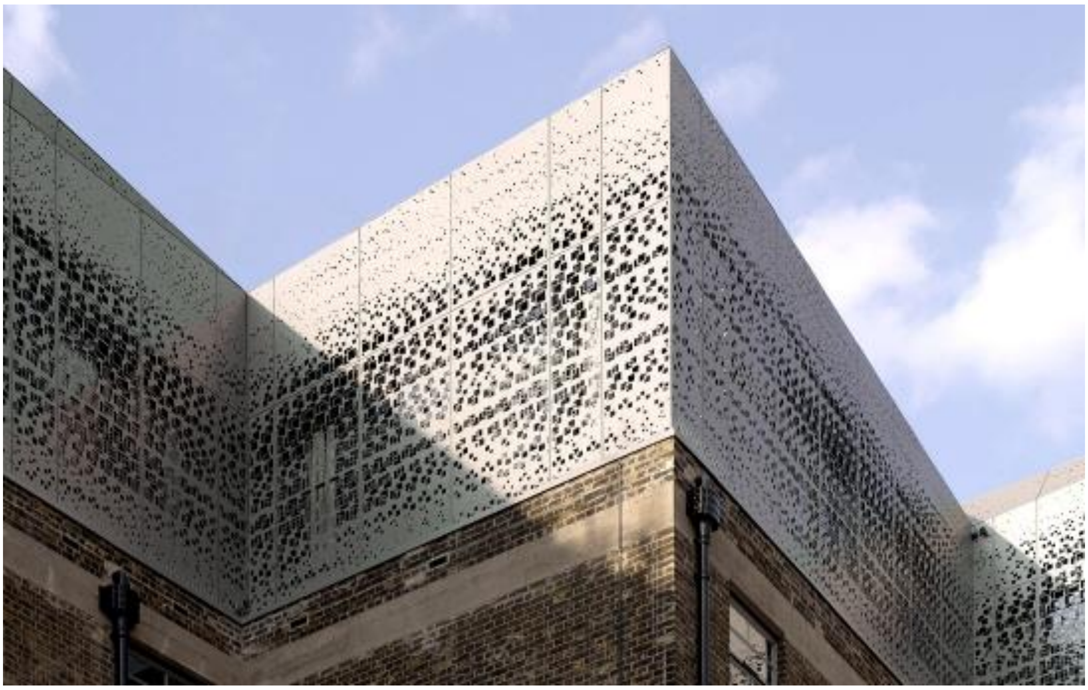


Figure 1. 39. Town Hall Hotel by RARE.
Source: designhotels.com

Rather than using screen filters, these two houses were examples of using louvers or horizontal strips shading devices. The first case was McKinley House[90]. David Hertz/ Syndesis was the architect for the expansion projects from 1996 McKinley house in Venice, California (figure 1.40). The original 2400 square feet house was expanded to 7200 square feet by adding new wing and building components in 2004. The architects used certified epe, a tropical hardwood to create the slats for shading the new wings. The slats gave unique looks of the buildings, distinguish the appearance from the old constructions. The slat did not only filter the sun light and excessive wind but also the view. The slats visually blurred the distinctions between inside and outside.

[90] Alanna Stang, Christopher Hawthorne (2005) Green House: New directions in sustainable architecture. Princeton Architectural Press. p135-139

Figure 1. 40. Mc Kinley house slats in front of the openings.
Source: Green House: New directions in sustainable architecture p136

In the second example, Lahz Nimmo Architects massively used slatted timber cladding and louvered windows in Casuarina beach house Kingscliff, New South Wales (figure 1.41)[91]. The architects reused blue gum, a native hardwood from Railway Bridge for the battens and cladding. Since the building was located in tropical area with no concern of heat loss year round, standard single pane glass were used in the building. The large proportions of the glass in the building were carefully shaded with overhangs or battens. This building utilized no mechanical air conditioning but used shutters and louvers to control the lights and wind into the building. The architects explained that this is the way the house "is breathing".

[91] Alanna Stang, Christopher Hawthorne (2005) Green House: New directions in sustainable architecture. Princeton Architectural Press. p162-167

Figure 1. 41. Casuarina beach house exterior view.
Source: Green House: New directions in sustainable architecture p164

Some researches focused on large buildings, from commercial to office buildings, rather than small structure, such as small residential houses. Some researches were done by testing or simulating customized sun shading device which were not widely accessible by public, rather than exploring the available building materials or elements. However, considering the possible condition in the future of cooling energy demand in emerging economic countries, the International Energy Agency (2018) urged the need of lower costs for high-performance building components, potential economic and environmental benefits of technological advances in cooling research[92]. Cost is important since it plays a large role for design as well as construction decision.

Responding to the previous research, architectural implementations of shading devices into building designs and urgent research needs noted specifically by the International Energy Agency, this research offered a new sun shading device which is simple – easy to build and construct, using widely available materials, and maintenance-free. The L-shaped mini-louvers offers a novel sun shading design that could be environmentally and economically beneficial.

[92] The International Energy Agency (2018) The Future of cooling. p81

1. 7. Research structure

This dissertation was divided into nine chapters, which sequentially structured to find the conclusion (figure 1.42). The research methodology and or the results for each chapter were presented or published in scientific seminars and journals.

Chapter 1 Introduction

The first chapter in this dissertation contains the background of the research, such as the cooling energy, shadow in architecture, Japanese *koshi*, previous researches as well as architecture case studies, and the condition in Indonesia – related to the cooling energy demand. The research problem, research purpose, and research structure are also presented in this chapter

The use of shadow in Indonesian architecture was presented in a paper *"Bayangan sebagai Bagian dari Arsitektur Nusantara"* (Shadow as Part of Indonesian Architecture). The topic was related to the first, introduction chapter in this dissertation. It was presented at *Seminar Arsitektur Nusantara*, an architecture seminar focusing on Indonesian architecture. This presentation was conducted to show that the use of shadow in architecture can culturally be accepted in Indonesia.

Chapter 2 Preliminary research on L-shaped mini-louvers

The second chapter focuses in shading devices, which is one of green building features to support sustainability. Computational research methodology for this paper is presented in this chapter. This chapter contains the preliminary research, the first simulation to test the shading device: *Batik* pattern panel. Local traditional elements such as *batik* is used for designing sun shading device to filter the excessive solar radiation.

The paper related to this chapter entitled "*Batik* pattern panel performance of solar radiation reduction" was presented at the 4th International Conference in Indonesian Architecture and Planning.

Chapter 3 L-shaped mini-louvers for reducing solar radiation

This chapter introduces L-shaped mini-louvers which was inspired by traditional Japanese architecture element: *koshi* to inspire a novel modern design of sun shading devices. The L-shaped mini-louvers can reduce cooling energy consumption by blocking the solar heat before it enters the buildings. This chapter consists of the parametric making and simulation of L-shaped mini-louvers in solar radiation reduction.

The paper related to this chapter, "L-Shaped Mini Louvers Performance of Solar Radiation Reduction in Glass Windows" was presented at the 12^{th} South East Asian Technical University Consortium symposium international seminar.

Chapter 4 Wooden box with L-shaped mini-louvers thermal performance experiments

Indoor thermal experiments were conducted for the next step after confirming the performance of L-shaped mini-louvers of solar radiation reduction. The fourth chapter of this dissertation consists of a series of experiment of the L-shaped mini louvers.

This experiments were written into a paper "L-shaped mini-louvers performance for reducing indoor temperature". The paper was presented at the 5^{th} International Conference in Indonesian Architecture and Planning. The paper was published in IOP Conference Series: Earth and Environmental Science Volume 764 in 2021.

Chapter 5 L-shaped mini-louvers for cooling Energy Reduction in residential in Jakarta, Indonesia

Chapter five consists of the research of cooling energy reduction by utilizing L-shaped mini-louvers in residential setting in Jakarta, Indonesia. Window without shading was used as base case while an overhang, a more common type of shading device in Jakarta was used for comparison. Series of computer simulation were executed to measure the effectiveness of L-shaped mini-louvers in reducing the cooling energy in residential building in one-year scenario.

There were two research paper, utilizing the same research methodology in this chapter. The first paper, "Mini-louvers performance of building cooling load energy reduction" was presented at the Grand Renewable international conference and published in J-stage proceedings. The second paper, "Performance of L-shaped mini-Louvers in tropical cities in cooling energy reduction: case study of Mumbai, Mexico City, and Lagos" was presented at the 3^{rd} Green Urbanism International Seminar. This paper was regarded as a distinguished paper in the conference. It was accepted and to be published as a book chapter in "Advanced Studies in Efficient Environmental Design and City Planning" within a book series titled "Advances in Sciences, Technology and Innovation" (ASTI) by Springer. The ASTI book series is submitted for indexation in Scopus and the ISI Web of Science. The book is currently in production stage and will be published in July 26, 2021.

Chapter 6 Economic aspect of L-shaped mini-louvers for calculating simple payback period

The sixth chapter in this dissertation brings the possibility of the application of L-shaped Mini-louvers in a real world scenario by considering economic benefit. The cost of L-shaped mini-louvers construction and maintenance was compared with the electric saving to reveal the simple payback period.

The paper "Environmental and Economic Benefits of Japanese *Koshi*-inspired Mini-Louvres in Residential Buildings in Jakarta, Indonesia" was published in Journal of Façade Design and engineering Vol. 8 No. 2 (2020), a Q-1 Architecture indexed Scopus journal.

Chapter 7 Daylight studies using L-shaped mini-louvers in a room with multiple windows

Rather than only cooling energy reduction, which is the main focus of environmental benefit in this research, day light studies were also presented to show other positive environment impacts of the L-shaped mini-louvers application, even for building functions other than residential.

The paper "Daylight Performance of L-shaped Mini-louvers in Office Buildings" was presented at the 16th Asia Institute of Urban Environment international conference. The presentation of this paper received the best presenter award in the conference.

Chapter 8 L-shaped mini-louvers' performance in office in Jakarta, Indonesia

Simulating L-shaped mini-louvers in different setting than residential is important to gather information of its performance. Following the results of previous chapter, this chapter shows simulation results of 15 mm × 15 mm and 30 mm × 30 mm L-shaped mini-louvers in office.

The paper "Economic Assessment of L-Shaped Minilouvers for Reducing Cooling Energy and Improving Daylight Condition in Offices: A Simulation Study in Jakarta" was published in Sustainability Journal Volume 13 Issue 7 (2021).

Chapter 9 Final Conclusion

The last chapter consists of the conclusion of all the research in this dissertation. The L-shaped mini-louvers could be beneficial in terms of environmental and economic according to this research results and analysis.

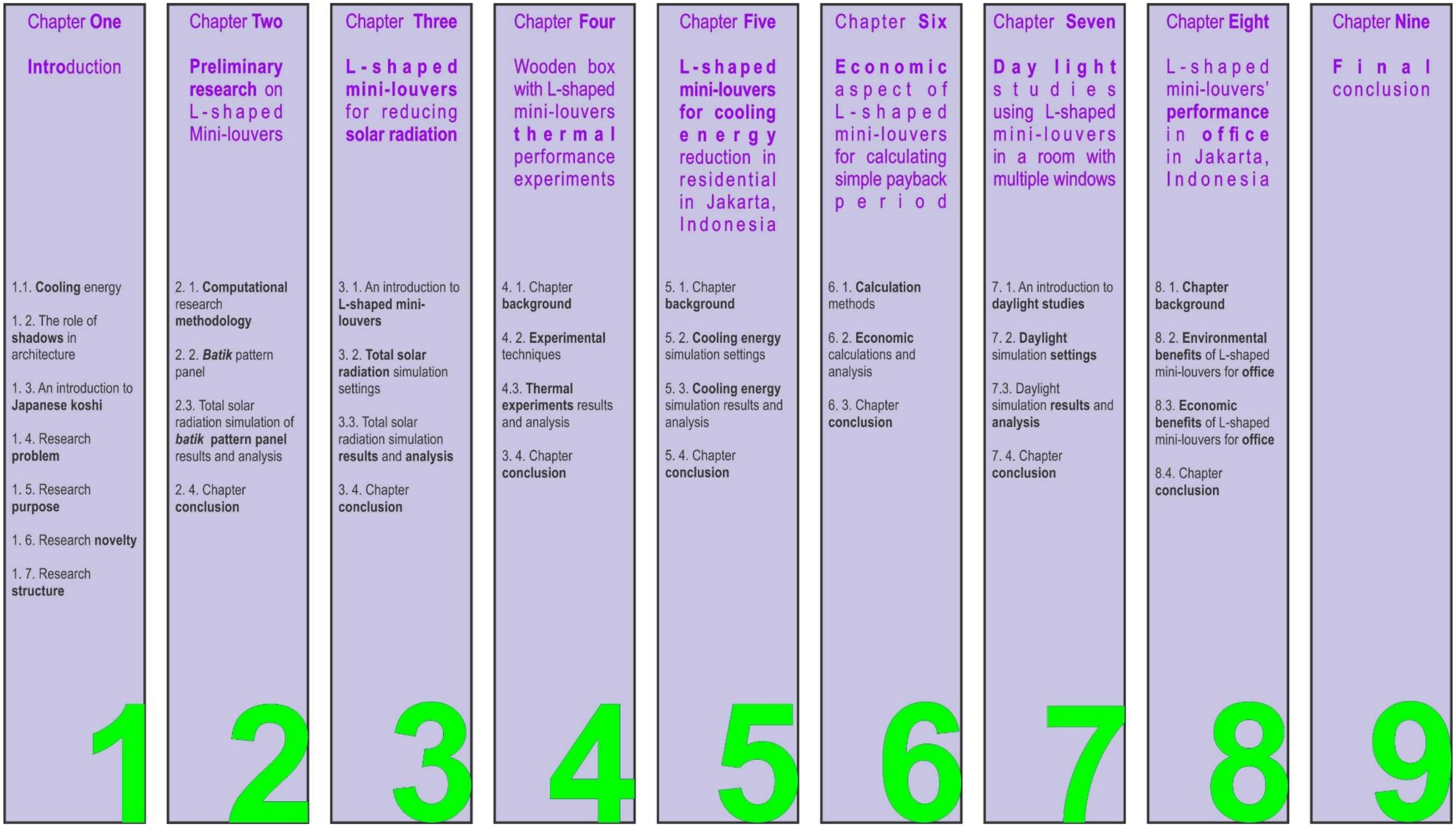


Figure 1. 42. Research structure.

Source: photographed by the author

Chapter 2 – Preliminary research on L-shaped mini-louvers

2. 1. Computational research methodology

According to the previous researches, as well as architectural case studies, sun shading device can reduce the cooling energy consumption in buildings. The first step to explore the potential use of shadow in architecture was by exercising simulation of solar radiation. Computer apparatus for this simulation was Microsoft Windows 8.1 system using hardware configuration as follows. The processor was Intel Core i7 – 5960X CPU @3.00 GHz. The graphic processor used in the computer was NVIDIA GeForce GTX-970 with independent graphic memory of 4 GB GDDR5. The main system was utilized with 32 GB of RAM. The hardware were compatible with the software for doing the simulation, post-processing the necessary documents and creating presentation of this study.

Rhinoceros 3-dimensional version 5 was the main software to host of all simulations. Rhinoceros using non-uniform rational B-spline which could precisely represent curves and freeform surfaces. Inside Rhinoceros 5, there was a parametric modeling plug-in, Grasshopper. Grasshopper, visual programing which operates in Rhinoceros, could be used for many purposes from parametric design to environmental analysis. Grasshopper was used for parametrically designing the sun shadings in this study, from the *Batik* pattern panel, overhangs to the novel L-shaped mini-louvers. Grasshopper brought the ability of parametric designs and acted as an interface for other simulation software. To do the environmental simulations, there were two main plug-ins inside Grasshopper: Ladybug and Honeybee. Ladybug could be used for reading and analyzing standard weather data (*.epw). Related to the study in this dissertation, Ladybug was used for downloading weather data, providing sun path, radiation-rose, and radiation analysis. Ladybug was used in all the simulation utilizing weather data in this study, even in the first chapter to present the weather condition of Jakarta, the specific chosen location in this research. In this dissertation, two simulation engines operated behind Ladybug and Honeybee were used. The first one was EnergyPlus, which simulated the building energy consumptions. The cooling energy consumption simulation was presented in chapter five. The other one was Radiance, which was used for simulating day lighting in chapter seven.

The software for calculating the results, creating tables and charts was Microsoft Excel. Microsoft Word was used for preparing the document, as well as saving it into Adobe portable document files (*.pdf). Microsoft Power Point was used for presenting the results.

All these three Microsoft software was in 2010 version. Another software, CorelDraw version X6, was used for creating graphics presentation and schematic images of the research.

The technique for simulation in this study was begun with analyzing the weather data. The Jakarta weather data was downloaded and analyzed for simulating annual total solar radiation. There are total 8760 hours of simulation for each direction in a year. In Jakarta and many other cities in Indonesia, the housing directions are vary, unlike the grid-based city layout in the western. This was the reason of eight major orientations are simulated in this study: north, northwest, west, southwest, south, southeast, east, and northeast were simulated. The sun shading devices in all eight orientations were simulated to measure their performance of reducing the solar radiation in different directions. The sky for this simulation was Reinhart sky which divided the sky into a very fine of 580 sky patches of sky dome. Reinhart sky was considered as the best since it provides more accurate results than Tregenza sky which divide the sky dome into 145 sky patches, even though the simulations took longer time. This method was used in this chapter and chapter three. In chapter four, another different method was executed to simulate the cooling energy. Rather than only used Ladybug, Honeybee is also used in chapter five. The EnergyPlus was the simulation engine behind Honeybee to measure the cooling energy consumption of the design. The detail of the parameters were provided in the same chapter. In chapter seven, there was another simulation engine: Radiance which allows day light simulation to be executed. In chapter seven, the detail parameters of the designs were also presented.

2. 2. *Batik* pattern panel

Batik pattern was chosen to be simulated in this chapter for reducing the total solar radiation falls in building facade. Other than that, sun shading devices can be used as a design response to the context. The exploration of *batik* as local pattern using parametric methods to obtain a pattern to be placed onto a filter panel was performed. The result of the panels were simulated to obtain the solar reduction as an effect of the panel attachment to a facade. Two Indonesian *batik* patterns were chosen to form the design of the screen panel.

Batik is a process of obtaining traditional motif into textiles that are commonly used in Indonesia, notably in Java. *Batik* was recognized by the UNESCO as a masterpiece of oral and intangible heritage of humanity in October 2009[93]. Considering previous architectural case studies and researches of the use of screen filters, this chapter presented the use of *batik*

[93] https://ich.unesco.org/en/RL/indonesian-batik-00170 Accessed September 11, 2019

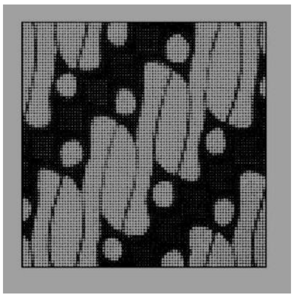
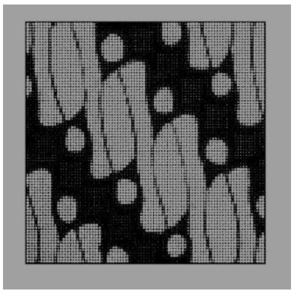
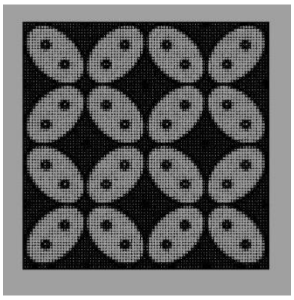
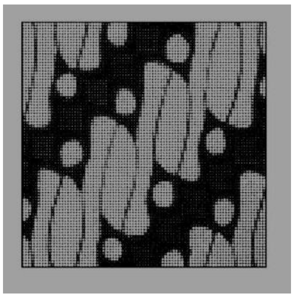
pattern as a starting point to design screen filter as a sun shading device. Screen filters have multiple functions. First, it can be visually seen and recognized as building identity. The identity can reflect the culture, concept, or the idea of the architects to present the buildings. Second, the screen filters are proven to be environmentally beneficial. Screen filters can reduce the cooling energy consumption in buildings. This building element can also filter the sun light, reducing excessive light into the buildings. Since it acts as a filter, rather than only considering sunlight, the screen panel can also be used to control the excessive noise and wind from the surrounding area and vice versa. However, since this study focus in the cooling energy reduction, the total solar radiation is the main focus of the experiment in this chapter. Taking inspirations from traditional Javanese *batik,* a paper entitled "Batik Pattern Panel performance of Solar Radiation Reduction" (2017) simulated the performance of filter panel of solar radiation reduction[94]. The paper was used in this chapter.

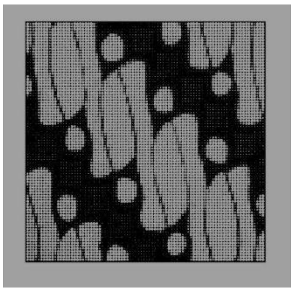
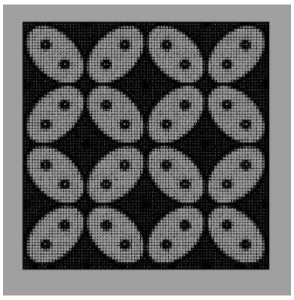
There were three different design of *batik* pattern panel used for the research in this chapter. Two panels were the results of the modification of the same *Parang* pattern, with a difference of the direction of the pattern. The first panel had most opening diagonally from bottom left to top right. The second *Parang* panel had most opening diagonally from the top left to the bottom right. The third panel took *Kawung* pattern which had a relatively even distribution of opening in all the surface in comparison with *Parang* pattern. The *Parang* and *Kawung* are two of commonly known *batik* pattern in Indonesia. The simulated panel are shown in table 2.1.

[94] Suryandono AR, Hariyadi A, Fukuda H (2018) Batik Pattern Panel Performance of Solar Radiation Reduction. The 4th International Conference of Indonesian Architecture and Planning.

Table 2. 1. The simulated base case and Batik pattern model.

Source:photographed by the author.

<table>
<tr><th>number</th><th>model name</th><th>front view</th><th>tested façade area (m²)</th><th>coverage area (m²)</th><th>gap between panel to façade (m)</th></tr>
<tr><td>1</td><td>base case</td><td>n/a</td><td rowspan="5">9
(3 m × 3 m)</td><td>0</td><td>n/a</td></tr>
<tr><td>2</td><td>model 1 - 600</td><td></td><td>5.22</td><td rowspan="3">0.6</td></tr>
<tr><td>3</td><td>model 2 - 600</td><td></td><td>5.22</td></tr>
<tr><td>4</td><td>model 3 - 600</td><td></td><td>5.67</td></tr>
<tr><td>5</td><td>model 1 - 800</td><td></td><td>5.22</td><td>0.8</td></tr>
</table>

6	model 2 - 800			5.22	
7	model 3 - 800			5.67	

The circular openings in the panel were based on chosen grey-scaled *batik* images. The diameters of the openings were parametrically controlled based of the depth of color of the selected images. The main component in Grasshopper to translate the selected images into circular opening pattern in the screen filters for sun shading was image mapper. The minimum opening diameter was 2 millimeter and the maximum was 30 millimeter. Base case for the simulation was a window surface with no shading device. The window size was 3000 millimeter by 3000 millimeter. The window and façade panel had 600 millimeter and 800 millimeter gap to mimic the real condition where a maintenance catwalk for maintenance was usually present (figure 2.1). All of the six panels, which had three different patterns, and one base case window were tested in eight different orientations in Jakarta, Indonesia (figure 2.2). Model 1-600 was the first *Parang* pattern panel with 600 millimeter gap from the window. Model 2-600 was the second *Parang* pattern panel with 600 millimeter gap from the window. Model 3-600 was the *Kawung* pattern panel with 600 millimeter gap from the window. Model 1-800 was the first *Parang* pattern panel with 800 millimeter gap from the window. Model 2-800 was the second *Parang* pattern panel with 800 millimeter gap from the window. Model 3-800 was the *Kawung* pattern panel with 800 millimeter gap from the window. The weather data for the simulation was downloaded directly from EnergyPlus website utilizing Ladybug plug-ins in Grasshopper. In total, there were 56 simulations that tested in one year period to get solar radiation. The grasshopper scripts, using LadyBug plug-ins is shown in figure 2.3. The results of the simulation were shown to obtain the performance of *batik* pattern panel on solar radiation reduction.

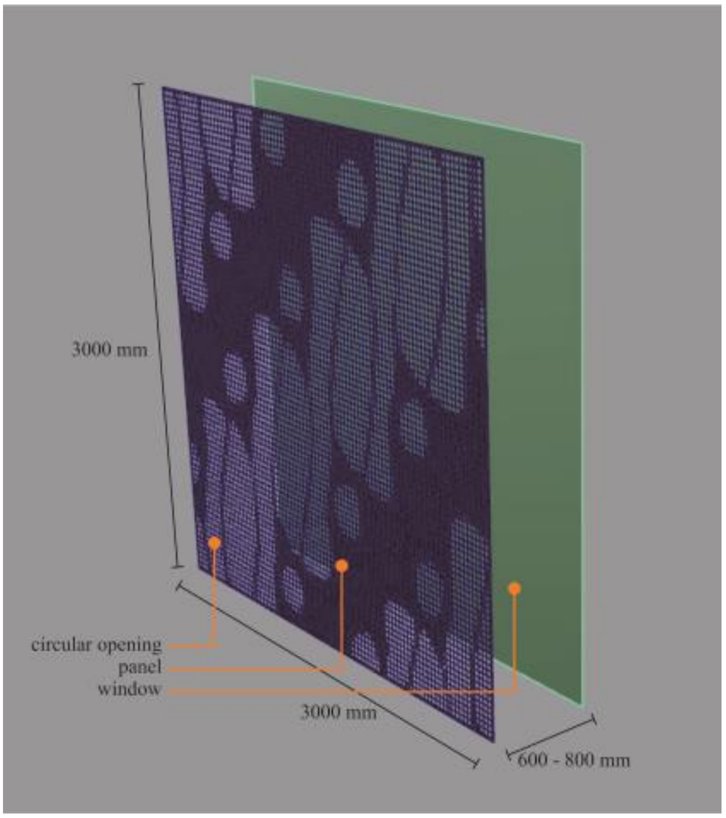


Figure 2. 1. The configuration of the simulated panel. The panel shown in the picture is model 1.

Source: photographed by the author

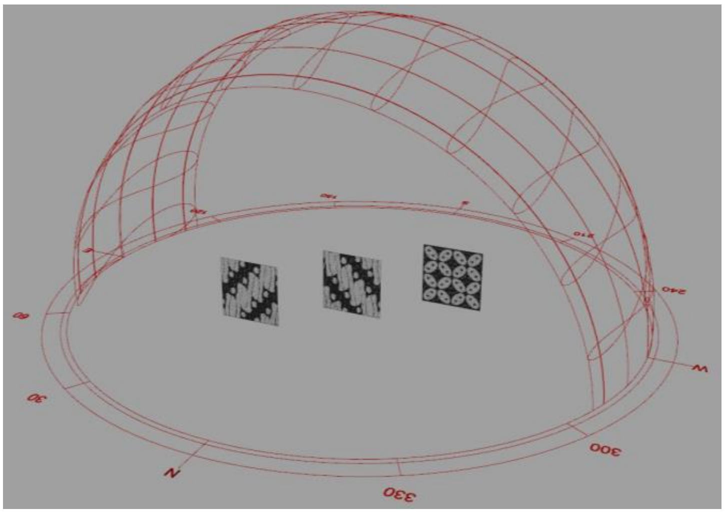


Figure 2. 2. The simulation setting for three tested screen panel with batik pattern.

Source: photographed by the author

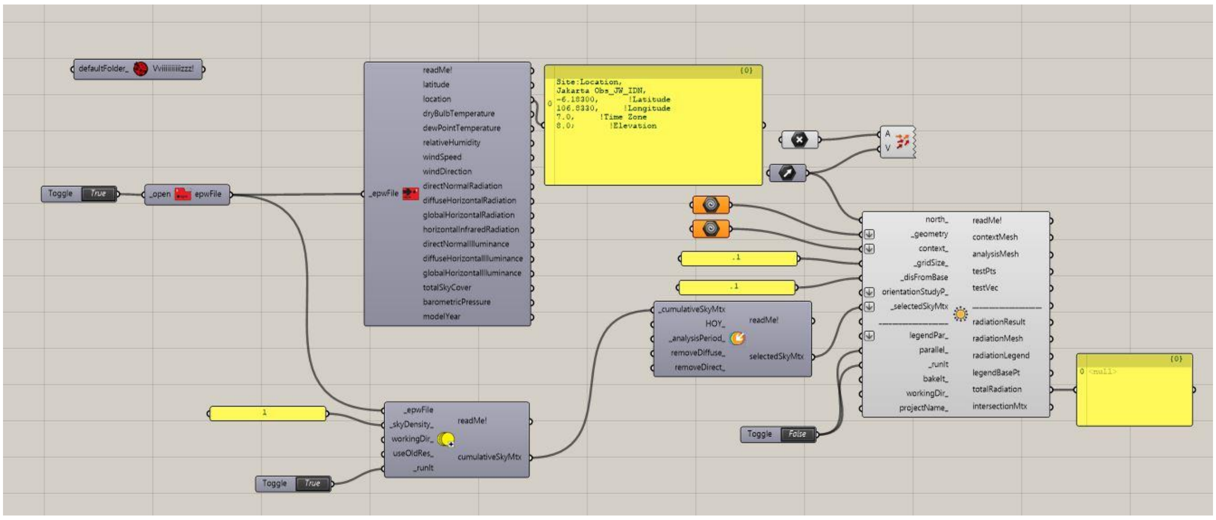


Figure 2. 3. Ladybug plug-ins in Grasshopper script for executing the solar radiation simulation.

Source: photographed by the author

2. 3. Total solar radiation simulation of *batik* pattern panel results and analysis

The west façade suffered the highest total solar radiation, followed by the northwest and the east. The south received the lowest total solar radiation, only around 50% of that of in the west. There was 531.10 kWh/ m² gap between the highest and the lowest total solar radiation. The simulation results of the base case in all orientations are shown in table 2.2.

Table 2. 2. Simulation results of the total solar radiation in the base case.

Source:photographed by the author.

experiment model	orientation							
	north	northeast	east	southeast	south	southwest	west	northwest
base case (Wh/m²)	772.47	872.43	936.73	711.70	535.82	797.14	1,066.92	971.09
Comparison with the west (%)	72%	82%	88%	67%	50%	75%	100%	91%

Panel shading devices had significant effect on solar radiation reduction at the window surface in comparison with the base case without shading. The simulation results of total solar reduction of the model 1 to 3 with 600 mm gap between the panel and facade can be seen in table 2.3. Leaving 600 millimeters gap between the *batik* pattern panels could reduce the amount of solar radiation in the outdoor surface of the window. Since the west façade suffered the highest total solar radiation, the results showed best performance of each model in that direction. Model 1 – 600 performed best in the west façade by reducing 584.46 kWh/m² of the solar radiation in comparison with the base case. Utilizing the reversed-design of model 1, Model 2 – 600 reduced slightly lower total solar radiation at 558 kWh/m² in the west. Model 3 – 600 worked best among other models in west by cutting the total solar radiation of 639.92 kWh/m². It was also seen that the reversed design of model 1 and model 2 work best in the opposite directions rather than east-west, and north-south orientation. While model 1 work better than model 2 in the northeast and southwest, model 2 was better than model 1 in the northwest and southeast.

Table 2. 3. Total solar radiation reduction by model 1 to 3 with 600 mm gap with the facade (kWh/m²).

Source:photographed by the author.

experiment model	orientation							
	North	North east	East	South east	South	South west	West	North west
model 1 - 600	375.28	467.57	487.11	268.39	225.26	408.34	584.46	408.25
model 2 - 600	391.86	369.44	501.35	373.86	228.88	291.46	558.00	514.41
model 3 - 600	362.54	484.38	549.54	363.49	246.46	402.50	639.92	550.83

Moving the *batik* pattern panel away from the exterior surface in the tested window from 600 millimeters to 800 millimeters reduced the effectiveness of the panel filtering the total solar radiation. Table 2.4 shows the total solar reduction by applying model 1 to 3 with 800 mm gap between the panel and the façade. The performance of Model 2 – 800 was the worst among other tested *batik* pattern. It worked best in the west façade by reducing only 425.83 kWh/m² of solar radiation. Model 1 – 800 could reduce the total solar radiation of 486.25 kWh/m² in the west, slightly worse than model 3 – 800 which cut 487.15 kWh/m² in the same orientation. The similar pattern was also seen that the reversed design of model 1 and model 2 worked best in the opposite directions rather than east-west, and north-south orientation.

Table 2. 4. Total solar radiation reduction by model 1 to 3 with 800 mm gap with the facade (kWh/m²).
Source:photographed by the author.

experiment model	orientation							
	North	North east	East	South east	South	South west	West	North west
model 1 - 800	222.67	379.54	375.49	190.67	134.50	330.53	486.25	303.18
model 2 - 800	212.85	268.68	425.83	288.40	138.00	218.78	425.83	406.58
model 3 - 800	274.77	376.56	399.95	253.10	173.05	347.73	487.15	413.09

From the figure 2.4 and 2.5, it can be seen that the opening distributions have an effect of the *batik* pattern panel performance of reducing the solar radiation. From the two *Parang* patterns simulation results, it could be inferred that different distribution of circular hole has effect of blocking solar radiation in different orientation, even though they perform similar in average of total eight orientations. Model 1, both with 600 and 800 millimeters gap showed their best performance in the northeast and southwest orientation in terms of percentage comparison with the base case in the same orientation. Model 1 – 600 slightly performed worse than the best performer, model 3 – 600 in the northeast direction, by only leaving around 2 percentage points differences of solar radiation among them. Model 1 – 600 was the best model among others, leaving a mere around 1 percentage points differences of the solar radiation reduction with the model 3 – 600 in the southwest orientation. The most effective solar radiation reduction of the model using 1 – 600 in all orientation was in the west by 55% in comparison with the base case. However in comparison with other models, model 3 – 600 showed the best performance among others by cutting the solar radiation around 60% in the west. The most effective solar radiation reduction of model 1 – 800 was in the west orientation by accepting a 54% of the total solar radiation of the base case model. It slightly performed worse than the model 3 – 800 in the solar radiation reduction by only around 0.9 kWh/m² when placing the panel at 800 millimeters gap with the window. Note that it had most of the openings placed diagonally from the bottom left to the top right.

Model 2, both 600 and 800 millimeters gap, which utilized the same pattern but had reversed opening placements with model 1 showed their best performance in the northwest and southeast facade. Model 2-600 and 2-800 had most of their circular opening lay in a diagonal distribution from upper left to bottom right, Model 2 – 600 showed best performance of the solar radiation reduction in the southeast and north orientation, leaving model 3 – 600 by around 2 and 4 percentage points accordingly. Model 2 – 600 performed best in the east orientation by reducing 54% of solar radiation, even though was still lower than model 3 – 600's 59%. The model 2 – 800 reduced around 45% of solar radiation in the east, the best among other tested models in all orientations in comparison with base case model.

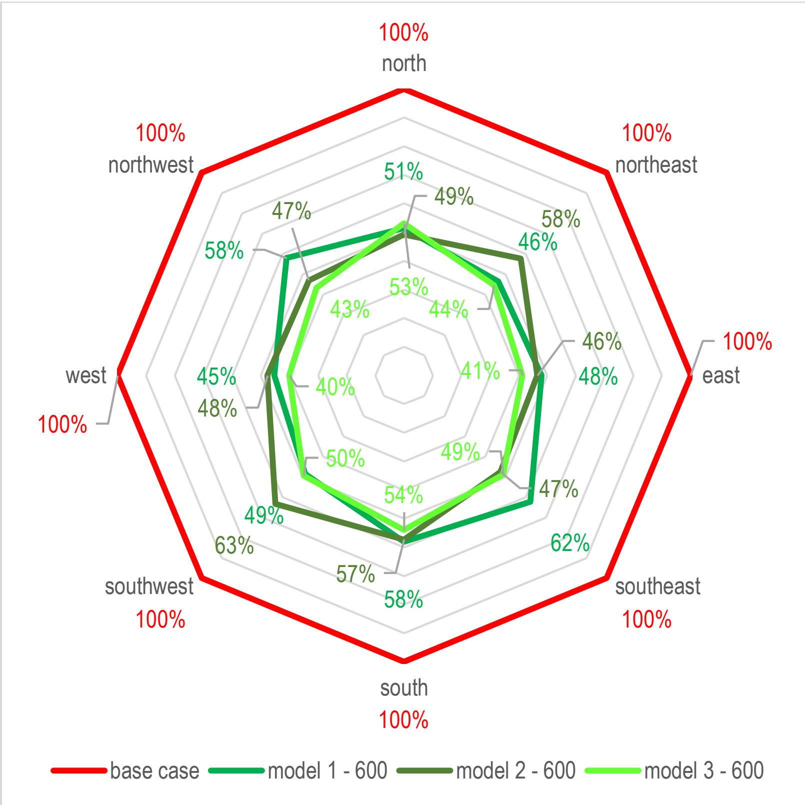


Figure 2. 4. Simulation results of the total solar radiation in batik pattern panel model with 600 mm gap with the window (%).

Source: photographed by the author.

In other orientations, both panels achieved similar performance of solar radiation reduction by only a small margin of 1 – 3 percentage points. The differences were higher when the gap size was larger. With 200 millimeter gap more, there was around 5 percentage point difference in east and west façade between model 1 and 2. The average performance of the panels for solar radiation reduction also decreased. Both model 1 and 2 with 600 millimeter gap showed 52% solar radiation falls in the window. In both 800 millimeter model 1 and 2, the average of the solar radiation reduction became 65%.

The model 3s which had a relatively even placement of opening performs similarly in all orientations. Model 3s was also generally the best model among others for reducing solar radiation in the facade. With relatively even circular holes distribution in its panel, *Kawung* pattern panels performed best in east and west orientation. These panels worked best in the orientations that were always hit by high solar radiation in comparison with other orientations. Model 3 – 600 blocked approximately 59% and 60% of solar radiation in the east and west façade accordingly. The west orientation was the most suffer area from solar radiation. The northwest orientation was the secondary orientation that also exposed by the solar radiation, even higher than the east. In the northwest façade, model 3 – 600 could reduce around 57% of the solar radiation. Similar with model 1 and 2, more gap made the effectiveness of solar radiation blocking decrease. Model 3 – 600 cut 53% of solar radiation in average for all orientation while model 3 – 800 only blocks 40%.

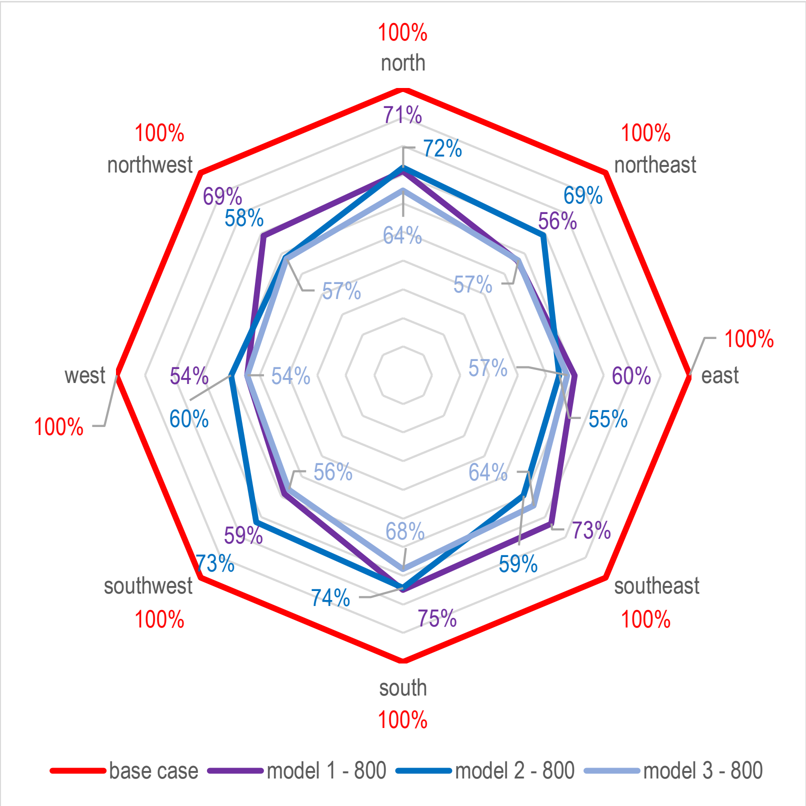


Figure 2. 5. Simulation results of the total solar radiation in batik pattern panel model with 800 mm gap with the window (%).

Source: photographed by the author.

The average of the solar radiation reduction for each *batik* pattern panel are shown in figure 2.6. In average the *parang* pattern panel in model 1 and 2 showed the same results. Both were better in terms of total solar radiation reduction in comparison with the base case, but worse than *kawung* pattern in model 3. However, the performance of *parang* pattern were different in every orientation as a result of different opening distribution.

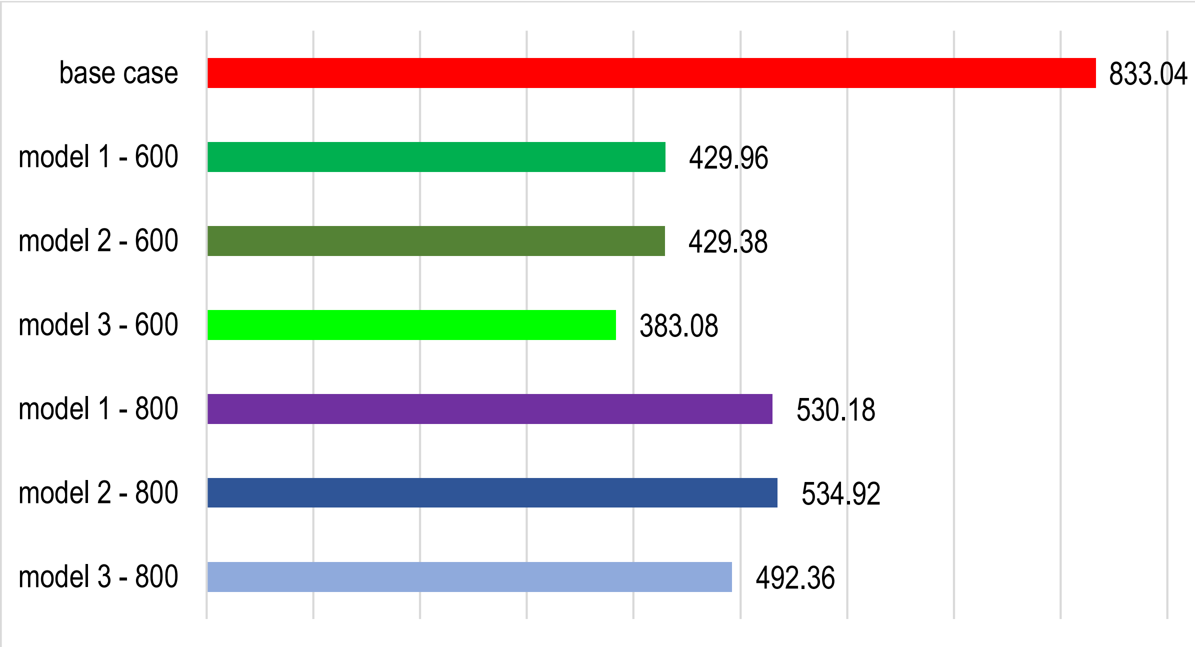


Figure 2. 6. The total solar radiation of all simulated model in average of all orientation. Source: photographed by the author.

All of the simulated the shading devices reduced significant amounts of solar radiation on window surface in comparison with base case. By placing the *batik* pattern panel 600 millimeters away from the outdoor surface of the window, both *parang* patterns could reduce an average of 48% of the solar radiation in all orientation. *Kawung* pattern panel with a gap of 600 millimeters with the window performed slightly better by reducing an average of 53% of the solar radiation in all orientation. This was the results of different opening area between two patterns. In comparison with the surface, *Parang* pattern shading area covered 58% of the window area, while *Kawung* pattern was at around 63% coverage. Comparing the performance of total solar radiation reduction in average of all orientations with the façade coverage, it is seen that closer the gap between the panel and the façade make the performance to coverage value higher (Figure 2.7). However, this value was not significantly different among the pattern itself, ranging by only 0.01 to 0.02. It means that more opening will make the performance worse. In this simulation, there were also no cover on the top and sides area between the façade and the panel gap. This condition made the top and left-right sides of the façade more exposed by the direct solar radiation

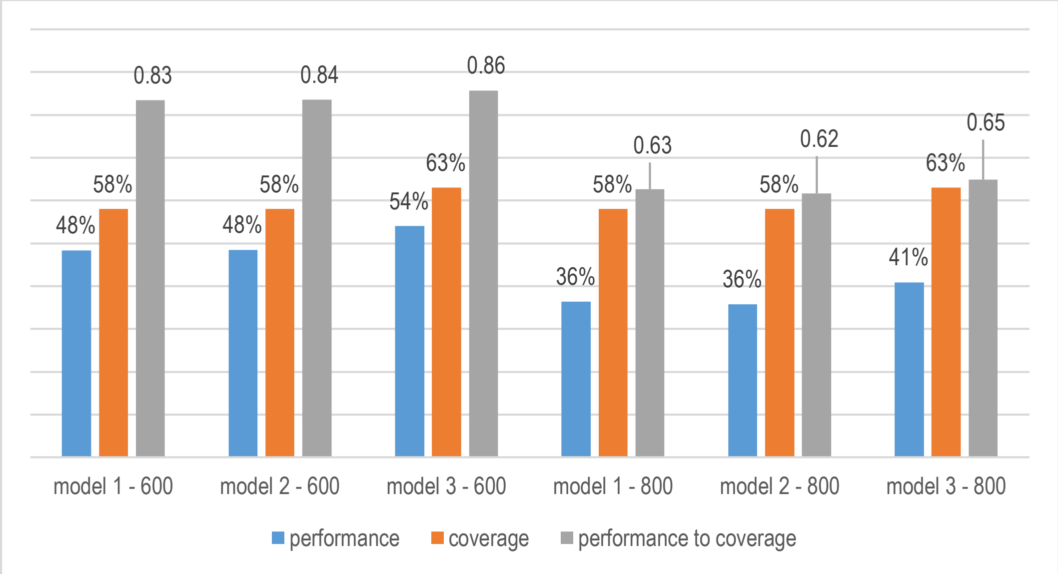


Figure 2. 7. The average performance of total solar radiation of each type and the coverage of the facade surface.

Source: photographed by the author.

There were several results from simulated *batik* pattern panel in this simulations. First, in general, *Kawung* pattern panel showed the best performance in comparison with base case and other panel designs. The *Kawung* pattern panels worked best for west oriented façade by reducing up to 60% solar radiation. It also worked best for northwest and east facade, which were the second and the third highest hit orientation by the solar radiation. Second, the distribution of the openings had effects of panel effectiveness on reducing solar radiation. Third, wider gap between panel and window gave higher differences of solar radiation reduction. The effectiveness reduction of the solar radiation was also the effect of the opening which present in the left, right, and the top side between the *batik* pattern panel and the tested window façade.

2. 4. Chapter conclusion

Green buildings offered strategies to deal with the environment condition toward sustainability. There were many principles of green buildings that could be applied, from the simplest to the most complicated ones. Exploring the examples of several architecture projects of the use of sun shading devices, the use of screen filters could be visually pleasing and functional. The similar method was brought to design a filtering panel which resembles local pattern such as *batik* pattern. The perforated panels were simulated to show their performance in solar radiation reduction.

Based on the simulation results, they effectively cut the solar radiation in the building façade, ranging from an average of 40% to 48% in comparison with the base case. Model 3 (*Kawung* pattern), the best model could reduce in average 54% and 41% of total solar radiation in all orientation with 600 and 800 mm gap between the panel and the façade accordingly. Model 3 also showed best performance in the west, the most crucial orientation since it suffered highest total solar radiation by reducing around 60% and 46% with 600 and 800 mm gap between the panel and the façade accordingly.

However, even perforated metal panel was relatively simple and easy to maintenance, there were possible problems of applying this type of sun shading. First, the panel was not widely available. It must be customized according to the designer intention. The size of the panel itself in this study was large, even though it could be divided into smaller pieces. This leads to the second problem: economic. Custom building elements were relatively expensive. Moreover, advanced technology was needed to create the panel. Cutting the panels to create the pattern was not a common tasks that could be done easily. It required industrial machines which might not be available in several area. Then, skillful workers as well as heavy construction machines might be needed during the assembling and disassembling process. These issues would become problem for the sun shading to be used by common people publicly. These lead to the search of the fit design of sun shading devices were continued in the next chapter: mini-louvers as sun shading devices.

Chapter 3 – L-shaped mini-louvers for reducing solar radiation

3. 1. An introduction to L-shaped mini-louvers

Continuing the idea of the previous chapter of solar radiation reduction in the outdoor surface of a window, this chapter utilized the novel sun shading design: L-shaped mini-louvers. There were several reasons of proposing this new sun shading design using L-shaped aluminum profiles. First, the availability of the component to be used as mini-louvers. The L-shaped aluminum profile is the main component to build the mini-louvers (Figure 3.1). It is widely available, not only in the selected research location but in other places. It can be found in nearby building component store. The author could easily find the material in Kitakyushu, Japan and managed to execute experimental research by building a 1:1 scale of the L-shaped mini-louvers. This experimental study was presented later in chapter four. This type of aluminum profile or aluminum extrusion can also be easily found in online market, which can ship their products worldwide. The aluminum extrusions are available in many colors, not only silver but also dark brown (Figure 3.2). Other colors are also available such as: bright gold, nickel, black in matte or glossy finishes and even can be customized by order it directly to the manufacturer. The size of L-shaped aluminum profiles are varied, commonly found from as small as 9 mm x 9 mm to a larger size of 500 mm x 500 mm. The shape of the aluminum extrusion are also varied, one is symmetrical, the legs' size are similar but there is another type which has different size of the legs, make them asymmetrical in section. Next, the price of L-shaped aluminum profile is relatively low. The L-shaped aluminum profile in this research costs around 0.29 USD to 0.72 USD per meter length in the chosen research location. The detail of the price and construction cost are analyzed further in chapter six. L-shaped aluminum profile does not only cheap but also requires no cost for preservation. The choice of aluminum as the material lead to low maintenance. Due to its mechanical properties, aluminum does not need maintenance during its long life span, as presented in the literature review in chapter one. It still show similar performance even after being used for more than 25 years without any maintenance. The long life of aluminum is a subject for discussion in terms of environmental consideration. High amount of energy is needed to create aluminum from raw materials. It makes aluminum is considered as not an environmental friendly materials. However, due to its long service life, this type of materials is recommended especially for extreme weather condition, for example for outdoor elements in buildings. Moreover, aluminum is recycle able. It can be recycled without experiencing degradation of its properties. Recycled aluminum has a relatively similar quality with the new ones. The amount of energy needed to recycle aluminum is significantly lower than those required to create a new one. Other than the reasons from the aluminum profiles, the novel proposed design of the sun shading itself has many aspect to consider.

Figure 3. 1. L-shaped aluminum profiles or aluminum extrusion with the size of 12 mm × 12 mm × 0.8 mm in a meter length in Nafco building material store, Kitakyushu, Japan. Source: photographed by the author.

Figure 3. 2. Different sizes and colors of the L-shaped aluminum profiles. Source: photographed by the author.

The L-shaped mini-louvers design is simple. The assembly from L-shaped aluminum profiles into L-shaped mini-louvers is easy. It can be done by ordinary people without specific engineering or technical skills. First, the L-shaped mini-louvers is cut according to the design. The L-shaped aluminum profile chosen in this study has a thickness of only 0.8 mm. It does not need advance cutting tools. Hand circular saw or metal scissors is enough. To smoothen the edge, a standard sandblasting paper can be used. This ensure the safety of the sharp edges that may appear after cutting the L-shaped aluminum profiles. Next, the installation of L-shaped mini-louvers to the opening, whether to cover glass window or door, is also simple. To put them directly into the outdoor surface of the glass, outdoor double-sided tapes can be applied. Another possibilities of placing the L-shaped mini-louvers is on the window or door frame. Rather than using outdoor double-sided tape, galvanized screws can be used. This will make mark on the frame whenever the L-shaped mini-louvers is taken. However, a simple compound can work to fix the mark. Since the screws are small, this condition relatively has no effect on harming or threatening the structural integrity of the frame itself. It is also easy to dissemble the L-shaped mini-louvers from the windows or doors. The outdoor double-sided tapes can be removed. Unscrew the galvanized screw from the frame also easy to be done. The L-shaped itself also has advantages in comparison with other shapes in terms of optimization.

Material optimization is another consideration. In comparison with other common aluminum profile shape, the L-shape is more optimized for this design. It requires less mass than other shapes (Figure 3.3). The amount of materials in the L-shaped is only half of those of in the hollow rectangular or O-shaped. The amount of the material is similar with those of in the T-shaped aluminum extrusion. The channels aluminum extrusion or C-shaped still uses roughly three quarters of the materials in the O-shaped. C-shaped profile utilizes the same amount of materials and weight of those of I or H-shaped profile. The O-shaped aluminum profile is commonly used as louvers, usually in a much larger size of 300 mm x 500 mm or larger with the thickness of more than 1 mm. The amount of materials are also effected the weight of the profile itself. The thickness of chosen aluminum profiles for this study is 0.8 mm. A meter of L-shaped aluminum profile with the size of 15 mm x 15 mm x 0.8 mm has the weight of approximately 0.06 kg. It means that utilizing the same dimension, O-shaped aluminum profile has the weight of 0.12 kg whereas C-shaped has 0.09 kg. L-shaped and T-shaped have similarities in the amount of materials and weight but to be used for sun shading, L-shaped can provide more shadow than the T-shaped.

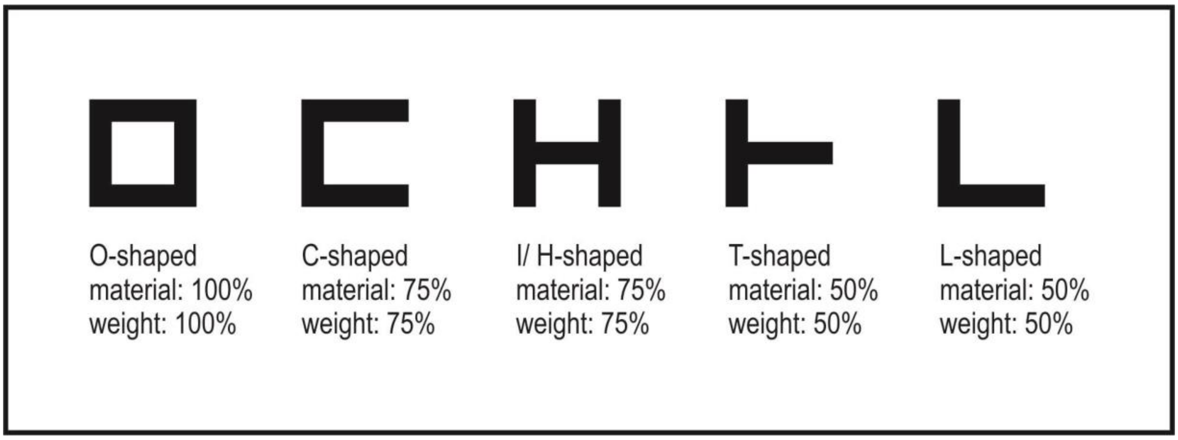


Figure 3. 3. Schematic section of the shapes of the aluminum profiles which shows the comparison amount of materials and weights.
Source: photographed by the author.

Proposed L-shaped mini-louvers design in this study also have advantages in comparison with common louvers, or overhangs. Smaller size, with less thickness in comparison with common louvers can reduce the load of the buildings. The L-shaped mini-louvers do not need additional structures. In comparison with larger louvers or overhangs, L-shaped mini-louvers also reduce the loads from the wind and seismic. It means that there is a possibility of applying the L-shaped mini-louvers not only in a single detached house but also for high rise buildings. Attaching L-shaped mini-louvers for retrofitting old buildings are also possible as well as for new construction.

Providing shadow is the main consideration for building elements as sun shading. It can block the solar radiation. Using the shape itself as protection, it can block solar radiation whether direct or indirect ones. The schematic image of the light and shadow condition is shown in section in figure 3.4. T-shaped aluminum profiles provide less shadow than the O-shaped, C-shaped, and L-shaped. It only blocks the lights without getting shadow on the outdoor surface. In comparison, T-shaped can only cast a half of shadows with the O-shaped, C-shaped, I/ H-shaped and L-shaped aluminum profiles. The O-shaped, C-shaped, I/ H-shaped and L-shaped create similar amount of the shaded area. The shape itself does not only blocks the light but also provides shadow underneath them. Roughly, the T-shaped aluminum profiles has only three quarters of the covered area as a result of blocking the light and providing shadow in comparison with the other three shapes. Moreover, I/ H-shaped, T-shaped and L-shaped can block the reflected or indirect light cast by the profile itself. However, the L-shaped provides more coverage by roughly blocking twice reflected light and heat in comparison with I/ H-shaped and T-shaped profiles. This is another advantages of the L-shaped aluminum extrusion among others. Since this research deal with the cooling energy, the amount of heat is also examined.

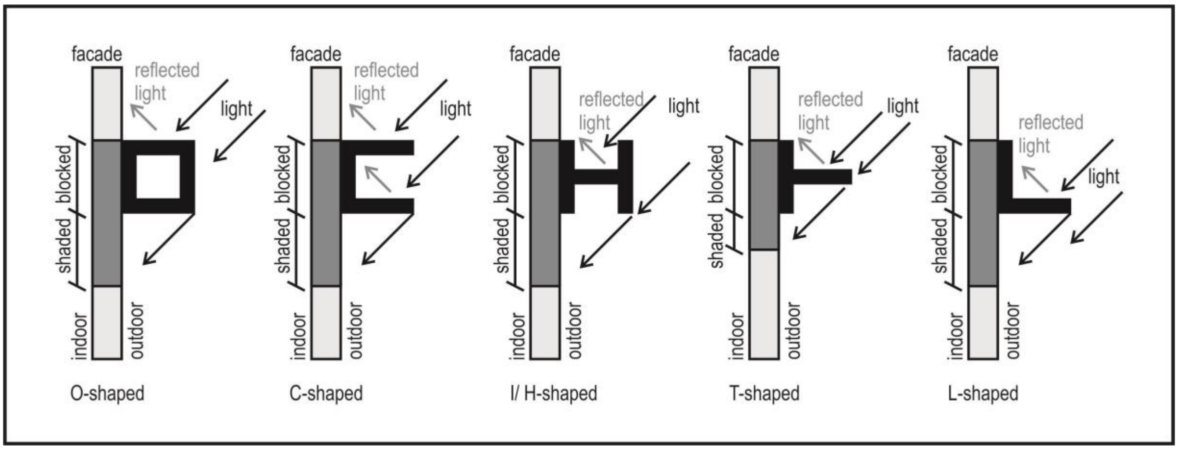


Figure 3. 4. Schematic section of the shapes of the aluminum profiles which shows the comparison amount of coverage from blocking the light and shaded area.
Source: photographed by the author.

Rather than only blocks the light, aluminum also catches, stores, and releases heat to the environments. This effect can be minimized by using small size and less materials. These are the reason of proposing the use of significantly smaller mini-louvers than common size louvers. Aluminum material is chosen since its lightweight, so it does not store as much as heat in comparison with those of in materials with more weight. However, comparing the five standard of the simple and common shapes of aluminum extrusion, L-shaped aluminum profiles has advantages (Figure 3.5). Other than exposed from the light, the surface of the aluminum is also exposed by the wind. The flowing wind can reduce the heat from the surface of the profiles. More potential heat emitted from the sun shading device which is larger in size, have more weight, and also acts as a thermal mass.

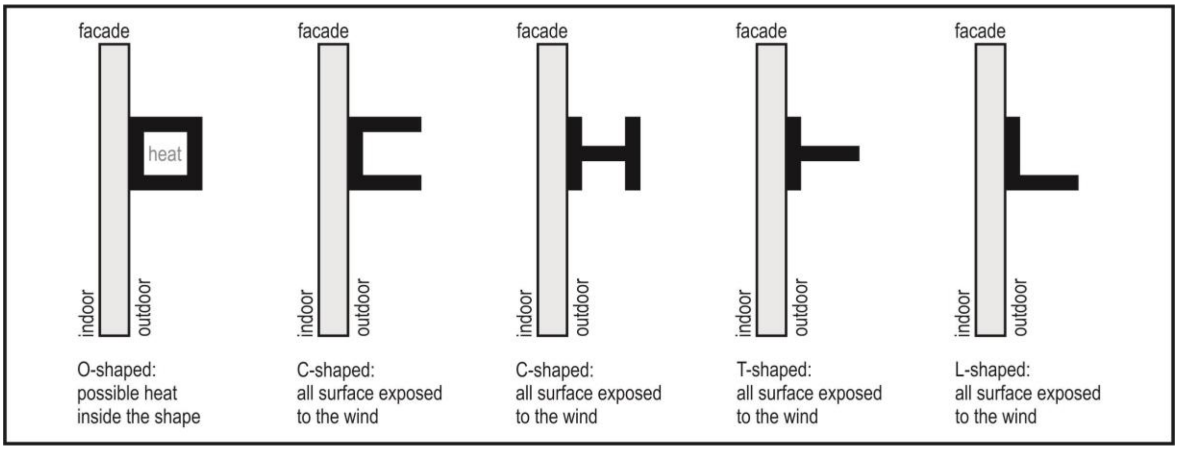


Figure 3. 5 Schematic section of the shapes of the aluminum profiles which shows the possible heat and wind exposure to the shape.
Source: photographed by the author.

Based on those reasons, the L-shaped aluminum profiles were chosen to be used for designing a unique but still simple sun shading devices: the L-shaped mini-louvers. A paper "L-shaped Mini-louvers Performance of Solar Radiation Reduction in Glass Windows (2018) was presented at the 12th South East Asia Technical University Consortium, an international seminar hosted by the Universitas Gadjah Mada, Indonesia[95]. SEATUC is an academic consortium, with the specific research focus in engineering and technical major, among eight universities in Southeast Asia in Vietnam, Thailand, Indonesia, Malaysia, and Japan. The paper showed that L-shaped mini-louvers could effectively block total solar radiation more than 70% in Sydney and more than 80% in Singapore, depend on the type and building orientations. This chapter utilized the same methodology with the aforementioned research to simulate the solar radiation reduction in Jakarta, Indonesia using L-shaped aluminum mini-louvers.

3. 2. Total solar radiation simulation settings

In this chapter, chosen L-shaped mini louvers were simulated to measure the effectiveness of total solar radiation reduction, which consists of the direct and indirect radiation. The base case for the study was 2000 mm x 2000 mm glass window without any shading devices. The L-shaped mini-louvers was attached in front of the window, in the exterior side, as a shading device for researched models. There was 1 mm gap between L-

[95] Suryandono AR, Hariyadi A, Fukuda H (2018) L-shaped Mini-louvers Performance of Solar Radiation Reduction in Glass Windows. The 12th South East Asia Technical University Consortium

shaped mini louvers to the glass window surface. The distance between the outdoor surface of the window and the L-shaped mini-louvers mimicked the real condition when there was a double-sided tape to attach the sun shading to the window. This gap was also presented to avoid overlapping surface in the software that might bias the simulation results. The raw materials to construct the L-shaped mini-louvers was L-shaped aluminum profiles. There were three L-shaped aluminum profiles chosen for this study. All of the L-shaped aluminum profiles had symmetrical section, meaning both the legs have the same size. The first size and smallest one was 12 mm × 12 mm. The medium size of the L-shaped aluminum profile was 15 mm × 15 mm. The largest one was 30 mm × 30 mm. The differences in size was chosen to measure the impact of the size of the mini-louvers to the shading performance. These three sizes of the L-shaped aluminum profiles were widely available in the market. The L-shaped aluminum profiles were arranged to make mini-louvers which have different size to opening ratio. The first model had 1 to 1 louvers' size to opening ratio. It meant that the openings among mini-louvers had the same size with the size of the L-shaped aluminum profiles themself. The second model had the ratio of 1 to 2 louvers' size to opening. The openings in the L-shaped mini-louvers were twice of the size of the L-shaped aluminum profiles. The last model uses 1 to 3 louvers' size to opening ratio. It meant that the openings among mini-louvers were three times of the size of the L-shaped aluminum profiles. The schematic image of the L-shaped mini-louvers is presented in figure 3.6, showing their placement and ratio. The detailed name and properties of all the simulated models are presented in table 3.1.

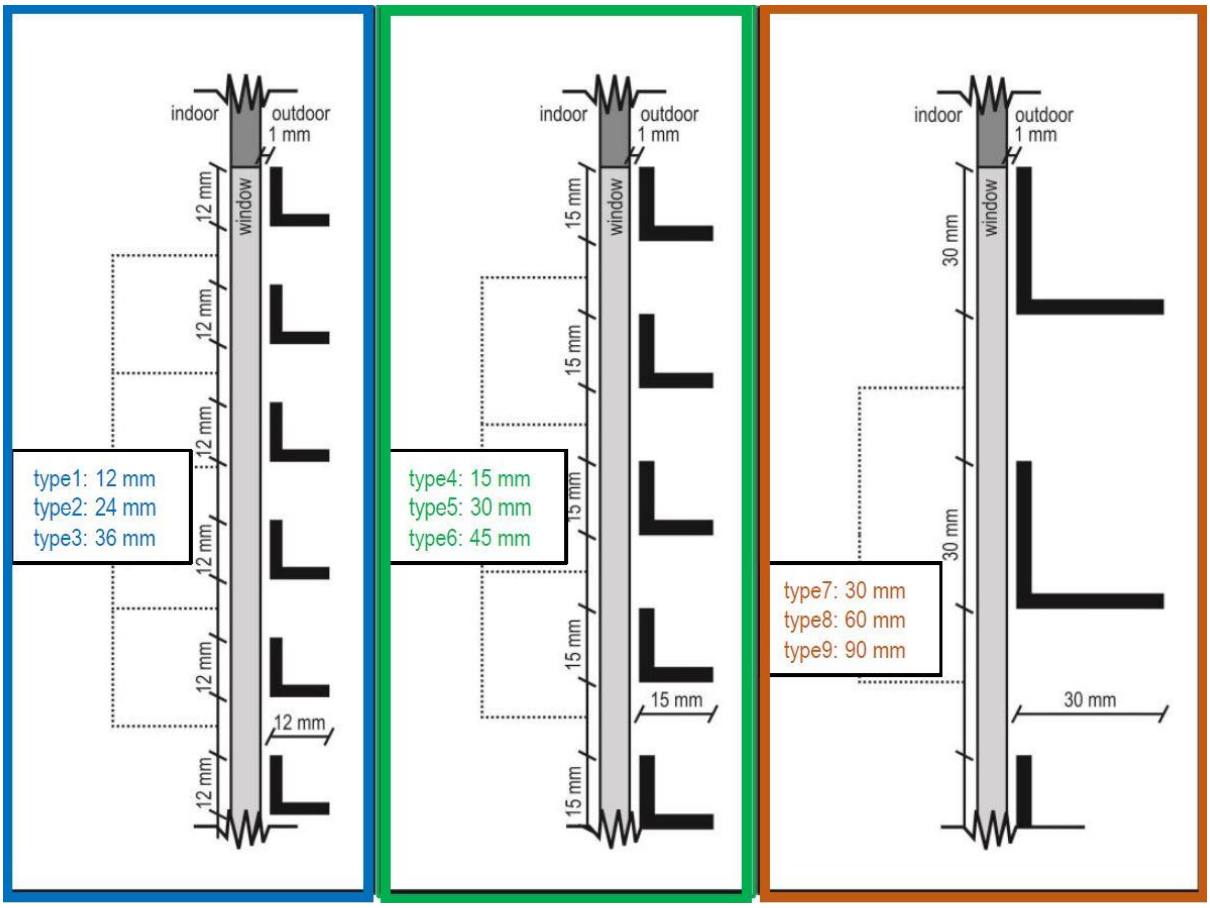


Figure 3. 6. Schematic section of L-shaped mini-louvers placement and ratio. Source: photographed by the author.

Table 3. 1. The dimension of the simulated models in this study. Source:photographed by the author.

model	size (mm)		ratio	area (m²)	
	louvers	opening		window surface	shading coverage
base case	n/a	n/a	n/a	4.00	n/a
type 1	12	12	1 to 1	4.00	2.00
type 2	12	24	1 to 2	4.00	1.32
type 3	12	36	1 to 3	4.00	0.94
type 4	15	15	1 to 1	4.00	1.98
type 5	15	30	1 to 2	4.00	1.32
type 6	15	45	1 to 3	4.00	0.99
type 7	30	30	1 to 1	4.00	1.98
type 8	30	60	1 to 2	4.00	1.32
type 9	30	90	1 to 3	4.00	0.96

The parametric grasshopper script to create the box and L-shaped mini-louvers is shown in figure 3.7. The L-shaped mini-louvers was obtained by placing the first reference point at the top right of the window. This reference point also became the top of L-shaped mini-louvers. The amount of mini-louvers members were distributed evenly according to the ratio of the louvers' size and opening. All the studied types utilized the same scripts, which was parametrically changed following the ratio. After the intended design was obtained, the geometry were "baked" and brought into the Rhinoceros 3-dimensional environment, attached to the box modelling.

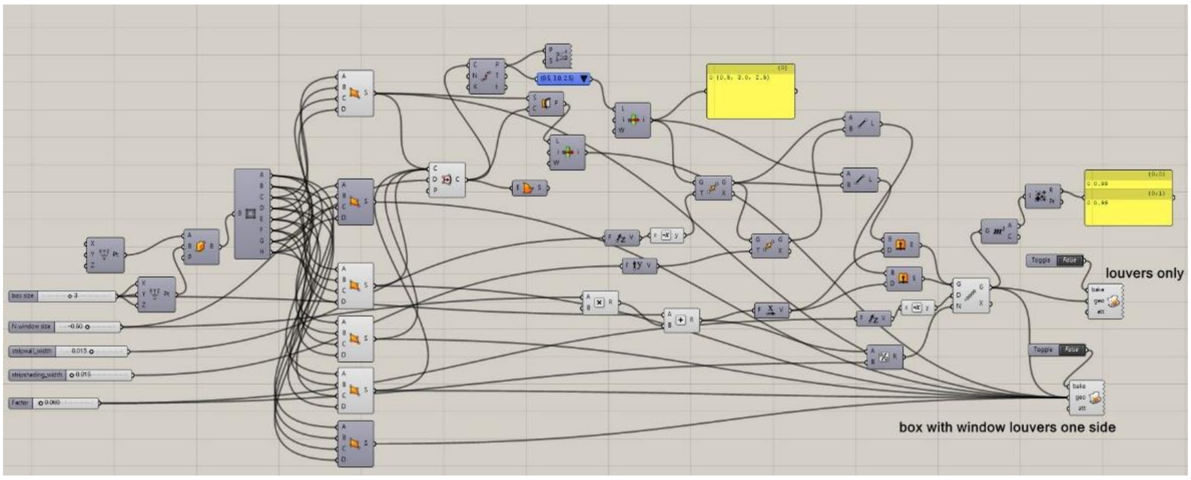


Figure 3. 7. Grasshopper script to parametrically creates the box and L-shaped mini-louvers. Source: created and photographed by the author

The complete 3-dimensional perspective view of all the simulated model are shown in figure 3.8. The base case was not shown since it has similarities with other models but without sun shading device attached in the window.

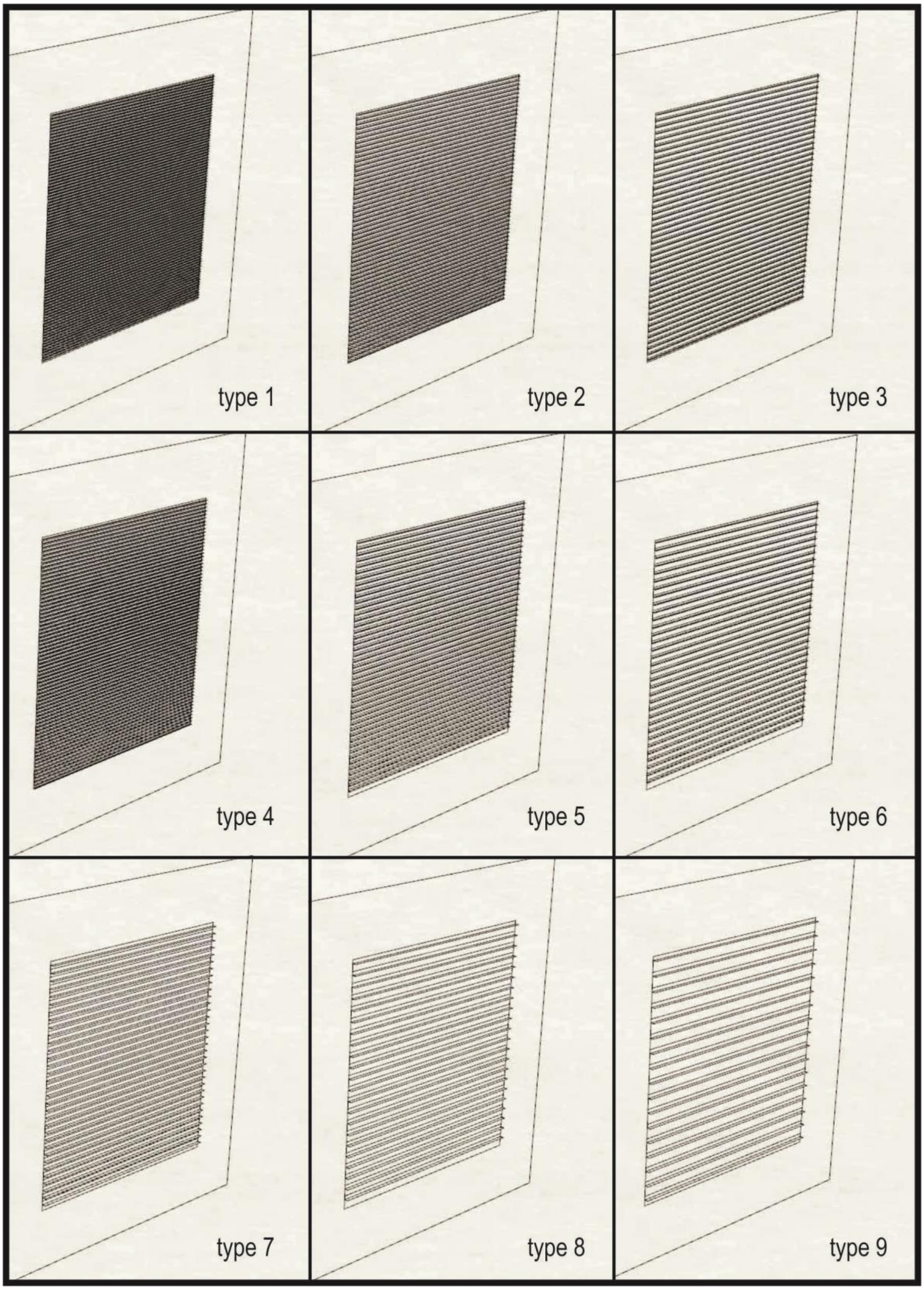


Figure 3. 8. Simulated model in 3-dimensional perspective view.

Source: photographed by the author

The grasshopper string for executing solar radiation simulation using LadyBug is shown in figure 3.9. The Ladybug inside Grasshopper plug-in downloaded weather data from OneBuilding website for Jakarta observatories location[96]. The geometry from Rhinoceros environment were brought and used as reference inside LadyBug to perform the solar radiation simulation. The results were analyzed to draw the conclusion for this chapter.

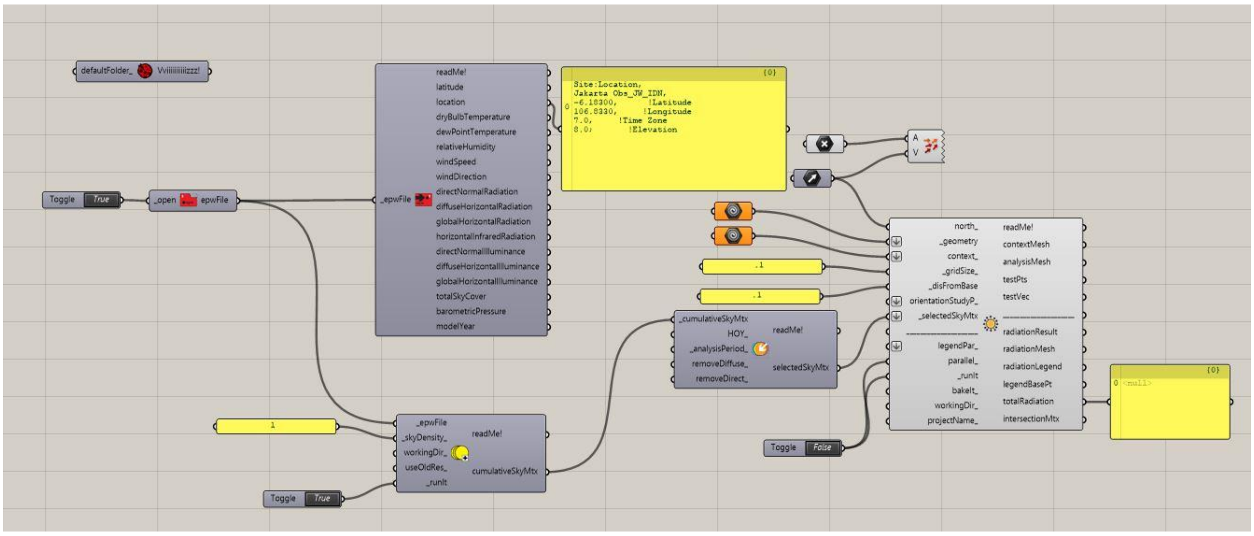


Figure 3. 9. Grasshopper string using LadyBug to perform solar radiation simulation.

Source: photographed by the author

3. 3. Total solar radiation simulation results and analysis

The simulations were divided into three groups. Each group contains the simulation of base case as the basic comparison for all models, along with three models utilizing the same L-shaped mini-louvers in different size to opening ratio. These models were simulated in Rhinoceros using Grasshopper and Ladybug for one year scenario. The results were total combination of not only the direct but also the indirect solar radiation in kWh/ m² for eight building orientations. The first group was the simulation of base case with type 1 to 3, using 12 mm L-shaped mini-louvers. The second group was the simulation of the base case with 15 mm L-shaped mini-louvers which were used by type 4-6. The last group was the simulation of the base case with type 7 to 9 which use 30 mm L-shaped mini-louvers. Simulation results for the base case was presented in table 3.2. The west orientation suffered highest total solar radiation by receiving 948.34 kWh/ m², followed by 879.50 kWh/ m² of total solar radiation

[96] Jakarta Indonesia TMY3. http://climate.onebuilding.org/WMO_Region_5_Southwest_Pacific/IDN_Indonesia/JW_Jawa/IDN_JW_Jakarta.Obs.967450_TMYx.zip Accesed October 3, 2019

in the northwest. The total solar radiation in the northwest was even higher than the east. In the perpendicular orientation with east – west, the south façade had the lowest solar radiation of 525.02 kWh/ m². The differences between the highest and lowest total solar radiation was significant, at around 423.32 kWh/ m². It meant that the same percentage of sun shading effectiveness could have larger difference in terms of total solar radiation, which might lead to different cooling energy consumed by the buildings.

Table 3. 2. Simulation results of total solar radiation in the base case along with the comparison of each orientation with the west's highest total solar radiation. Source: photographed by the author

model	north	northwest	west	southwest	south	southeast	east	northeast
base case (kWh/ m²)	730.63	879.50	948.34	733.07	525.02	652.00	832.21	796.34
Comparison with the west (%)	77	93	100	77	55	69	88	84

Placing type 1 to 3 L-shaped mini-louvers in the outdoor surface of the window could reduce the total solar radiation. The total solar radiation in each orientation for type 1 to 3 L-shaped mini-louvers in comparison with the base case is shown in figure 3.10. Type 1 worked best by reducing the total solar radiation. In comparison with the base case, the amount of the total solar radiation received by the façade only around 57% in average of all orientation, ranging from 48% in the north and 63% in the east. More openings made the total solar radiation higher in the window façade. Type 2 and 3 in average of all orientation suffered around 76% and 84% of total solar radiation in comparison with the base case. In all of the façade orientations, the decrease of sun shading effectiveness of blocking the total solar radiation as the effect of size to opening ratio in the L-shaped mini-louvers were constantly seen. Changing the size to opening ratio from 1:1 to 1:2, the decrease was around 17 to 21 percentage points. The same pattern occured when changing the size to opening ratio from 1:2 to 1:3 except in the north direction. In the other orientations, the effectiveness of L-shaped mini-louvers went down ranging from 5 to 8 percentage points. However, in the north façade, the change of size to opening ratio from 1:2 to 1:3 could lead up to around 13 percentage points of L-shaped mini-louvers performance of reducing the total solar radiation. This was important because the north orientation have larger amount of total solar radiation in comparison with the south. Since the amount of total solar radiation in each orientation was difference, the same percentage of reduction may have different amount of total solar radiation. For example, the same percentage reduction in the west façade, which received the highest total solar radiation had a significantly higher than that in the south façade, which suffered the lowest total solar radiation.

Figure 3. 10. The total solar radiation of the base case in comparison with the type 1, type 2, and type 3 L-shaped mini-louvers.

Source: photographed by the author.

The amount of total solar radiation reduction of all the type 1 to 3 in comparison with the base case are shown in the table 3.3. In average of all orientations, the type 1 works best of reducing the total solar radiation by around 323.39 kWh/ m², followed by type 2 (174.56 kWh/ m²) and type 3 (118.29 kWh/ m²). All three types of L-shaped mini-louvers worked best in the north orientation, reducing the most significant amount of the solar radiation in comparison with other orientation, even when was compared with that of in the west façade. Type 1 best performance was in the north by reducing total solar radiation around 376.86 kWh/ m², followed in the northwest (369.2 kWh/ m²) and in the west façade (353.94 kWh/ m²). The condition was different for type 2 and type 3. The best performance of type 2 was in the north façade, reducing 237.74 kWh/ m² of the total solar radiation, followed by second and third best performance in the northwest and northeast façade by 192.33 kWh/ m² and 181.5 kWh/ m² reduction accordingly. Type 3 showed its three best performance of total solar radiation reduction in the north by blocking around 140.07 kWh/ m², 138.84 kWh/ m² in the south and 126.75 kWh/ m² in the northwest façade.

Table 3. 3. Total solar radiation reduction by applying type 1 to 3 L-shaped mini-louvers (kWh/m²).

Source: photographed by the author

model	north	northwest	west	southwest	south	southeast	east	northeast
type 1	376.86	369.20	353.94	303.99	256.71	268.55	320.90	336.98
type 2	237.74	192.33	153.44	164.16	168.55	148.20	150.53	181.50
type 3	140.07	126.75	105.27	109.80	138.84	102.62	103.33	119.66

Similar with the type 1 to 3, using the type 4 to 6 L-shaped mini-louvers could reduce the total solar radiation. Figure 3.11 shows the total solar radiation in each orientation for type 4 to 6 of the L-shaped mini-louvers in comparison with the base case. Type 4 worked best among other L-shaped mini-louvers utilizing 15 mm aluminum profiles by reducing the total solar radiation. In comparison with the base case, the amount of the total solar radiation received by the façade only around 48% in average of all orientation, ranging from 38% in the north and 54% in the west. More openings made the total solar radiation higher in the window façade. However, there was only a relative small difference between the average of total solar radiation in all orientations by using type 5 and 6, by around 64% and 67% in comparison with the base case accordingly. In all of the façade orientations, the decrease of sun shading effectiveness of blocking the total solar radiation as the effect of size to opening ratio in the L-shaped mini-louvers were constantly seen. The decrease of the L-shaped mini louvers' performance was around 15 to 16 percentage points as the effect of changing the size to opening ratio from 1:1 to 1:2, except in the north orientation which showed a drop of 20%. The same pattern occured when changing the size to opening ratio from 1:2 to 1:3 except in the north direction. In the other orientations, the effectiveness of L-shaped mini-louvers went down ranging from 1 to 5 percentage points. However, in the north façade, the change of size to opening ratio from 1:2 to 1:3 did not negatively impact the L-shaped mini-louvers performance of reducing the total solar radiation. Even though type 5 had less mini-louvers than the type 6, it showed 2 percentage points better performance of total solar radiation reduction in the north façade. Since the amount of total solar radiation in each orientation was difference, the same percentage of solar radiation reduction can have different amount of solar energy.

Figure 3. 11. The total solar radiation of the base case in comparison with the type 4, type 5, and type 6 L-shaped mini-louvers.
Source: photographed by the author

Table 3.4 shows the amount of the total solar radiation reduction of all the type 4 to 6 in comparison with the base case. The type 3 L-shaped mini-louvers worked best by reducing around 390.40 kWh/ m², while type 2 cutting around 267.70 kWh/ m² and type 3 blocks around 246.21 kWh/ m² in all orientation. Type 4 showed its best performance in the north orientation by cutting 450.64 kWh/ m² of the total solar radiation, followed by 448.62 kWh/ m² in the northwest, and 438.38 kWh/ m² in the west. The type 5 had a slightly different best performance, which was obtained in the northwest by cutting 309.46 kWh/ m², followed by 303.82 kWh/ m² in the west, and the third best performance in the west by 245.52 kWh/ m². Type 6 could reduce 320.85 kWh/ m² at its best performance in the north façade, 278.09 kWh/ m² in the northwest, and 245.52 kWh/ m² in the west.

Table 3. 4. Total solar radiation reduction by applying type 4 to 6 L-shaped mini-louvers (kWh/m²).

Source: photographed by the author

model	north	northwest	west	southwest	south	southeast	east	northeast
type 4	450.64	448.63	438.38	368.57	295.82	324.56	388.19	408.43
type 5	303.82	309.46	290.80	254.03	217.93	224.56	258.04	282.94
type 6	320.85	278.09	245.52	228.55	213.36	203.31	223.55	256.48

The last simulations in this chapter was exercising the performance of the type 7 to 9 L-shaped mini-louvers in the outdoor surface of the window to reduce the total solar radiation. The mini-louvers' size in type 7 to 9 was the largest among three selected size: 30 mm. The total solar radiation in each orientation for type 7 to 9 L-shaped mini-louvers in comparison with the base case is shown in figure 3.12. Type 7 worked best by reducing the total solar radiation among other 15 mm L-shaped mini-louvers in this study. In comparison with the base case, the amount of the total solar radiation received by the façade only around 14% in average of all orientation, ranging from 12% in the north and 15% in the west, south, and southeast direction. More openings from type 7 to type 8 made the total solar radiation higher in the window façade. However, more opening in type 9 did not affect the average of the total solar radiation in the window. Type 2 and 3 in average of all orientation received a similar amount of around 37% of total solar radiation in comparison with the base case. Changing the size to opening ratio from 1:1 to 1:2, the decrease of the average of the total solar radiation was around 23% as a result of the range from around 18% at the lowest in the south orientation to the highest 25% in the west.

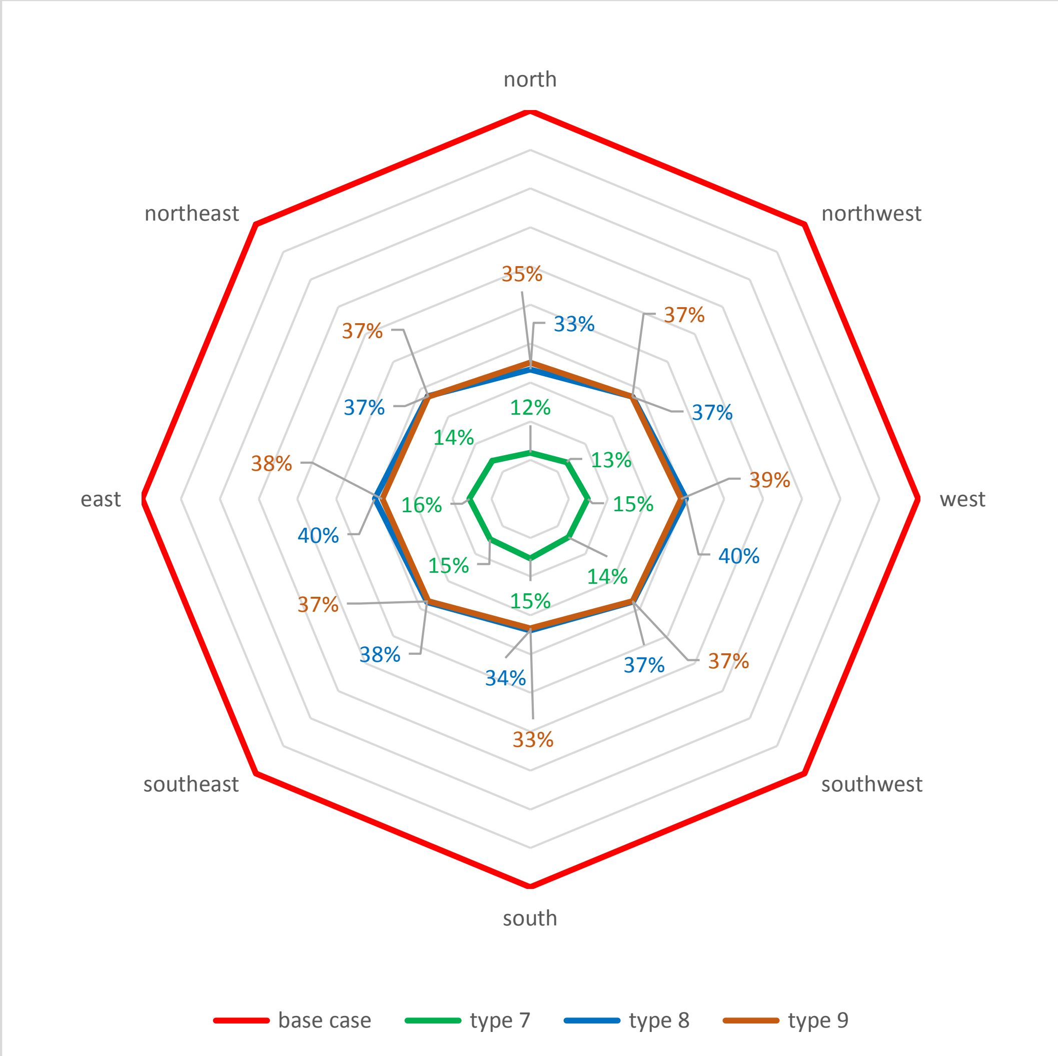


Figure 3. 12. The total solar radiation of the base case in comparison with the type 7, type 8, and type 9 L-shaped mini-louvers.

Source: photographed by the author

The amount of the total solar radiation reduction of all the type 7 to 9 in comparison with the base case are shown in the table 3.5. In average of all orientations, the type 7 performed best by reducing around 654.02 kWh/ m², followed by type 8 which reduced around 477.10 kWh/ m², and type 3 which cut around 480.04 kWh/ m² of the total solar radiation. All three types of L-shaped mini-louvers worked best in the west orientation, reducing the highest amount of the solar radiation in comparison with other orientation. The sun shading performance in the west façade was really significant since the west was the orientation which suffered the highest amount of total solar radiation. Type 7 best performance was in the west by reducing total solar radiation around 807.28 kWh/ m², followed in the northwest (762.11 kWh/ m²) and in the east façade (701.73 kWh/ m²). This condition was similar with type 9. The best performance of type 9 was in the north façade, reducing 579.79 kWh/ m² of the total solar radiation, followed by second and third best performance in the northwest and east façade by 552.77 kWh/ m² and 514.5 kWh/ m² reduction accordingly. Type 8 showed its three best performance of total solar radiation reduction in the north by blocking around 568.39 kWh/ m², 552.3 kWh/ m² in the northwest and 498.83 kWh/ m² in the northeast façade.

Table 3. 5. Total solar radiation reduction by applying type 7 to 9 L-shaped mini-louvers (kWh/m²).

Source: photographed by the author

model	north	northwest	west	southwest	south	southeast	east	northeast
type 7	643.61	762.11	807.28	631.02	444.24	556.10	701.73	686.10
type 8	486.57	552.30	568.39	458.77	347.22	406.43	498.29	498.83
type 9	473.71	552.77	579.79	460.26	350.03	408.89	514.50	500.35

The total solar radiation could be reduced by attaching L-shaped mini-louvers, despite their small size. The larger size of mini-louvers member lead to better performance of reducing total solar radiation in the window surface in average of all orientations (figure 3.13). Type 1, type 4, and type 7, which had the size to opening ratio of 1:1, had a relatively similar coverage of the window at around 1.9 m² which blocks a 4 m² window. The increase of the performance of total solar radiation reduction was clearly seen, from around only 42% by using type 1 to a 51% and 86% by applying type 4 and 7 accordingly. The same pattern were also shown in 1:2 and 1:3 size to opening ratio. Type 2, type 5, and type 8 have 1:2 size to opening ratio and covered around 1.32 m² of the 4 m² window surface. Type 3, type 6, and type 9 covered 0.96 m² of 4 m² window surface since they had 1:3 size to opening ratio. The performance of type 2, which is around 22 percentage points increase to 33% and 62 % by using type 5 and type 8 accordingly. From type 3 to type 6, the increase of the L-shaped mini-louvers' performance was around 15 percentage points to 31%. From type 6 to type 9, the increase of the L-shaped mini-louvers' performance was around 31 percentage points to 62%. However, the performance in the larger size of mini-louvers, by using 15 mm and 30 mm were not significant. There was only around 2 percentage points and almost no difference in applying different size to opening ratio from type 5 to type 6, and type 8 to type 9 accordingly.

Performance to coverage was obtained by dividing the average of total solar radiation in all orientation with the window coverage. In terms of performance to window coverage, the largest mini-louvers size were the most effective sun shading device, with type 9 was the best L-shaped mini-louvers. Comparing the performance to coverage, type 9 achieved 2.62, significantly higher than the average performance to coverage value of all shading at 1.32. The worst performance to coverage value was type 3, a 1:3 size to opening ratio, L-shaped mini-louvers with the members' size of 12 mm and 36 mm opening among them. Type 3 performance to coverage value was similar with that of type 2, leaving only 0.05 difference. Type 4 was slightly better at 0.04 performance to coverage value in comparison with type 5, both were utilizing 15 mm L-shaped mini-louvers with different size to opening ratio.

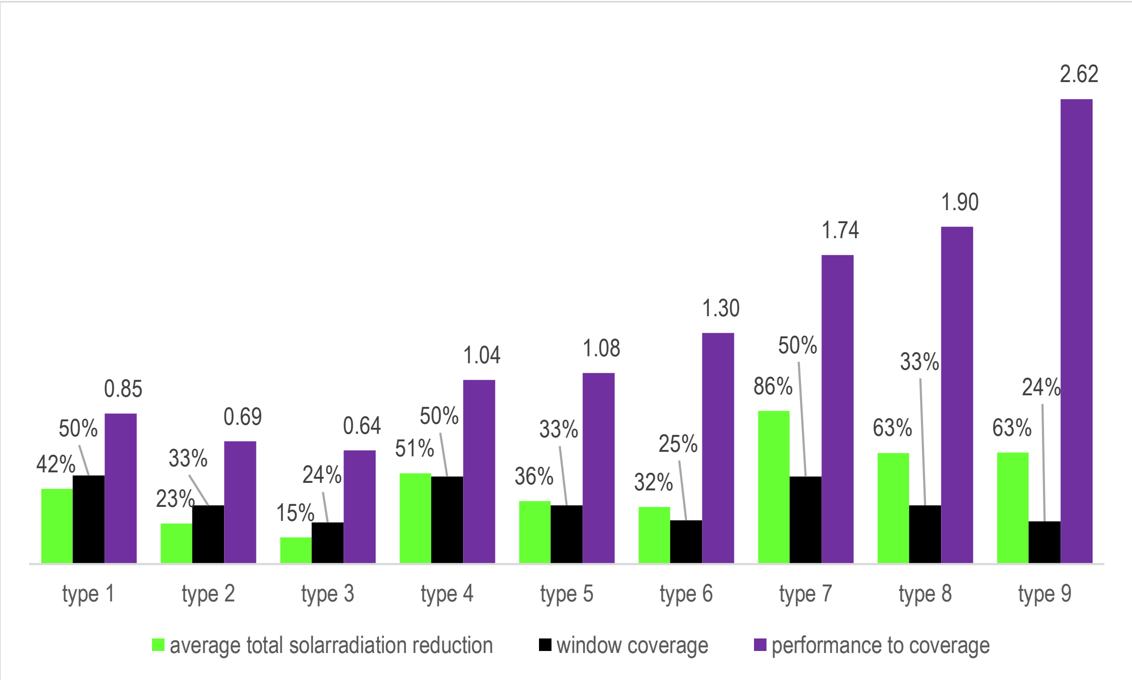


Figure 3. 13. The average performance of each type and the coverage of the window surface. Source: photographed by the author

3. 4. Chapter conclusion

Blocking the sunlight before it entered the buildings was the main concern to reduce the cooling energy consumptions. One of the possible solution was applying sun shading devices. Rather than using custom-fabricated screen filters in the previous chapter, a more simple sun shading device was tested in this third chapter. The use of L-shaped aluminum profile was one of the possible promising alternatives to be used as mini-louvers. The proposed sun shading design had many benefits. First, the raw materials for creating the L-shaped mini-louvers, L-shaped aluminum profiles are widely available in most places in the world. The assembling and constructing of the L-shaped aluminum profiles into mini-louvers are simple and easy. It requires no specific working or technical skills. The L-shaped aluminum profiles are durable and need no maintenance during the operating period.

In this chapter, the proposed designs of L-shaped mini-louvers were tested to measure their performance. The simulation results in this chapter show that the L-shaped mini-louvers had a potential of reducing total solar radiation, which was the main factors of heat gain in buildings even though they are relatively small. The total solar reduction were varied, depending on the L-shaped mini-louvers size and opening ratio, ranging from as low as around 15% to up as high as around 86%. Type 7 (15 mm size with 15 mm openings) was the best, cutting 85% of annual total solar radiation. Considering the coverage of the window, some L-shaped mini-louvers types were significantly had better value than the others. Type 9 (15 mm size with 45 mm openings) had the best performance to coverage value of 2.62, significantly higher than 1.9 of type 8 (15 mm size with 30 mm openings) and 1.74 type 7 (15 mm size with 15 mm openings). However, rather than only simulating the total solar radiation, which was one of the factors affecting the cooling energy consumption, the next step of this chapter was simulating the performance of L-shaped mini-louvers in cooling energy consumption in residential buildings setting by applying the same sun shading device, the L-shaped mini-louvers.

Chapter 4 – Wooden box with L-shaped mini-louvers thermal performance experiments

4. 1. Chapter background

In the previous chapter, the simulation results showed that the L-shaped mini-louvers could effectively block the solar heat gain by reducing the total solar radiation in Jakarta. This chapter experiments the L-shaped mini-louvers effects on the indoor temperature condition as a results of lower solar radiation. The experiments method were chosen not only for exploring the performance of L-shaped mini-louvers but also to check and clarify the results from computer simulation. Theoretically, when the solar radiation decrease, the indoor temperature becomes lower too. The experiments in this chapter aimed to know the performance of L-shaped mini-louvers in reducing the indoor temperature. The thermal recorder saved both the average indoor temperature and peak temperature data during the experiment period. A paper entitled "L-shaped mini louvers performance for reducing indoor temperature" showed the experiments in this chapter[97]. The paper was presented at the 5th International Conference on Indonesian Architecture and Planning in October 2020. This paper was selected and published in IOP Conference Series: Earth and Environmental Science Volume 764 in 2021.

4. 2. Experimental techniques

Rather than used computer simulation, the research in this chapter used experiment by building real models. The computer software was still used for preparing the real models for experiments. First, computer models were made parametrically in Rhinoceros 3-dimension using grasshopper plug-in. There were two sun shading types in this experiments: L-shaped mini-louvers and mini-overhangs, which were schematically shown in figure 4.1. The L-shaped aluminum profile was also used on the top of the mini-overhangs to attach the mini-overhang to the glass surface and wooden box. The L-shaped aluminum profile and mini-overhangs were attached using the outdoor double-sided tape. The ratio between the size of shading and the opening among the shading, which expose the window surface, were 1 to 1, 1 to 2, and 1 to 3. Model A was the box utilizing L-shaped mini-louvers with size to opening

[97] Suryandono AR, Hariyadi A, Fukuda H (2020) L-shaped mini louvers performance for reducing indoor temperature. The 5th International Conference in Indonesian Architecture and Planning.

ratio of 1:1. Model B was the box utilizing L-shaped mini-louvers with size to opening ratio of 1:2. Model C was the box utilizing mini-overhangs with size to opening ratio of 1:3. Model D was the box utilizing mini-overhangs with size to opening ratio of 1:1. Model E was the box utilizing mini-overhangs with size to opening ratio of 1:2. Model F was the box utilizing mini-overhangs with size to opening ratio of 1:3. Table 4.1 shows the dimensional properties of the sun shadings that were used in this study.

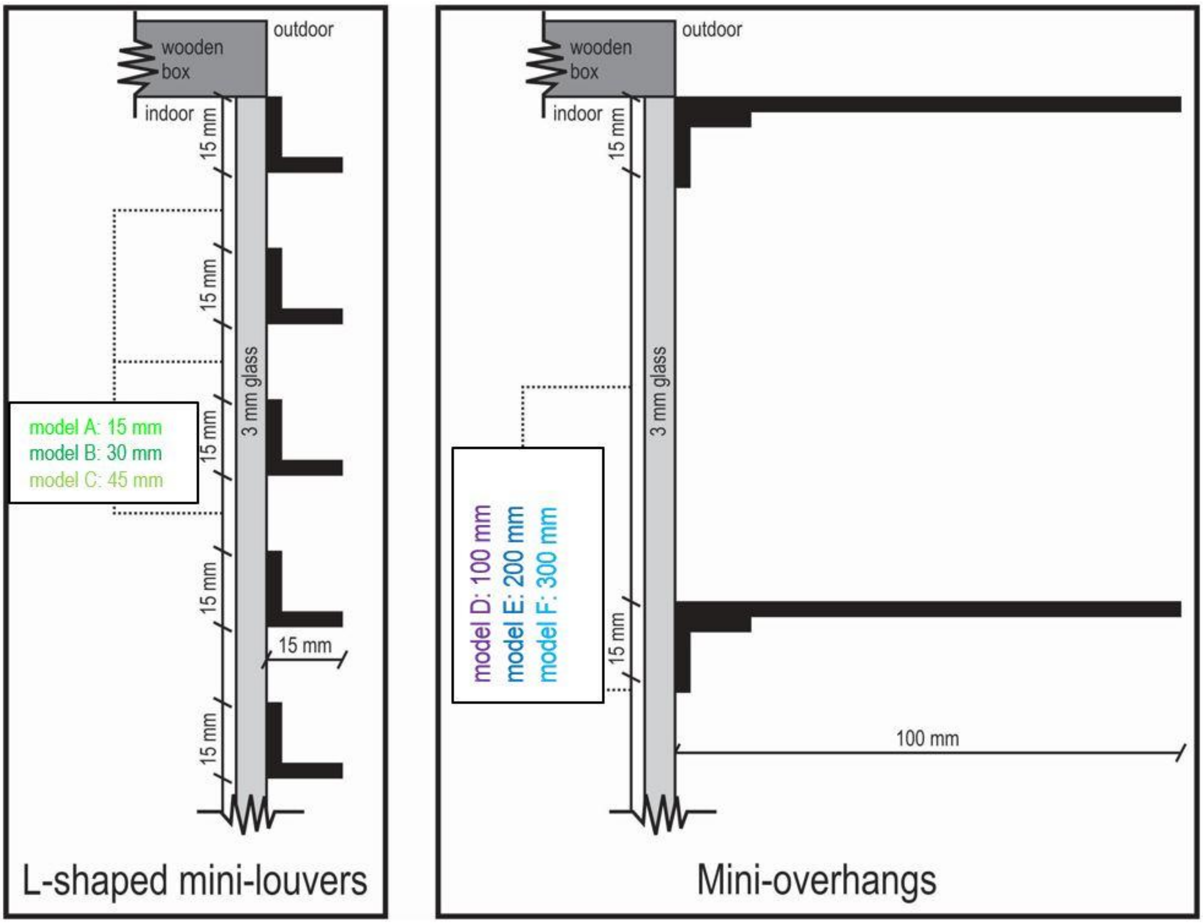


Figure 4. 1. Schematic section of L-shaped mini-louvers and mini-overhangs in the experiments in this chapter.

Source: photographed by the author

Table 4. 1. Sun shading properties in this experiment.

Source:photographed by the author.

name	sun shading type	size	thickness	length	opening	attachment
model A	L-shaped mini-louvers	15 mm	0.8 mm	300 mm	15 mm	double-sided tape
model B	L-shaped mini-louvers	15 mm	0.8 mm	300 mm	30 mm	double-sided tape
model C	L-shaped mini-louvers	15 mm	0.8 mm	300 mm	45 mm	double-sided tape
model D	mini-overhangs	100 mm	0.8 mm	300 mm	100 mm	double-sided tape
model E	mini-overhangs	100 mm	0.8 mm	300 mm	200 mm	double-sided tape
model F	mini-overhangs	100 mm	0.8 mm	300 mm	300 mm	double-sided tape

The complete 3-dimensional models of the experiments are shown in figure 4.2. One side was opened but covered with 3 mm glass, and shaded with either L-shaped mini-louvers or mini-overhangs. Base case experimental model was left without any shading devices. The 3-dimensional computer model of the experiment environmental setting is shown in figure 4.3. The experiments were done during late summer in 2019. The environmental condition, in terms of outdoor temperature and humidity in Kitakyushu, Japan during the experiments were relatively similar with the condition in Jakarta, Indonesia. The sun path in the figure showed the condition around Kitakyushu, Japan, the location for this experiments. The south area was exposed the most from the sun so the south direction was chosen in the experiments. The east facade was also chosen for L-shaped mini-overhang to compare the results in a different orientation.

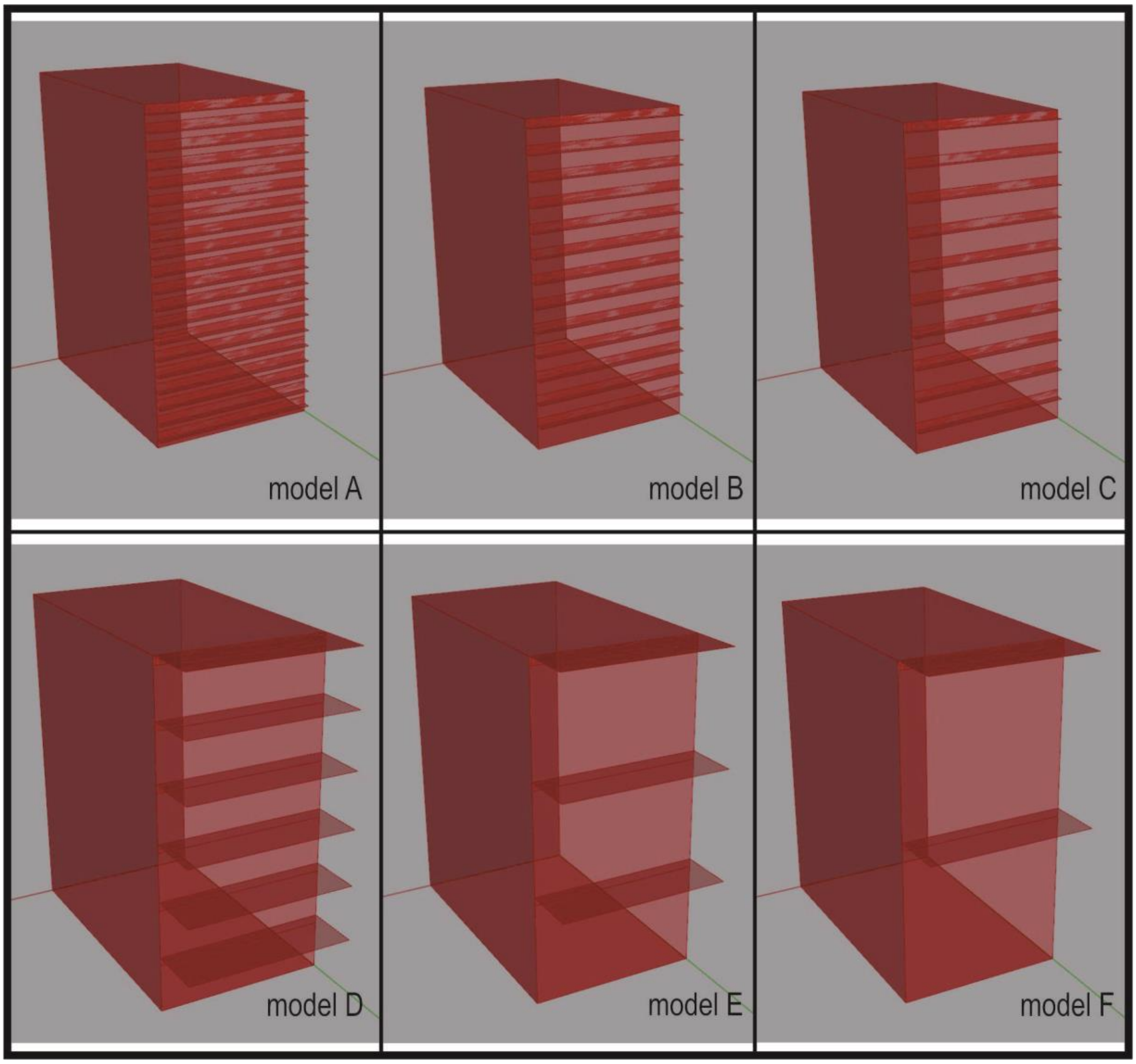


Figure 4. 2. The 3-dimensional computer models of L-shaped mini-louvers.

Source: photographed by the author

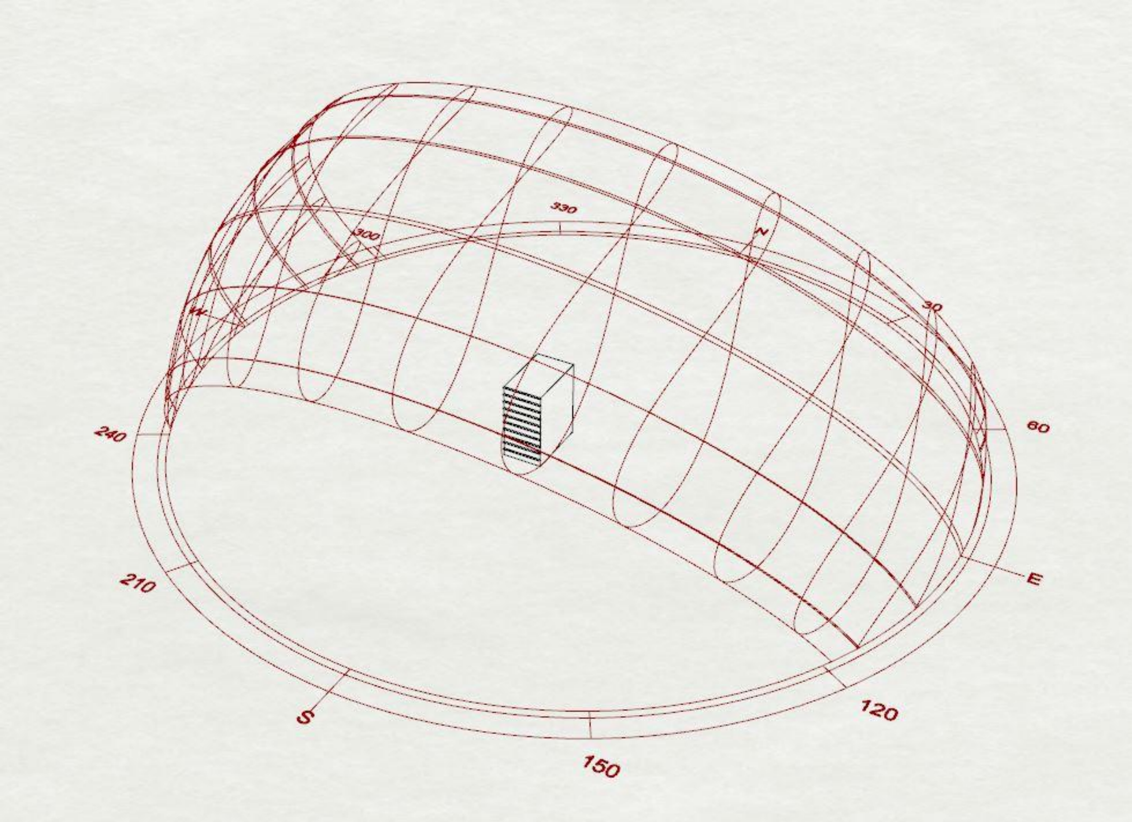


Figure 4. 3. The 3-dimensional computer model of the environmental setting of the experiments. Model C is shown in the picture.
Source: photographed by the author

The materials of both proposed sun shadings were widely available building materials. The L-shaped aluminum profile with the size of 15 mm × 15 mm, with the thickness of 0.8 mm, was chosen to be used as mini-louvers (figure 4.4). The size of the aluminum plates for mini-overhangs were 100 mm × 300 mm (figure 4.5). Then, four wooden boxes with the dimension of 300 mm × 300 mm × 600 mm were built. One side of the box was the openings, covered by one layer of 3 mm glass (figure 4.6). The wood thickness for this experiment was 12 mm. These boxes were used for testing the interior temperature. One box without any sun shading was used as base case for benchmarking purpose. All sun shadings were tested in Kitakyushu, Japan in September 2019. The data were recorded using thermal data logger. The thermal recorder, data logger TR-72U, that were used in the experiments are made by T&D (figure 4.7). For this experiment, only the temperature data were needed. According to the user manual of the thermal data logger, the external sensor could be detached except the humidity data were needed. In this experiment, only the internal sensor of the thermal data logger was used for measuring the temperature.

The thermal recorder was placed inside of each box in the middle bottom side (figure 4.8). After placing the temperature all the wooden boxes were closed (figure 4.9) and remain closed during the experiments.

Figure 4. 4. L-shaped aluminum profile for mini-louvers.

Source: photographed by the author

Figure 4. 5. Aluminum plate for mini-overhangs.

Source: photographed by the author

Figure 4. 6. The wooden boxes for experiments before the attachments of sun shading devices. The top of the wooden boxes were also still opened.

Source: photographed by the author

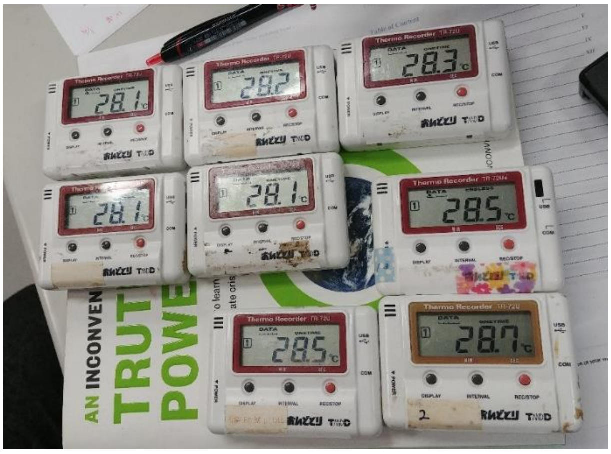


Figure 4. 7. T&D data logger type TR-72U for recording indoor temperature.

Source: photographed by the author

Figure 4. 8. Temperature recorder placement in the middle of the base inside of the box.

Source: photographed by the author

Figure 4. 9. The model D is shown in the picture with thermal recorder inside.
Source: photographed by the author

4. 3. Thermal experiments results and analysis

Four boxes, three boxes with sun shading and one without sun shading were tested facing south. First, the L-shaped mini-louvers were tested for five days (Figure 4.10). After the designated experiment period was finished, the L-shaped mini-louvers were replaced with mini-overhangs with the same orientation to compare each sun shading performance of temperature reduction (Figure 4.11). The L-shaped mini-louvers were tested again for east orientation to explore the performance of L-shaped mini-louvers in a different orientation.

Figure 4. 10. The experiment setting of one base case box without sun shading and three boxes using L-shaped mini louvers.

Source: photographed by the author

Figure 4. 11. The experiment setting of one base case box without sun shading and three boxes using mini overhangs.

Source: photographed by the author

The interior thermal recordings were set every 30 minutes for five days. There were 240 data for each model. In total there were 2880 interior thermal data. The experimental results were presented in the table 4.2. The results of the south facing L-shaped mini louvers experiments showed significant differences both in terms of average and peak temperature during the experiment period among models. The range of the average temperature was reduced from 2°C to be more than 4°C. Model A worked best in reducing the average temperature among other models by cutting around 4.18°C. Placing the L-shaped mini-louvers made the peak temperature decrease, ranging from 16.3°C to be more than 22°C.

Similar with the average temperature reduction condition, model A also performed better among other models by cutting around 22.4°C of the peak temperature.

Table 4. 2. Experiment results of south oriented boxes: the base case and models with the L-shaped mini-louvers.

Source:photographed by the author.

Model	Shading type	average temperature	peak temperature (°C)
	no shading/ base case	34.11	68.30
A	L-shaped mini-louvers 1 to 1	29.93	45.90
B	L-shaped mini-louvers 1 to 2	30.60	48.00
C	L-shaped mini-louvers 1 to 3	31.26	52.00

After the first series of experiments, utilizing the same wooden boxes, the L-shaped mini-louvers were changed to the mini-overhangs. Similar with the first experiments, all the wooden boxes faced south direction. The direction stayed the same because the results of the L-shaped mini-louvers would be compared later with mini-overhang. The results of the south facing mini-overhangs experiments showed differences both in terms of average and peak indoor temperature during the experiment period among models, the base case wooden box without any shading devices and wooden boxes using mini-overhangs (table 4.3). Mini-overhangs could also reduce the indoor temperature, both the average and in the peak condition, even though not as significant as L-shaped mini-louvers. The range of the average temperature was reduced around 1°C. Model D works best in reducing the average temperature among other mini-overhangs by cutting around 1.82°C. The range of the reduction of the peak temperature was around 17°C. Similar with the average indoor temperature reduction, model D performed best among other models by cutting around 17.7°C of the indoor peak temperature. Despite their small size, both L-shaped mini-louvers and mini-overhangs could cut down the average and peak indoor temperature in the experiment.

Table 4. 3. Experiment results of south oriented boxes: the base case, and models with mini-overhangs.

Source:photographed by the author.

Model	Shading type	average temperature	peak temperature (°C)
	no shading/ base case	28.35	63.30
D	Mini-overhangs 1 to 1	26.53	45.60
E	Mini-overhangs 1 to 2	26.86	46.30
F	Mini-overhangs 1 to 3	27.06	46.80

The L-shaped mini-louvers showed superior performance in comparison with mini-overhangs (figure 4.12). Comparing the same size to opening ratio, best performance of mini-overhangs, which was obtained by placing model D as sun shading devices was still significantly worse than model A which was the best L-shaped mini-louvers in reducing average and peak temperature. There was around 6 percentage point differences in the reduction of average indoor temperature. In terms of peak indoor temperature reduction, an approximately 5 percentage points differences in the performance of type A and type D. Both sun shading devices were at 1:1 size to opening ratio. The same condition also occured by comparing the same size to opening ratio of L-shaped mini-louvers and the mini-overhangs. Even the worst performance of L-shaped mini louvers, model C was still better than the best performance of mini-overhangs, model D in terms of reducing the average temperature by around 2 percentage points.

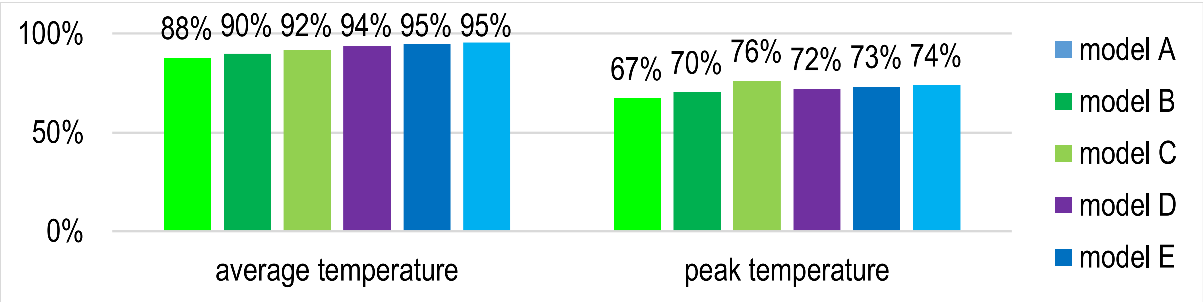


Figure 4. 12. Comparison of the sun shading devices performance in reducing the average and peak temperature (%). Note: the base case is at 100% with no sun shading to reduce the indoor average and peak temperature.

Source: photographed by the author

To explore the performance of L-shaped mini louvers in different orientation, similar experiments were conducted with the setting of the first experiments using model A, B, and C. Rather than facing south, the boxes were facing east orientation. The results of the experiments are shown in table 4.4. There were similar effects of the L-shaped mini-louvers placement as sun shading devices with the first experiment. The reduction, both the average and peak temperature were significant. The average of the temperature reduced from around 3% to 9%, depends on the chosen L-shaped mini-louvers. The peak temperature could be cut around 35% to 15%. Model A performed best among others by reducing 2.9°C and 22.5°C of the average and peak temperature respectively. Model B could reduce the average indoor temperature of 1.92°C and the peak indoor temperature of 14.3°C. Model C, which showed worst performance among others could still reduce the average indoor temperature of 1.05°C while cut indoor peak temperature of 9.8°C.

Table 4. 4. Experiment results of east oriented boxes.

Source:photographed by the author.

Model	Shading type	average temperature	peak temperature
	no shading/ base case	32.31	63.40
A	L-shaped mini-louvers 1 to 1	29.41	40.90
B	L-shaped mini-louvers 1 to 2	30.39	49.10
C	L-shaped mini-louvers 1 to 3	31.26	53.60

4. 4. Chapter conclusion

The experiments result in this chapter showed that the sun shading blocks and reduces the solar radiation in the buildings. It lead to the indoor temperature reduction both in average and peak condition. The best sun L-shaped mini-louvers was type A (15 mm size with 15 mm openings) which could reduce around 12% of average and 33% of the peak indoor temperature in the east orientation. The best mini-overhangs was type D (100 mm size with 100 mm openings) by reducing around 6% of average and 28% of the peak indoor temperature in the same orientation. Model A could also reduce 9% of average and 35% of the peak indoor temperature when facing east. The experiments also showed superior performance of the L-shaped mini-louvers in comparison with mini-overhangs. In the south direction, there was a gap of around 6 percentage points of average indoor temperature and 5 percentage points of peak indoor temperature between the best L-shaped mini-louvers and mini-overhangs. The best models were utilizing the same size to opening ratio of 1: 1.

Despite the small members' size, there was significant differences considering the average and peak temperature reduction. Reduction of the average indoor temperature was important to reduce the cooling energy consumptions in buildings. The indoor peak temperature reduction was also important since it could help the electricity systems' work during the highest demand of electricity. It would reduce the electric demand during the critical period so the electricity could be used not only for cooling but also for other electricity demands.

The next chapter focused on continuing the experiment results in this chapter by executing the L-shaped mini-louvers as sun shading in building simulations to obtain the performance of cooling energy reduction.

Chapter 5 – L-shaped mini-louvers for cooling energy reduction in residential in Jakarta, Indonesia

5. 1. Chapter background

In the third chapter, computer simulation was executed to measure the effectiveness of proposed sun shading device, L-shaped mini-louvers to block the total solar radiation that was received by the outdoor surface of a building. The fourth chapter proofed that the L-shaped mini-louvers could reduce the average indoor temperature as well as the peak indoor temperature. This chapter continued the simulations in the third chapter and the findings in the fourth chapter by measuring the impact of the L-shaped mini louvers to reduce cooling energy in buildings.

A paper was presented the research of L-shaped mini-louvers in Grand Renewable Energy international conference in a paper "Mini-louvers performance of building cooling load energy reduction"[98]. In this paper, the performance of the L-shaped mini-louvers in blocking total solar radiation and reducing cooling energy were tested in several locations across Japan: Hokkaido, Tokyo, and Naha. The results showed that the L-shaped mini-louvers work best in south orientation by reducing up to around 85% of total solar radiation in Sapporo, and around 82% in Tokyo and Naha. In terms of cooling energy, the L-shaped mini-louvers also reduced up to 45%, 25%, and 14% in Sapporo, Tokyo, and Naha accordingly. To show the performance of L-shaped mini-louvers in different location with different environmental condition, a paper was also presented the L-shaped mini-louvers performance on cooling energy reduction in other cities in the world in "Performance of L-shaped mini-louvers in Tropical Cities in Cooling Energy Reduction: Case study of Mumbai, Mexico City, and Lagos"[99]. The paper was presented at the 3rd Green Urbanism international conference in Rome, Italy. This research was also selected as a distinguished paper in the aforementioned conference, accepted and to be published in "Advanced Studies in Efficient Environmental Design and City Planning" within a book series "Advances in Sciences, Technology, and Innovation" by Springer. The result showed that the L-shaped mini-louvers can reduce up to 32% and 30% in average of all simulated building orientations of annual cooling energy in Lagos and Mumbai accordingly. In Mexico City, the area which needed not only cooling but also heating energy, the L-shaped mini-louvers was still positively beneficial

[98] Suryandono AR, Hariyadi A, Fukuda H (2018) Mini louvers performance of building cooling load energy reduction. Grand renewable energy 2018. P-At-16

[99] Suryandono AR, Hariyadi A, Fukuda H (2018) Performance of L-shaped mini-louvers in tropical cities in cooling energy reduction: case study of Mumbai, Mexico City, and Lagos. 3rd Green Urbanism

in terms of total annual cooling and heating energy. The L-shaped mini-louvers boosted heating energy up but cut cooling energy down which brought total cooling and heating energy in average of all building orientations up to 75% in comparison with the base case without any shading devices. The best proposed L-shaped mini-louvers in this study could reduce total annual cooling and heating energy in Mexico City in average of all orientations up to around 25%. Calculating the cooling energy was also used in the paper entitled "Environmental and economic benefits of Japanese *Koshi* inspired Mini-louvres in residential buildings in Jakarta, Indonesia" from Journal of Façade Engineering Vol.8 No. 2 (2020). This paper also used for the next chapter substances[100].

5. 2. Cooling energy simulation settings

The research methodology in this chapter was similar with the research methodology in the aforementioned papers. The weather data, downloaded from OneBuilding used in this chapter's simulations was the same with the one that were used in the third chapters. The location was at Jakarta observatories. The parametric script in Grasshopper to build the box, L-shaped mini-louvers, and overhangs were also the same with the one used in chapter three. However, rather than only LadyBug, the simulation of cooling energy consumption in this chapter used HoneyBee to host the EnergyPlus simulation engine.

First, a 3000 mm × 3000 mm box was constructed to mimic a simple construction of a single room. One side of the wall was opened to accommodate a window. The simple window size was 2000 mm × 2000 mm with single glass pane, located right in the middle of the wall. The materials for the buildings in this simulation were customized, reflecting the real common materials of the buildings in Jakarta, Indonesia. The roof construction consisted of 100 mm lightweight concrete, ceiling air space resistance, and acoustic tiles. Brick walls were on all four sides in the box buildings. These brick walls, with a total thickness of 150 mm were constructed from 120 mm bricks; with 15 mm stucco covering both the interior and exterior surfaces of the bricks. The floor construction consisted of 50 mm insulation board and 200 mm heavyweight concrete. The detailed properties of the construction materials for the roof, walls, and floor are shown in table 5.1. The window was made from a single pane of clear 3 mm glass, which properties are shown in table 5.2. The EnergyPlus shading object property for both diffuse solar and visible reflectance of the unglazed part of shading surface were 0.2.

[100] Suryandono AR, Hariyadi A, Fukuda H (2020) Environmental and economic benefits of Japanese koshi inspired mini-louvers in residential buildings in Jakarta, Indonesia. Journal of Façade Design and Engineering Vol. 8 No. 2.

Table 5. 1. Properties of the opaque materials.

Source:photographed by the author.

Material type	Roughness	Thickness (mm)	Conductivity (W/m-K)	Density (kg/m³)	Specific heat (J/kg-K)	Thermal Absorptance	Solar Absorptance
Lightweight concrete	Medium rough	101.60	0.53	1,280	840	0.90	0.50
Acoustic tile	Medium smooth	19.10	0.06	368	590	0.90	0.30
Stucco	Smooth	15.00	0.69	1,858	836.99	0.90	0.92
Brick	Medium rough	120.00	0.89	1,920	790	0.90	0.70
Insulation board	Medium rough	50.80	0.03	43	1,210	0.90	0.70
Heavyweight concrete	Medium rough	203.20	1.95	2,240	900	0.90	0.70

Table 5. 2. Window properties of single clear 3mm glass pane.

Source:photographed by the author.

Optical data type	Spectral average
Thickness	2.9 mm
Solar transmittance at normal incidence	0.837
Front side solar reflectance at normal incidence	0.075
Visible transmittance at normal incidence	0.898
Front side visible reflectance at normal incidence	0.081
Front side infrared hemispherical emissivity	0.84
Back side infrared hemispherical emissivity	0.84
Conductivity	0.9 W/m-K
Dirt correction factor for solar and visible transmittance	1

The base case for the comparison study in this paper was a simple box building without any shading device attached to the single glass pane window (figure 5.1). Box buildings, along with eighteen models of L-shaped mini-louvers and two overhangs were made parametrically utilizing the same script. The differences among L-shaped mini-louvers types were the size of the L-shaped aluminum profiles, the openings among these profiles, and the gap between the L-shaped mini-louvers and the outdoor surface of the windows. Three sizes of L-shaped aluminum profiles 12 mm × 12 mm, 15 mm × 15 mm, and 30 mm × 30 mm were chosen to represent the different sizes of available materials and their performance. There were two possible L-shaped mini-louvers attachments to the window, whether for new constructions or retrofitting old buildings. The first possibility was to directly put the L-shaped mini-louvers to the exterior window surface using outdoor double-sided tape. A second possibility was to use screws to attach the L-shaped mini-louvers to the window frame. Outdoor double-sided tape and screws for attaching L-shaped mini-louvers were also widely available in the selected research locations. The performances of different shading types in reducing annual cooling energy were analyzed in this chapter.

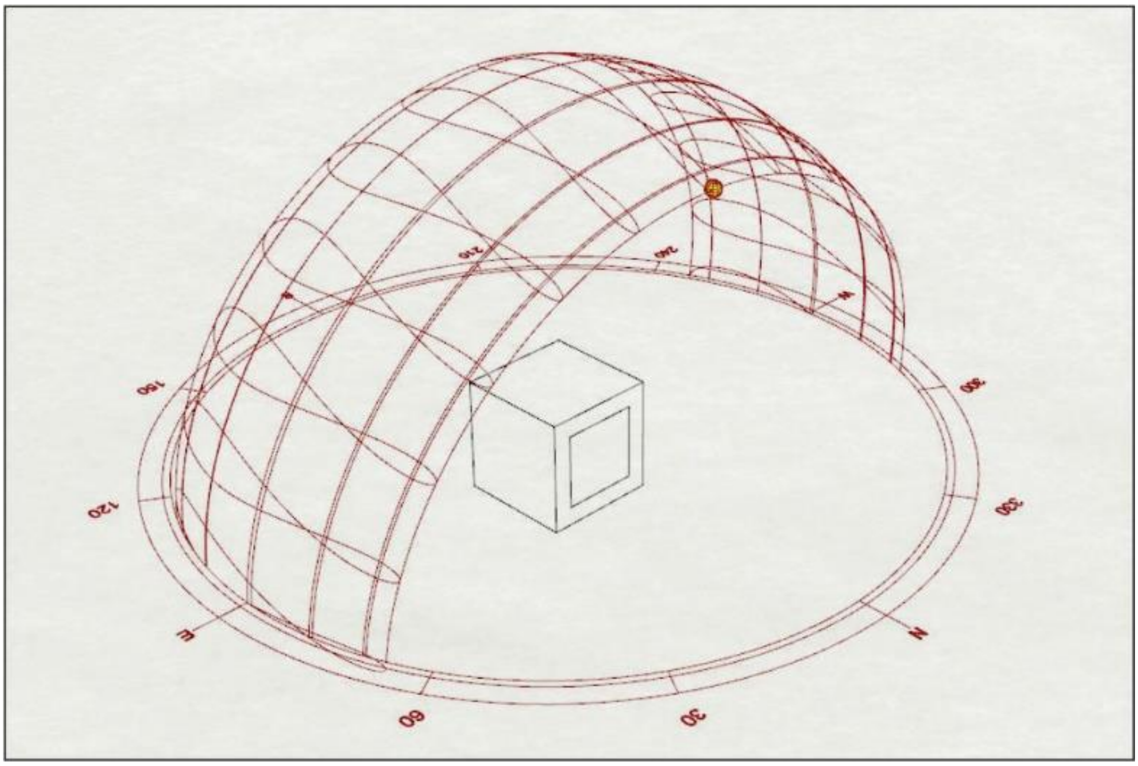


Figure 5. 1. Simulation setting. The picture shows the base case model without a shading device.

Source: photographed by the author

Simulation model types A 1 to 9 were designed to mimic the condition of direct attachment by leaving only a millimeter gap between the L-shaped mini-louvers and the window's outdoor surface. Simulation model types B 1 to 9 were proposed to imitate the attachment of the L-shaped mini-louvers to the window frame with a 50 mm gap between the mini-louvers and the window's exterior surface. There were three basic ratios of L-shaped mini-louvers according to the L-shaped aluminum profiles' size, which act as mini-louvers, to the openings among them. The first was 1:1 ratio. In a :1 ratio, the openings had the same size as the aluminum profiles to form the L-shaped mini-louvers. The second ratio was 1:2, which meant the opening size was twice of the size of the L-shaped aluminum profiles. The last ratio was 1:3, which had he size of the opening three times larger than the size of the L-shaped aluminum profiles. An additional two horizontal overhang types, which were more common shading devices in the selected research location, were simulated for comparison with the performance of the L-shaped mini-louvers. These overhang models were type C1 and C2. Details of 21 buildings with shading sizes and types for simulation are shown in table 5.3. Visualization of L-shaped mini-louvers types A and B 1 to 9 can be seen in figure 5. 2. Figure 5.3 shows the visualization of the perspective and schematic section of the overhang types.

Table 5. 3. Simulated model types size parameters.

Source:photographed by the author.

Model name	Shading type	Size (mm)	Openings (mm)	Gap between the mini-louvers and the window (mm)
Base case	No shading	-	-	-
Type A1	L-shaped mini-louvers	12	12	1
Type A2			24	
Type A3			36	
Type A4		15	15	
Type A5			30	
Type A6			45	
Type A7		30	30	
Type A8			60	
Type A9			90	
Type B1		12	12	50
Type B2			24	
Type B3			36	
Type B4		15	15	
Type B5			30	
Type B6			45	
Type B7		30	30	
Type B8			60	
Type B9			90	
Type C1	Overhang	750	-	1
Type C2		1000	-	

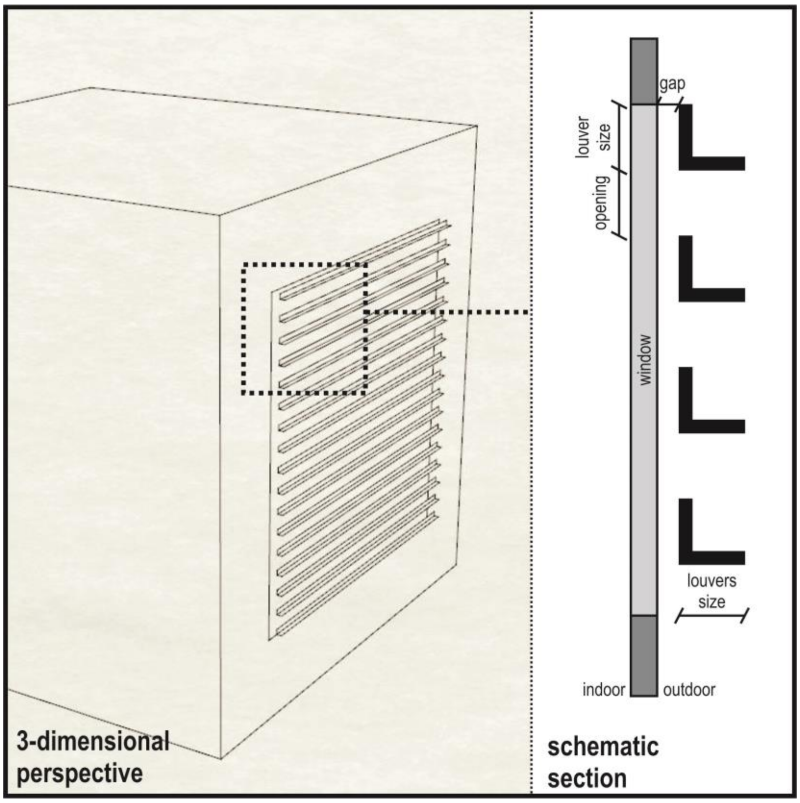


Figure 5. 2. Schematic model of the L-shaped mini-louvers.

Source: photographed by the author

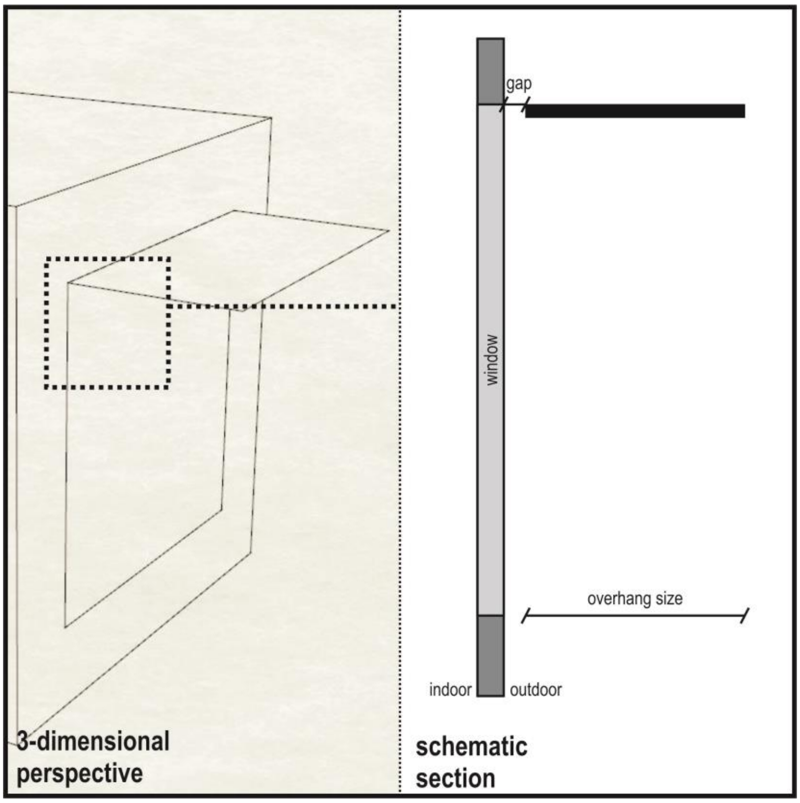


Figure 5. 3. Schematic model of the overhang.

Source: photographed by the author

The weather data for Jakarta, Indonesia were Typical Meteorological Year 3 (TMY3) downloaded directly using Ladybug from the OneBuilding website which were also used for simulations in chapter three in this research. Since the EnergyPlus was the simulation engine behind HoneyBee, the program of the building and setting also follows EnergyPlus. There were various building programs in EnergyPlus. One of them was midrise apartment which has three schedule of rooms: apartment, office and corridor. The target building type for the simulation was residential, so the building schedule of apartment zone program was chosen to mimic the general residential room condition. The settings of midrise apartment zone programs are shown in table 5.4. The equipment and infiltration load, lighting density, and the number of the people per area value were changed hourly according to the chosen apartment program schedule in the simulation. The heating and cooling set point were constant through the year. However, this research focused on cooling energy consumption since the temperature in Jakarta is high all year round.

Table 5. 4. EnergyPlus settings for apartment zone program.

Source:setting from EnergyPlus, photographed by the author.

Apartment	
Equipment load per area	3.875028 W/m²
Infiltration load per area	0.000227 m³/s-m² at 4Pa
Lighting density per area	11.840357 W/m²
Number of people per area	0.028309 People/m²
Ventilation per area	0
Ventilation per person	0
Honeybee zone schedule	default midrise apartment schedule
Ideal air load system	True
Heating set point	21.1°C
Cooling set point	23.9°C

5. 3. Cooling energy simulation results and analysis

All 21 buildings were tested in a one-hour based simulation to obtain the cooling energy results for one year. There were 8760 hours of simulation per building in a year. Residential houses in Jakarta had random directions. The layout was different with grid or circular based cities, as usually seen in the western city planning. The city layout was more organic, and in several area was scattered, as an effect of the sprawl city development. In this research, rather than only 4 major orientations, additional 4 minor orientations were also simulated so in total there are 8 buildings orientations simulation results. The houses could use the closest orientation to predict the proposed sun shading device performance in a real world scenario. The simulation results for the base case, a box building without any shading device are presented in table 5.5. The simulation results showed the differences in total annual cooling energy consumption, depended on the orientations of the building. The west orientation, the most exposed area by the solar radiation, consumed the highest annual cooling energy by 29,851.84 mega Joule per hour. The lowest annual cooling energy was obtained by the the south orientation by 25,779.81 mega Joule per hour, only around 86% in comparison with the west. The second and third orientations which require a huge amount of annual cooling energy was not the east, but west-related orientation: the northwest and southwest. There was a 4,072.04 mega Joule per hour difference between the lowest and the highest annual cooling energy. This number was noted since even in some cases the percentage saving was higher in one orientation other than that of in the west, the largest saving still probably occured in the west orientations.

Table 5. 5. Simulation results of annual cooling energy in the base case along with the comparison of each orientation with the west's highest annual cooling energy. Source:photographed by the author.

Model name	north	northeast	east	southeast	south	southwest	west	northwest
base case (mega *Joule*)	26,336.1	27,195.71	27,849.91	26,713.51	25,779.81	28,068.58	29,851.84	28,487.34
Comparison with the west (%)	88	91	93	89	86	94	100	95

Type A1 to A9 L-shaped mini-louvers were put directly to the outdoor surface of the window. Type B1 to B9 used the same L-shaped mini-louvers with that of type A1 to A9 but were placed in the window frame, while type C1 and C2 were overhangs. The simulation results and analysis were carefully separated, based on the size of the L-shaped mini louvers and their placement to obtain the detailed comparison.

Type A1 to A3 used the same size of L-shaped aluminum profiles but have a different size to opening ratio. The annual cooling energy in each orientation by applying type A1 to A3 in comparison with the base case are presented in figure 5.5. Type A1 which had most window coverage performs best by using around 92% of annual cooling energy in comparison with the base case. More openings constantly reduced the effect of the L-shaped mini-louvers by around 2 percentage points of annual cooling energy. Type A2 performed 2 percentage points worse than type A1 and type A3 performed 2 percentage points worse than type A2. All of the type A1 to A3 showed best their performance in the north and northwest orientation by consuming around 90 to 94% of the annual cooling energy in comparison with the base case. All of the type A1 to A3 showed their worst performance in the south orientation by consuming around 94 to 96% of the annual cooling energy in comparison with the base case. Since the annual cooling energy in each orientation was difference, the same percentage of reduction might have different amount of cooling energy. For example, the same percentage reduction in the west façade, which requires the highest cooling energy was higher than that in the south façade, which required the lowest cooling energy.

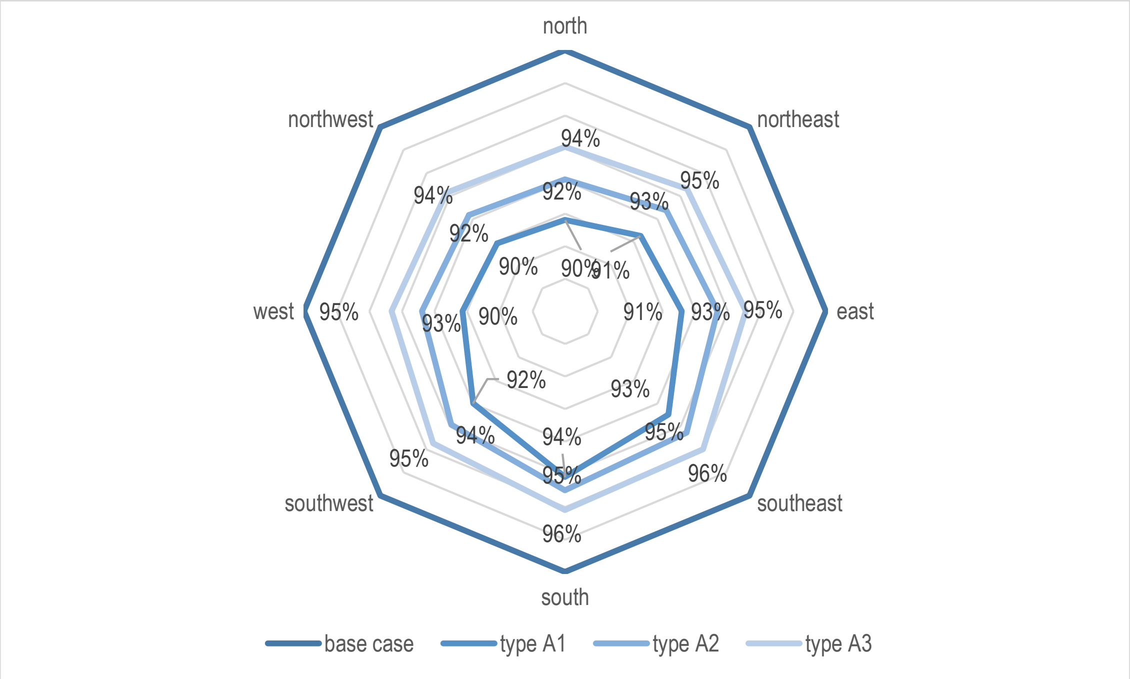


Figure 5. 2. The annual cooling energy of the base case in comparison with type A1, A2, and A3 L-shaped mini-louvers.

Source: photographed by the author

The cooling energy reduction as an effect of attaching the L-shaped mini-louvers type A1 to A3 are presented in table 5.6. Type A1 worked best in the west orientation by reducing 2,901.99 mJ/ h of annual cooling energy, followed in the northwest orientation (2,879.79 mJ/h). Changing the size to opening ratio from 1:1 to 1:2 and 1:3 lead to the change the best orientation of type A2 and A3 from the west to the northwest. Type A2 and type A3 showed their best performance of the annual cooling energy reduction by 2,182.81 mJ/h and 1,632.35 mJ/ h in the northwest, followed by 2,158.28 mJ/ h and 1,602.66 mJ/ h in the west accordingly. In average of all orientation, type A1 was the best among three 12 mm × 12 mm L-shaped mini-louvers which were placed directly to the window surface by reducing 2,397.84 mJ/ h of annual cooling load. It was followed by type A2 and A3 which reduced 1,840.08 mJ/ h and 1,369.28 mJ/ h of the average of annual cooling load in all orientation in comparison with the base case.

Table 5. 6. Annual cooling energy reduction by attaching L-shaped mini-louvers type A1 to A3 (mega Joule/ h).
Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type A1	2,738.14	2,573.15	2,460.30	1,876.97	1,503.35	2,249.06	2,901.99	2,879.79
type A2	2,079.56	1,966.65	1,852.18	1,462.64	1,292.82	1,725.67	2,158.28	2,182.81
type A3	1,551.85	1,466.62	1,369.34	1,074.32	980.33	1,276.78	1,602.66	1,632.35

The mini-louvers type A4, A5, and A6 use the15 mm × 15 mm of L-shaped aluminum profiles using 1:1, 1:2, and 1:3 different size to opening ratio accordingly. The effect of using type A4 to A6 of L-shaped mini-louvers in annual cooling energy in each orientation in comparison with the base case are presented in figure 5.6. Type A4 which had most window coverage performed best by using around 89% of annual cooling energy in comparison with the base case. More openings in these types had a positive impact considering the annual cooling energy. Type A5 performed around 1 percentage points better than type A6 despite more coverage provided by type A5. Louvers did not only cover and provide shadow which were positively reduce the cooling load but also emit the radiation and reflect the heat which had negative impacts to the cooling energy. Type A5 performed worse than type A6 in the north, southeast, and south orientations, all by around 1 percentage point difference. Type A4 worked best in the north and northwest orientation by consuming around 87% of cooling energy in comparison with the base case in average all orientation, while type A5 performed best in the north, northeast, west and northwest, and type A6 worked best in the north.

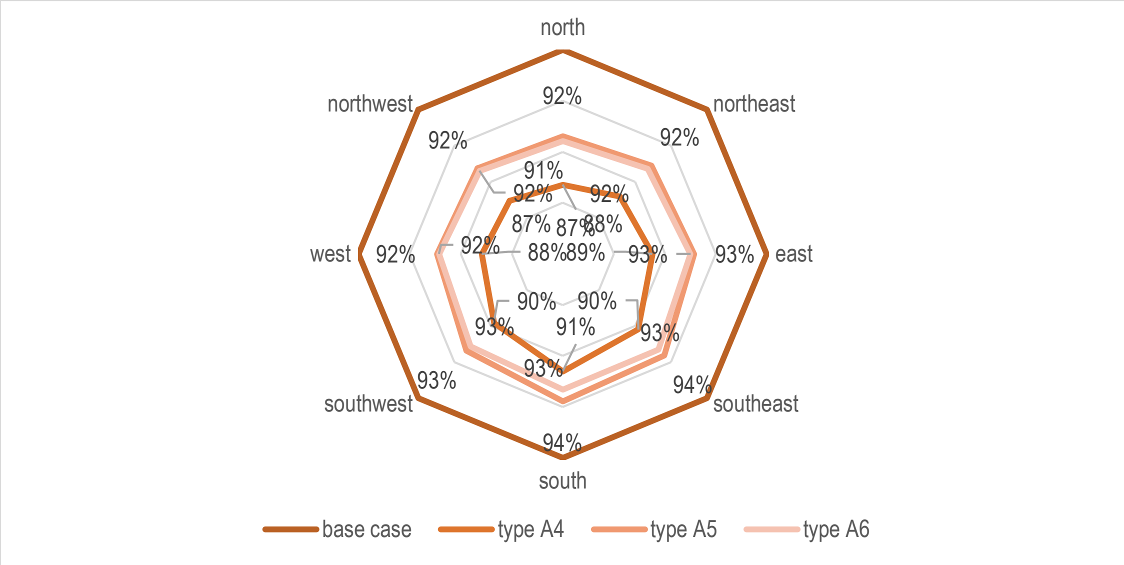


Figure 5. 3. The annual cooling energy of the base case in comparison with type A4, A5, and A6 L-shaped mini-louvers.

Source: photographed by the author

Table 5.7 showed the cooling energy reduction as an effect of attaching the L-shaped mini-louvers type A4 to A6. Type A4 worked best in reducing the annual cooling energy in average of all orientation by cutting 3,423.13 mJ/ h. Type A8 performed worse than type A9. It only cut 1,932.90 mJ/ h of annual cooling energy in average of all orientation in comparison with type A9 of 1,932.9 mJ/ h. All type A4, A5, and A6 showed their best performance in the northwest orientation. Type A7 reduced 3,943.03 mJ/ h in the northwest and 3,601.53 mJ/ h in the west. Type A5 reduced 2,324.4 mJ/ h in the northwest and 2,293.58 mJ/ h in the west. Type A4 reduced 2,409.31 mJ/ h in the northwest and 2,347.08 mJ/ h in the west.

Table 5. 7. Annual cooling energy reduction by attaching L-shaped mini-louvers type A4 to A6 (mega Joule/ h).

Source:photographed by the author.

Model name	north	northeast	east	southeast	south	southwest	west	northwest
type A4	3,476.93	3,282.04	3,127.71	2,545.11	2,191.55	2,935.09	3,601.53	3,604.69
type A5	2,225.19	2,103.02	1,980.62	1,587.17	1,427.80	1,855.19	2,293.58	2,324.40
type A6	2,350.66	2,227.87	2,087.16	1,803.57	1,735.26	2,022.49	2,347.08	2,409.31

The L-shaped mini-louvers type A7 to A9 used 30 mm × 30 mm aluminum profiles with different size to opening ratio of 1:1, 1:2, and 1:3 accordingly. The effect of using L-shaped mini-louvers type A7 to A9 in annual cooling energy in each orientation in comparison with the base case are presented in figure 5.7. Type A7 which had most window coverage performed best by using around 88% of annual cooling energy in comparison with the base case. More openings slightly reduced the effect of the L-shaped mini-louvers in the annual cooling energy consumption. Type A8 performed 6 percentage points worse than type A7. However, type A9 only performed 1% worse than type A8 despite they had significantly more openings. The type A7 and A9 showed best their performance in the north and northwest orientation by consuming around 86% and 92% of the annual cooling energy in comparison with the base case accordingly. Type A8 showed its best performance only in the north by demanding cooling energy around 92% in comparison with the best case and around 93% in the northwest, west, and northeast orientation.

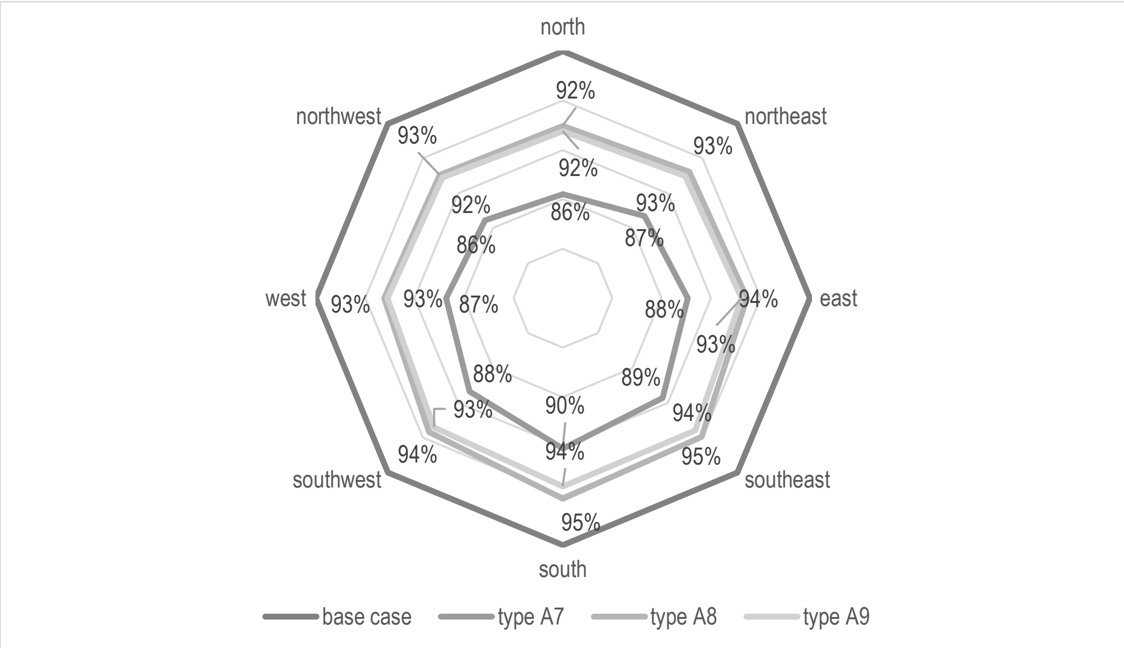


Figure 5. 4. The annual cooling energy of the base case in comparison with type A7, A8, and A9 L-shaped mini-louvers.

Source: photographed by the author

The cooling energy reduction as an effect of attaching the L-shaped mini-louvers type A7 to A9 are shown in table 5.8. Type A7 performed best in reducing the annual cooling energy in average of all orientation by cutting 3,424.13 mJ/ h, followed by type A8 which reduced 1,754.08 mJ/ h and type A9 which cut 1,932.9 mJ/ h. All type A7, A8, and A9 showed their best performance in the northwest orientation. In that orientation, type A7 reduced 3,943.03 mJ/ h, type A8 reduced 2,092.44 mJ/ h, and type A9 reduced 2,210.56 mJ/ h of annual cooling energy demand.

Table 5. 8. Annual cooling energy reduction by attaching L-shaped mini-louvers type A7 to A9 (mega Joule/ h).
Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type A7	3,810.17	3,612.05	3,446.34	2,864.35	2,523.13	3,262.84	3,931.13	3,943.03
type A8	1,988.93	1,879.46	1,772.40	1,379.37	1,208.56	1,640.08	2,071.40	2,092.44
type A9	2,132.67	2,034.90	1,920.67	1,623.38	1,533.16	1,836.52	2,171.36	2,210.56

The L-shaped mini-louvers type B were using the same design with type A, with only difference in their attachment to the window. However, the annual cooling energy among the models were significantly difference. The L-shaped mini-louvers type B1 to B3 use 12 mm × 12 mm aluminum profiles with different size to opening ratio of 1:1, 1:2, and 1:3 accordingly. The effect of using L-shaped mini-louvers type B1 to B3 in annual cooling energy in each orientation in comparison with the base case are presented in figure 5.8. Type B1 which had most window coverage performed best by using around 84% of annual cooling energy in comparison with the base case. More openings slightly reduced the effect of the L-shaped mini-louvers in the annual cooling energy consumption. Type B2 performed 3 percentage points worse than type B meanwhile type B3 performed 4 percentage points worse than type B2. The type B1 and type B3 showed their best performance in the west orientation by consuming around 80% and 89% of the annual cooling energy in comparison with the base case accordingly. Type B2 consumed 85% of annual cooling energy in comparison with the base case in the west and northwest orientation, showing its best performance.

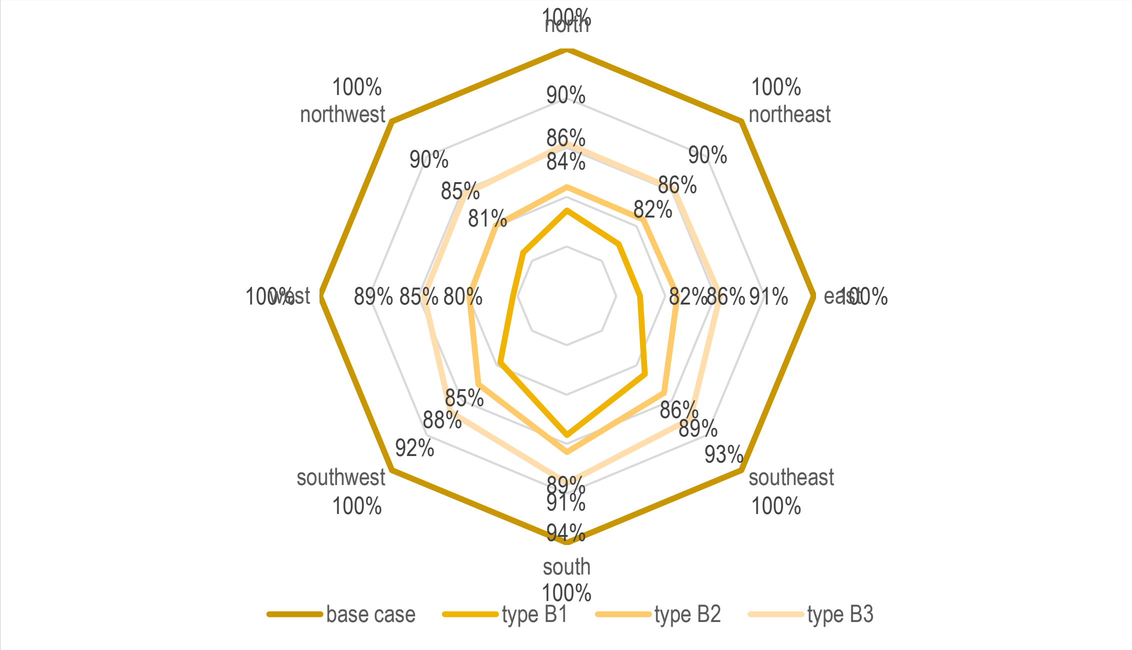


Figure 5. 5. The annual cooling energy of the base case in comparison with type B1, B2, and B3 L-shaped mini-louvers.

Source: photographed by the author

Table 5.9 showed the cooling energy reduction in the box buildings by using the L-shaped mini-louvers type B1 to B3. Type B1 worked best in reducing the annual cooling energy in average of all orientation by cutting 4,502.38 mJ/ h, followed by type B2 which cut 3,609.97 mJ/ h and type B3 which reduced 2,474.53 mJ/ h. All type B1, B2, and B3 showed their best performance in the west orientation. In that orientation, type B1 reduced 4,502.38 mJ/ h, type B2 reduced 3,609.97 mJ/ h, and type B3 reduced 2,474.53 mJ/ h of annual cooling energy demand.

Table 5. 9. Annual cooling energy reduction by attaching L-shaped mini-louvers type B1 to B3 (mega Joule/ h).

Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type B1	4,305.70	4,775.25	4,905.48	3,686.14	2,807.33	4,341.76	5,845.07	5,352.30
type B2	3,676.02	3,821.28	3,847.44	2,963.23	2,361.28	3,453.94	4,514.00	4,242.59
type B3	2,529.43	2,642.90	2,642.56	1,969.75	1,566.11	2,342.77	3,141.10	2,961.59

The L-shaped aluminum profiles with the size of 15 mm x 15 mm with different size to opening ratio of 1:1, 1:2, and 1:3 were used for mini-louvers type B4, B5, and B6 accordingly. Figure 5.9 presents the effect of using L-shaped mini-louvers type B4 to B6 in the annual cooling energy in each orientation in comparison with the base case. Type B4 which has 1:1 size to opening ratio performed best by using around 83% of annual cooling energy in comparison with the base case. More openings in the L-shaped mini-louvers lead to the worse performance in terms of cooling energy reduction. Type B5 and B6 used around 87% and 90% of the annual cooling energy in average of all orientation in comparison with the base case accordingly. Type B4 best performance occured in the west orientation by using around 80% of the annual cooling energy in comparison with the base case. Type B5 and B6 showed their best performance in the west and northwest orientation by consuming around 85% and 88% of the annual cooling energy in comparison with the base case accordingly.

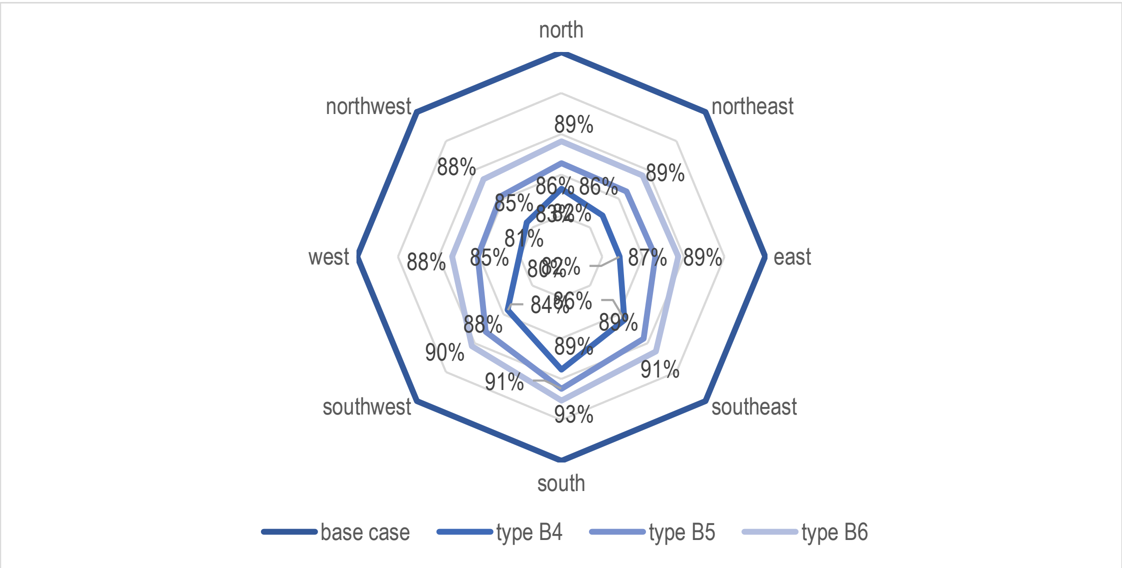


Figure 5. 6. The annual cooling energy of the base case in comparison with type B4, B5, and B6 L-shaped mini-louvers.

Source: photographed by the author

The simulation results showed the cooling energy reduction in the box buildings by using the L-shaped mini-louvers type B4 to B6 (table 5.10). Type B4 reduced the annual cooling energy in average of all orientation by 4,578.51 mJ/ h, the best among other types, followed by type B5 (3,512.42 mJ/ h) and type B6 (2,803.55 mJ/ h). In the west orientation, all type B4, B5, and B6 showed their best performance. In the west, type B4 reduced

5,923.17 mJ/ h, type B5 reduced 4,409.08 mJ/ h, and type B6 reduced 3,467.34 mJ/ h of annual cooling energy in comparison with the base case without any shading device.

Table 5. 10. Annual cooling energy reduction by attaching L-shaped mini-louvers type B4 to B6 (mega Joule/ h).

Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type B4	4,398.15	4,856.68	4,976.38	3,751.76	2,877.21	4,413.78	5,923.17	5,430.95
type B5	3,579.61	3,722.75	3,745.10	2,869.63	2,274.40	3,357.25	4,409.08	4,141.53
type B6	2,869.24	2,974.04	2,959.71	2,294.97	1,898.67	2,672.78	3,467.34	3,291.63

The effect of using L-shaped mini-louvers type B7 to B9 in the annual cooling energy in each orientation in comparison with the base case are shown in figure 5.10. Type B7 to 9 use 30 mm × 30 mm L-shaped mini-louvers with different size to opening ratio. Type B7 which has 1:1 size to opening ratio performed best by using around 83% of annual cooling energy in comparison with the base case. The effectiveness of the L-shaped mini-louvers to reduce the cooling energy decreased when there were more openings. Type B8 used around 88% while type B9 uses around 90% of the annual cooling energy in average of all orientation in comparison with the base case accordingly. Type B7 best performance occured in the west orientation by using around 80% of the annual cooling energy in comparison with the base case. Type B5 performed best among other orientations in the west and northwest, consuming around 86% of annual cooling energy in comparison with the base case. Type B6 showed its best performance similarly in the west, northwest, north, and northeast orientations by consuming around 89% of the annual cooling energy in comparison with the base case.

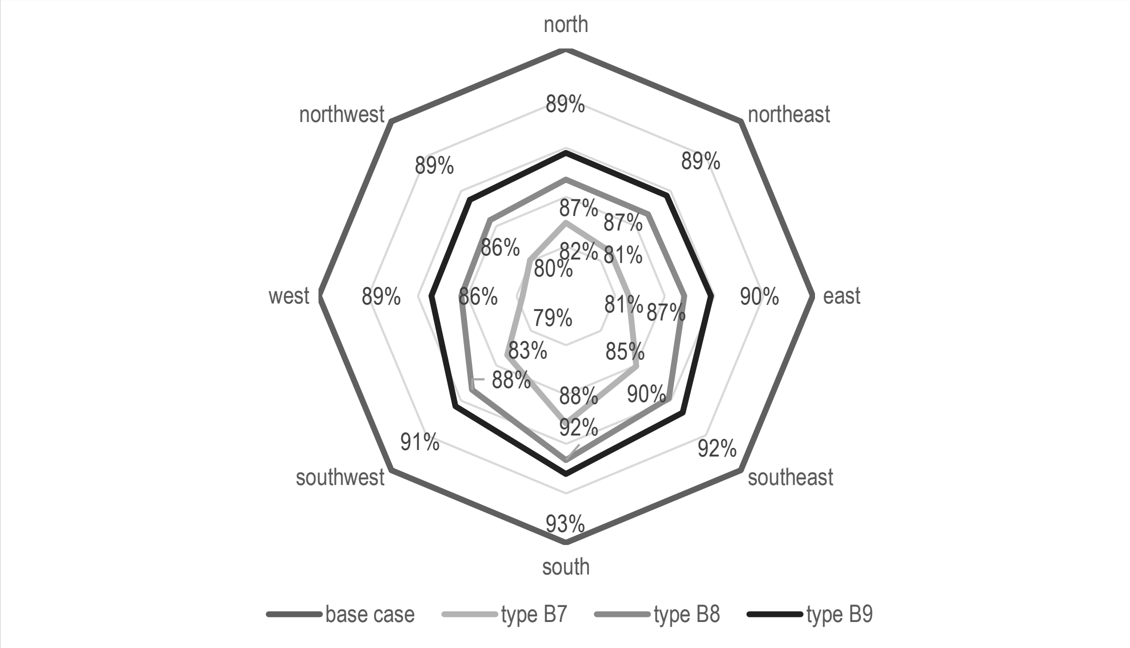


Figure 5. 7. The annual cooling energy of the base case in comparison with type B7, B8, and B9 L-shaped mini-louvers.

Source: photographed by the author

The amount of energy reduction in the box buildings by using the L-shaped mini-louvers type B7 to B9 were shown in table 5.11. Type B7 reduced the annual cooling energy in average of all orientation by 4,808.62 mJ/ h, the best in comparison with type B8 which could reduce 3,401.05 mJ/ h and type B9 which cuts 2,716.2 mJ/ h. Type B7, B8, and B9 show their best performance in the west façade. In that direction, type B7, B8, and B9 reduced 6,148.62mJ/ h, 4,297.48 mJ/ h, and 3,393.05 mJ/ h of annual cooling energy in comparison with the base case without any shading device respectively.

Table 5. 11. Annual cooling energy reduction by attaching L-shaped mini-louvers type B7 to B9 (mega Joule/ h).

Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type B7	4,632.87	5,078.85	5,194.98	3,985.54	3,123.10	4,646.77	6,148.62	5,658.20
type B8	3,480.39	3,615.37	3,625.55	2,752.61	2,158.63	3,240.75	4,297.48	4,037.61
type B9	2,773.92	2,886.51	2,881.60	2,207.53	1,795.94	2,581.72	3,393.05	3,209.33

Two overhangs, which were commonly used as sun shading devices, were also simulated. In average of all building orientations, type C1 and C2 used 94 and 93% of annual cooling energy in comparison with the base case (figure 5.11). Both showed their best performance in the west and northwest orientation by using 93% (type C1) and 91% (type C2) of annual cooling energy in comparison with the base case.

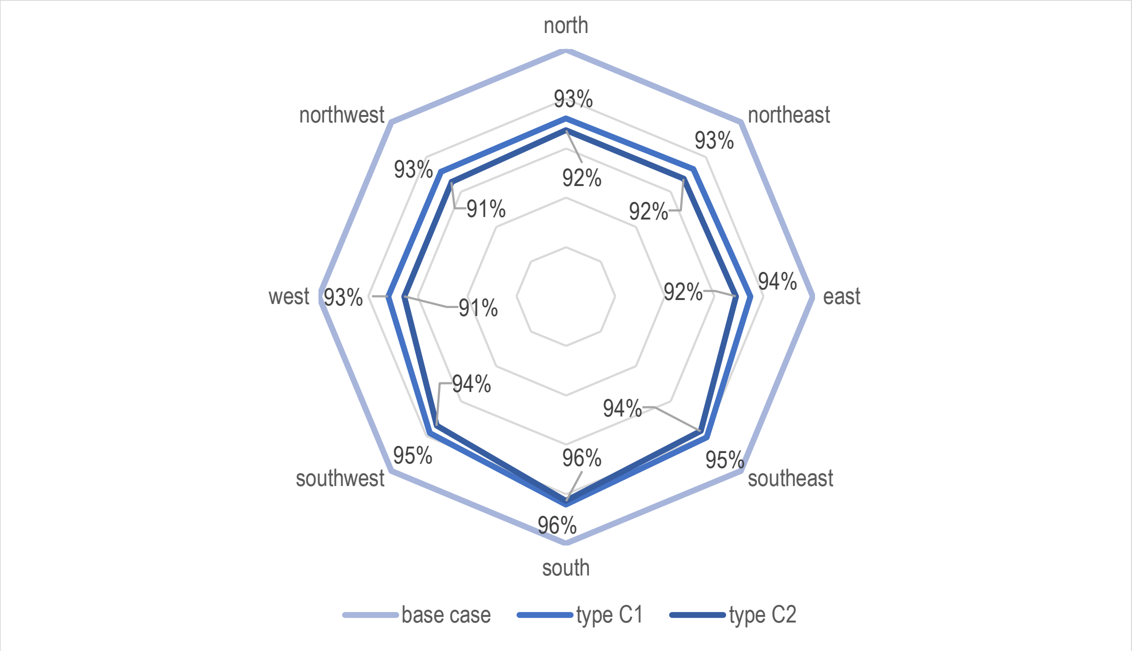


Figure 5. 8. The annual cooling energy of the base case in comparison with overhang type C1 and C2.

Source: photographed by the author

The annual cooling energy reduction of type C1 in average of all orientations was 1,676.15 mJ/ h while type C2 was 2,003.03 mJ/ h. The detailed results of the simulations for all type Cs sun shading is shown in table 5.12.

Table 5. 12. Annual cooling energy reduction by using type C1 and type C2, both are overhangs (mega Joule/ h).

Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type C1	1,832.99	1,840.07	1,769.22	1,292.13	1,020.14	1,538.46	2,086.59	2,029.60
type C2	2,154.43	2,217.36	2,169.45	1,528.94	1,106.79	1,824.19	2,572.63	2,450.46

The performance of all the sun shading in average of cooling energy consumption in all building orientations is presented in figure 5.12. Type B7 was the best performance among others. Type B7 was L-shaped mini louvers using 30 mm × 30 mm aluminum profiles with 1:1 size to opening ratio. The annual cooling energy consumption was around 83% in comparison with the base case. Type B1 to B9, which used the same L-shaped mini louvers with type A1 to A9 showed significantly better performance, ranging between around 2 percentage points (type A6 and B6) to 8% (type A1 and B1). The 50 mm gap between L-shaped mini-louvers and the window lead to this positive impact of cooling energy reduction, even though the left, right, and top sides of the louvers and the window were not covered. In comparison with the overhang, the L-shaped mini-louvers performed better in general, with the only exception of type A3. Type A3 was the L-shaped mini-louvers with 12 mm × 12 mm aluminum profiles in 1:3 size to opening ratio.

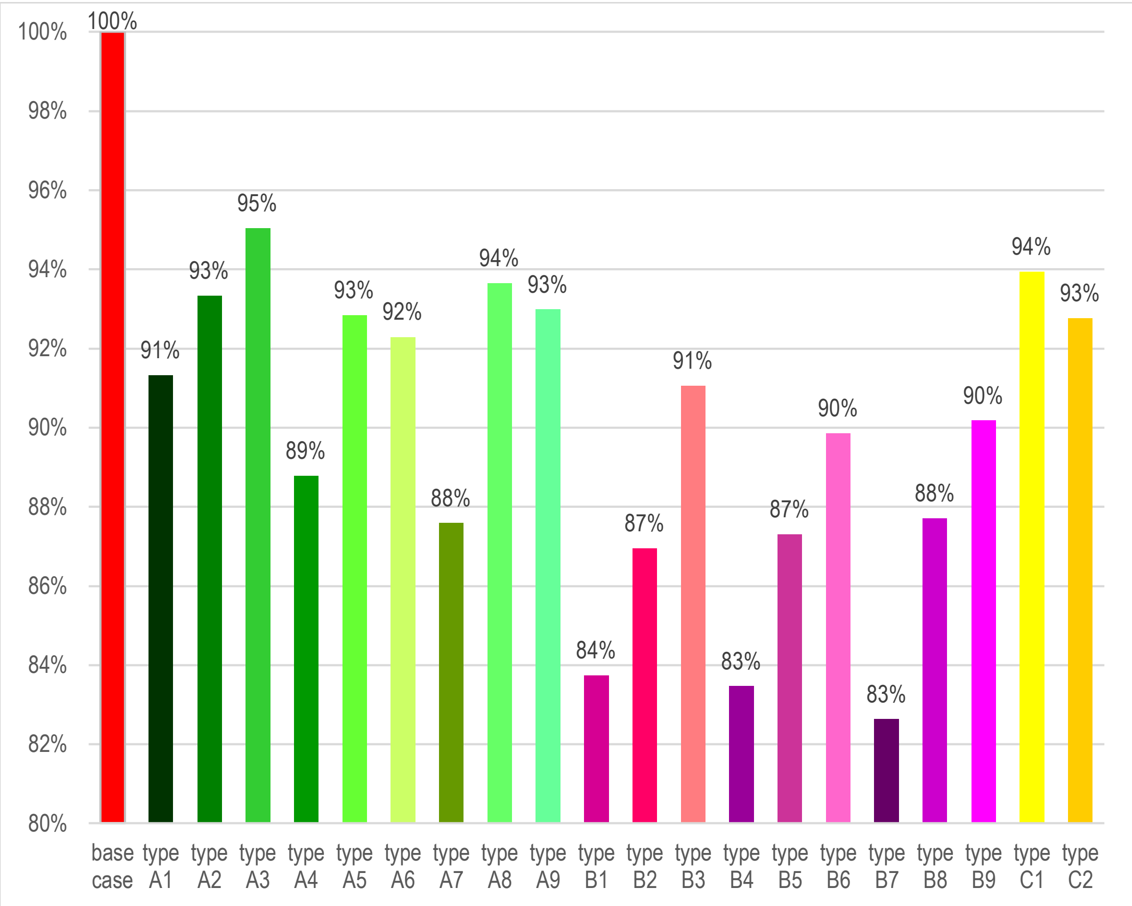


Figure 5. 9. The average annual cooling energy in all orientations of the base case and all the sun shading devices simulated in this study.

Source: photographed by the author

5. 4. Chapter conclusion

Considering the annual cooling energy consumption in a building, attaching the L-shaped mini-louvers to the window lead to a positive impact. Since the west orientation required the highest cooling energy consumption, it was noted the best performance among sun shading models in this orientation. Type A7 (30 mm size with 30 mm openings, 1 mm gap with the window) was the best among all type A by cutting 3,931.13 mJ/ h in the west. However, in the northwest, it could reduce slightly higher cooling energy at 3,943.03 mJ/ h. Type B7 (30 mm size with 30 mm openings, 50 mm gap with the window) was the best among not only all type B but all sun shading type in this study in the west orientation by reducing 6,148.62 mJ/ h of cooling energy consumption. Type C2 (1000 mm size, 1 mm gap with the window) worked better than type C1 (750 mm size, 1 mm gap with the window) by reducing 2,572.63 mJ/ h of cooling energy consumption in the west.

In average of all orientation, type A7 could cut 3,424.13 mJ/ h of annual cooling energy. Type A7 was the best among all A types L-shaped mini-louvers. Type B7, which was the best sun shading devices could significantly reduce 4,808.62 mJ/ h of cooling energy. Type C2, the best overhang, could only cuts 2,003.03 mJ/ h of cooling energy in this study.

Placing the L-shaped mini-louvers in the window frame made a better effect of reducing the annual cooling energy in comparison with placing them directly to the window surface. Most of the L-shaped mini-louvers showed better performance with a more common, overhang type shading devices. However, there was a cost to bring the design into construction and during operational periods. The energy saving from cooling could be converted into electricity saving. This topic was brought to the next chapter, the economic consideration of the design to predict the accessibility of their application in the real condition

Chapter 6– Economic aspect of L-shaped mini-louvers for calculating simple payback period

6. 1. Calculation method

A paper with the title “Environmental and economic benefits of Japanese *koshi* inspired mini-louvers in residential buildings in Jakarta, Indonesia” which were accepted in the Journal of Façade Design and Engineering showed economic consideration of the L-shaped mini-louvers[101]. The research showed that placing the L-shaped mini-louvers in the window frame could lead to simple payback period of the shading device in less than a year even using the most effective air-conditioning units. This chapter presented more detailed insight of the L-shaped mini-louvers application to show the economic benefits of their application. This chapter continued the results of annual cooling energy reduction in the previous chapter. The annual cooling energy reduction was converted to calculate the electrical savings. The price of electric was used as a basic to calculate the economic benefits. Economic aspect was important to assess the possibility of design application in the real conditions. If a design could be beneficial in terms of economic, there was a possibility of its application. Monetizing the environmental benefit could be useful for common people to understand rather than using technical terms.

First, the annual cooling energy reduction in Joule per hour were converted to British Thermal Units per hour. The unit conversion was necessary since the government of Indonesia uses Energy Efficiency Ratio (EER) for standardizing the air-conditioning units. The EER is used for showing the electricity consumption of selected air conditioning systems. According to the mandatory regulations issued in 2017 by the Ministry of Energy and Mineral resources number 57, there are four ratings of air-conditioning units based on the number of the stars. The air-conditioning unit is single split wall mounted inverter and non-inverter type with a capacity less than 27,000 Btu/ h. This type of air conditioning is commonly used for residential buildings and is suitable for following up the simulation results by calculating the electricity consumption for cooling in this study. Since all the four air-conditioning units were still used, the electricity saving by applying all sun shading devices were calculated. The electric saving was obtained from the calculations of annual cooling energy saving by utilizing specific type of star-rated air-conditioning units.

[101] Suryandono AR, Hariyadi A, Fukuda H (2020) Environmental and economic benefits of Japanese koshi inspired mini-louvers in residential buildings in Jakarta, Indonesia. Accepted in The Journal of Façade Design and Engineering. Planned to be published in the Fall 2020 edition.

The application cost of sun shading devices were obtained from the price of raw materials used for constructing L-shaped mini-louvers as well as overhang. The construction costs for the overhangs were also calculated. However, the proposed L-shaped mini-louvers design did not need specific skill to construct, therefor there was no construction cost for the mini-louvers. The price and cost for sun shading devices were based of the survey data in the middle of 2019. The price of electric power was based on the survey in the middle of 2019. The saving from electric price was compared with the construction and application cost of all the sun shading devices to measure the simple payback period. The workflow of calculation method is presented in figure 6.1.

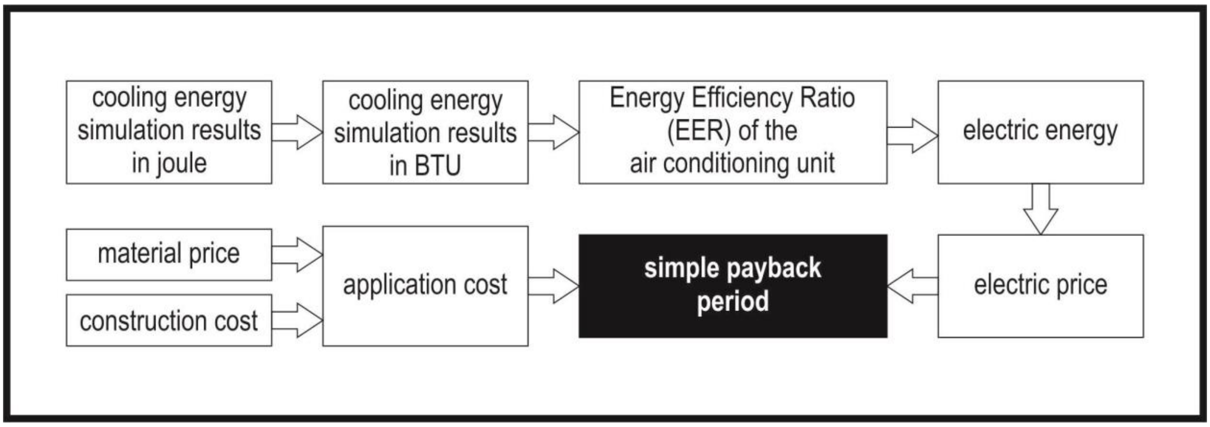


Figure 6. 1. Calculation method workflow.

Source: photographed by the author.

6. 2. Economic calculations and analysis

The step of converting from joule to British Thermal Units (BTU) was necessary to calculate the electric consumption of the air-conditioning units by multiplying cooling energy with the EER. The minimum energy performance standard using EER was officially applied since the end of 2017. The regulations was still in effect during the writing of this research report. The conversion result of annual cooling energy reduction in kBTU per hour of all sun shading devices in this study are presented in figure 6.1. The annual cooling reduction for all type As were at the highest in the west orientation. Type A7 had the highest annual cooling energy saving of 3,725.99 kBTU. Type A3 was the worst among all type A by saving 1,519.03 kBTU of annual cooling energy. In type B, in the west orientation, the highest cooling energy saving was obtained by type B7, saving 5,827.76 kBTU of annual cooling energy. Type B3 which was the worst among all type B could only save 2,977.18 kBTU of annual cooling energy. Similar with the L-shaped mini-louvers, the overhangs showed best performance in the west direction. Type C1 and C2 overhang sun shading could save 1,977.71 kBTU and 2,438.39 kBTU in the west orientation accordingly.

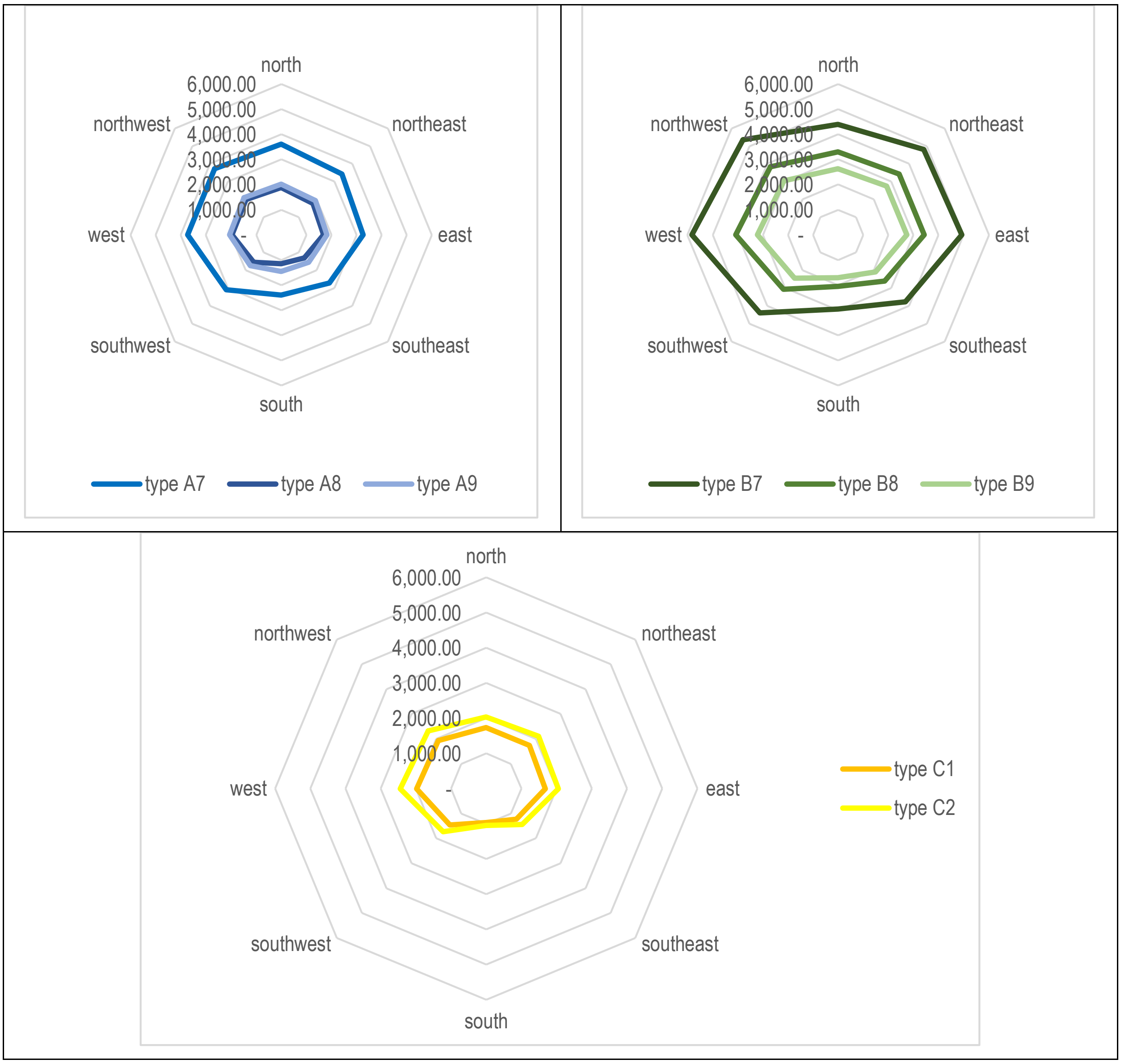


Figure 6. 2. The annual cooling energy saving of L-shaped mini-louvers (kBTU).

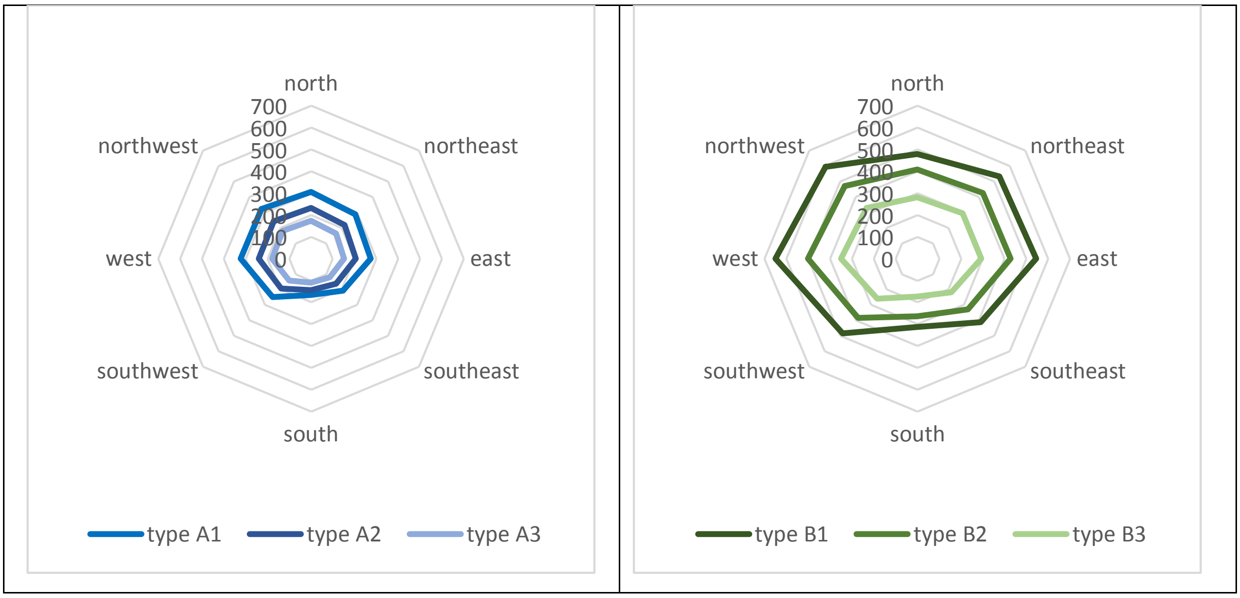
Source: photographed by the author

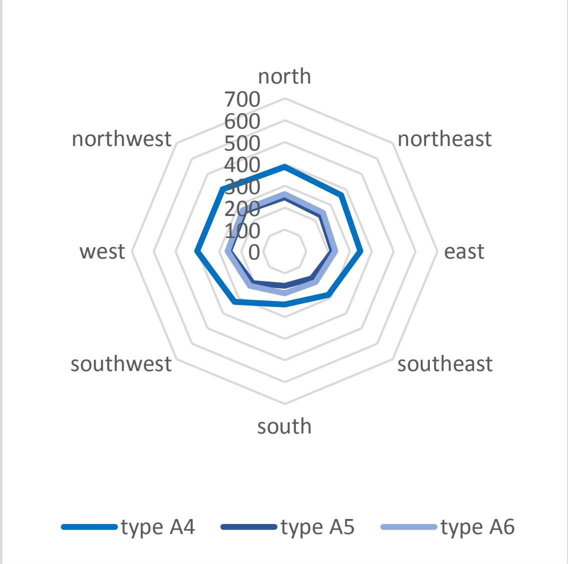
According to the government of Indonesia regulation, one-star air-conditioning, which was the lowest rating, was used for air-conditioning units which have an EER from 8.53 to be less than 9.01. Two-stars air-conditioning units had an EER from 9.01 to be less than 9.96. Three-stars air-conditioning units had an EER from 9.96 to be less than 10.41. The highest rating, four-stars, could only be obtained if the air-conditioning units had EER values equal to or more than 10.41. The formula to convert the units from cooling energy to electrical energy by using EER was:

$$EER = \frac{output\ cooling\ energy}{input\ electrical\ energy}$$

The EER value of 8.53, 9.01, 9.96, and 10.41 were used to calculate the electric energy consumption used by the air-conditioning unit with one-star, two-stars, three-stars, and four-stars ratings respectively.

The results of annual electric saving from utilizing one-star air-conditioning unit are presented in figure 6.2. Using one-star air-conditioning unit, L-shaped mini louvers type A7 in the west orientation achieved the best performance by saving 436.81 kWh of annual electric energy from cooling among other type As. In average of all orientation, the annual electric energy saving by type A7 was 380.47 kWh. Utilizing the same air-conditioning unit, the west-faced L-shaped mini louvers type B7 achieved the best performance by saving 683.21 kWh of annual electric energy from cooling among other type Bs. In average of all orientation, the annual electric energy saving by type A7 was 534.31 kWh. Type C2 performance was better than type C1. However the performance of type C2 was significantly lower than that of type A7 and B7, leaving around 157.91 kWh and 311.75 kWh of annual electric energy saving in average of all orientations.

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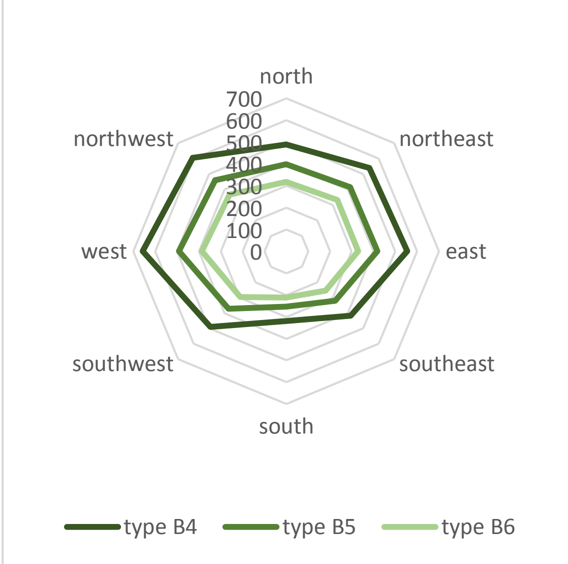
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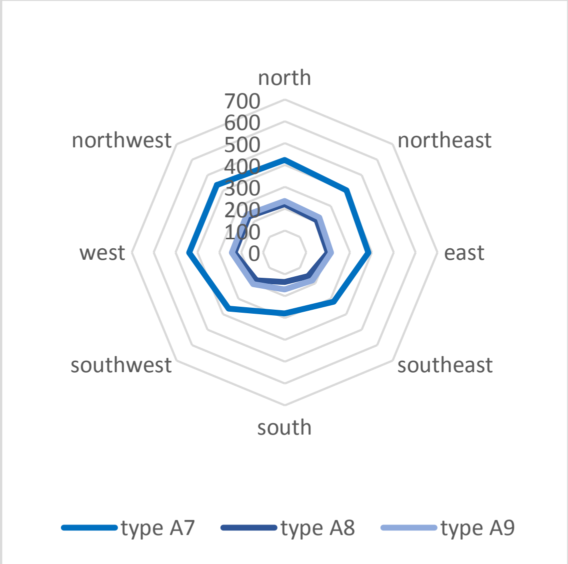
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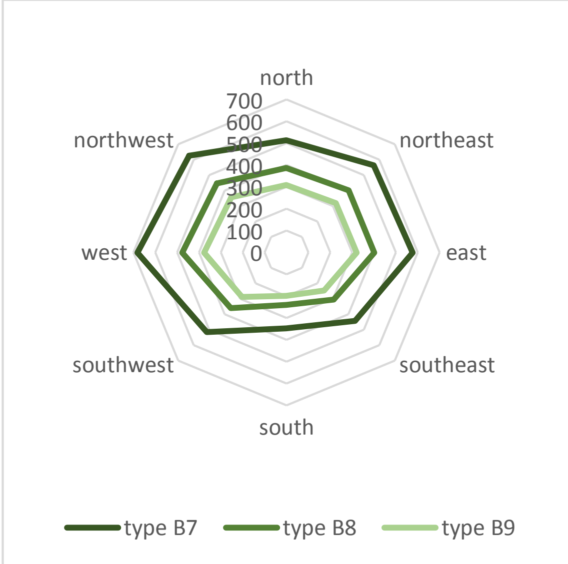
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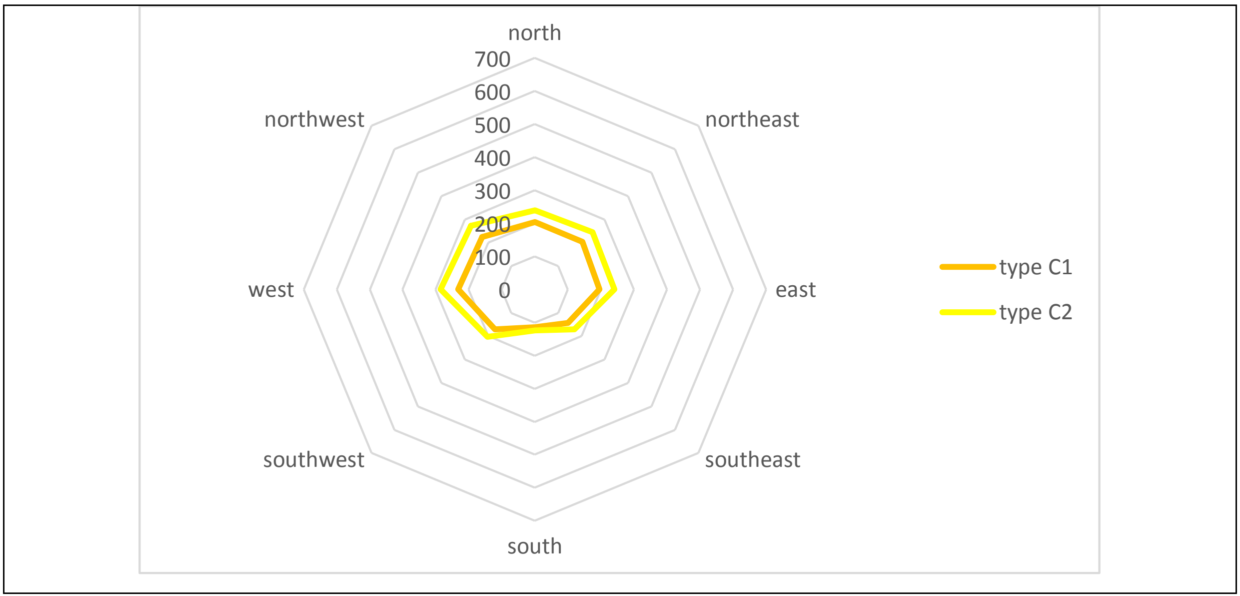
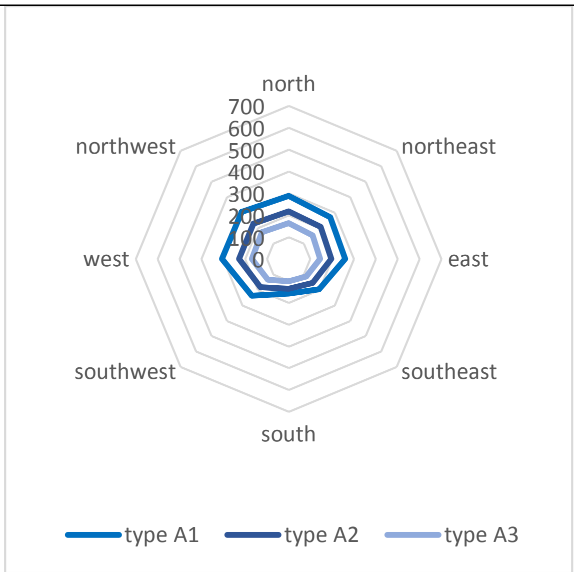


Figure 6. 3. The annual electric energy saving of all simulated sun shading devices using one-star air-conditioning unit (kWh).

Source: photographed by the author

Figure 6.3 shows the annual electric energy saving of all simulated shading devices by using two-stars air-conditioning unit. L-shaped mini louvers type A7 in the west orientation achieved the best performance by cutting 413.54 kWh of annual electric energy from cooling among other type As by using two-star air-conditioning unit. In average of all orientation, the annual electric energy saving by type A7 was 360.21 kWh. Utilizing the same air-conditioning unit, the west-faced L-shaped mini louvers type B7 achieved the best performance by saving 646.81 kWh of annual electric energy from cooling among other type Bs. In average of all orientation, the annual electric energy saving by type B7 was 505.85 kWh. Overhang sun shading type C2 was better than type C1. The performance of type C2 in average of all orientations was still a lot lower than that of type A7 (149.49 kWh) and B7 (295.14 kWh) of annual electric energy saving.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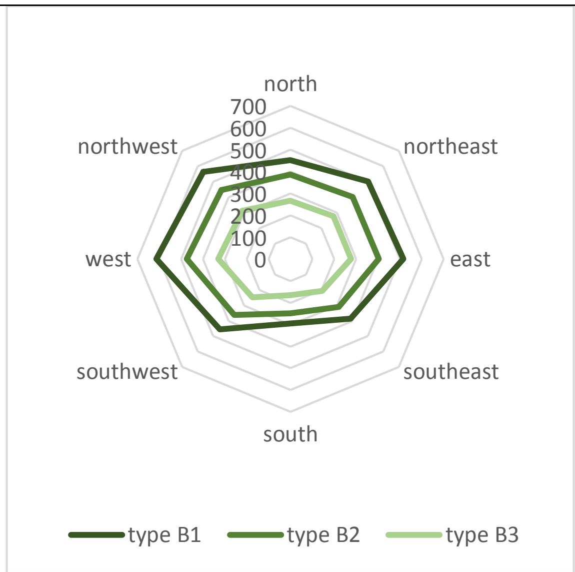
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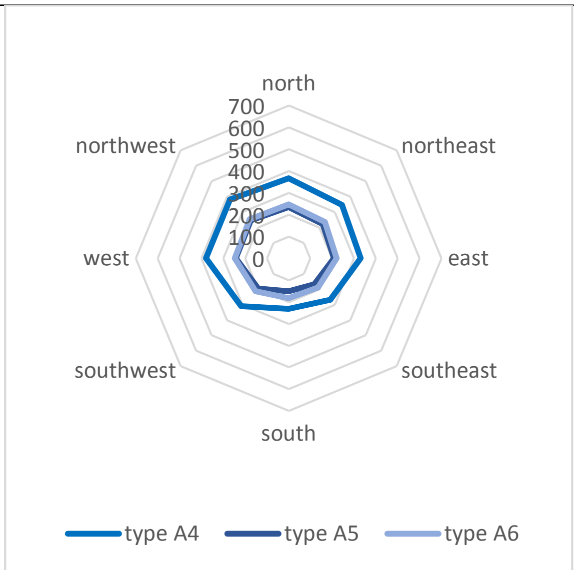
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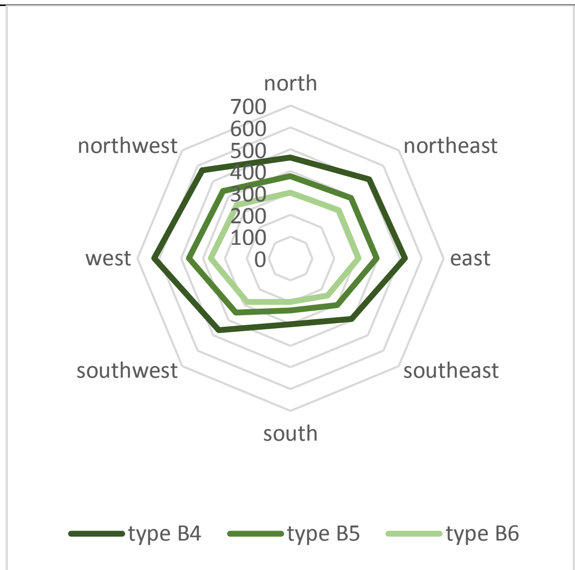
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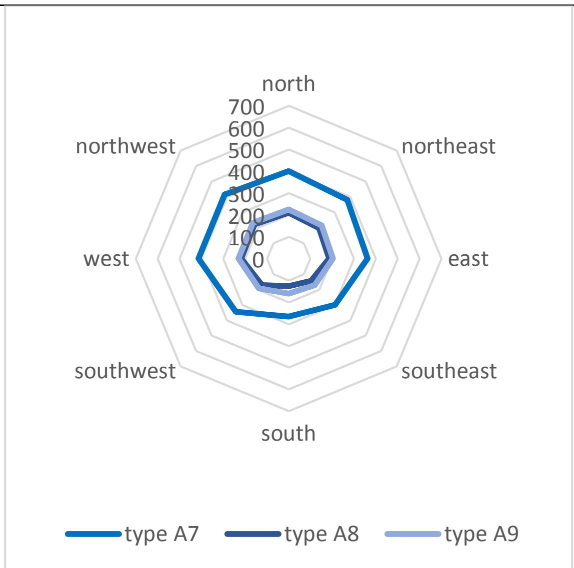
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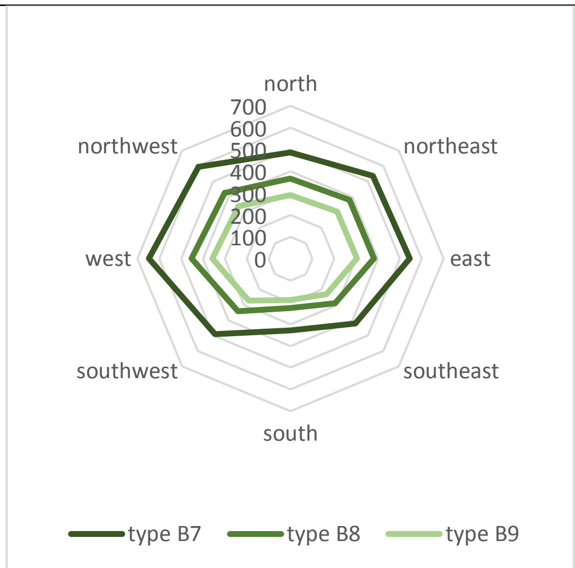
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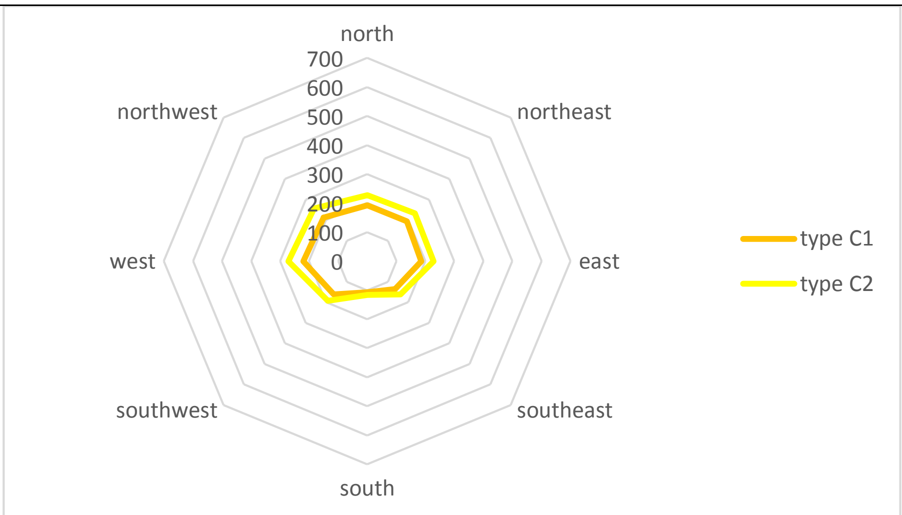

Figure 6. 4. The annual electric energy saving of all simulated sun shading devices using two-stars air-conditioning unit (kWh).

Source: photographed by the author

Using three-stars air-conditioning device, the electric energy could be saved more (Figure 6.4). With this type of air-conditioning, the L-shaped mini louvers type A7 in the west orientation achieved the best performance by reducing 374.10 kWh of annual electric energy from cooling among other A types shading. Type A7 was also the best shading in annual electric energy saving in average of all orientation, achieving around 325.85 kWh. By utilizing the same air-conditioning unit, the west-faced L-shaped mini louvers type B7 achieved the best performance by saving 585.12 kWh of annual electric energy from cooling among other type Bs. In average of all orientation, the annual electric energy saving by type B7 was 457.60 kWh. Overhang sun shading type C2 was better than type C1, around 31.11 kWh in average of all orientations. However, there was a gap of 266.99 kWh and 135.23 kWh of annual electric saving from cooling in average of all orientations was still a lot lower than that of type B7 and A7 respectively.


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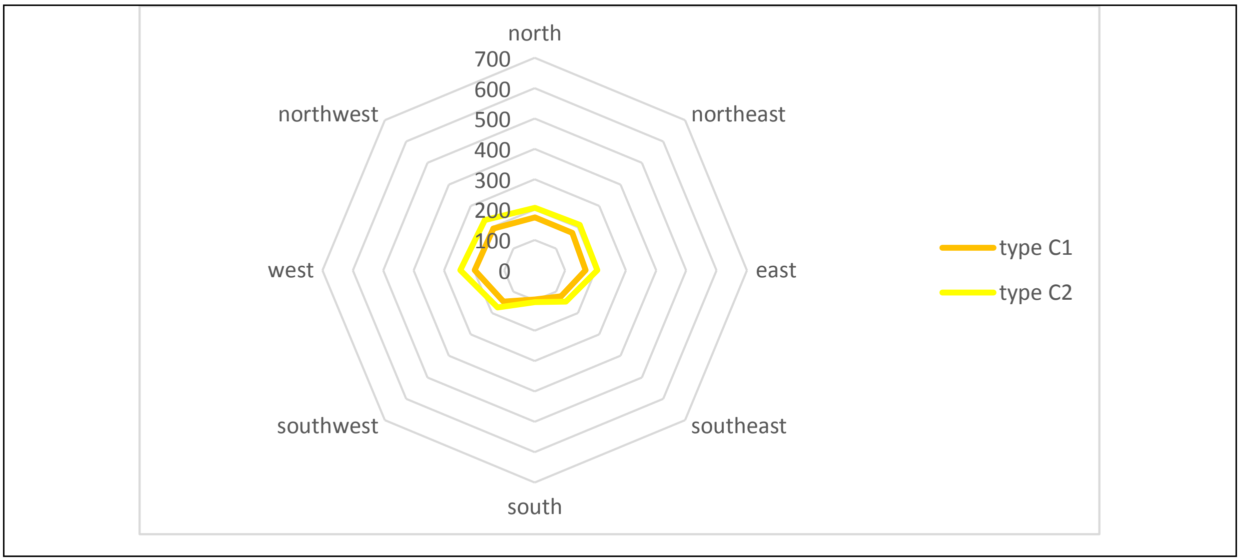

Figure 6. 5. The annual electric energy saving of all simulated sun shading devices using three-stars air-conditioning unit (kWh).

Source: photographed by the author

Four-stars air-conditioning device was the highest-rated air-conditioning unit that was used in this simulations. The electric energy could be saved more but still the sun shading positively contributed (Figure 6.5). The L-shaped mini louvers type A7 in the west orientation achieved the best performance by reducing 357.92 kWh of annual electric energy from cooling among other type As with four-stars air-conditioning (chart 6.13). Around 311.76 kWh of annual electric energy saving in average of all orientation could be achieved by type A7. Chart 6.14 showed that by utilizing the same air-conditioning unit, type B7 achieved the best performance by saving 559.82 kWh of annual electric energy from cooling among other type Bs in the west orientation. The annual electric energy saving by type B7 was 437.82 kWh in average of all orientation. Chart 6.15 showed that the overhang sun shading type C1 showed lower results than that of type C2 with around 29.76 kWh of gap in average of all orientations. In comparison of the annual electric saving from cooling in average of all orientations with the type B7 and A7, there was a gap of 255.44 kWh and 129.39 kWh accordingly.


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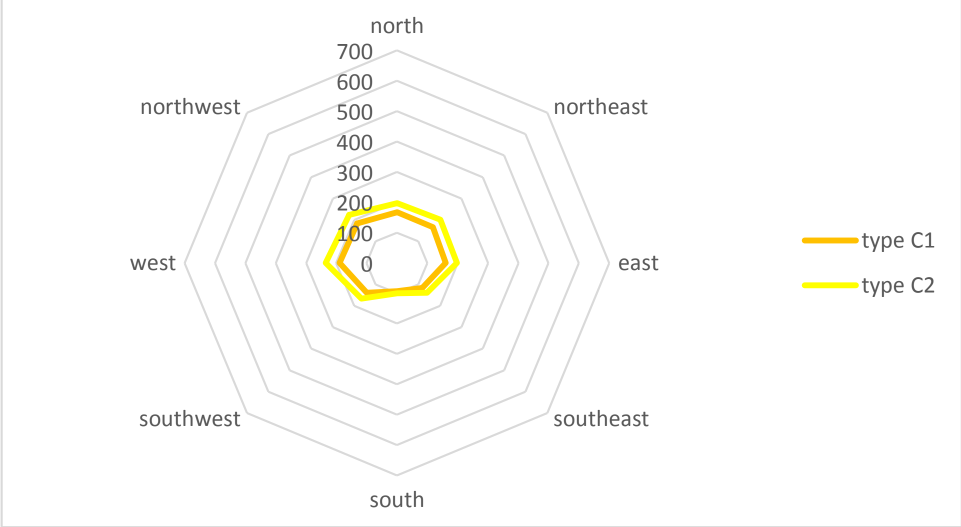


Figure 6. 6. The annual electric energy saving of all simulated sun shading devices using four-stars air-conditioning unit (kWh).
Source: photographed by the author

The electric saving could be monetized by multiplying the electric energy used by the air-conditioning unit with the price of electric per kWh in the selected area. Based on the current condition, the price per kWh in Indonesia for residential with the electrical power of 1,300 VA was IDR 1,467.28 or around USD 0.1. The electric price for all types of sun shading in all orientation were compared with the cost of the sun shading devices.

The application cost of sun shading devices consisted of the material for shading, and construction cost. Since L-shaped mini-louvers and overhang relatively free maintenance, the maintenance cost during operational period was omitted. The cost for disassembling the shading was also excluded since the aim in this study was obtaining the simple payback period. Moreover, the L-shaped mini-louvers used aluminum which could be recycled. According to the SNI (Indonesian Standard), the construction cost of the reinforced concrete for overhang is presented in table 6.1. The material price of sun shading device is presented in table 6.2.

Table 6. 1. Construction cost of the reinforced concrete for overhang.
Source:surveyed data, calculated, and photographed by the author.

item name	units		unit price (idr)	price
portland cement	247	kg	800.00	197,600.00
sand	869	kg	3,000.00	2,607,000.00
aggregate	999	kg	4,500.00	4,495,500.00

water	215	liter	100.00	21,500.00
worker	1.65	person/ day	100,000.00	165,000.00
bricklayer	0.275	person/ day	150,000.00	41,250.00
foreman	0.028	person/ day	200,000.00	5,600.00
supervisor	0.083	person/ day	300,000.00	24,900.00
steel	77.73	kg	12,000.00	932,760.00
formwork	14.5	m²	200,000.00	2,900,000.00
			total cost (idr)/ m³	11,391,110.00
			total cost (usd)/ m³	759.41

Table 6. 2. Material cost of sun shading device.

Source:surveyed data and photographed by the author.

Material name	unit		Unit price (usd)
L-shaped aluminum profiles 12 mm x 12 mm x 0.8 mm	1	m	0.29
L-shaped aluminum profiles 15 mm x 15 mm x 0.8 mm	1	m	0.32
L-shaped aluminum profiles 30 mm x 30 mm x 0.8 mm	1	m	0.72
outdoor double-sided tape	1	m	1.43
galvanized screw	1	piece	0.005
concrete for overhang	1	m³	759.41

Three different sizes of the L-shaped aluminum profiles were used for making the L-shaped mini-louvers according to their type. The double-sided tape was used to directly attach L-shaped mini-louvers to the outdoor glass window surface. A quarter of a meter of double-sided tape was used to attach every one meter of L-shaped aluminum profile. Galvanized screws were used to attach the L-shaped mini-louvers to the window frame. Two screws were used per meter of L-shaped aluminum profile. For overhang sun shading, the material commonly used was reinforced concrete. The total construction cost of each type of sun shading can be seen in chart 6.6. The construction cost consisted of the price of the sun shading material include the attachment elements, and labor cost. The overhang needed concrete beam to support its placement. However the cost of the supporting system was also excluded in this calculation, considering only the price of sun shading itself.

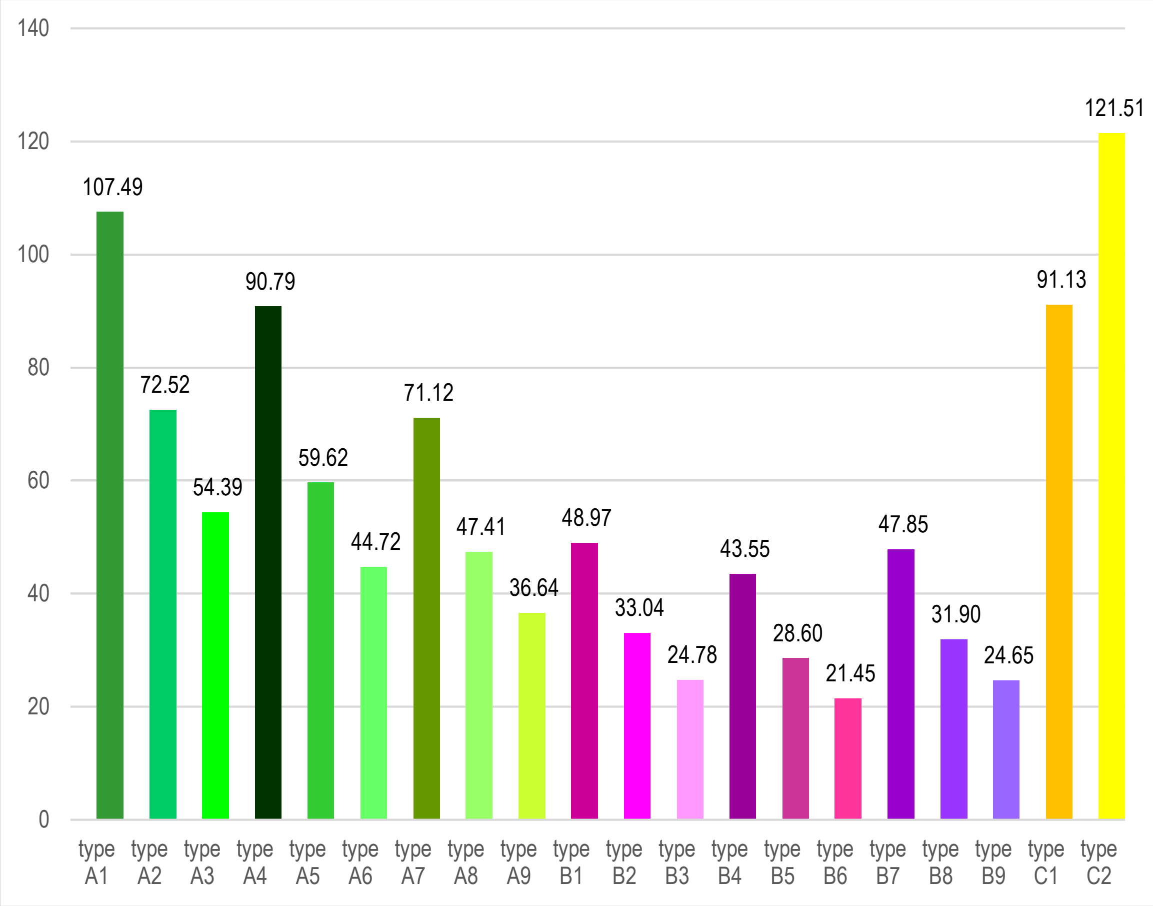


Figure 6. 7. Construction cost of the sun shading devices.

Source:photographed by the author.

The comparison of electrical saving and construction cost revealed the simple payback period for each type of sun shading. The simple payback period by using the best available, four-stars air-conditioning units and the worst, lowest one-star air-conditioning unit were presented to show the best and worst case scenario.

Combining the sun shading type A1 to A3 with one-star and four-stars air-conditioning, the simple payback period could be obtained fastest in the west and northwest orientation (figure 6.7). Type A2 was the best among others by achieving 2.99 years using one-star air-conditioning, and 3.65 years using four-stars air-conditioning of simple payback period in the northwest. In average of all the building orientations, type A2 also showed best performance by achieving simple payback period of 3.66 years with one-stars air-conditioning and 4.47 years using four-stars air-conditioning (Figure 6.8).

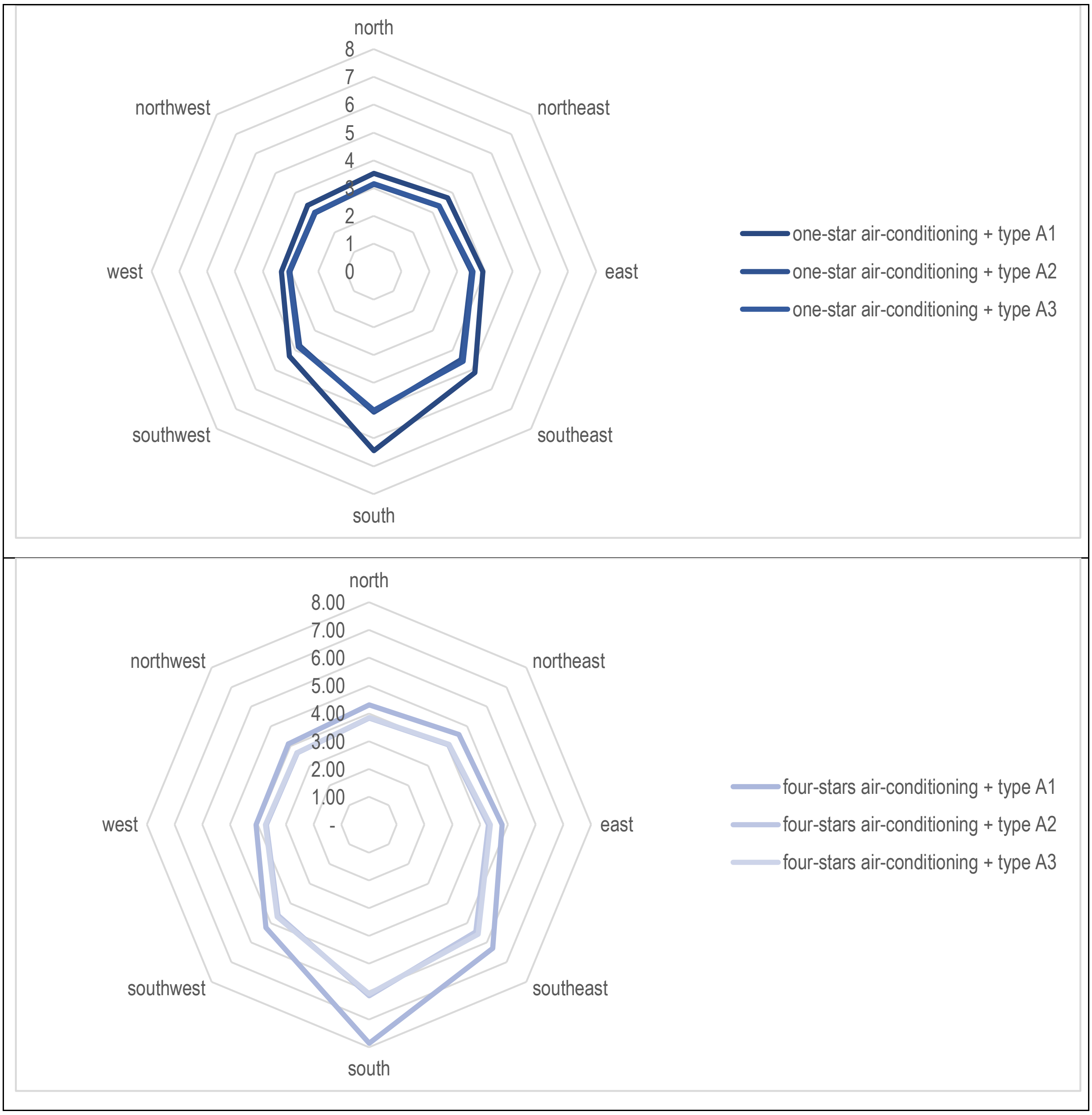


Figure 6. 8. Simple payback period in each orientation by using one-star and four-stars air-conditioning units with sun shading type A1 to A3.

Source:photographed by the author.

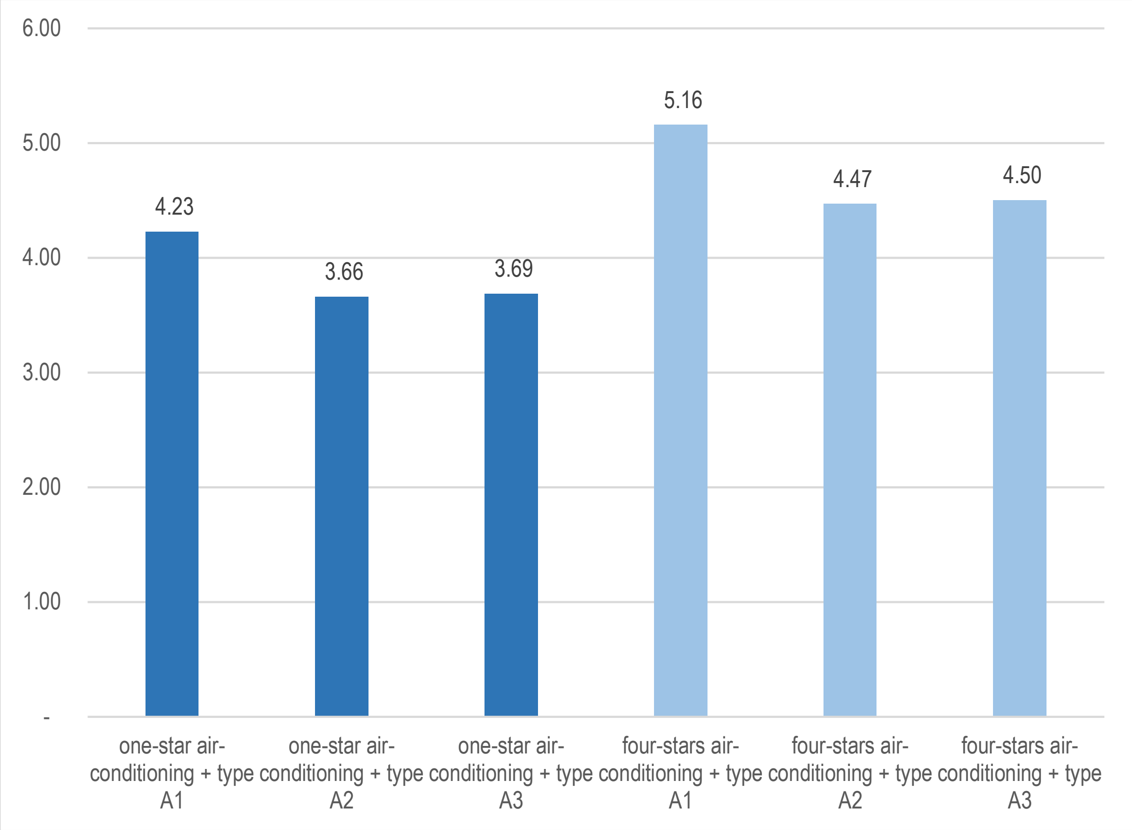


Figure 6. 9. The average simple payback period by using one-star and four-stars air-conditioning units with sun shading type A1 to A3.

Source:photographed by the author.

Combining the sun shading type A4 to A6 with one-star and four-stars air-conditioning, the simple payback period could be obtained fastest in the west and northwest orientation (figure 6. 9). Type A6 was the best among others by achieving 1.67 years using one-star air-conditioning, and 2.04 years using four-stars air-conditioning of simple payback period in the northwest. Type A4 showed similar performance in the west and northwest, achieving its best simple payback period of 2.27 by using one-star air-conditioning and 2.77 years by using four-stars air-conditioning unit. In average of all orientations, type A4 also showed best performance by achieving simple payback period of 1.92 years with one-stars air-conditioning and 2.34 years using four-stars air-conditioning (figure 6.10).

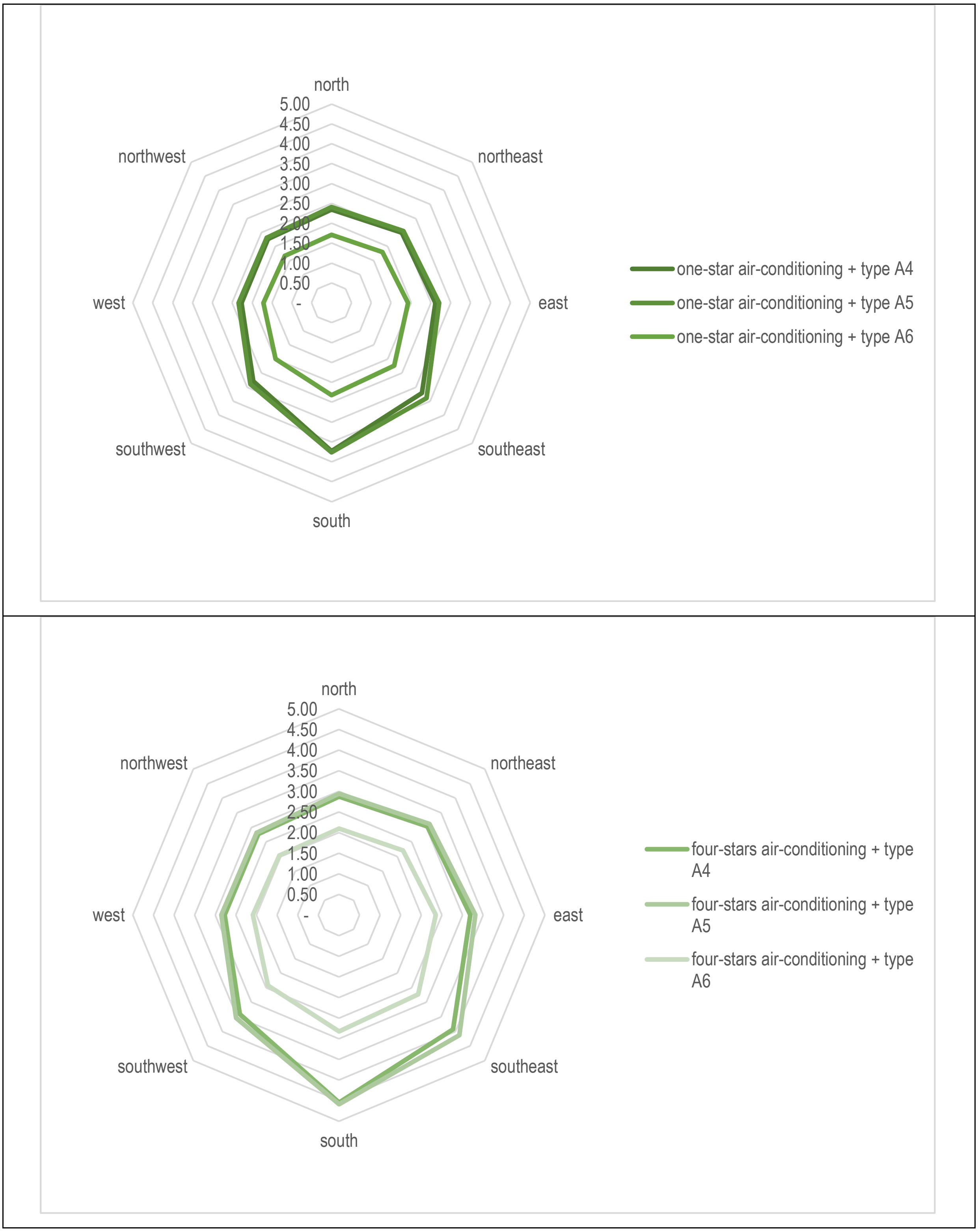


Figure 6. 10. Simple payback period in each orientation by using one-star and four-stars air-conditioning units with sun shading type A4 to A6.

Source:photographed by the author.

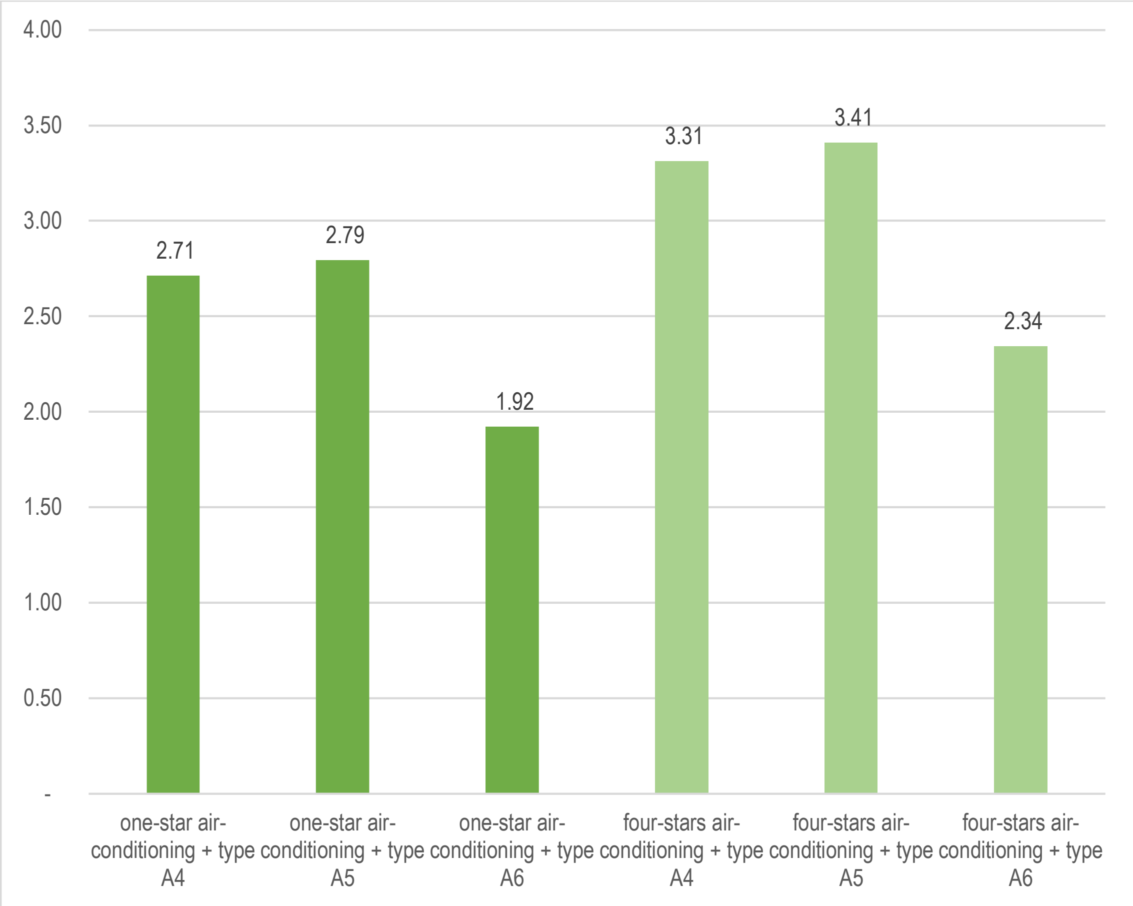


Figure 6. 11. The average simple payback period by using one-star and four-stars air-conditioning units with sun shading type A4 to A6.

Source:photographed by the author.

The simple payback period could be obtained fastest in the northwest orientation by combining the sun shading type A7 to A9 with one-star and four-stars air-conditioning (figure 6.11). Type A9 was the best among others by achieving 1.49 years using one-star air-conditioning, and 1.82 years using four-stars air-conditioning of simple payback period in the northwest. The simple payback period in the northwest was only slightly better in comparison with that of in the west. Type A9 simple payback period in the northwest was only 0.03 years faster than that in the west. Type A8 and type A7 simple payback period difference between the northwest and west orientation was smaller, at only around 0.02 and 0.01 years respectively. Figure 6.12 shows that in average of all orientations, type A9 also showed best performance by achieving simple payback period of 1.73 years with one-stars air-conditioning and 2.12 years using four-stars air-conditioning.

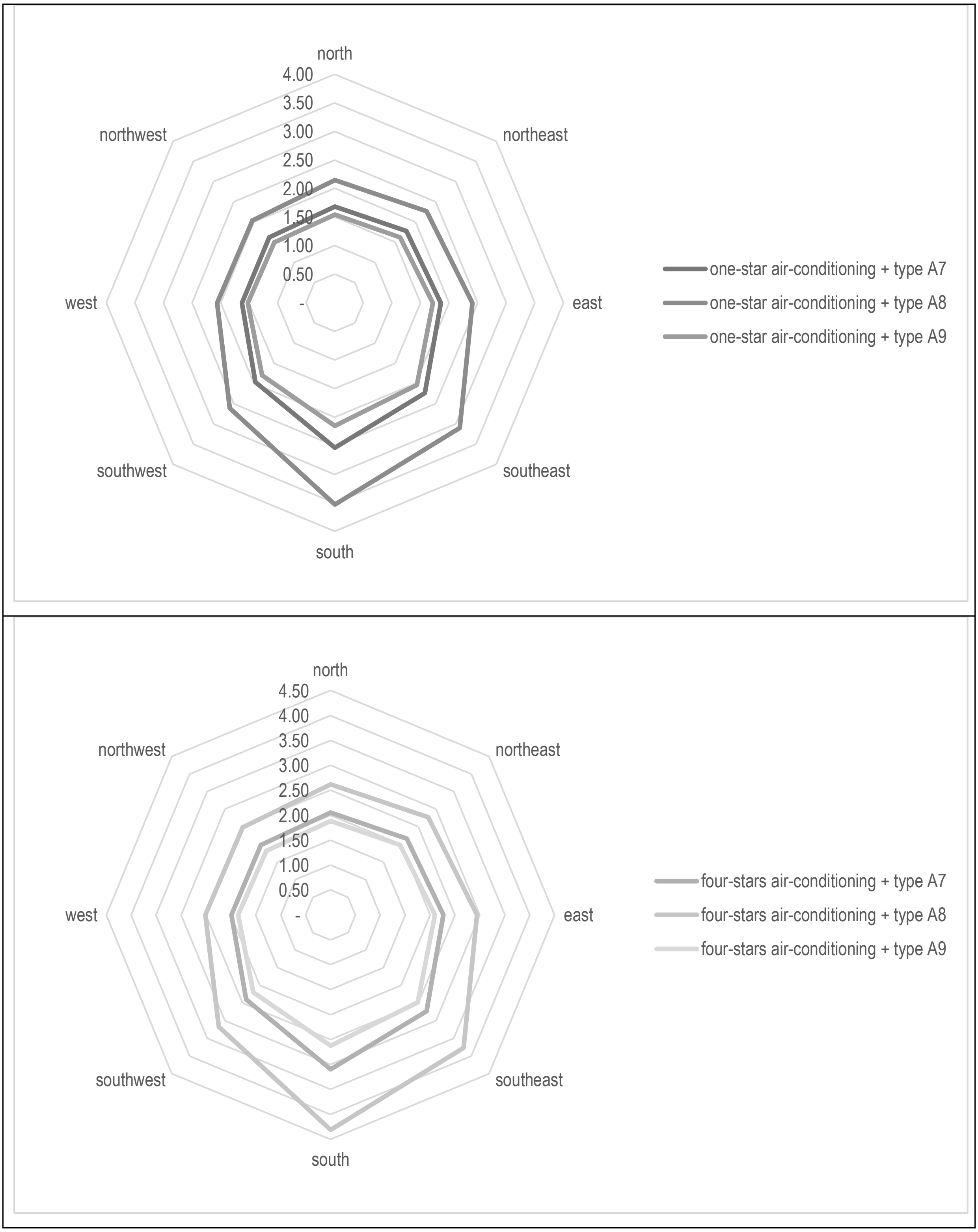


Figure 6. 12. Simple payback period in each orientation by using one-star and four-stars air-conditioning units with sun shading type A7 to A9.

Source:photographed by the author.

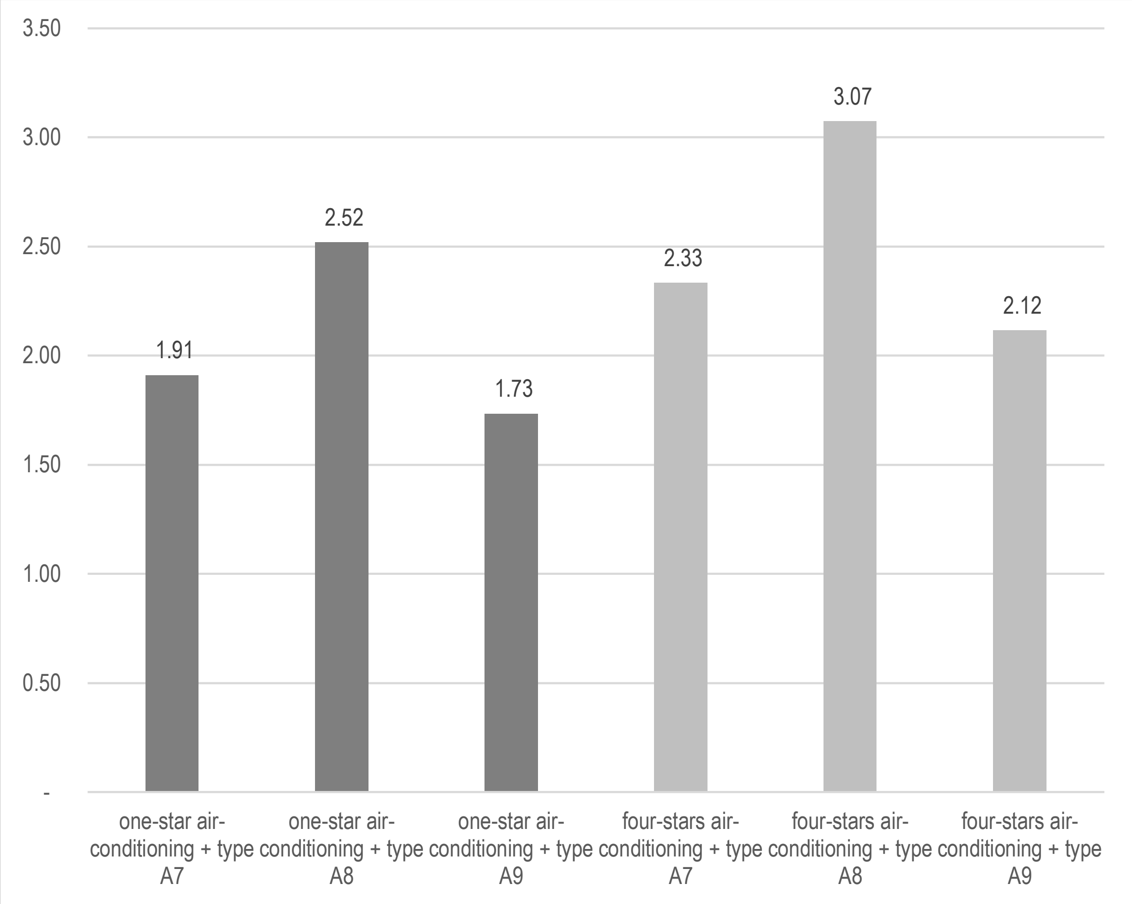
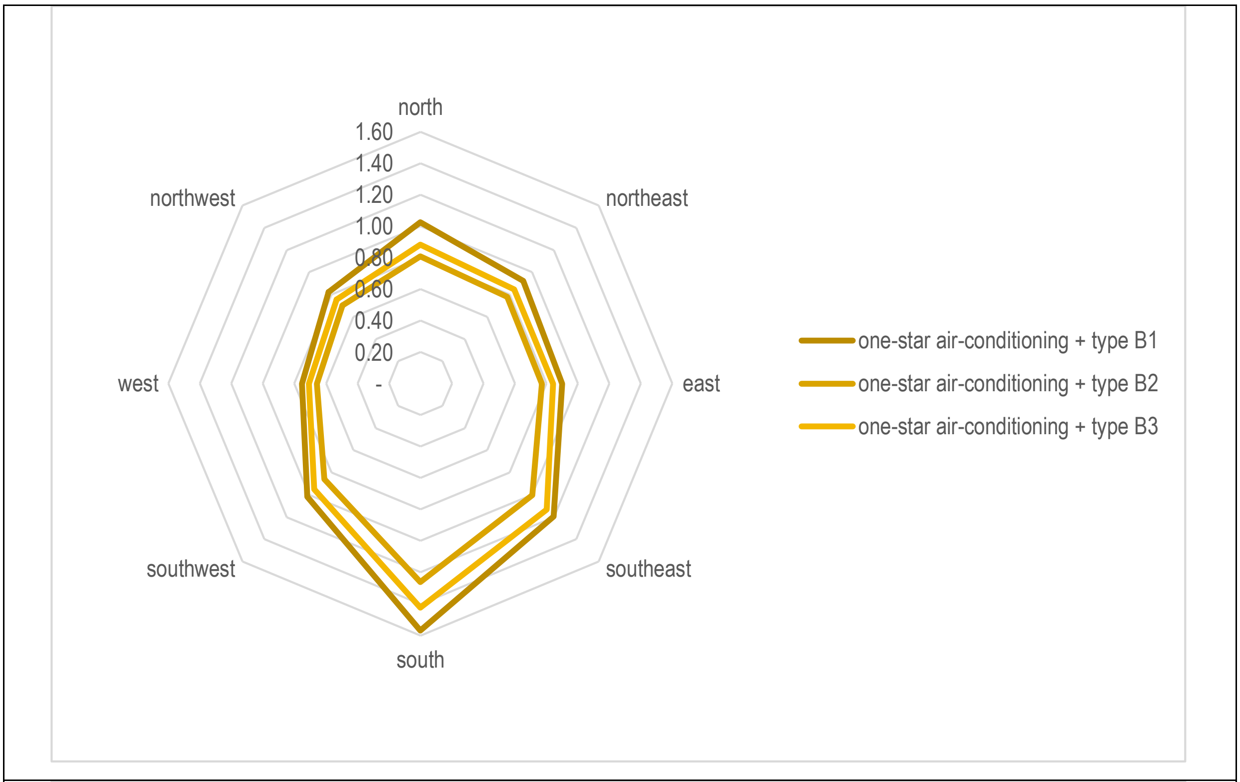


Figure 6. 13. The average simple payback period by using one-star and four-stars air-conditioning units with sun shading type A7 to A9.
Source:photographed by the author.

Moving the L-shaped mini-louvers further from the outdoor surface of the window positively impacted the simple payback. There were two reasons for this impact. First, the performance of the L-shaped mini-louvers was better in reducing the cooling energy. Second, the application cost of the mini-louvers was cheaper in comparison with the placement of L-shaped mini-louvers in the surface of the window.

The combination of sun shading type B1 to B3 with one-star and four-stars air-conditioning lead to the simple payback period that can be obtained fastest in the west direction (figure 6.13). Type B2 was the best among others by achieving 0.66 years using one-star air-conditioning, and 0.8 years using four-stars air-conditioning of simple payback period in the west. Type B2 performed best by achieving simple payback period of 0.86 years with one-stars air-conditioning and 1.04 years using four-stars air-conditioning in average of all orientations (figure 6.14).



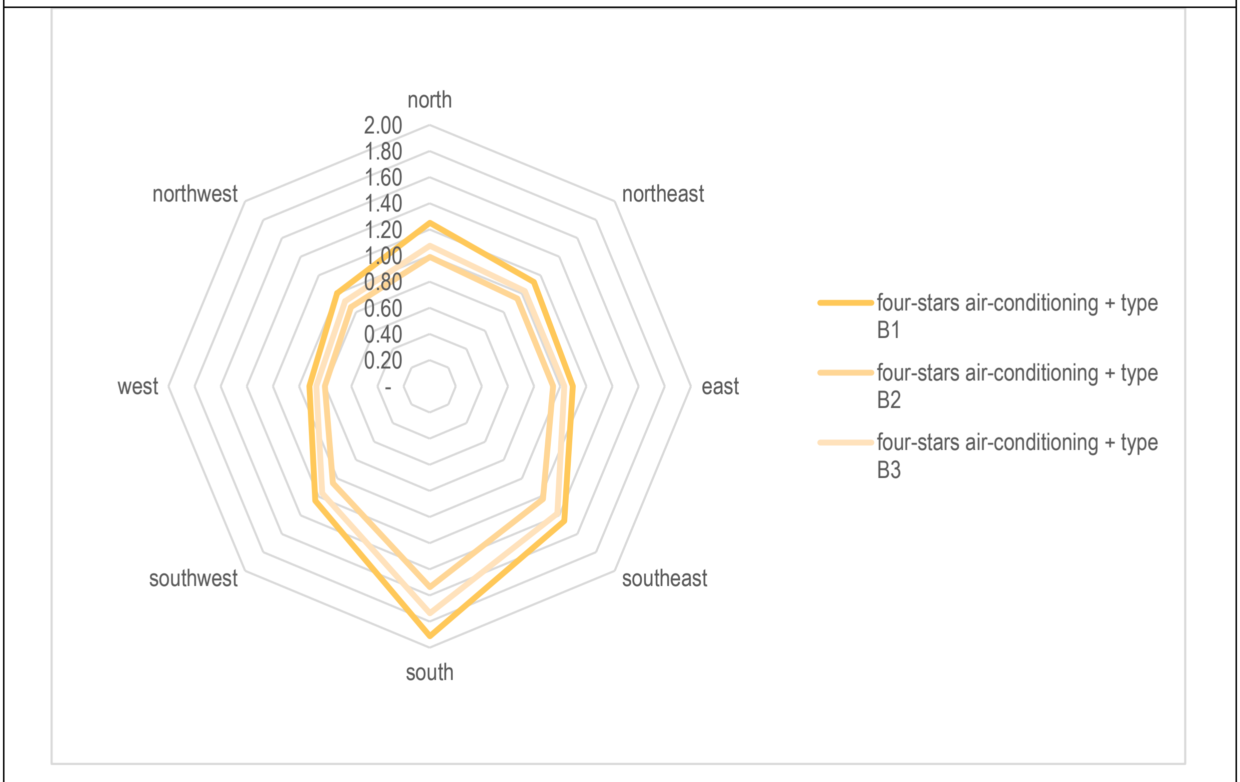


Figure 6. 14. Simple payback period in each orientation by using one-star and four-stars air-conditioning units with sun shading type B1 to B3.

Source:photographed by the author.

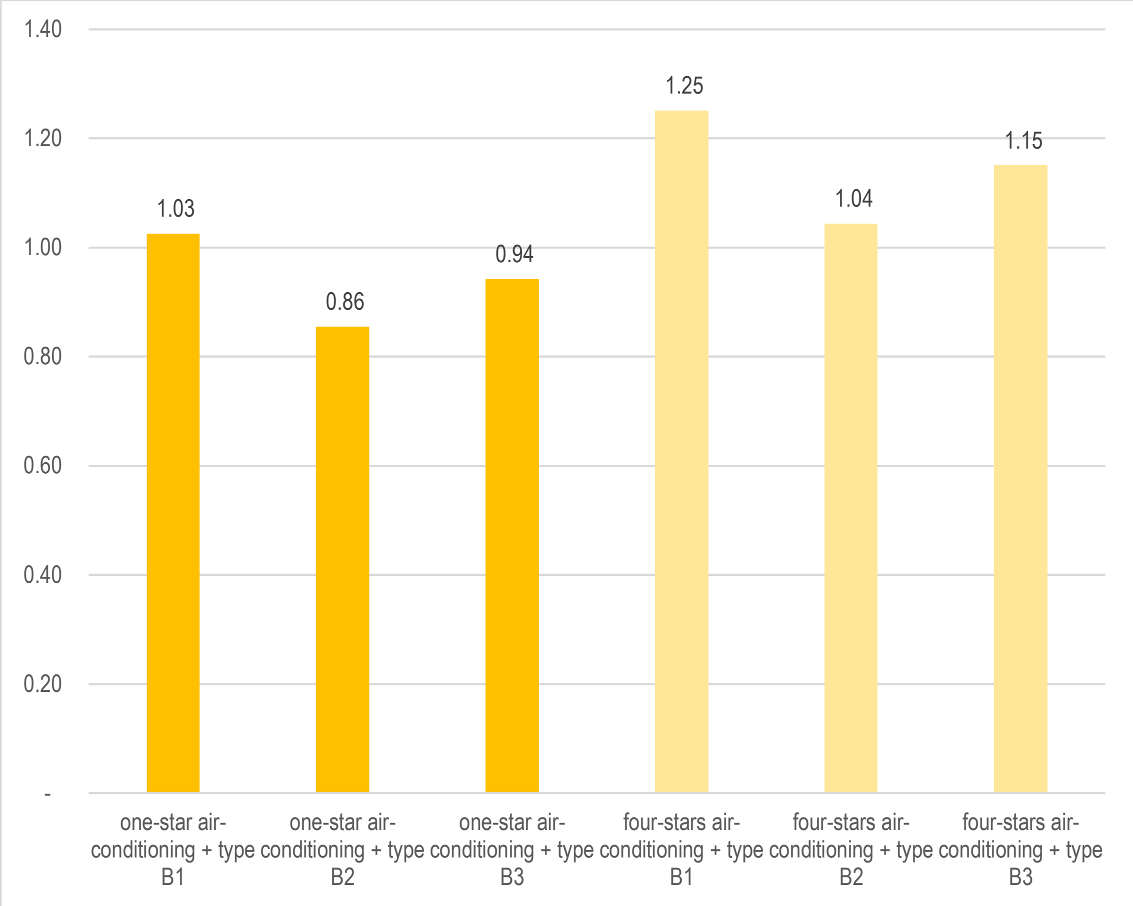
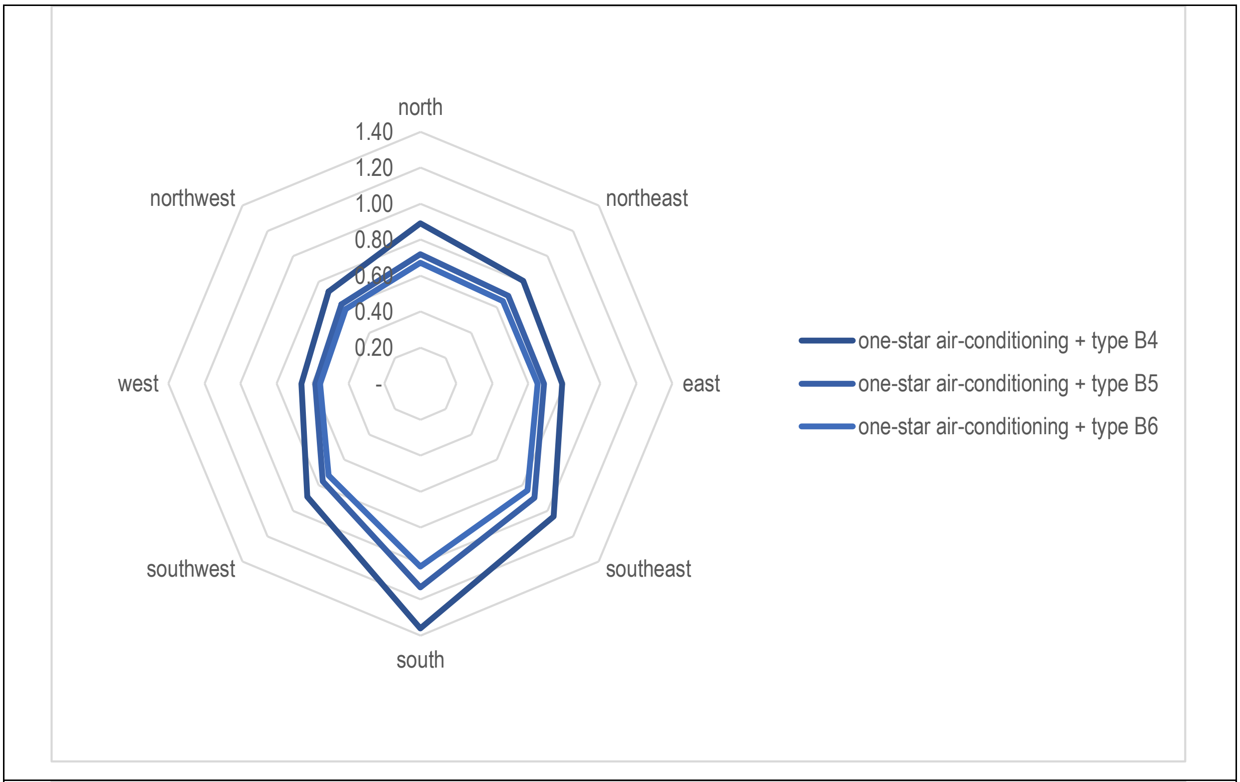


Figure 6. 15. The average simple payback period by using one-star and four-stars air-conditioning units with sun shading type B1 to B3.
Source:photographed by the author.

Figure 6.15 shows that the placement of sun shading type B4 to B6 with one-star and four-stars air-conditioning in west the lead to the fastest simple payback period. Type B6 was the best among others by achieving 0.56 years using one-star air-conditioning, and 0.68 years using four-stars air-conditioning of simple payback period in the west. Figure 6.16 shows that the type B6 showed best performance by achieving simple payback period of 0.71 years with one-stars air-conditioning and 0.87 years using four-stars air-conditioning in average of all orientations.



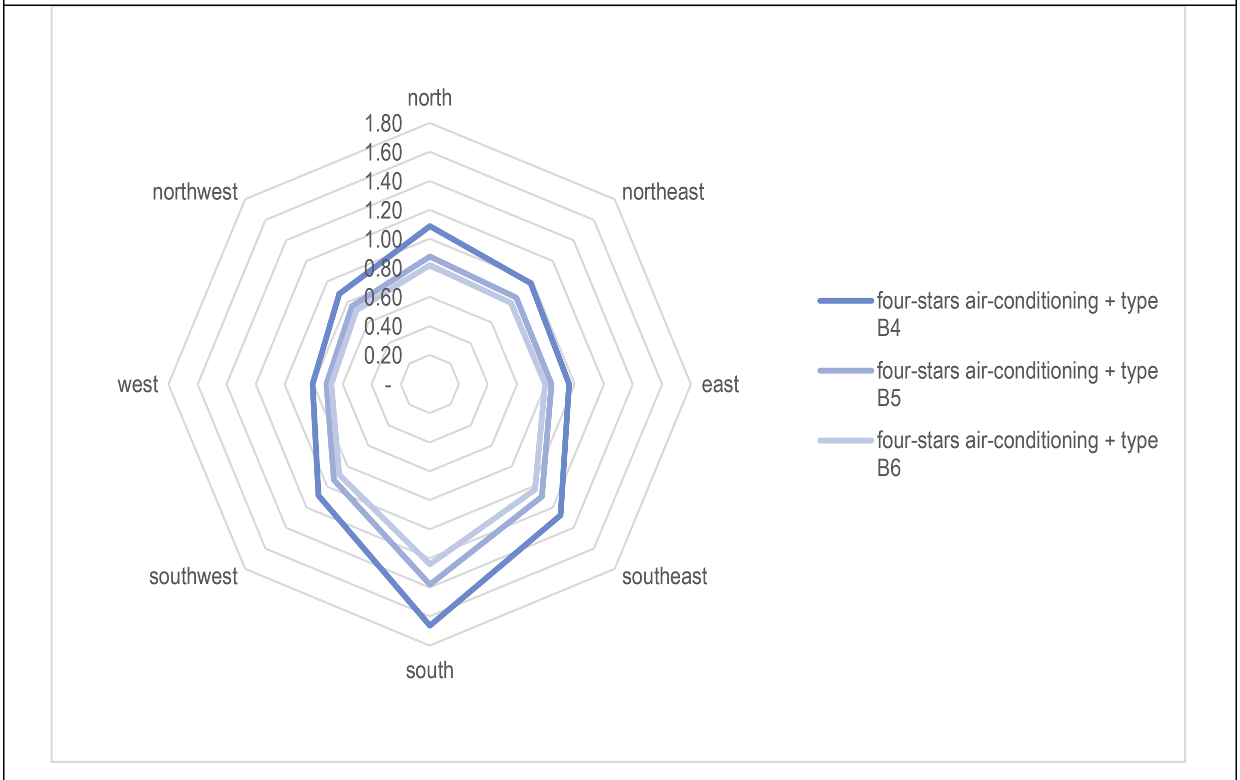


Figure 6. 16. Simple payback period in each orientation by using one-star and four-stars air-conditioning units with sun shading type B4 to B6.

Source:photographed by the author.

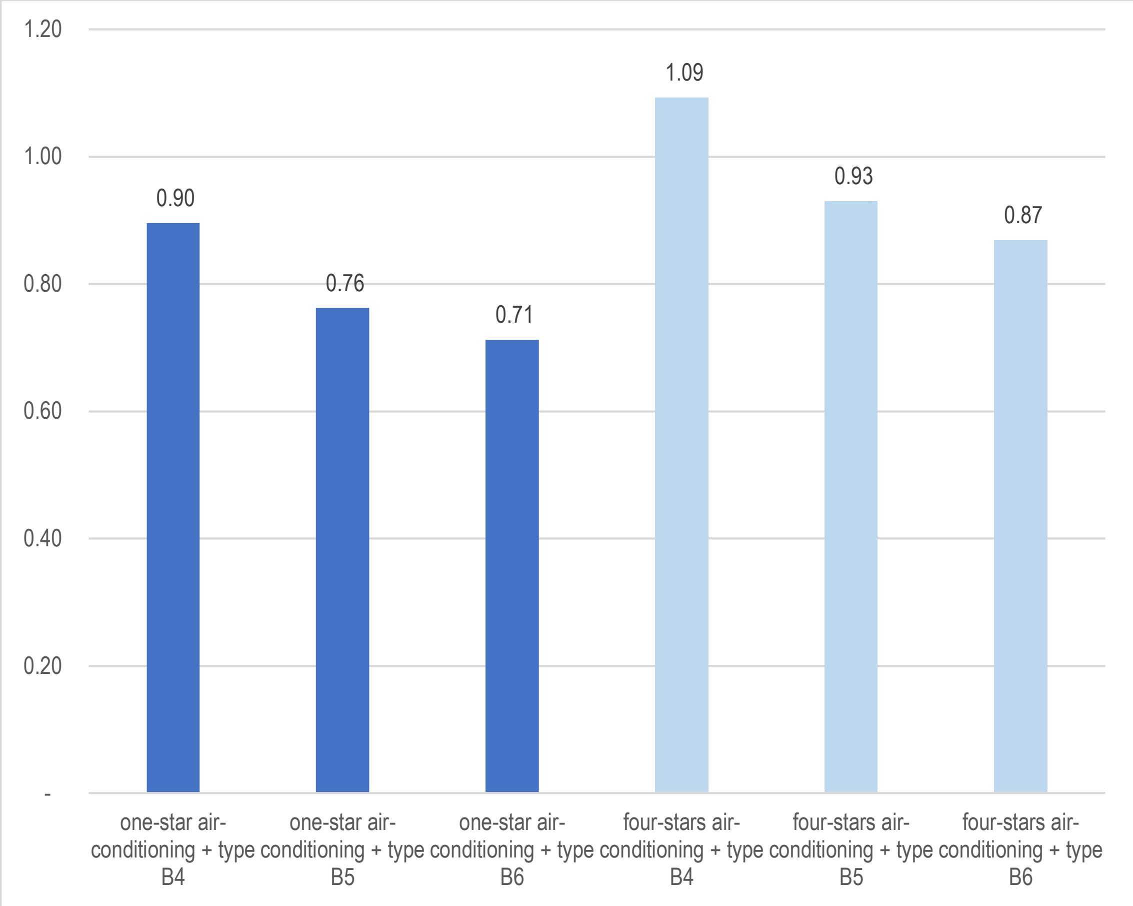
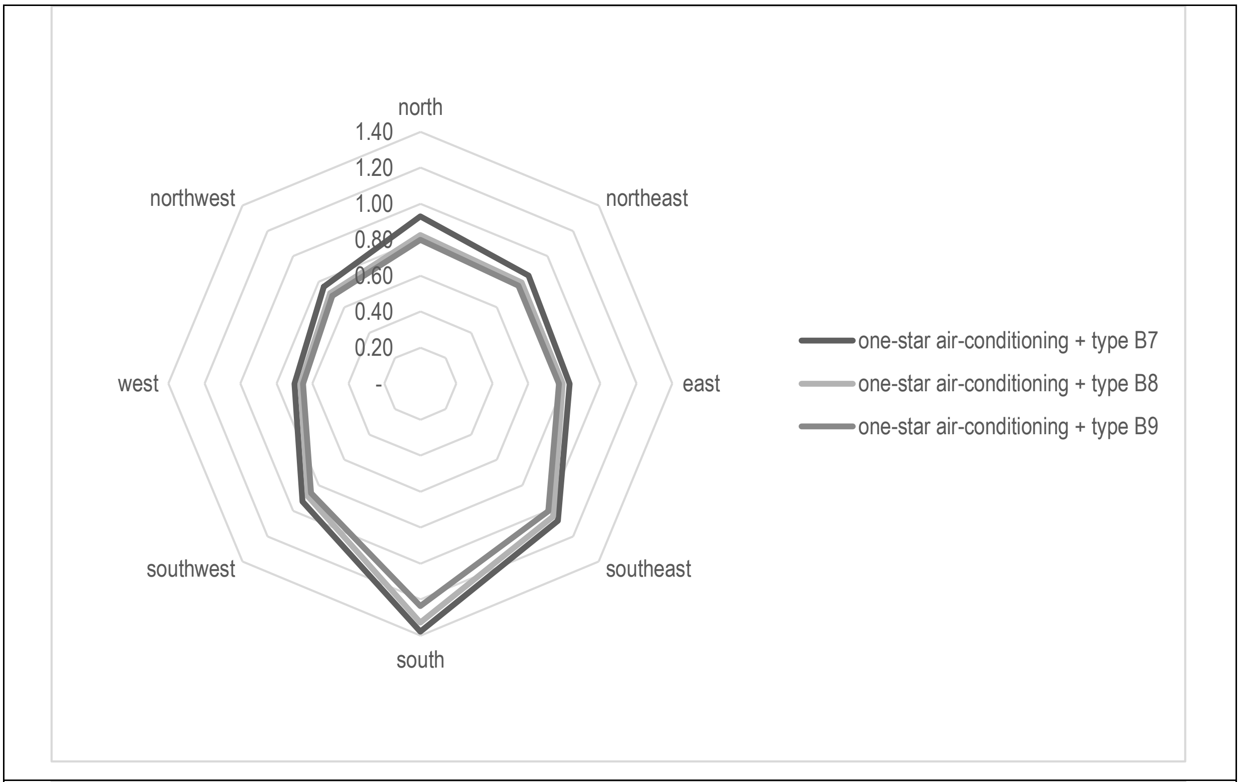


Figure 6. 17. The average simple payback period by using one-star and four-stars air-conditioning units with sun shading type B4 to B6.
Source:photographed by the author.

The sun shading type B7 to B9 with one-star and four-stars air-conditioning in west direction made the fastest simple payback period (figure 6.17). Type B9 was the best among others by achieving 0.65 years using one-star air-conditioning, and 0.8 years using four-stars air-conditioning of simple payback period in the west. Figure 6.18 shows that the type B9 showed best performance by achieving the simple payback period of 0.85 years with one-stars air-conditioning and 1.03 years using four-stars air-conditioning in average of all orientations.



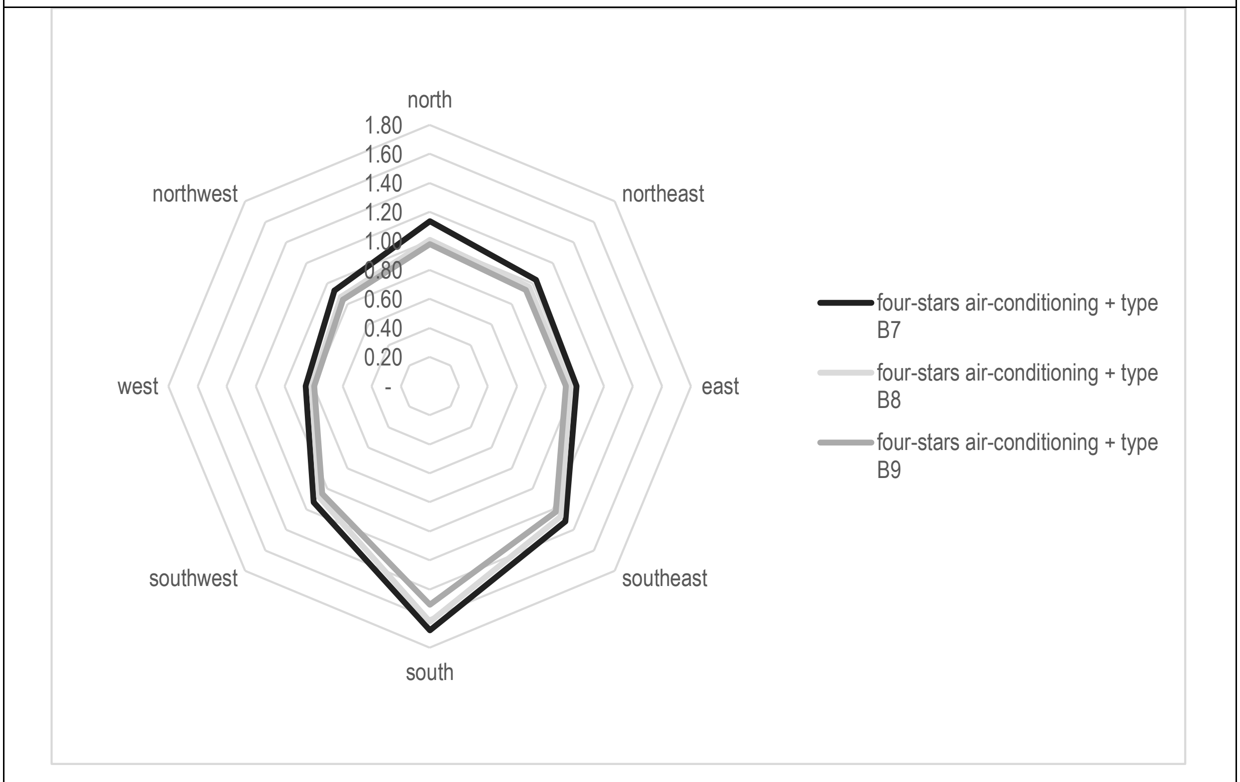


Figure 6. 18. Simple payback period in each orientation by using one-star and four-stars air-conditioning units with sun shading type B7 to B9.

Source:photographed by the author.

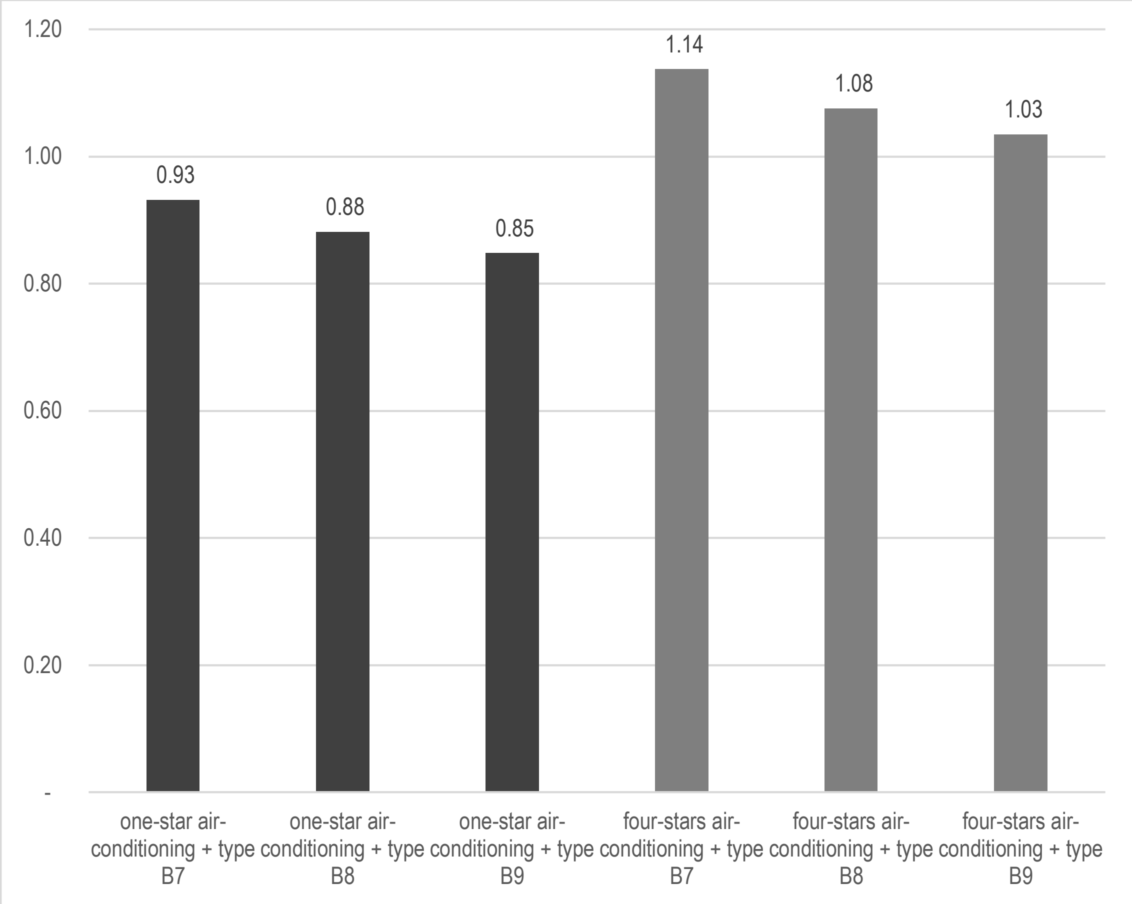


Figure 6. 19. The average simple payback period by using one-star and four-stars air-conditioning units with sun shading type B7 to B9.
Source:photographed by the author.

The overhangs, the sun shading type C1 to C2 with one-star and four-stars air-conditioning also made the fastest simple payback period in the west façade (figure 6.19). However, the simple payback period was significantly longer than that of all type B L-shaped mini-louvers. Type C1 performed better than type C2 by achieving 3.93 years using one-star air-conditioning, and 4.8 years using four-stars air-conditioning of simple payback period in the west direction. Figure 6.20 shows that the type C1 performed best by achieving the simple payback period of 5.16 years with one-stars air-conditioning and 6.29 years using four-stars air-conditioning in average of all orientations.

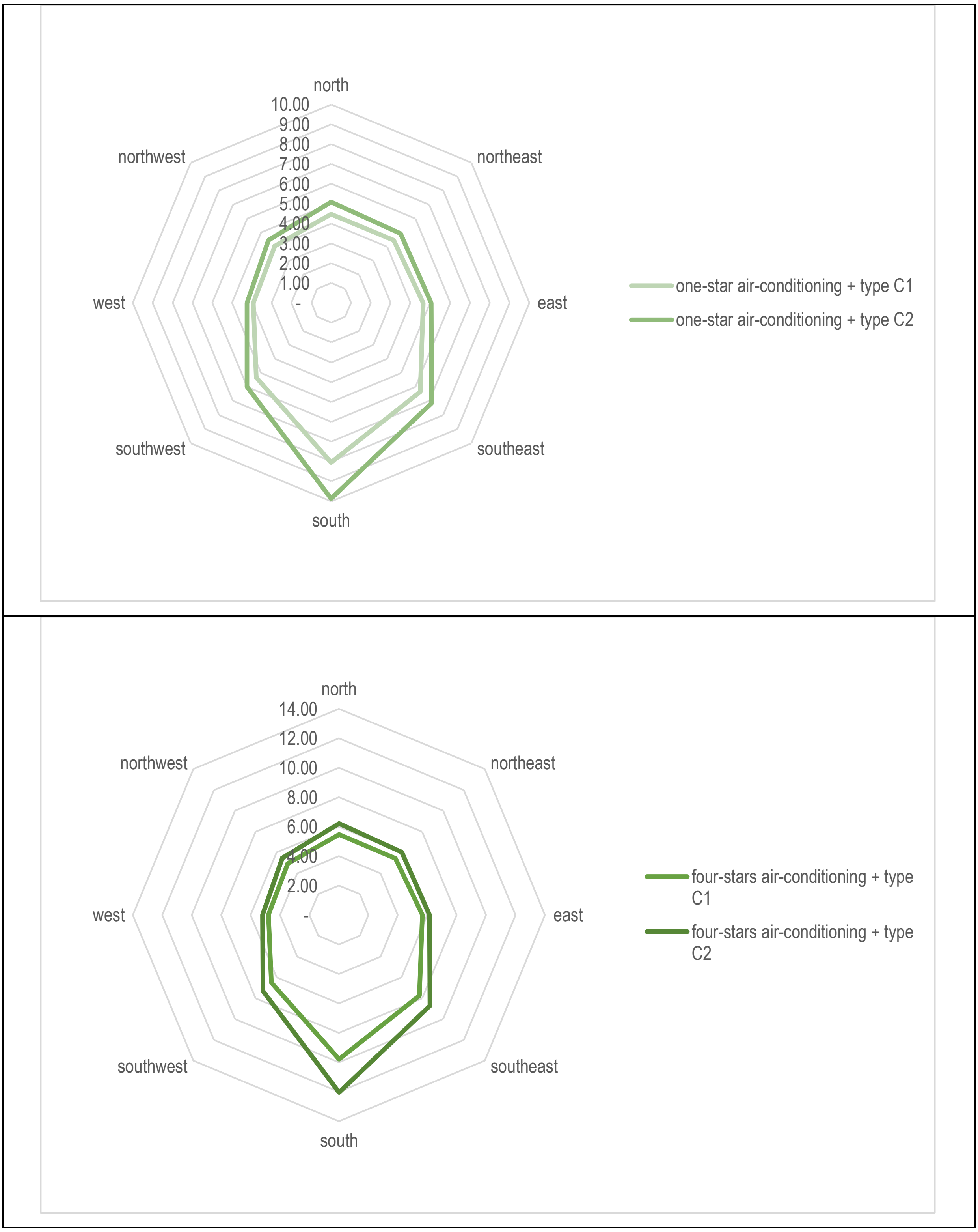


Figure 6. 20. Simple payback period in each orientation by using one-star and four-stars air-conditioning units with sun shading type C1 and C2.

Source:photographed by the author.

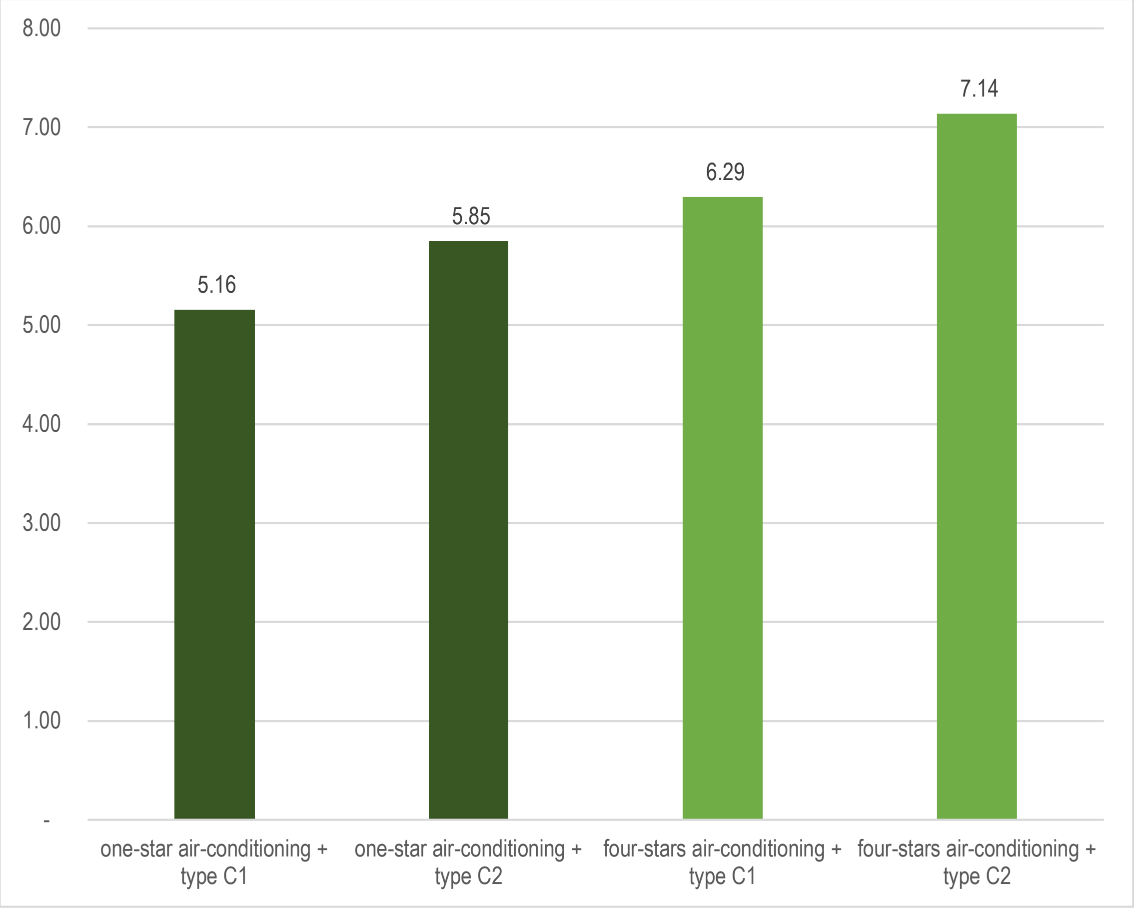


Figure 6. 21. The average simple payback period by using one-star and four-stars air-conditioning units with sun shading type C1 and C2.
Source:photographed by the author.

Utilizing two-stars and three-stars air-conditioning units lead to the simple payback period falls between one-star air-conditioning, which lead to the fastest and four-stars air-conditioning unit, which made the longest simple payback period. The complete calculations of these scenario using two-stars air-conditioning units and sun shading device are presented in table 6.4, while using the same sun shading device with three-stars air-conditioning unit are presented in table 6.5. The average simple payback period for all sun shading device using two-stars and three-stars air-conditioning units are presented in figure 6.21 and 6.22 respectively.

Table 6. 3. Simple payback period of simulated sun shading device with two-stars air-conditioning unit (years).

Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type A1	3.73	3.97	4.15	5.44	6.80	4.54	3.52	3.55
type A2	3.32	3.51	3.72	4.71	5.33	3.99	3.19	3.16
type A3	3.33	3.53	3.78	4.81	5.27	4.05	3.23	3.17
type A4	2.48	2.63	2.76	3.39	3.94	2.94	2.40	2.39
type A5	2.55	2.69	2.86	3.57	3.97	3.05	2.47	2.44
type A6	1.81	1.91	2.04	2.36	2.45	2.10	1.81	1.76
type A7	1.77	1.87	1.96	2.36	2.68	2.07	1.72	1.71
type A8	2.27	2.40	2.54	3.27	3.73	2.75	2.18	2.15
type A9	1.63	1.71	1.81	2.15	2.27	1.90	1.60	1.58
type B1	1.08	0.97	0.95	1.26	1.66	1.07	0.80	0.87
type B2	0.85	0.82	0.82	1.06	1.33	0.91	0.70	0.74
type B3	0.93	0.89	0.89	1.20	1.50	1.01	0.75	0.80
type B4	0.94	0.85	0.83	1.10	1.44	0.94	0.70	0.76
type B5	0.76	0.73	0.73	0.95	1.20	0.81	0.62	0.66
type B6	0.71	0.69	0.69	0.89	1.07	0.76	0.59	0.62
type B7	0.98	0.90	0.88	1.14	1.46	0.98	0.74	0.80
type B8	0.87	0.84	0.84	1.10	1.40	0.94	0.71	0.75
type B9	0.84	0.81	0.81	1.06	1.30	0.91	0.69	0.73
type C1	4.73	4.71	4.90	6.70	8.49	5.63	4.15	4.27
type C2	5.36	5.21	5.32	7.55	10.44	6.33	4.49	4.71

Table 6. 4. Simple payback period of simulated sun shading device with three-stars air-conditioning unit (years).

Source:photographed by the author.

model name	north	northeast	east	southeast	south	southwest	west	northwest
type A1	4.13	4.39	4.59	6.02	7.51	5.02	3.89	3.92
type A2	3.66	3.87	4.11	5.21	5.89	4.42	3.53	3.49
type A3	3.68	3.90	4.17	5.32	5.83	4.48	3.57	3.50
type A4	2.74	2.91	3.05	3.75	4.35	3.25	2.65	2.65
type A5	2.82	2.98	3.16	3.95	4.39	3.38	2.73	2.70
type A6	2.00	2.11	2.25	2.61	2.71	2.32	2.00	1.95
type A7	1.96	2.07	2.17	2.61	2.96	2.29	1.90	1.90
type A8	2.50	2.65	2.81	3.61	4.12	3.04	2.41	2.38
type A9	1.81	1.89	2.00	2.37	2.51	2.10	1.77	1.74
type B1	1.20	1.08	1.05	1.40	1.83	1.19	0.88	0.96
type B2	0.94	0.91	0.90	1.17	1.47	1.01	0.77	0.82
type B3	1.03	0.99	0.99	1.32	1.66	1.11	0.83	0.88
type B4	1.04	0.94	0.92	1.22	1.59	1.04	0.77	0.84
type B5	0.84	0.81	0.80	1.05	1.32	0.90	0.68	0.73
type B6	0.79	0.76	0.76	0.98	1.19	0.84	0.65	0.68

type B7	1.09	0.99	0.97	1.26	1.61	1.08	0.82	0.89
type B8	0.96	0.93	0.92	1.22	1.55	1.03	0.78	0.83
type B9	0.93	0.90	0.90	1.17	1.44	1.00	0.76	0.81
type C1	5.22	5.20	5.41	7.41	9.39	6.22	4.59	4.72
type C2	5.93	5.76	5.89	8.35	11.54	7.00	4.96	5.21

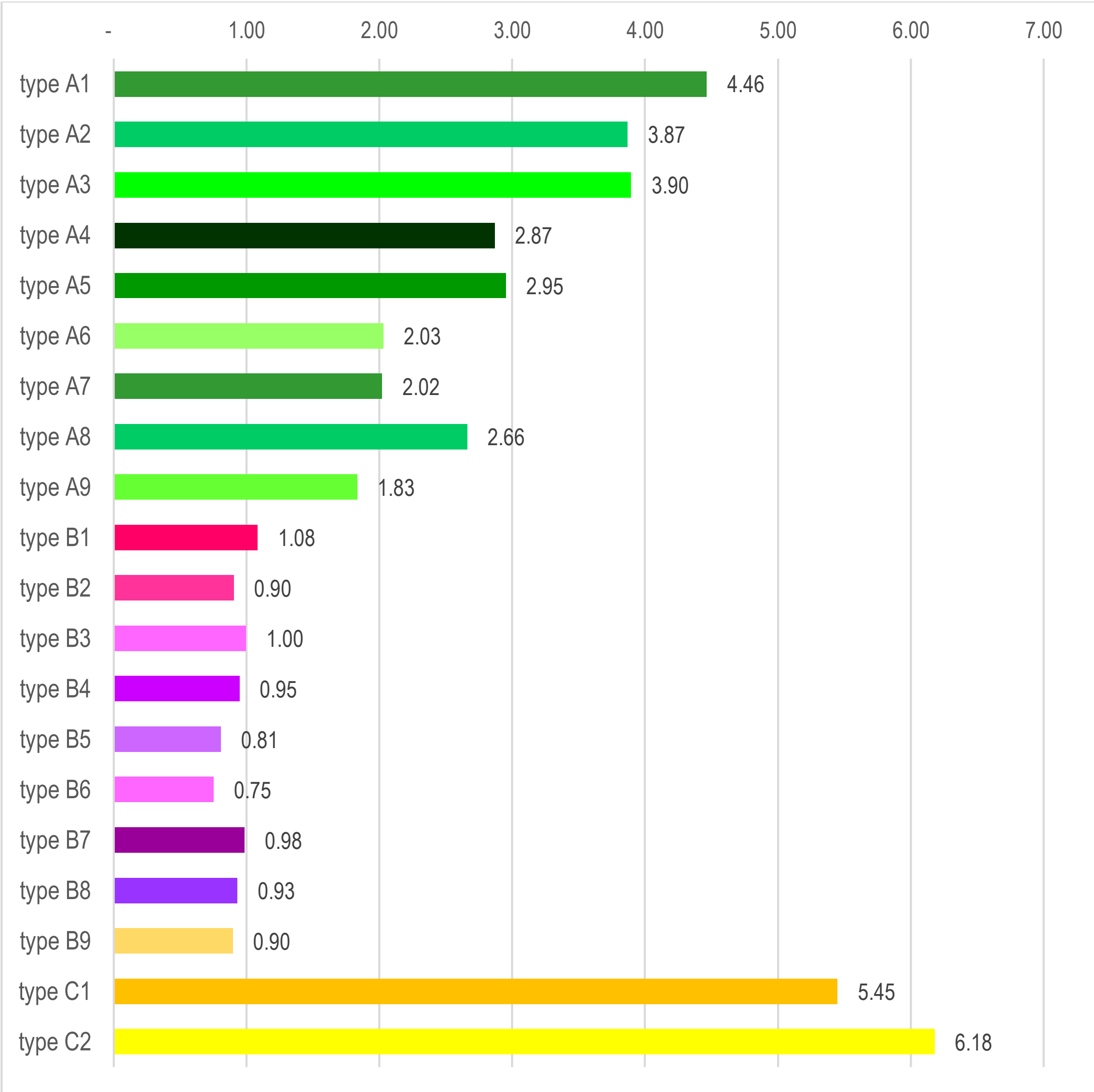


Figure 6. 22. The average simple payback period by combining sun shading devices with two-stars air-conditioning units in average of all orientations.

Source: photographed by the author.

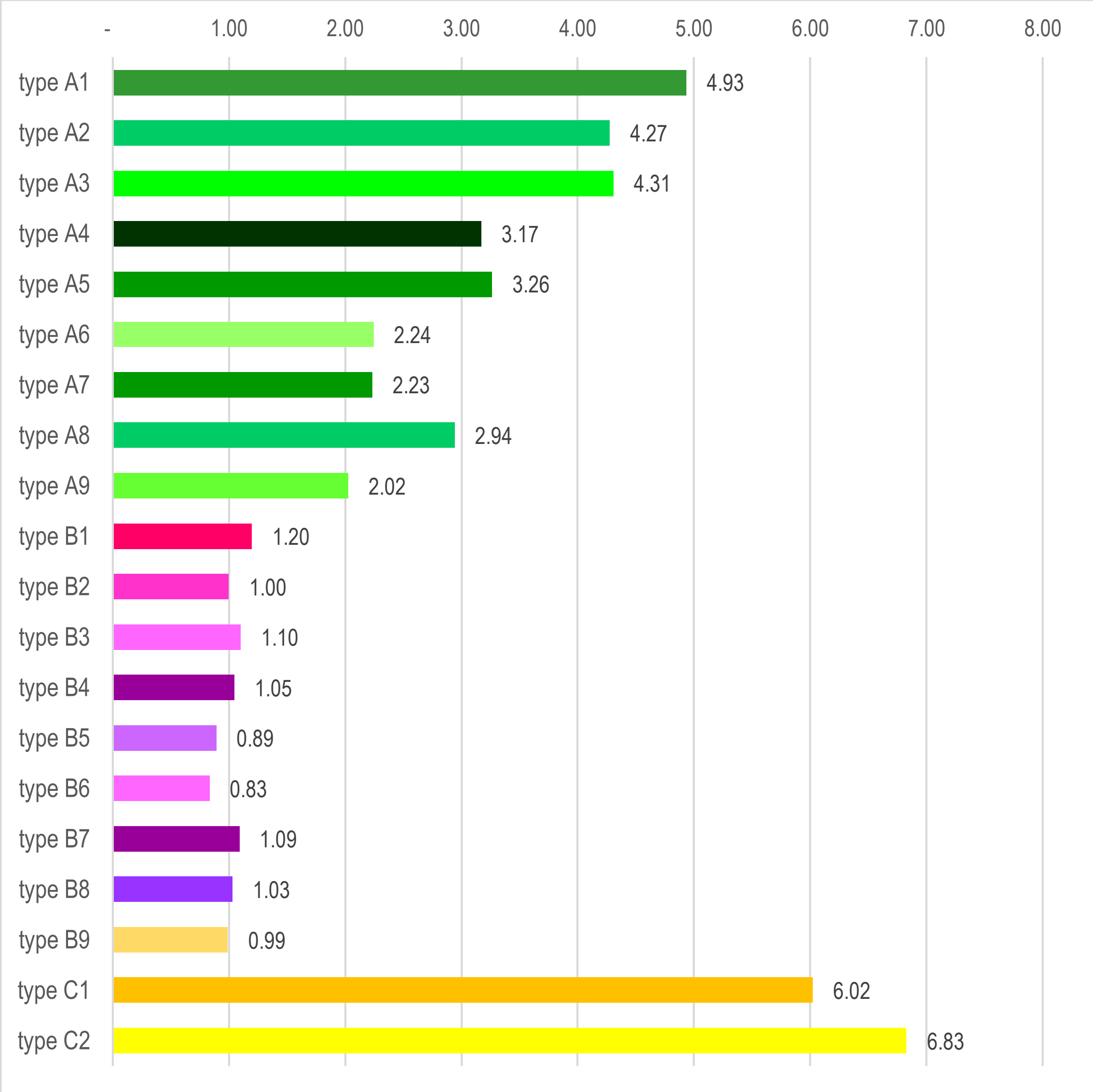


Figure 6. 23. The average simple payback period by combining sun shading devices with three-stars air-conditioning units in average of all orientations.

Source: photographed by the author.

Picking the best sun shading devices based on the similarity of the design, figure 6.23 shows the simple payback period in average of all orientation from the selected sun shading. All the L-shaped mini-louvers achieved faster simple payback period than the overhang. There was 1.5 and 1.82 years of gap of simple payback period by attaching type C1 in comparison with type A2 sun shading with one-star and four-stars air-conditioning unit accordingly. Note that type A2 was the worst among other selected L-shaped mini-louvers. Placing the L-shaped mini-louvers further from the outdoor surface of the window was significantly shorten the payback period. Other than different placement in the window, type A2 used the exact same design with type B2 L-shaped mini-louvers. However, there was a significant gap of 2.81 and 3.42 years of the simple payback period between type A2 and B6 using one-star and four-stars air-conditioning accordingly. Even though not as long as the difference between type A2 and B2, there was still a gap of simple payback period around 0.89 and 1.08 years between the type A9 and type B9 by utilizing one-star and four-stars air-conditioning unit.

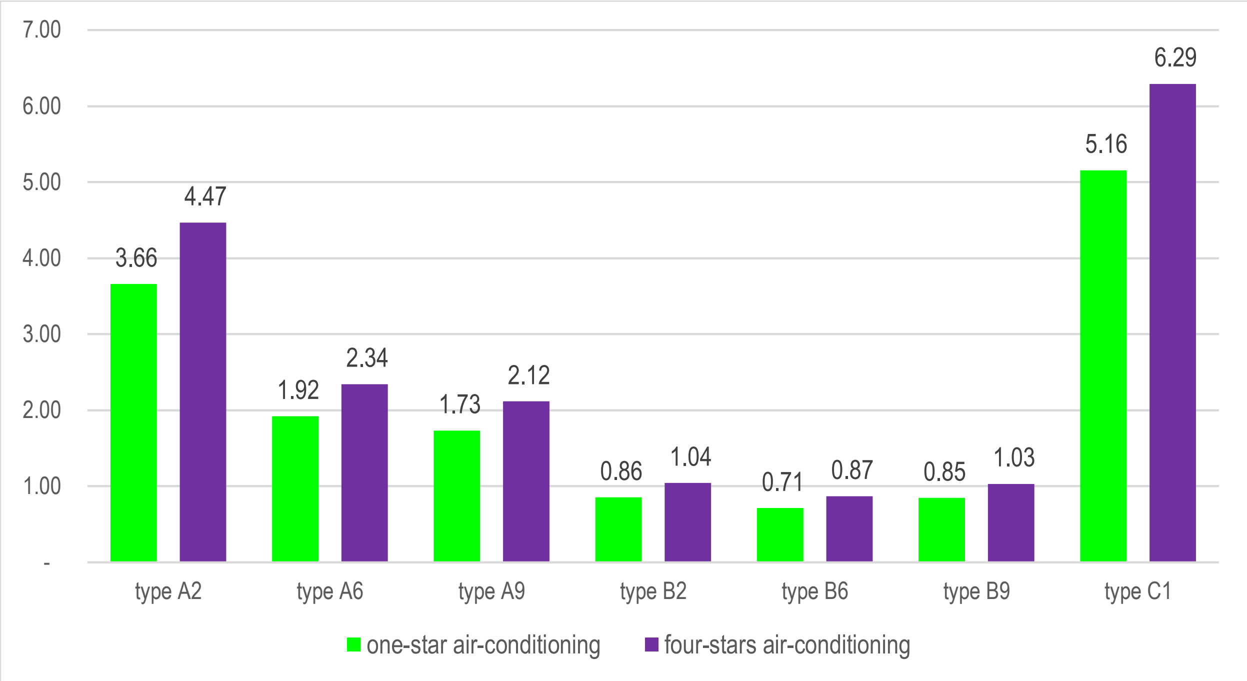


Figure 6. 24. The best sun shading devices based on the similarity of the design

6. 3. Chapter conclusion

Considering environmental impact of sun shading in terms of cooling energy reduction, the results were obvious: more shadows mean better result. However, in the real world application, economic aspect also became one of the consideration. Economic perspective was also more understandable by common people than engineering terms. The lowest construction cost of the sun shading device was type B6 (15 mm size with 45 mm openings, 50 mm gap with the window). It only required USD 21.45 to create the type B6 L-shaped mini-louvers. Type A9 (30 mm size with 90 mm openings, 1 mm gap with the window) was the cheapest among other type A. It cost USD 36.64 to construct type A sun shading. Type C1 (750 mm overhang) was cheaper than type C2. However, this overhang still needed application cost of USD 91.13, significantly more expensive than type A9 and type B6.

This chapter showed the meeting point between economic and environmental considerations to conclude the best sun shading device. In the west orientation, which required the highest cooling energy, type B6 was the best among all tested sun shading devices in this study. Even using the best four-stars air-conditioning, it only took 0.68 years to meet the simple payback period. Among all the A types, type A9 was the best by achieving simple payback period of 1.85 years. However, overhang type C1 significantly needed 4.8 years to meet the simple payback period.

In average of all building orientations using four-stars air-conditioning, type B6 was also the best among all simulated sun shading devices in this study by achieving only 0.87 years of simple payback period. Type A9 was the best among other A types while type C1 was the best overhang. Type A9 met simple payback period in 2.12 years while type C1 in 6.29 years.

Type B6 L-shaped mini-louvers was the best among other tested sun shading device in this study. The L-shaped mini-louvers consisted of aluminum profiles with the size of 15 mm × 15 mm with 1:3 size to opening ratio.

The next chapter would explore further possibilities of these sun shading device in terms of filtering the day light, another environmental consideration. In residential, the lighting energy did not have as significant portion of the overall energy consumption. Moreover, the lighting level standards were varied for rooms in residential. It depends on the activities inside the room and also user preferences. However, in other functions, an office for example, natural lighting played a role not only in environmental but also psychological, affecting the occupant that were using the indoor space. There were common lighting level standards to support activities in the office.

Chapter 7 – Daylight studies using L-shaped mini-louvers in a room with multiple windows

7. 1. An introduction to the daylight studies

Daylight is the practice of bringing natural light into a building to support the activity inside a building. Day lighting standard is vary since it depends on the functions of the rooms. However, in an office building, there are lighting standard that have to be achieved to ensure the optimum functions of the room. This chapter use three simulations of day lighting which were commonly used in the daylight research. The first simulation was daylight factor (DF). Daylight factors showed the percentage of the daylight available inside a plan in a room in comparison with the outdoor daylight under overcast sky condition. This simulation calculated the number of daylight factor 2 to 5 in the selected area. The daylight factor under 2 meant the room would be too dark for common activities. The daylight factor of 2 to 5 was the best since the room condition was well lit. However, the daylight factor above 5 was bright but there is possible unwanted glare and heat from the excessive light into the room. The daylight factor was not geographical-based but depended on the sky component. The daylight factor was the simplest study in day lighting and considered as preliminary step to more advanced and precise day lighting research. The next two simulations were geographical-based: Day Light Autonomy (DLA) and Useful Daylight Illuminance (UDI). Location-based simulation was considered better since the natural light data could be obtained from the sun path, which mimic the real condition in the specific location. Daylight autonomy in this study represented the percentage of annual daytime hours to the area which were above 300 lux for at least 50% of all the time. UDI showed the percentage of the percentage of annual daytime hours to the area which had illuminance level range between 100 – 2000 lux for at least 50% of all the time in this research. UDI was considered as one of the best simulation methods to predict the optimum amount of natural daylight in a room. The target for the study in this chapter was obtained the highest UDI by applying L-shaped mini-louvers.

A paper consisted the research of L-shaped mini-louvers performance in day lighting was presented in “Daylight performance of L-shaped mini louvers in office buildings”. This study examined the performance of L-shaped mini-louvers in different hemisphere across the world: Tokyo, Singapore, and Sydney[102]. The research showed that in three places, type 2 L-shaped mini-louvers sun shading, which consists of 25 mm × 25 mm L-shaped aluminum-profiles with size to opening ratio of 1:1 can achieve 100% of UDI. This results was significantly higher than that of in the base case buildings, which only had UDI of 12.89% in Tokyo, 8.67% in Singapore, and 8.56% in Sydney. The paper was presented and published in an international conference, the 16th Asia Institute of Urban Environment. The presentation itself was received best presenter award in the conference. The research methodology in this paper was used for this chapter.

7. 2. Daylight simulation settings

The daylight study in this chapter used computer software to simulate the L-shaped mini-louvers performance in terms of day lighting optimization. The environment and objects were similar with the simulation in chapter three. A 3000 mm × 3000 mm simple box building was constructed in Rhino 3-dimension program to mimic simple box building. Then, four openings, 2000 mm × 2000 mm single glass window panel in the middle of each, were placed in the four sides of the box. The number of the windows as opening in the wall was the only difference. In chapter three, only one side of the wall contained window. In this daylight study, all four sides of the wall had a window.

The base case was the same box with four windows without any shading devices. The shading devices were L-shaped mini-louvers. There were three different L-shaped aluminum profiles which acted as the members of mini-louvers: 12 mm × 12 mm, 15 mm × 15 mm, and 30 mm × 30 mm. The L-shaped mini-louvers had three different size to opening ratio of 1:1, 1:2, and 1:3. The schematic section of all simulated models are shown in figure 7.1. In total, there were nine types of L-shaped mini-louvers for shading devices (table 7.1). The 3-dimensional models of all simulated box buildings are shown in figure 7.2. These L-shaped mini-louvers were also similar with L-shaped mini-louvers in chapter three. The experimented area for daylight was at 750 mm height above the floor, mimicking the height of common working space in a table. The grid size for this area was 100 mm × 100 mm.

[102] Suryandono AR, Hariyadi A, Fukuda H (2019) Daylight performance of L-shaped mini louvers in office buildings. the 16th Asia Institute of Urban Environment international conference

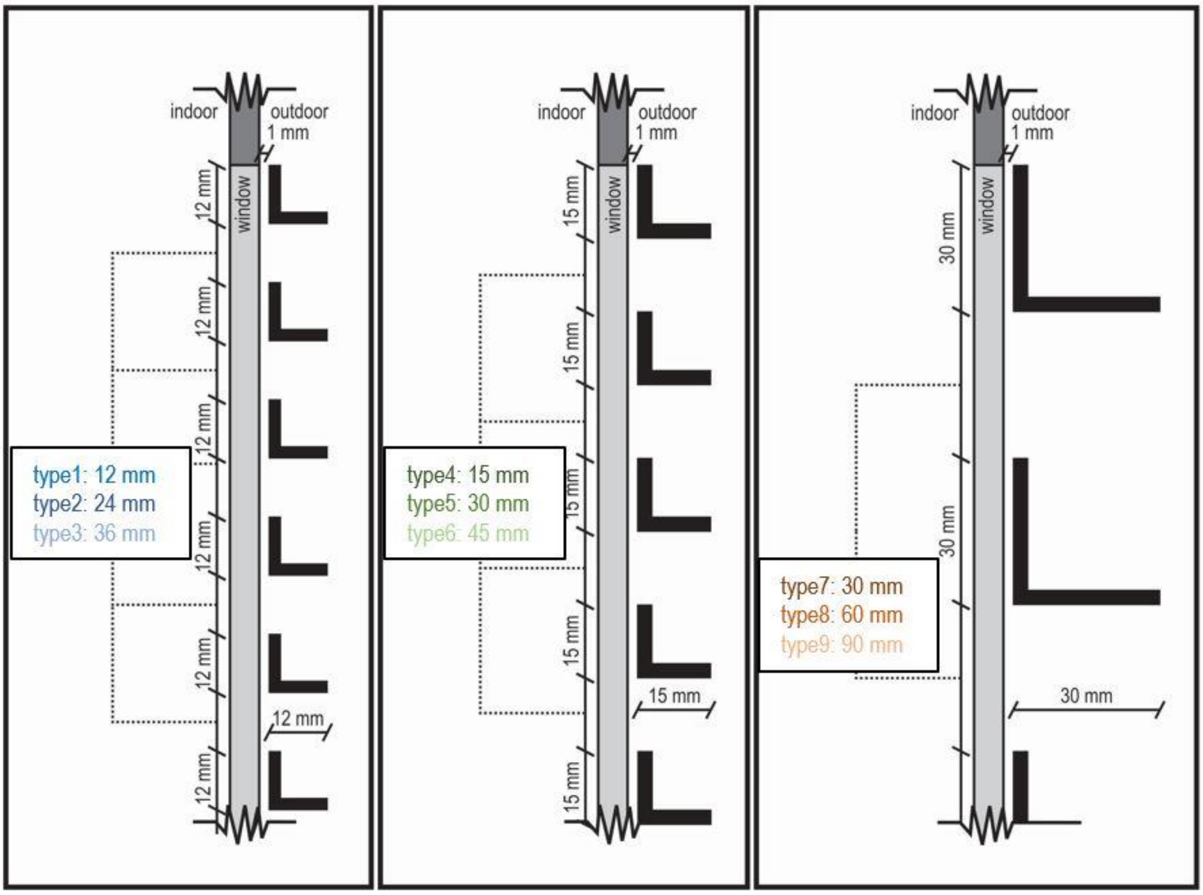


Figure 7. 1. Schematic section of simulated sun shading models for daylight study. Source: photographed by the author.

Table 7. 1. The simulated sun shading device and the dimensional properties. Source:photographed by the author.

model name	L-shaped mini-louvers	
	size (mm)	opening (mm)
base case	no shading	
type 1	12	12
type 2		24
type 3		36
type 4	15	15
type 5		30
type 6		45
type 7	30	30
type 8		60
type 9		90

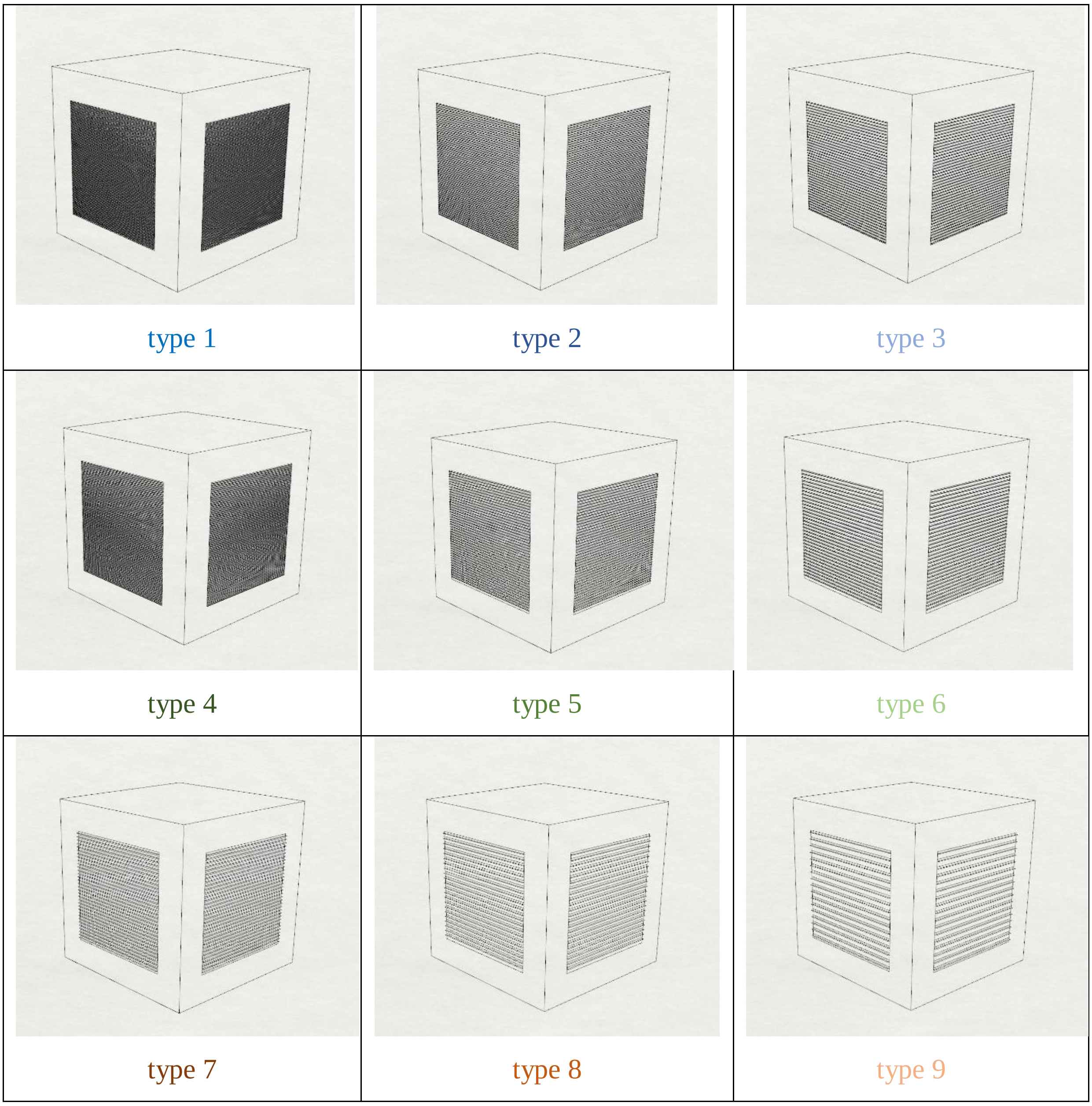


Figure 7. 2. All simulated box with sun shading device.

Source: photographed by the author

There were three simulations in this day lighting study. The first simulation was Daylight Factor (DF). DF was a ratio of the illumination in the indoor of a building in comparison with outdoor illumination under overcast skies condition. The presented results show daylight factor 2 to 5. The number 2 to 5 of the daylight factor followed British Standard Institution. The second simulation was Day Light Autonomy (DLA). DLA simulation showed the percentage of annual daytime hours at the grid space above the specified illumination level. DLA threshold in this study was set to 300 lux. The third simulation was Useful Daylight Illuminance (UDI). This third simulation was the modification of DF and DLA. UDI divided three basic illumination ranges: 0 – 100 lux, 100 – 2000 lux, and above 2000 lux. The UDI was between 100 – 2000 lux. The illuminance level of 0 – 100 lux was considered to be too dark to support common activities. The illuminance level above 2000 lux created potential glare and possible unwanted overheating. Selected area in UDI must have at least 50% of the UDI in a year.

The computer models were first simulated to obtain the non-geographical based, DF simulations. The sky matrix was Reinhart, which divided sky into a fine 580 sky patches. To do the second and third simulations, the downloaded weather files was used. The locations was in Jakarta observatories, Indonesia. The 3-dimensional model of the simulation environment is shown in figure 7.3.

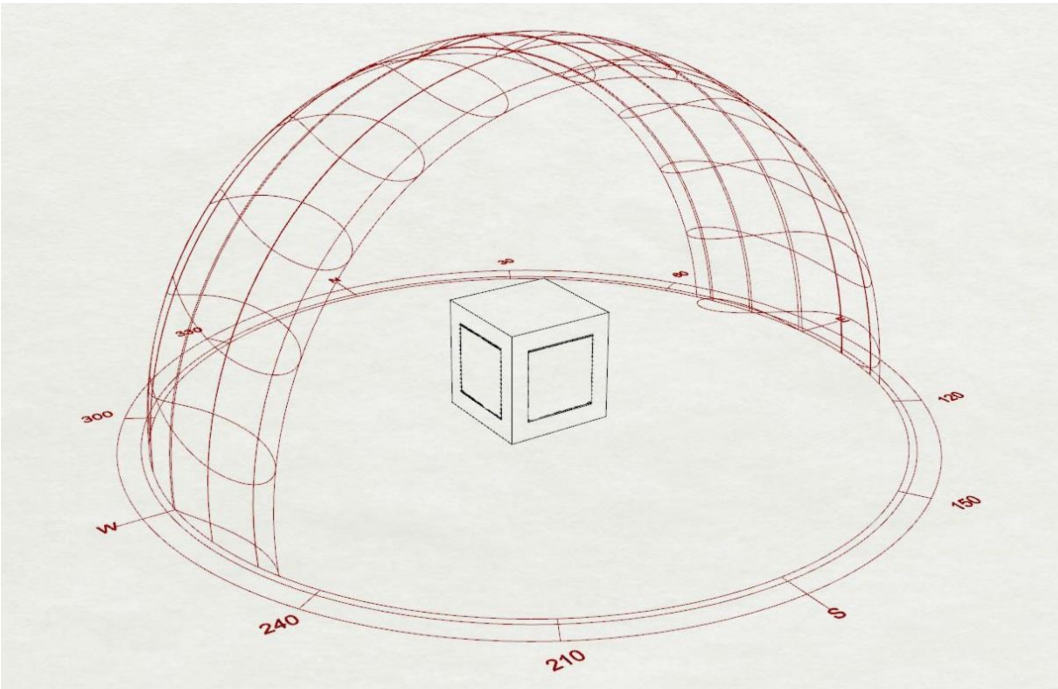


Figure 7. 3. Model perspective of simulation environment with the base case box building. Source: photographed by the author.

7. 3. Daylight simulation results and analysis

The simulation results of the daylight factors for one base case and nine models are shown in figure 7.4. The 7.89 DF of the box buildings with type 1 was the best among all other sun shading device. It performed slightly better than the type 7 7.88 of DF. The placement of sun shading devices, despite of the type, was significantly better by the base case, box building without any shading device on its windows. Type 3, type 6, and type 9 which had 4.44 daylight factor was still a lot higher than 2.56 DF of the base case. The daylight factor distribution at the specific area for the base case and all types of L-shaped mini-louvers are shown in the figure 7.5.

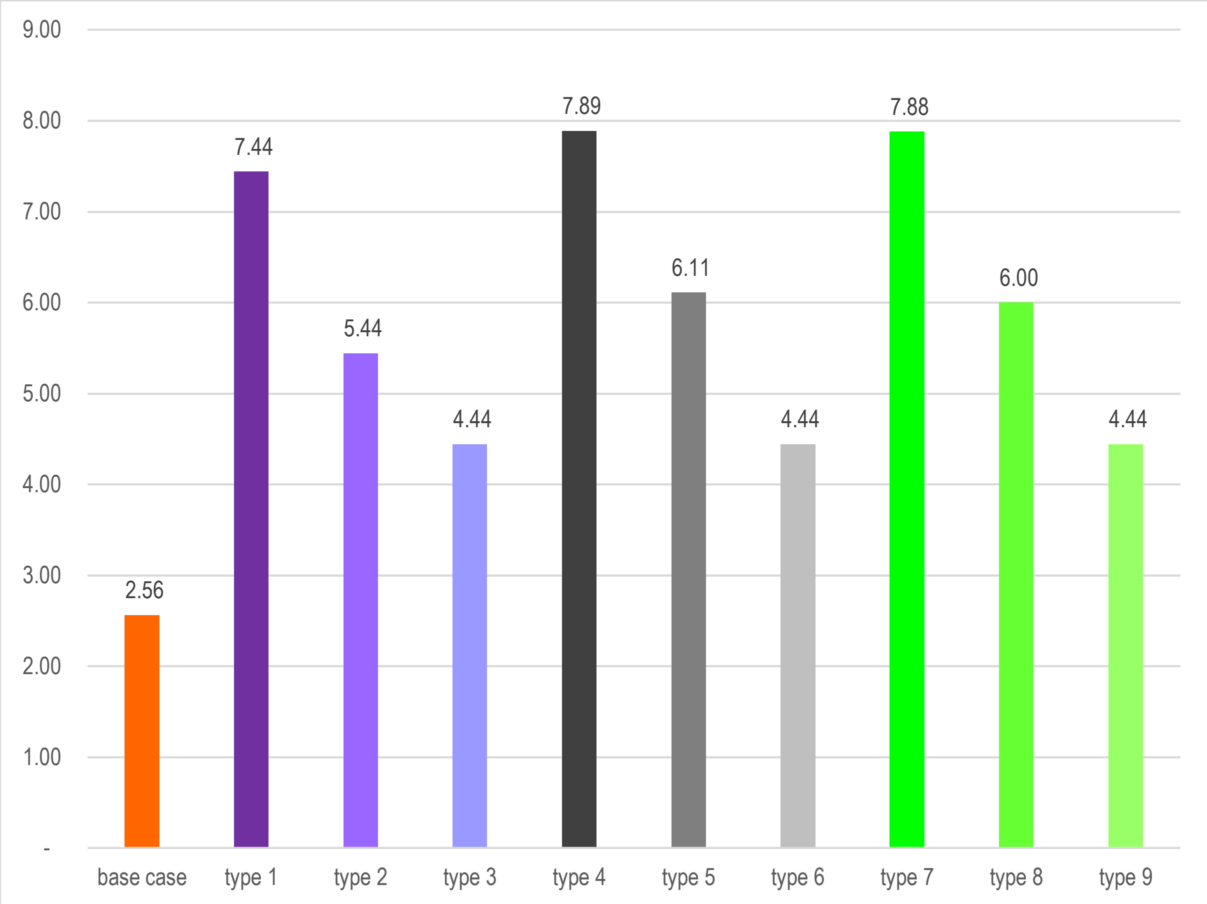
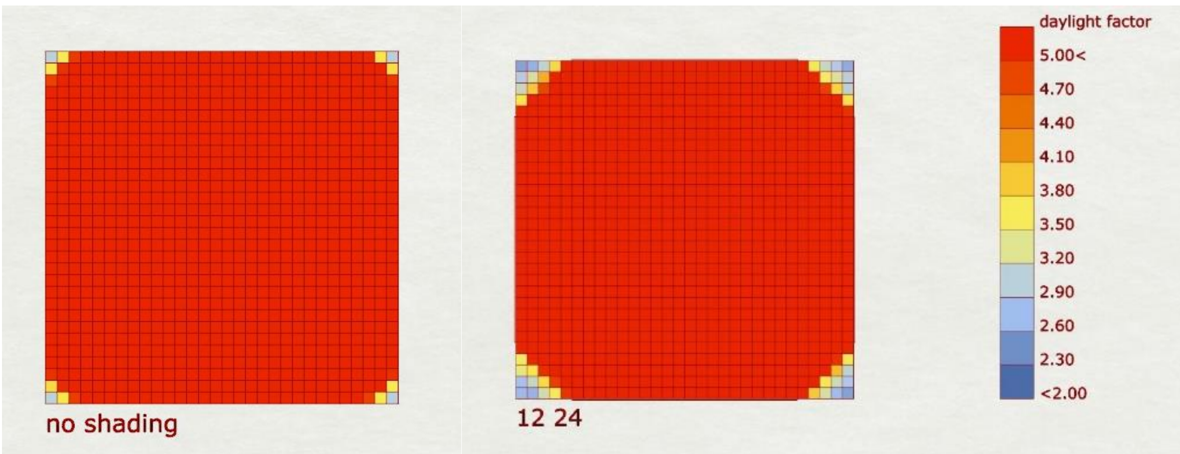
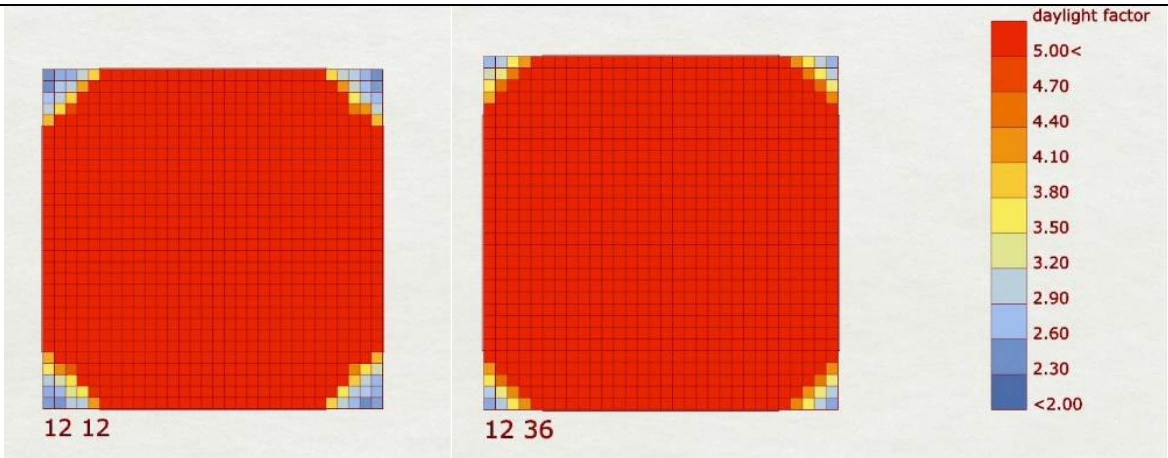


Figure 7. 4. The daylight factor simulation results of all models.

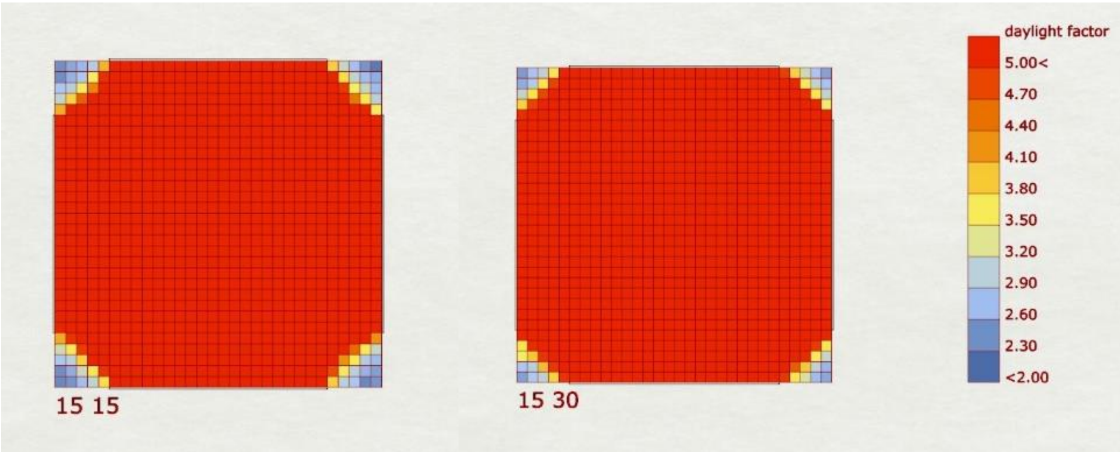
Source: photographed by the author



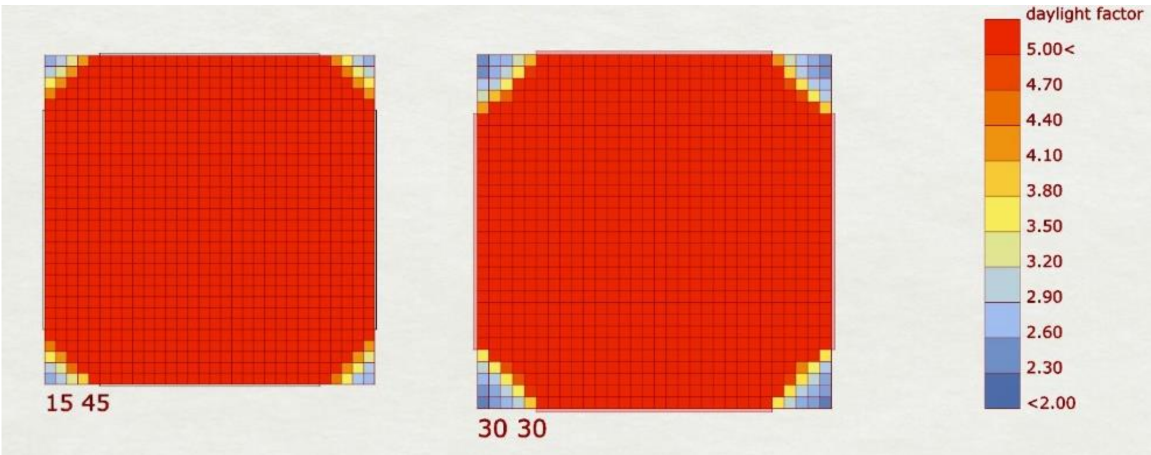
no shading/ base case type 1



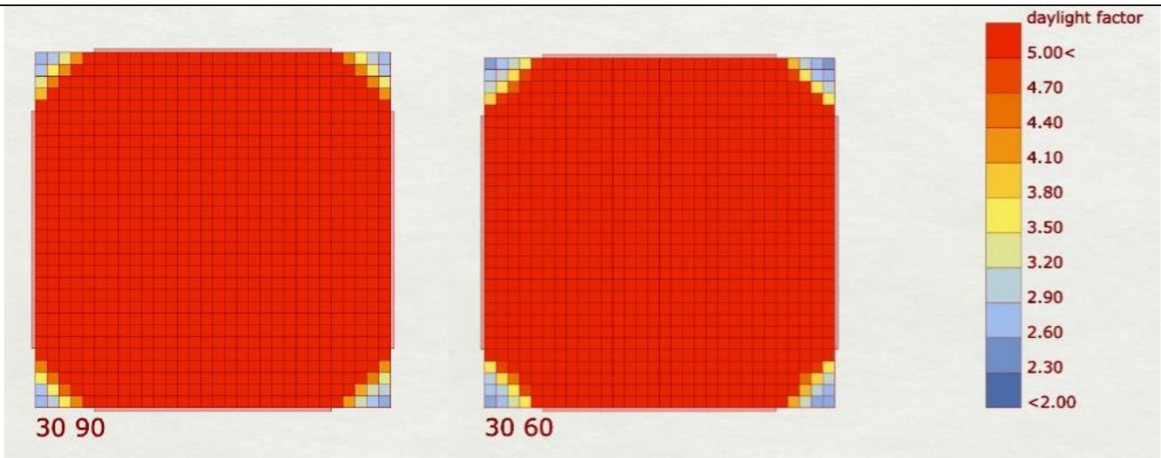
type 2 type 3



type 4 type 5



type 6 type 7



type 8 type 9

Figure 7. 5. Daylight factor distribution grid in plan view.
Source: photographed by the author

The second simulation showed the daylight autonomy (DA) for all the models. The results showed that all the models can achieve 100% of DA. The indoor area in all the model received at least 300 lux during the day in a year. Placing the sun shading did not affected the results. However, the third simulations, showed different results among the models.

The third simulation was the useful daylight illuminance (UDI). Placing the sun shading could optimize the day lighting condition in the indoor area (figure 7.6). Type 4 L-shaped mini-louvers brought the UDI to 18, slightly better than type 1's 17.67 but significantly higher than that of the base case's 2.22. Even the worst performance of L-shaped mini-louvers, type 6 could still achieve UDI of 5.67, more than double in comparison with the base case results. The spatial distribution of the useful daylight can be seen in figure 7.6.

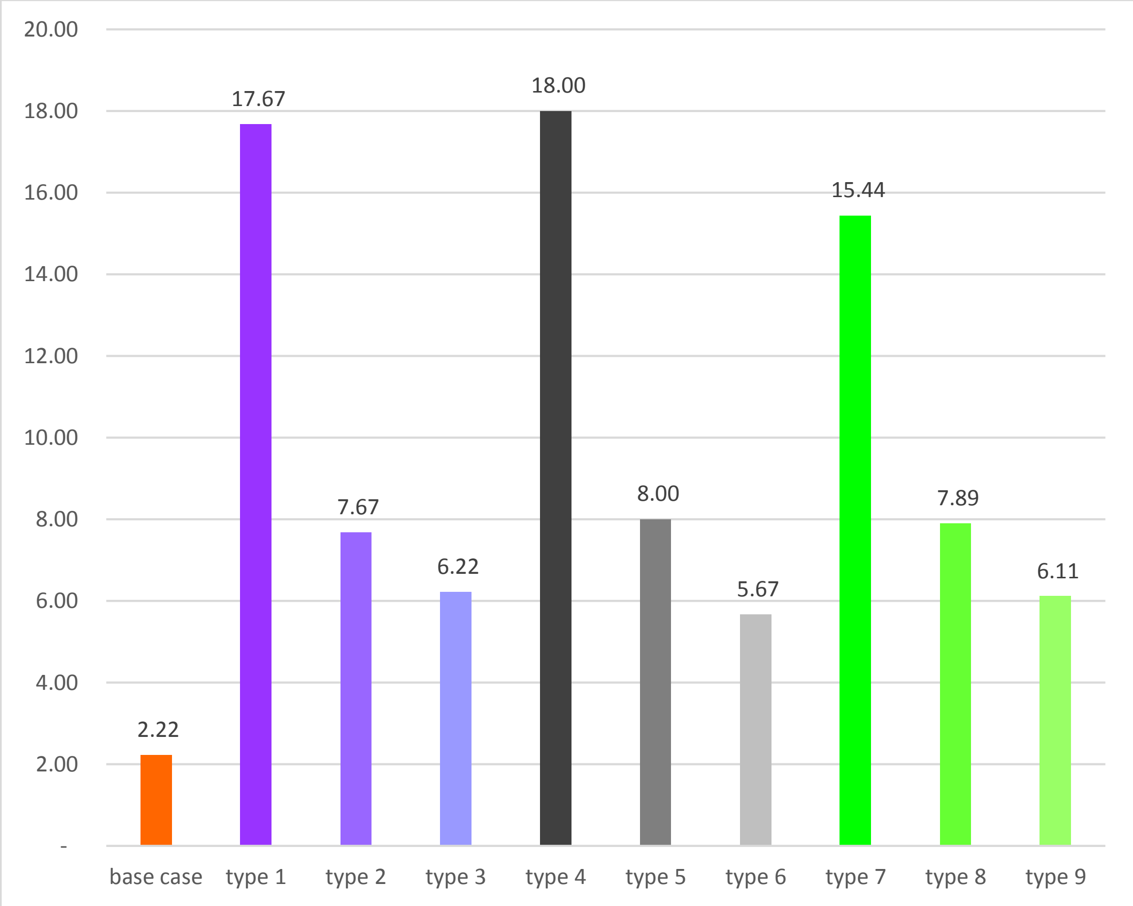
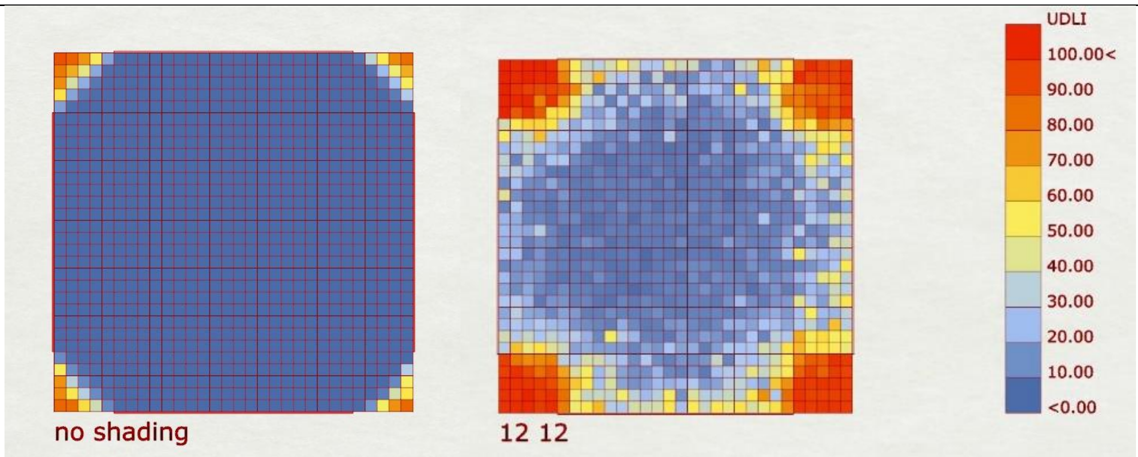
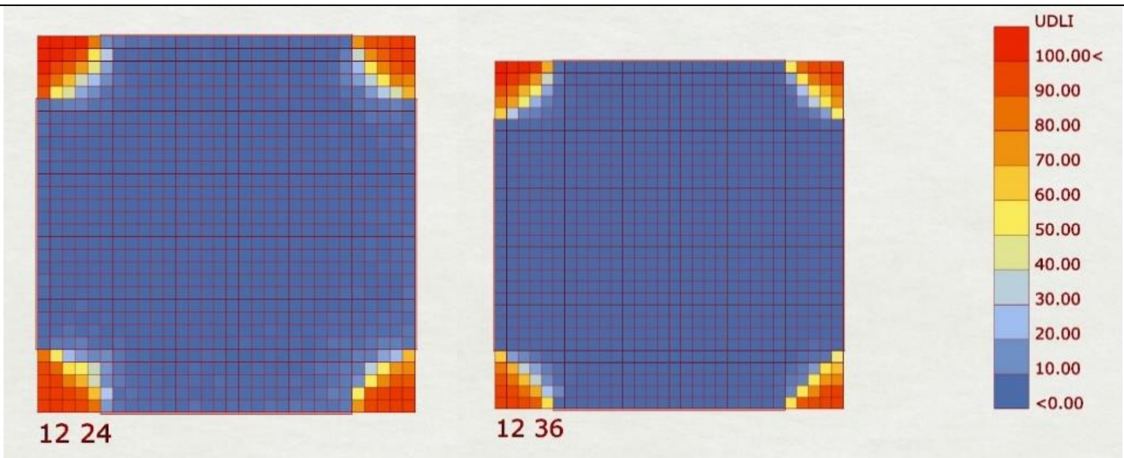


Figure 7. 6. Useful daylight illuminance simulation results of all the models. Source: photographed by the author

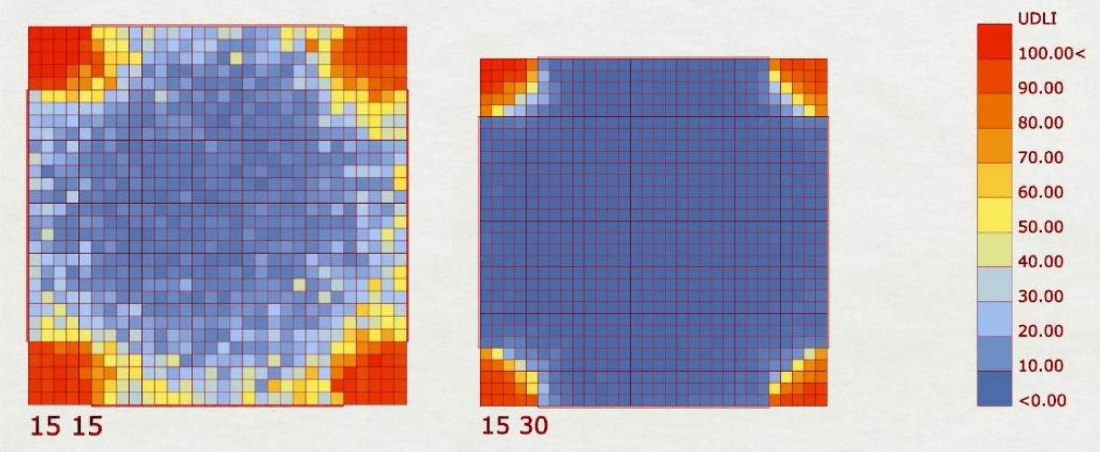


no shading/ base case

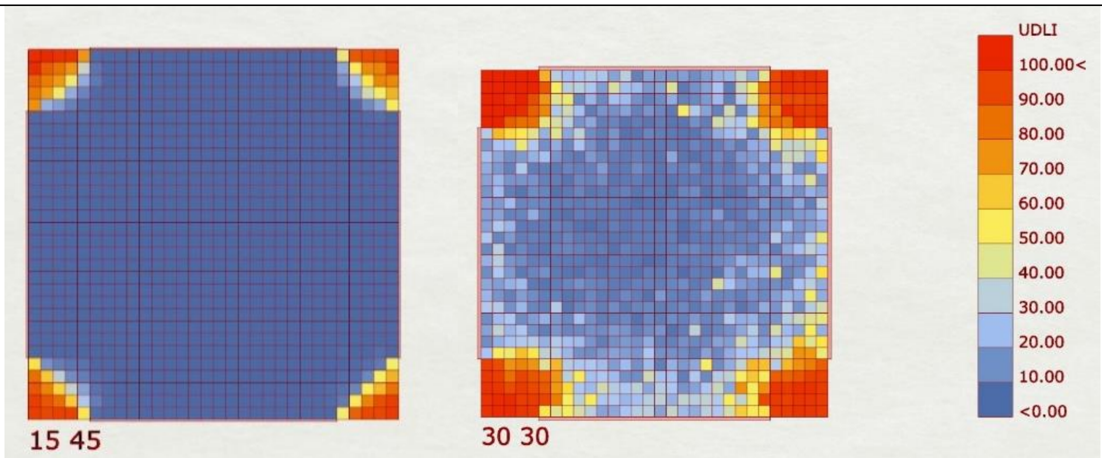
type 1



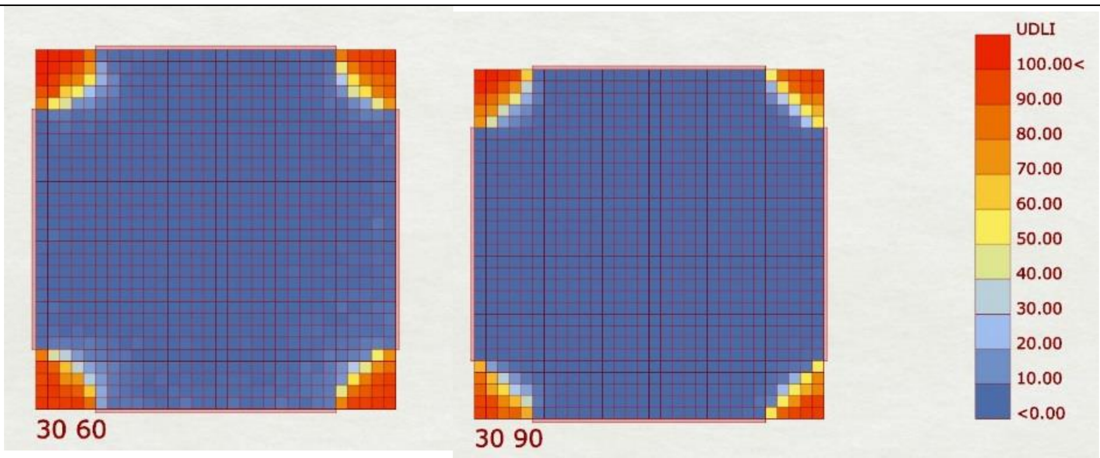
type 2 type 3



type 4 type 5



type 6 type 7



type 8 type 9

Figure 7. 7. Useful daylight illuminance spatial distribution at 750 mm height above the floor using 100 mm x 100 mm grid.
Source: photographed by the author

Placing the sun shading device in the box gave better performance of the daylight in the indoor space. However, the number was still relative small. In the next simulations, the best L-shaped mini-louvers: type 4, 5, and 6 were tested using the same box with different size of the window. First, the size of the window is reduced from 2000 mm × 2000 mm to be 1500 mm × 1500mm. Then the window size of 1000 mm × 1000 mm was also simulated using L-shaped mini-louvers by the same settings with previous simulations. The DF are shown in figure 7.8. Smaller window size affected positively in terms of the DF. Type 4 L-shaped mini-louvers daylight factor performance increased significantly from 7.9 by using 2000 mm × 2000 mm windows to be more than four times at 33.1 using 1000 mm × 1000 mm windows. However, this increase was still smaller in comparison with the base case. Using 2000 mm × 2000 mm windows, the base case only achieves 2.6 DF. Using 1000 mm × 1000 mm windows make the DF of the base case steeply increased to be more than seven times at the daylight factor of 19. It meant that the size of the window plays a bigger role in terms of DF.

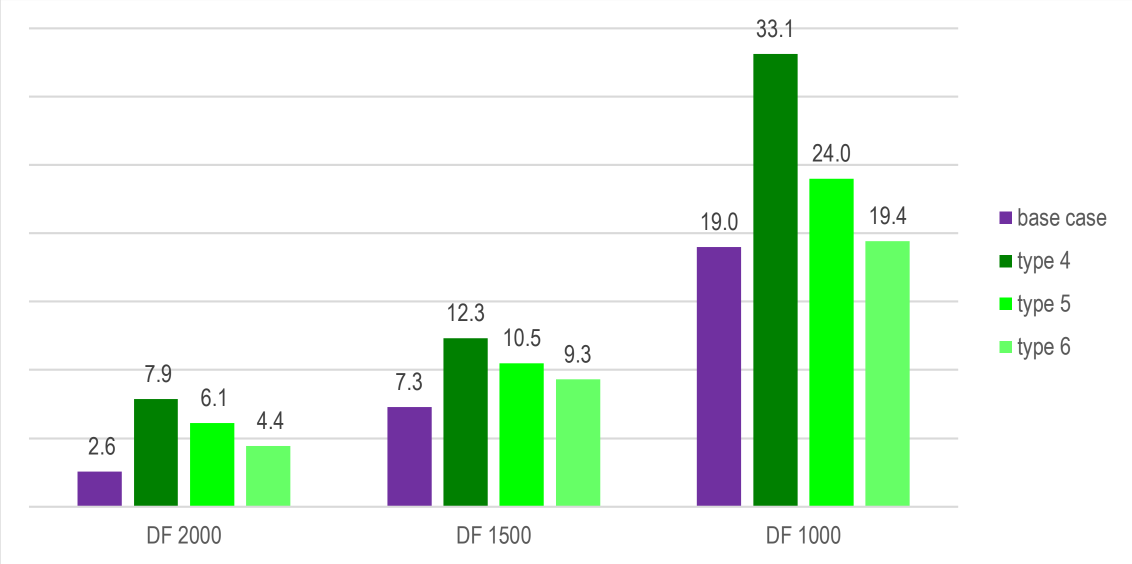


Figure 7. 8. Simulation results of the daylight factor.

Source: photographed by the author

The next simulation, the daylight autonomy was more specific since it is a location-based simulation. The results of changing the size of the window in DA are shown in figure 7.9. Placing type 4 sun shading device had a negative impact in the daylight autonomy of 98 by using 1500 mm × 1500 mm windows. All types of the L-shaped mini-louvers had negative effects in daylight autonomy by using 1000 mm × 1000 mm windows.

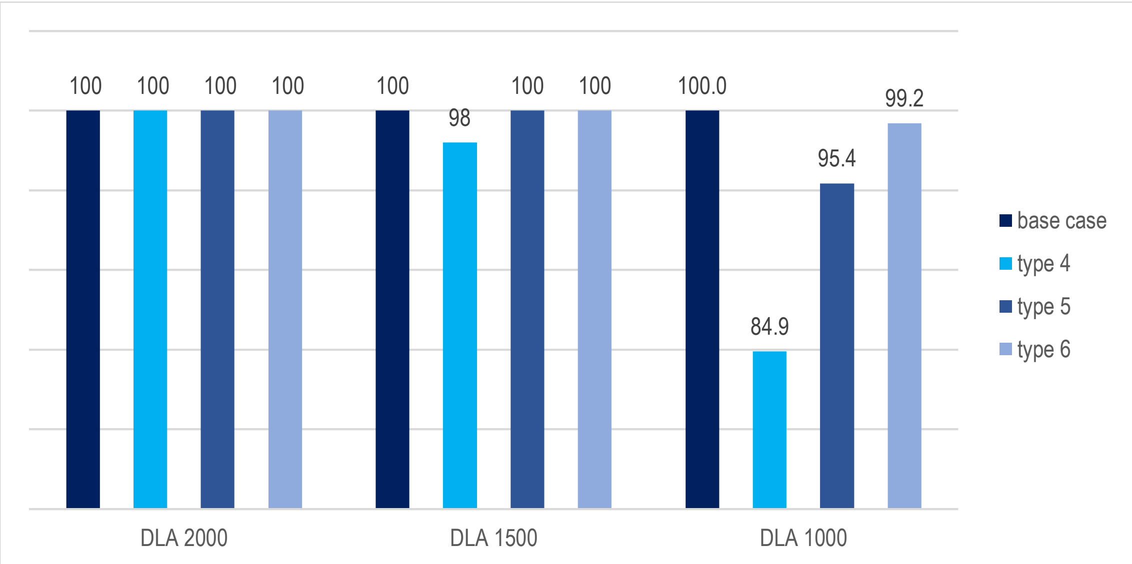


Figure 7. 9. Simulation results of the daylight autonomy.

Source: photographed by the author

The last simulation, useful daylight illuminance, which was considered as the best simulations to predict the use of indoor spatial daylight reveal the performance of L-shaped mini-louvers to optimize the day lighting. The results are shown in cfigure 7.10. Changing the size of the window had positive impacts in UDI. In the base case, the UDI at 2.22 increase to 9.2 by using 1500 mm × 1500 mm window and to 34.4 using 1000 mm × 1000 mm window. Re-size the window into half the original size impacted of more than fifteen times of UDI in the base case. Placing the type 4 could boost the UDI of 100 using 1000 mm × 1000 mm windows in all four sides of the buildings. Type 3 only had a slightly worse result at 98.2 UDI using the same 1000 mm × 1000 mm windows. Even only reducing 500 mm of the size of the window, type 4 could achieve 70.8 UDI in comparison with only 18 using the 2000 mm × 2000 mm windows.

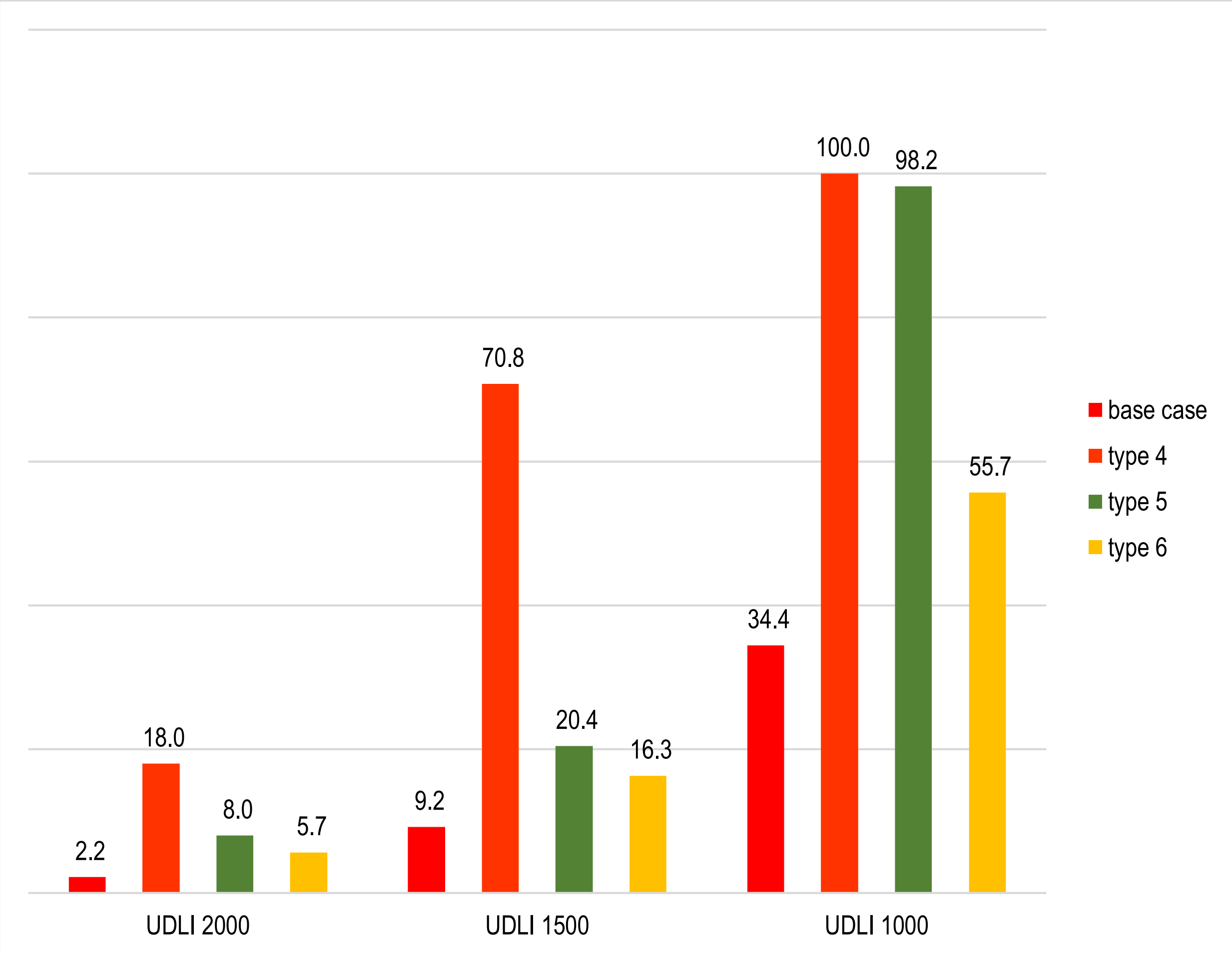


Figure 7. 10. Simulation results of the useful daylight illuminance.

Source: photographed by the author

7. 4. Chapter conclusion

Utilizing L-shaped mini-louvers could have many benefits, one of them was day lighting optimization. This chapter showed the results of its application to the window could filter the excessive lighting to achieve a useful level of the light inside the room. Type 4 (15 mm size with 15 mm openings), 5 (15 mm size with 30 mm openings), and 6 (15 mm size with 45 mm openings) were better than other L-shaped mini-louvers. The middle size, 15 mm × 15 mm aluminum profiles performed better than a smaller 12 mm x 12 mm aluminum profiles in type 1 to 3 and a larger size of 30 mm × 30 mm of those of type 7 to 9. Type 4 worked best by achieving 18 UDI in comparison with base case which can only meet 2.2.

There was another factor that related to the improvement: the size of the windows. However, by using type 4 L-shaped mini-louvers, a UDI of 100 can be achieved, even there were four windows in every side of the buildings. Even using type 5, a slightly lower UDI of 98.2 could still be achieved. This chapter showed another environmental benefits of applying L-shaped mini-louvers in buildings.

Chapter 8 – L-shaped mini-louvers' performance in office in Jakarta, Indonesia

8. 1. Chapter background

L-shaped mini-louvers showed environmental benefits by reducing cooling energy consumption and improving daylight condition while still economically feasible for residential. This chapter brought the optimum models of L-shaped mini-louvers using 15 mm × 15 mm aluminum profiles to be tested in an open-office. This simulation needed to be executed to show the performance of L-shaped mini-louvers in a different room function. The paper "Economic assessment of L-shaped mini louvers for reducing cooling energy and improving daylight condition in offices: a simulation study in Jakarta" was published in Sustainability journal Vol. 13 Issue 7 in 2021.

The same setting from previous chapter was used in this chapter in office setting. Box building with the size of 3000 mm × 3000 mm was constructed using same files with one 2000 mm × 2000 mm window opening in one side of the wall. The zone program for EnergyPlus was open-office. The detailed settings are presented in table 8.1.

Table 8. 1. Open-office zone program setting in EnergyPlus for the simulation. Source: photographed by the author.

Open office	
Equipment load per area	7.642412 W/m²
Infiltration load per area	0.000227 m³/s-m² at 4Pa
Lighting density per area	11.840357 W/m²
Number of people per area	0.056511 People/m²
Ventilation per area	0.000305 m³/s-m²
Ventilation per person	0.00236 m³/person
HoneyBee zone schedule	default open office
Ideal air load system	true
Heating set point	21 °C
Cooling set point	24 °C

Two size of L-shaped mini-louvers, 15 mm × 15 mm and 30 mm × 30 mm were used since they were the most optimum models. The same size to ratio opening with previous models were used in office setting: 1:1, 1:2 and 1:3. The size of the simulated models are presented in table 8.2. Figure 8.1 shows schematic sections of the models. A window without any shading device was used as base case while an overhang with the size of 1000 mm was used for benchmark. The weather data of Halim Perdanakusuma International Airport were downloaded from OneBuilding website[103]. Total 8760 hours annual based simulations were executed. All 8 models were simulated facing 4 major orientations to measure two environmental benefits. First, useful daylight illuminance (UDI) simulation using standard range from 100 – 2000 lux at more than 50% for one year. UDI were simulated at 750 mm height, mimicking working table in offices in 100 mm × 100 mm grid. Second simulation was the annual cooling energy consumption. The results from cooling energy simulation were monetized to calculate the economic benefit. Four-stars air-conditioning unit was used to show that even using the best AC unit according to the government of Indonesia regulation, L-shaped mini-louvers still show significant effects in reducing cooling energy consumption.

Table 8. 2. Detailed size of shading device types.

Source: photographed by the author.

Model name	Shading type	Louvers' size	Opening size
Base case	No shading	-	-
Type A	L-shaped mini louvers	15 mm	15 mm
Type B	L-shaped mini louvers	15 mm	30 mm
Type C	L-shaped mini louvers	15 mm	45 mm
Type D	L-shaped mini louvers	30 mm	30 mm
Type E	L-shaped mini louvers	30 mm	60 mm
Type F	L-shaped mini louvers	30 mm	90 mm
Type G	Overhang	1000 mm	-

[103] *Jakarta Halim Perdanakusuma International Airport weather data.* http://climate.onebuilding.org/WMO_Region_5_Southwest_Pacific/IDN_Indonesia/JW_Jawa/IDN_JW_Jakarta-Halim.Perdanakusuma.Intl.AP.967470_TMYx.zip Accessed January 1, 2021

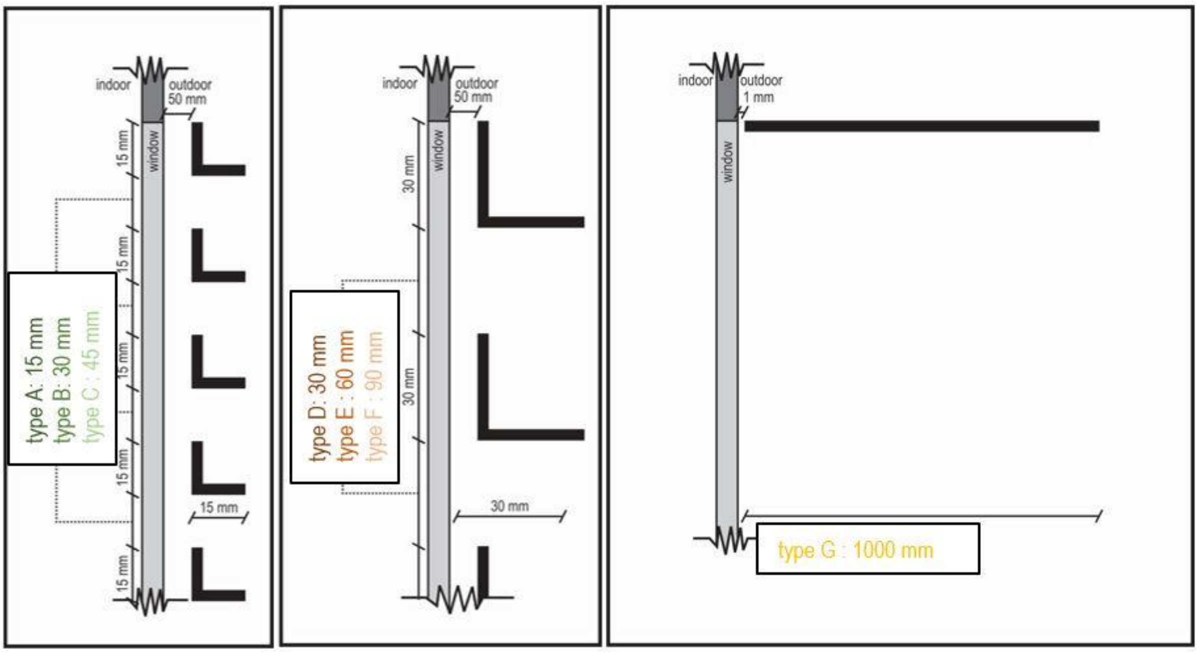


Figure 8. 1. Schematic section of simulated shading models.

Image source: photographed by the author.

8. 2. Environmental benefits of L-shaped mini-louvers in office

The first simulation showed the UDI results of all the models in two output: numerical and graphic data. Numerical results of UDI are shown in table 8.3.

Table 8. 3. Simulation results of UDI.

Source: photographed by the author.

Object name	North	South	East	West	Average
Base case	74.33	79.67	80.22	68.33	75.64
Type A	96.78	95.33	95.33	97.44	96.22
Type B	98.67	98.56	98.33	96.44	98.00
Type C	89.67	98.22	98.67	83.11	92.42
Type D	96.78	95.78	94.78	97.67	96.25
Type E	98.55	98.78	98.33	97.33	98.25
Type F	90.22	98.78	98.78	83.22	92.75
Type G	85.44	88	89	81.33	85.94

The use of shading device improve UDI in comparison with the base case. Common overhang with the size of 1000 mm could boost UDI around 11 points in comparison with the base case in the north orientation. In the south, east, and west, overhang improved around 8, 9, and 13 points of UDI respectively. The base case only provided 74.33 points of UDI in the north, 79.67 points in the south, 80.22 points in the east, and 68.33 points in the west.

However, all L-shaped mini-louvers showed significant improvements of UDI. The best L-shaped mini-louvers could improve 24.34 points of UDI in the north, 19.11 points in the south, 18.56 points in the east, and 29.34 points in the west in comparison with the base case. The improvements were also significant even in comparison with more common overhang, ranging from 9.78 points of UDI in the east to 16.34 points in the west. In average of all orientation, all simulated L-shaped mini-louvers provided more than 90 points of UDI. Type F, the worst L-shaped mini-louvers still provided 92.75 UDI, higher than that of overhang type G which could only reach 85.94. These UDI were significantly higher, more than 10 points of UDI in comparison with the base case, which only achieved 75.64 of UDI.

Modifying the size to opening ratio affected the improvements of UDI. Changing the size to opening ratio from 1:1 to 1:2 improved UDI in the north, south, and east orientations ranging from 1.77 points to 3.55 points, depends on the size of the louvers and the orientation. More opening allowed more light to enter the interior so the UDI was higher. However, in the west, the change of ratio from 1:1 to 1:2 reduced the UDI by 1 points in 15 mm × 15 mm and 0.34 in 30 mm × 30 mm mini-louvers. More light in the west was not beneficial since it made the room too bright, above 2000 lux. Changing the size to opening ratio from 1:2 to 1:3 showed more varied results of UDI in different orientation and mini-louvers’ size. In the north and west façade, it significantly reduced the UDI from 8.33 points to 14.11 points. There was no difference of UDI using type F and G in the north and only less than 0.5 points differences of UDI using type C and B. Less than 0.5 points difference of UDI also happened in the east, whether using 15 mm × 15 mm or 30 mm × 30 mm L-shaped mini-louvers. Figure 8.1 to 8.4 showed the distribution of the UDI at 750 mm height in 100 mm × 100 mm grid for 4 simulated orientations.

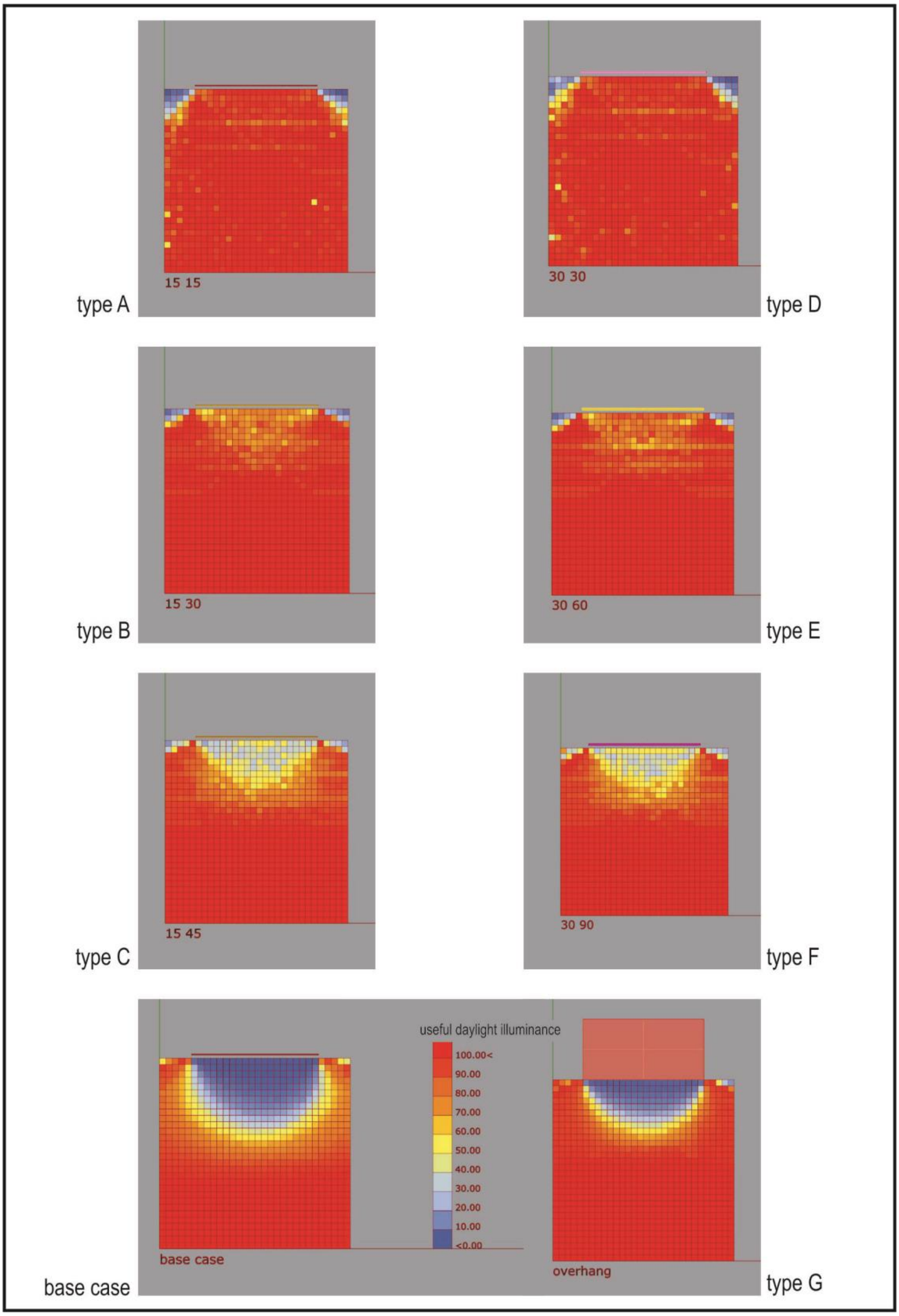


Figure 8. 2. Plan view of UDI distribution for the north orientation.

Source: photographed by the author.

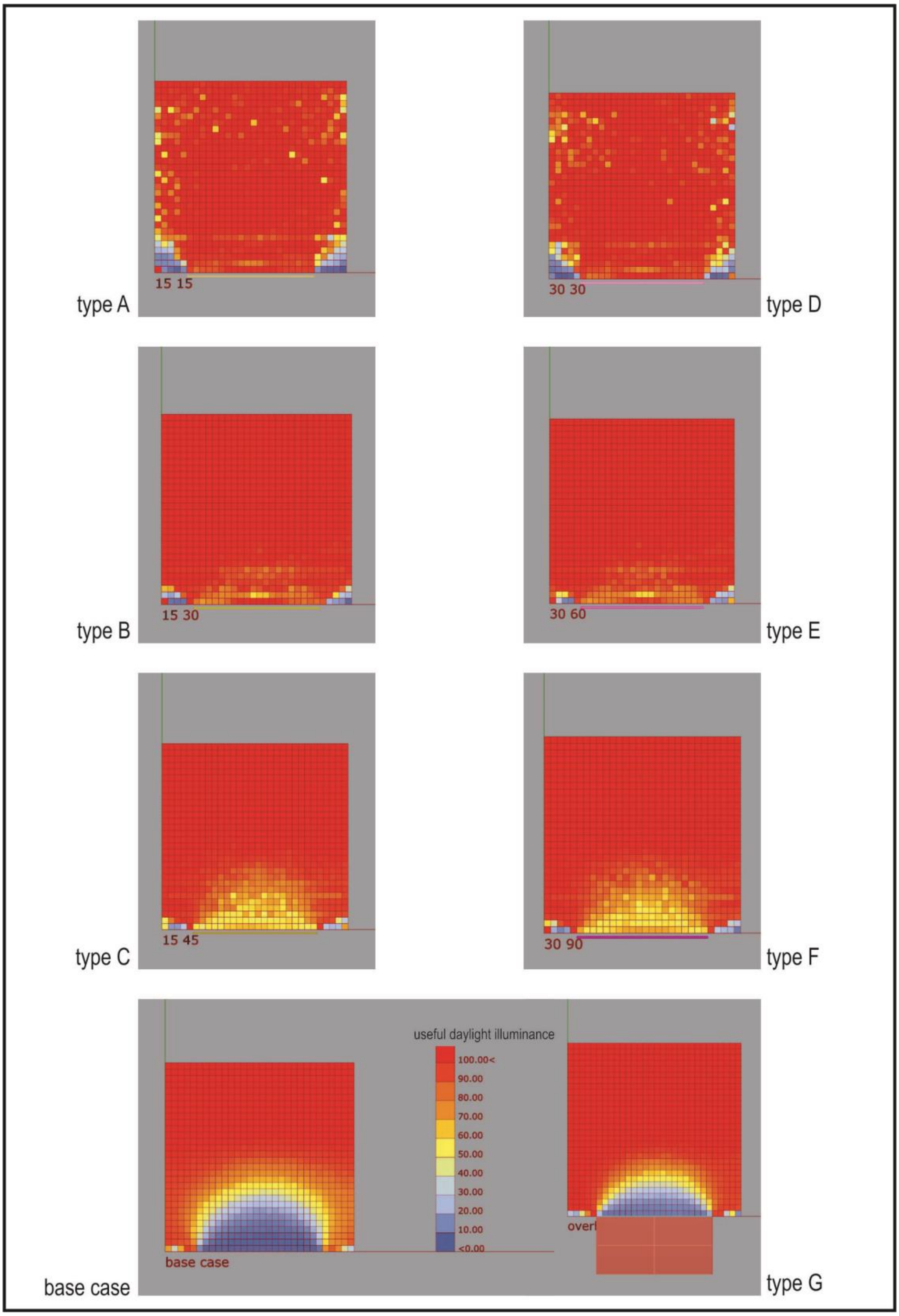


Figure 8. 3. Plan view of UDI distribution for the south orientation.

Source: photographed by the author.

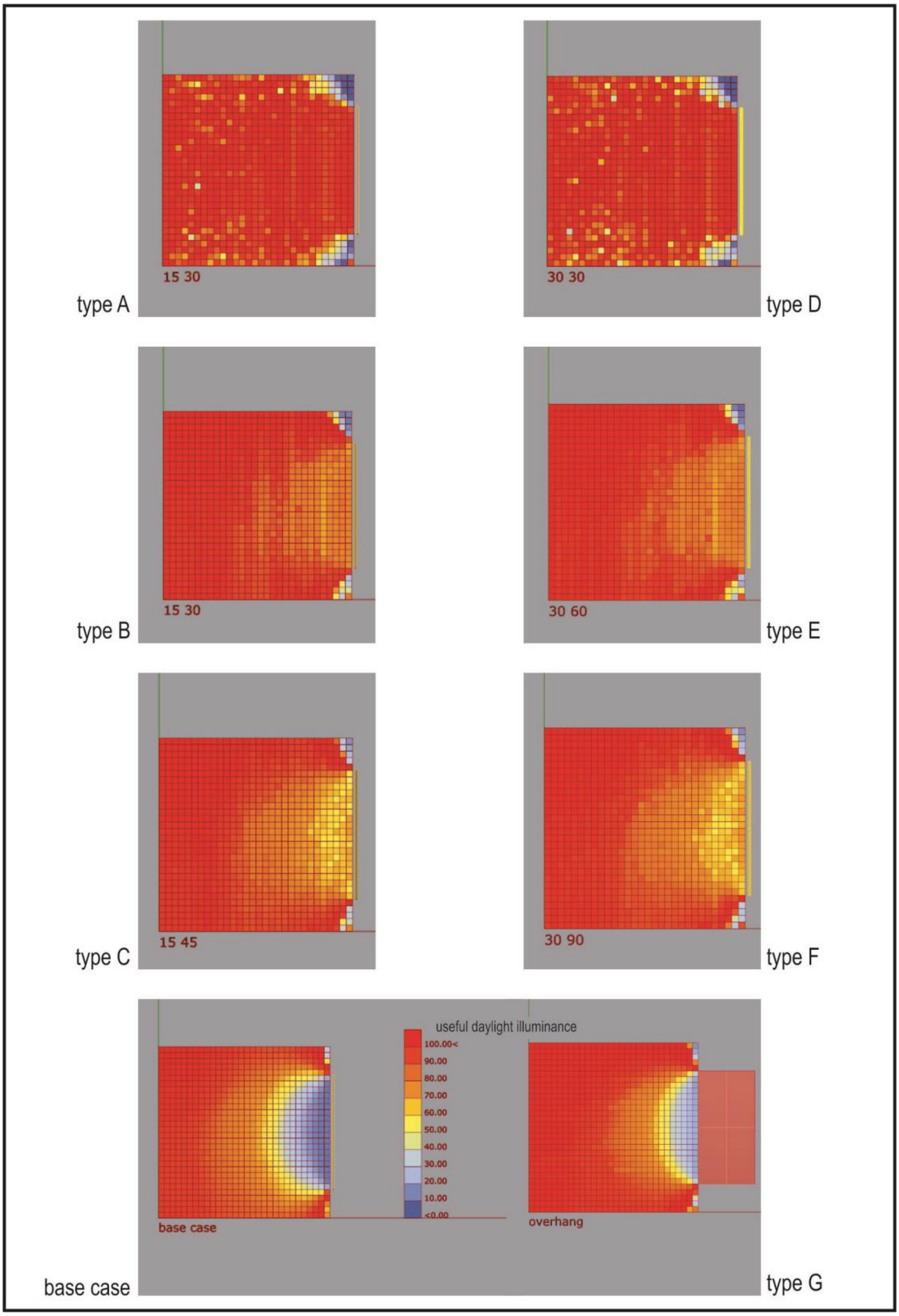


Figure 8. 4. Plan view of UDI distribution for the east orientation.

Source: photographed by the author.

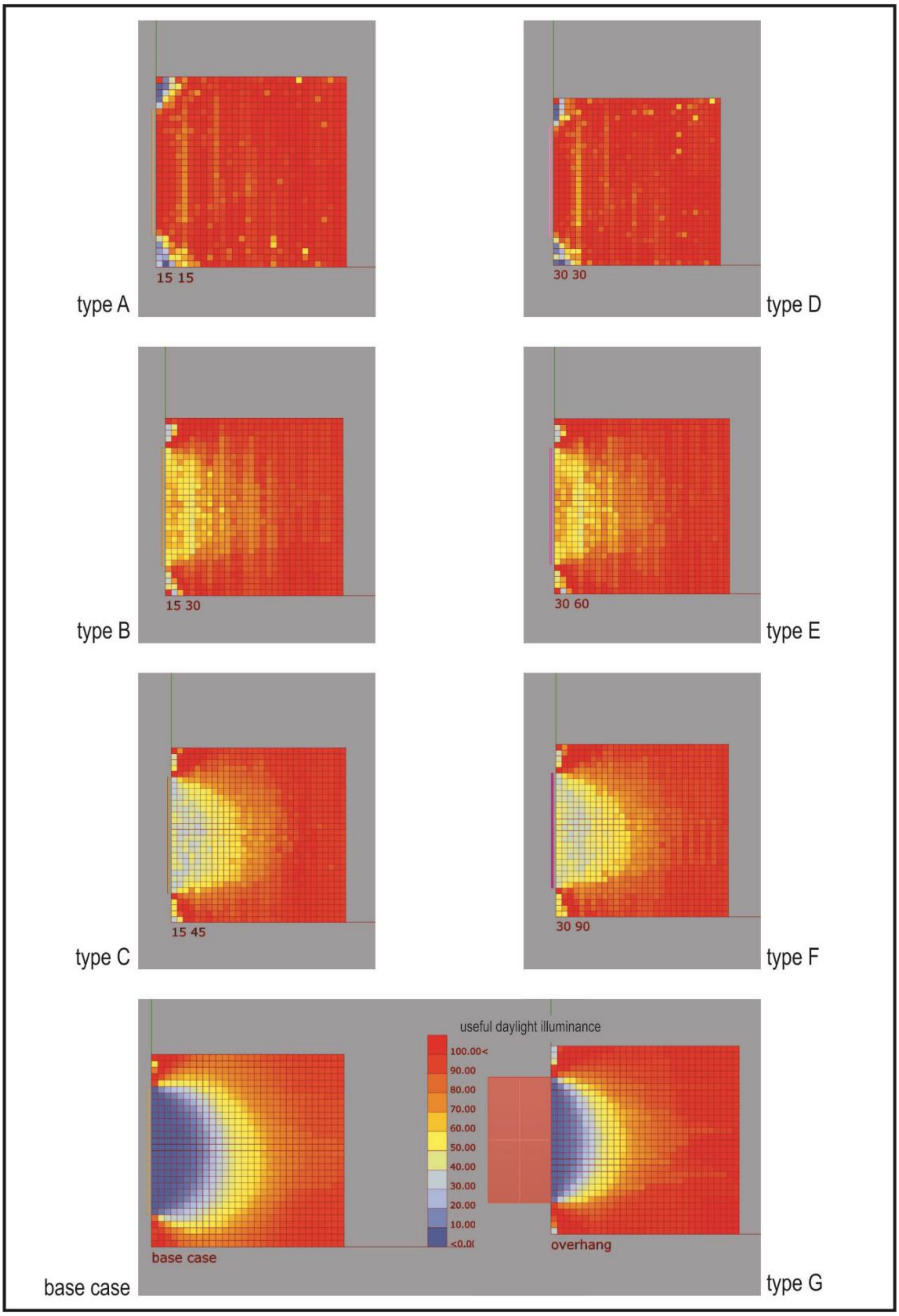


Figure 8. 5. Plan view of UDI distribution for the west orientation.

Source: photographed by the author.

Regarding UDI, the best shading was type B in the north orientation. Type E and F were the best in the south since they achieve the same UDI. Type F was also the best shading for east façade while type D was the best in west façade (Figure 8.5). However, L-shaped mini-louvers achieved more than 90 of UDI in average all orientations. Only small amount of energy was saved from lighting in comparison with the energy for cooling. Artificial lighting required much lower energy consumption than cooling did. Next simulation showed the performance of shading devices in reducing cooling energy in office in Jakarta, Indonesia.

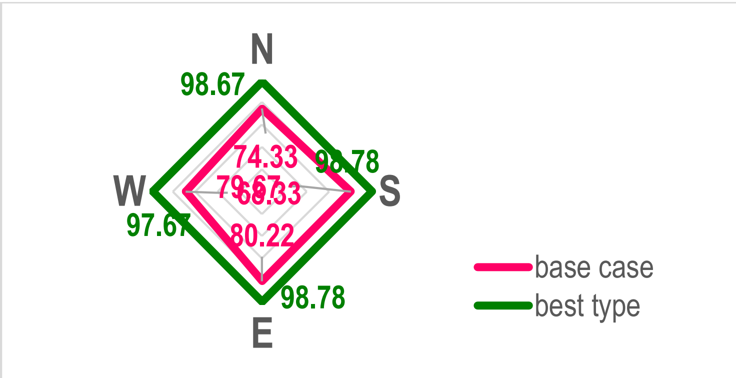


Figure 8. 6. UDI by the best type of shading and base case in four orientations.

Source: photographed by the author.

Similar with residential, the use of L-shaped mini-louvers in office significantly reduced annual cooling energy consumption. More reduction of cooling energy consumption could be achieved by lowering size to opening ratio that provide more cover to the window. Figure 8.6 shows the total annual cooling energy consumption in the simulated models.

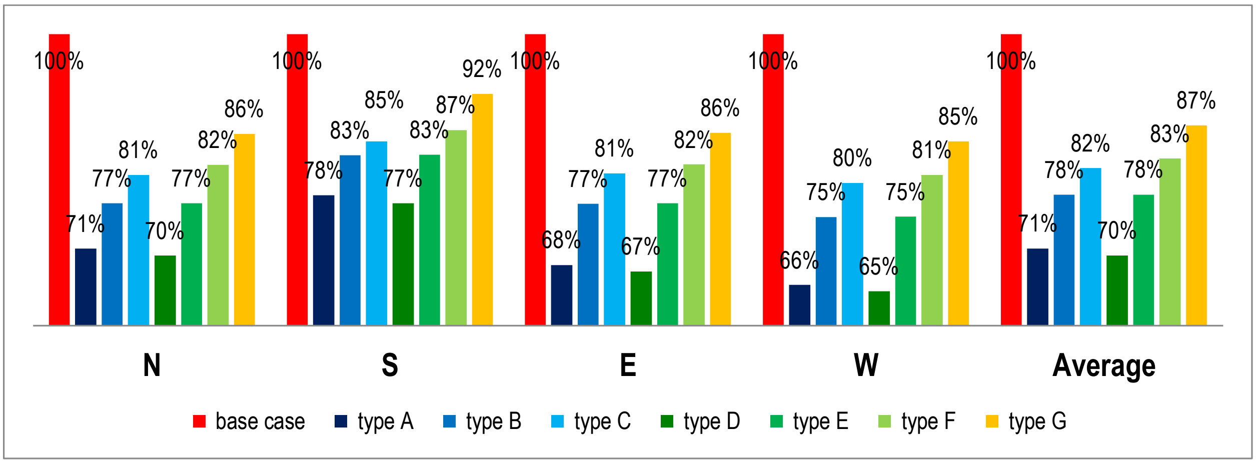


Figure 8. 7. Annual cooling energy consumption of all simulated models.

Source: photographed by the author.

Shading devices reduced cooling energy consumption from around 7% to 34%. All shading devices performed best in the west façade which suffered the highest total solar radiation. Note that the L-shaped mini-louvers delivered better performance than overhang. The worst performance of type F in the south could reduce around 13%, still better around 5 percentage points above type G. There was consistently around 4 percentage point gap of performance of cooling energy reduction between type F and G in all other three tested orientations.

Reducing the size to opening ratio affected in the increasing of cooling energy consumption regardless mini-louvers' size. Modifying the size to opening ratio among mini-louvers from 1:1 to 1:2 increased cooling energy consumption, ranging from the lowest, 5 percentage point in the south to the highest, around 10 percentage points in the west. In average there was 7 percentage point gap between 1:1 and 1:2 ratio of cooling energy consumption reduction. Similarly, changing the size to opening ratio from 1:2 to 1:3 also increased cooling energy consumption, even though they were not as high as the increase from 1:1 to 1:2 changes. The differences were ranging from 2 percentage point, the lowest in the south to 5 percentage points, the highest in the west. In average, 1:1 size to opening ratio delivered best performance at cutting around 29% of annual cooling energy, followed by 1:2 and 1:3 which reduced around 21% and 16% respectively, while type G could only cut around 13%.

Type D was the best among other simulated shading devices by reducing 1,282.08 kWh of annual cooling energy consumption in average of all orientation. In the west facade, which received highest total solar radiation, type D saved 1,598.78 kWh of annual cooling energy. Type A which used same size to opening ratio of 1:1 like the one that was used in type D performed slightly worse by reducing 1,242.64 kWh of annual cooling energy consumption in average of all orientation. Note that type D used 30 mm × 30 mm mini-louvers while type A was 15 mm × 15 mm. In the west, type A cut 1,598.78 kWh of annual cooling energy. Type F, the worst L-shaped mini-louvers, could reduce 189.13 kWh of annual cooling energy in average of all orientation in comparison with type G. In the west, there was still 209.36 kWh of cooling energy consumption gap between type F and type G. This showed that L-shaped mini-louvers performed better than overhang. The annual cooling energy saving for all shading devices are presented in table 8.4.

Table 8. 4. Annual electricity saving by using four-star air conditioning (kWh).

Source: photographed by the author.

Object name	North	South	East	West	Average
Type A	398.29	266.65	452.19	510.79	406.98
Type B	313.90	200.31	332.13	372.12	304.62
Type C	260.85	177.63	272.52	302.70	253.42
Type D	411.34	279.82	464.81	523.62	419.90
Type E	314.22	199.52	331.00	371.65	304.10
Type F	242.33	158.62	255.43	286.26	235.66
Type G	185.03	98.74	193.41	217.69	173.72

The annual cooling energy saving were converted to electricity consumption by using mechanical air conditioning unit. Rather than used all four types of air-conditioning in the chapter six, only four-star air conditioning was used in this chapter to show that even when using the best mechanical air conditioning, L-shaped mini-louvers could still be economically feasible. Four-star air conditioning in Indonesia had an Energy Efficiency Ratio or EER of 10.41 according to the government regulation. Calculating the electric consumption and electricity price showed the amount of saved money from cooling energy. The electric price was IDR 1428.67 or around USD 0.1 per kWh. Table 8.5 shows the annual electricity payment by using four-star air conditioning and simulated shading devices.

Table 8. 5. Annual electricity payment saving by using four-star air conditioning (USD).

Source: photographed by the author.

Object name	North	South	East	West	Average
Type A	39.83	26.67	45.22	51.08	40.70
Type B	31.39	20.03	33.21	37.21	30.46
Type C	26.08	17.76	27.25	30.27	25.34
Type D	41.13	27.98	46.48	52.36	41.99
Type E	31.42	19.95	33.10	37.16	30.41
Type F	24.23	15.86	25.54	28.63	23.57
Type G	18.50	9.87	19.34	21.77	17.37

Type D was the best among other shadings by saving USD 41.99 in average of all orientations, followed by type A by saving USD 40.70. Type F was the worst L-shaped mini-louvers by only save USD 23.57. However, it was still better than overhang type G which could only save USD 17.37. Electricity saving were ranging from USD 28.63 to 52.36 in the west by using L-shaped mini-louvers. Overhang type G could only save USD 21.77 in the west. The next step was considering economic benefit from the annual electricity saving and application cost.

8. 3. Economic benefit of L-shaped mini-louvers in office

The construction detail for shading device was the same and described in chapter 6. The price of galvanized screw for attaching L-shaped mini-louvers was USD 0.005 per piece. The price of 0.8 mm thick L-shaped aluminum profiles with the size of 15 mm × 15 mm and 30 mm × 30 mm were USD 0.33 and 0.75 per meter length respectively. The calculation method of reinforced concrete for building construction by the government of Indonesia was used as the basis of overhang's price. Structural support for overhang was not included in the construction cost. Figure 8.7 shows the application cost of all simulated shading devices.

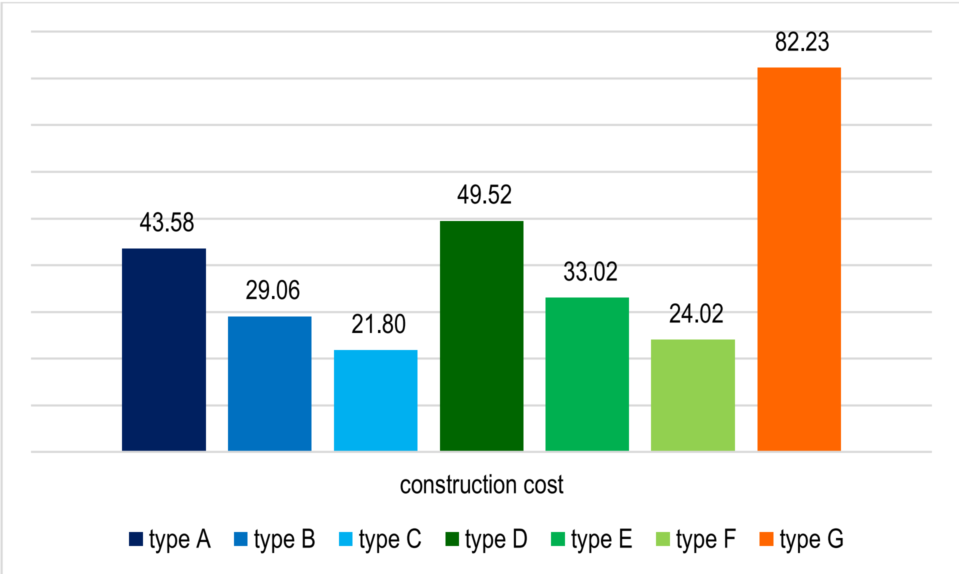


Figure 8. 8. Application cost of simulated shading devices.

Source: photographed by the author.

The most expensive L-shaped mini-louvers, type D was still USD 32.72 cheaper than type G's price. The price of L-shaped mini-louvers were lower than overhang while their performance of saving cooling energy are higher. These data were used for calculating the simple payback period. Simple payback period of shadings were the results of comparison between application cost of the shading devices with electricity saving. Simple payback period for all shading devices are shown in 8.8.

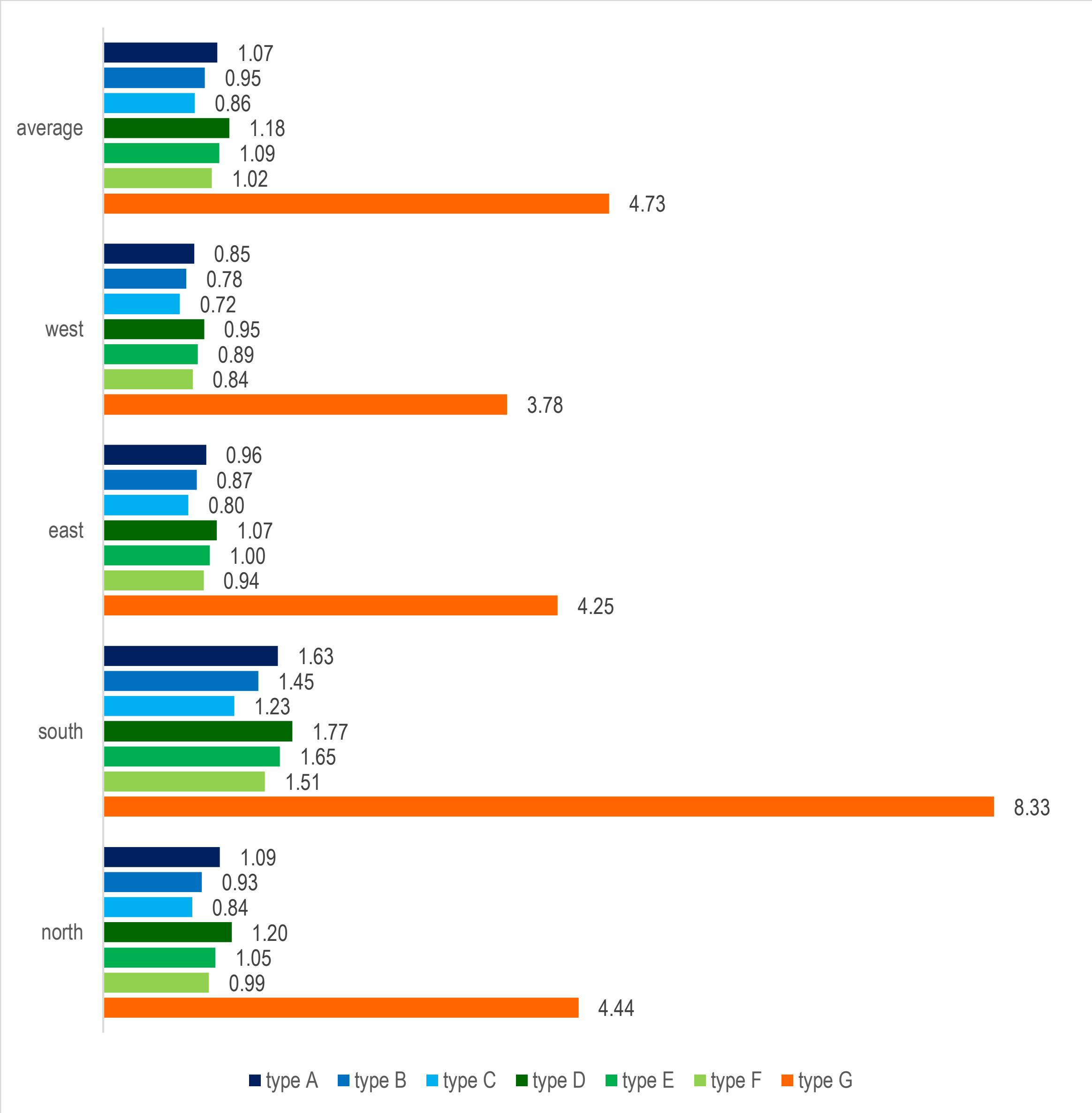


Figure 8. 9. Simple payback period (years).

Source: photographed by the author.

Regarding simple payback period, type C was the best among other shading by requiring only 0.86 years in average of all orientations. All L-shaped mini-louvers needed only around one year, significantly faster than type G which needs 4.73 years. While type C was the best by 0.72 years of simple payback period, all L-shaped mini-louvers needed less than one year of simple payback period. Type G needed 3.78 years to get simple payback period in the west. Even in the south, the orientation that got the least total solar radiation, placing L-shaped mini-louvers was still feasible. All L-shaped mini-louvers required less than 2 years of simple payback period, with type C being the best by 1.23 years. Type D, the worst among other L-shaped mini-louvers, still had a simple payback period of 1.77 years, significantly shorter than that of type G at 8.33 years.

8. 4. Chapter conclusion

L-shaped mini-louvers was not only environmentally but also economically beneficial, not only for residential but also for office. The analysis of this chapter showed several results of placing shading devices in the office. First, L-shaped mini-louvers could improve indoor environmental condition by increasing UDI. Without altering the window, L-shaped mini-louvers could provide more than 90 of UDI, ranging from type F to type D which delivers 92.75 to 97.67 of UDI respectively in average of all orientation. Their UDI were far higher above base case (75.64) and overhang type G (85.94). Second, L-shaped mini-louvers positively impacted the environment by cooling energy consumption reduction. Annual cooling energy consumption could be reduced from around 29% by using type D to 16% by using type F. These results were significantly higher than the cooling energy saved by type G by around 4 percentage points. The annual cooling energy saving by shading devices also affected the electricity payment. Annual electricity payment could be saved at USD 23.57 by using type F to USD 41.99 using type D. The use of L-shaped mini-louvers was economically feasible. A simple payback period of around one year could be achieved by using all type of L-shaped mini-louvers in average of all orientations. It was significantly faster than using overhang by more than 3 years.

Chapter 9 – Final conclusions

Shadow in Architecture has many potential, from materializing the philosophical perspectives to providing environmental benefits. In some area, shadows are accepted and play a role in the culture, including in Architecture. Sustainability, one of the issues in architecture, is related closely with energy consumption. This research focuses on dealing with steeply growing cooling energy in most area in the world, especially in the warm and hot area by utilizing shadows.

The purpose of this study was examining the environmental performance of the L-shaped mini-louvers by optimizing daylight condition and reducing the cooling energy consumption, and economic performance by analyzing the L-shaped mini-louvers simple payback period in the chosen location: Jakarta, Indonesia. There were several findings according to the researches which are presented from chapter one to chapter eight.

Several findings were related to the environmental issues from the reduction of the solar radiation which leads to the cooling energy consumption reduction to daylight optimization. Placing L-shaped mini-louvers could cut annual total solar radiation in window, ranging from 13% to be more than 80% in average of 8 orientations. L-shaped mini-louvers could significantly reduce the annual cooling energy consumption for residential, ranging from 4% to 16% in average of all orientations, depend on the types and the placement in the window. However, placing L-shaped mini-louvers at the window frame, leaving 50 mm gap between the sun shading and the window lead to the highest cooling energy saving, even they were using the same design. The best L-shaped mini-louvers could reduce from 11% to 20%, depends on the orientations or around 16% in average of all orientation. In an open-office setting, L-shaped mini louvers cut annual cooling energy consumption from 12% to 34%, depends on the types and orientations or around 29% in average of all orientations. It meant that 4,808.62 mJ/ h of annual cooling energy can be saved for residential and 5,751 mJ/ h for office. An experiment in Kitakyushu, Japan during the late summer of 2019 showed that 15 mm L-shaped mini-louvers with 15 mm openings could reduce average indoor and peak temperature by around 12% and 33%. The condition during the experiment had similarities with the environmental condition in Jakarta in terms of temperature and humidity. In a 3000 mm × 3000 mm box building with windows in all four sides of the walls, a 15 mm L-shaped mini-louvers with 15 mm openings could boost the useful daylight illuminance (UDI) to be 70 in 1500 mm × 1500 mm and 100% in 1000 mm × 1000 mm size window. Even using more openings, 15 mm L-shaped mini-louvers with 30 mm opening could still achieve UDI of 98.7 in 1000 mm × 1000 mm windows. Using only one window with the size of 2000 mm × 2000 mm, UDI above 90 could still be achieved despite using 15 mm or 30 mm L-shaped mini-louvers with gap to size ratio from 1:1 to 1:3.

Other findings were related to the economic aspect. The cheapest L-shaped mini-louvers application cost was relatively low, around USD 21.45. This L-shaped mini-louvers using the size of 15 mm L-shaped aluminum louvers with 45 mm openings among them. The best L-shaped mini-louvers could save the annual electric cost, ranging from USD 25.3 to 31.15, in average of all orientations, depend on the rating of the air-conditioning unit that was used for cooling the simulated room. This saving lead to the simple payback period of 0.87 years or around 10 months and two weeks, even using the best four-star mechanical air-conditioning unit for residential by placing 1:3 size to opening ratio of L-shaped mini-louvers with the size of 15 mm. For office, a simple payback period of 0.72 years could be achieved utilizing the same L-shaped mini-louvers.

In conclusion, this research showed that L-shaped mini-louvers could be beneficially in terms of environmental and economic in residential and office. The placement of L-shaped mini-louvers contributed positively in the cooling energy reduction and adding economic value during the operational period.

References

Ando, T. (1990). *Light, shadow and form: the Koshino House*. In *VIA 11: architecture and shadow*. (pp 52 - 61) Graduate School of Fine Arts, University of Pennsylvania.

Badan Pusat Statistik. (2015). *Kelembaban udara rata-rata Jakarta menurut bulan, 2009 – 2013*. https://jakarta.bps.go.id/statictable/2015/04/20/56/kelembaban-udara-rata-rata-jakarta-menurut-bulan-2009-2013.html

Badan Pusat Statistik. (2018). *Registrasi penduduk menurut jenis kelamin, rasio jenis kelamin, dan kabupaten/ kota administrasi di provinsi Jakarta, 2018*. https://jakarta.bps.go.id/dynamictable/2020/03/04/414/3-1-4-registrasi-penduduk-menurut-jenis-kelamin-rasio-jenis-kelamin-dan-kabupaten-kota-administrasi-di-provinsi-dki-jakarta-2018.html

Badan Pusat Statistik. (2019). *Statistik Indonesia 2019*. https://www.bps.go.id/publication/2019/07/04/daac1ba18cae1e90706ee58a/statistik-indonesia-2019.html

Badan Pusat Statistik. (2015). *Suhu udara Jakarta menurut bulan, 2009 – 2013*. https://jakarta.bps.go.id/statictable/2015/04/20/57/suhu-udara-jakarta-menurut-bulan-2009-2013.html

Casati, R. (2004). *Shadows: unlocking their secrets, from Plato to our time*. Vintage Books.

Charles Eley Associates. (1992). *Passive solar design strategies: guidelines for home building*. Passive solar industries council NREL.

Davison, J. (1998a). *The house as a ritually ordered space*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp.18 - 19). Archipelago Press.

Davison, J. (1998b). *Traditional architecture*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp. 8 - 9). Archipelago Press.

Design Hotels. (n.d.). Townhall hotel apartments. https://www.designhotels.com/hotels/united-kingdom/london/townhall-hotel-apartments/architecture

Dinas Komunikasi, Informatika, dan Statistik Pemprov DKI Jakarta. (2020). *Mengenal Jakarta: tentang Jakarta*. https://jakarta.go.id/

Domenig, G. (1998). *Structures without nails*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp.13). Archipelago Press.

Eicker, U. (2009). *Low energy cooling for sustainable buildings*. John Wiley and sons ltd.

Evola, G., Gullo, B., Marletta L., (2017). The role of shading devices to improve thermal and visual comfort in existing glazed buildings. *Energy Procedia 134.* 346 - 355

Gore, A. (2017). *An inconvenient sequel: truth to power*. Rodale

Gore, A. (2006). *An inconvenient truth: the planetary emergency of global warming and what we can do about it.* Rodale

Hachise Co.Ltd. (n.d.). *Koshi lattice.* http://www.hachise.com/kyomachiya/features/exteriorKoshi.html

Happle, G., Wilhelm, E. , Fonseca, J.A., Schlueter, A.(2017) Determining air-conditioning usage patterns in Singapore from distributed, portable sensors. Energy Procedia 122. P 313-318

Hariyadi, A., Fukuda, H., and Ma Q., S. (2017). The effectiveness of the parametric 'Sudare' blind as external shading for energy efficiency and visibility quality in Jakarta. *Architectural Design and Management* 13 (5). 384-403

Herzog & de Meuron Basel Ltd. (n.d.). *De Young museum*. https://www.herzogdemeuron.com/index/projects/complete-works/151-175/173-de-young-museum.html

Hillier, K., Woodfin, K. (1990). *Suite: luna de miel.* In *VIA 11: architecture and shadow*. (pp. 124 - 133). Graduate School of Fine Arts, University of Pennsylvania.

Invidiata, A., Ghisi, E. (2016). Life-cycle energy and cost analyses of window shading used to improve the thermal performance of houses. *Journal of cleaner production 133*. 1371 - 1383

Japan Architecture. (n.d.). *Koshi latticework*. https://www.japan-architecture.org/latticework/

Japanese Architecture and Art Net Users System. (2001). Koushi. http://www.aisf.or.jp/~jaanus/deta/k/koushi2.htm

John Ruskin (n.d) *The seven lamps of architecture.* Createspace independent publishing platform 2018.

Kats, G.,H. (2003). *Green building costs and financial benefits*. Massachusetts technology collaborative.

Kurokawa, K. (1990). *Shadows, symbiosis, and a culture of wood.* In *VIA 11: architecture and shadow*. (pp. 26 - 31) Graduate School of Fine Arts, University of Pennsylvania.

Kwok, A., Grondzik, W. (2011) *Green studio handbook 2nd edition*. Routledge.

Lai, K., Wang, W., Giles, H. (2017). Solar shading performance of window with constant and dynamic shading function in different climate zones. *Solar Energy 147.* 113 – 125

Laugier, M.A. (1755) *An essay on architecture*. T. Osbourne and Shipton.

The Ministry of Energy and Mineral Resources, The Government of Republic Indonesia (2017) The minimum energy performance standards and energy saving label for air-conditioning http://jdih.esdm.go.id/peraturan/Permen%20ESDM%20Nomor%2057%20Tahun%202017.pdf. Accessed October 19, 2019

Miksic, J. (1998). *Sources of early Indonesian stone architecture*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp.54 - 55). Archipelago Press

Office of Energy Efficiency & Renewable Energy. (n.d.) *Weatherization assistance program*. www.energy.gov/eere/wap/weatherization-assistance-program

Palmero-Marrero, A., I., Oliveira, A., C. (2010). Effect of louver shading devices on building energy requirements. *Applied Energy 87*. 2040-2049

Reed, A. (1990). *Signifying shadows.* In *VIA 11: architecture and shadow.* (pp. 12 - 26). Graduate School of Fine Arts, University of Pennsylvania.

Robson, D. G. (2009) *Anjalendran: architect of Sri Lanka.* Tuttle Publishing

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., Wang M. (2014) Anthropogenic heating of the urban environment due to air conditioning. Journal of Geophysical Research: Atmospheres/ Vol 119 Issue 10. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2013JD021225

Saliya, Y. (1998). *Architecture of the 17th to 19th centuries*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp. 105). Archipelago Press

Sasaki, T., Aso, Y., Evans, J. (2020). *The Japanese house: the basic elements of traditional Japanese residential architecture.* https://manabi-japan.jp/en/art-design/20200401_20235/

Smithson, A., Smithson, P., (1990). *Working with shadow: Damascus gate, Jerusalem.* In *VIA 11: architecture and shadow*. (pp. 76 - 83) Graduate School of Fine Arts, University of Pennsylvania.

Somalyo, Y. (1998). *Attempted synthesis: Dutch architects in the indies*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp. 122 - 123). Archipelago Press

Sukada, B.A. (1998). *The Emergence of a new indies style*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp. 120 - 121). Archipelago Press

Sukada, B.A. (1998). *Regionalism and identity in contemporary architecture*. In Gunawan Tjahjono (ed), *Indonesian heritage volume 6: architecture* (pp. 132 - 133). Archipelago Press

Suiko, M. (2009). *Kyoto center for community collaboration: Machiya revival in Kyoto*. Shoin publication.

Sunarto. (1989). *Wayang kulit purwa gaya Yogyakarta*. Balai Pustaka.

Suryandono, A.,R., Wihardyanto, D. (2018 March 12 - 14) *Bayangan sebagai bagian dari identitas arsitektur nusantara*. Prosiding seminar arsitektur nusantara IPLBI 2018. (pp. B069 – B073). https://seminar.iplbi.or.id/bayangan-sebagai-bagian-dari-identitas-arsitektur-nusantara/

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2018 July 26 - 27) *Batik pattern panel performance of solar radiation reduction.* The 4th International Conference of Indonesian Architecture and Planning.

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2021) *Economic Assessment of L-shaped Minilouvers for Reducing Cooling Energy and Improving Daylight Condition in Offices: A Simulation Study in Jakarta*. Sustainability Volume 13 Issue 7. 4021

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2020) *Environmental and Economic Benefits of Japanese Koshi-inspired Mini-louvres in Residential Buildings in Jakarta, Indonesia*. Journal of Façade Design and Engineering Vol 8 Number 2. 001-018

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2018 March 12 - 13) *L-shaped mini-louvers performance of solar radiation reduction in glass windows*. The 12th South East Asia Technical University Consortium. OS02-10

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2020 October 15 - 16) *L-shaped mini louvers performance for reducing indoor temperature.* The 5th International Conference in Indonesian Architecture and Planning.

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2018 June 18 - 22) *Mini louvers performance of building cooling load energy reduction.* Grand renewable energy 2018. P-At-16

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2018 December 11 - 13) *Performance of L-shaped mini-louvers in tropical cities in cooling energy reduction: case study of Mumbai, Mexico City, and Lagos*. 3rd Green Urbanism

Suryandono, A.,R., Hariyadi, A., Fukuda, H. (2019 November 8 - 10) *Daylight performance of L-shaped mini louvers in office buildings*. The 16th Asia Institute of Urban Environment international conference. pp. 25 - 30

Sutedjo, Suwondo Bismo. (1996). *Konsepsi Arsitektur Indonesia* in Eddy Supriyatna Marizar (ed) *Upaya Membangun Citra Arsitektur, Interior, dan Seni Rupa Indonesia* (pp.45-62). Jakarta: Djambatan.

Stacey, M. & Bayliss, C. (2015). Aluminium and durability: reviewed by inspection and testing. *Materials Today: Proceedings 2*. 5088-5905. https://doi.org/10.1016/j.matpr.2015.10.100

Stang, A., Hawthorne, C. (2005). *Green House: new directions in sustainable architecture*. Princeton Architectural Press.

Szokolay, S.V. (2004). *Introduction to architectural acience: the basis of sustainable design*. Architectural Press.

Tanizaki, J. (1977). *In Praise of Shadows*. Leete's Island Books.

The International Energy Agency. (2017a). *Energy Efficiency 2017: Laporan Khusus Efisiensi Energi di Indonesia.* https://www.iea.org/publications/freepublications/publication/EnergyEfficicency2017IndonesiaFocusBahasaIndonesia.pdf

The International Energy Agency. (2018). *Market Report Series Energy Efficiency 2018: Analysis and Outlook to 2040.* https://doi.org/10.1787/9789264024304-en

The International Energy Agency (2015). *Indonesia 2015: Energy policies beyond IEA countries.* https://webstore.iea.org/energy-policies-beyond-iea-countries-indonesia-2015

The International Energy Agency (2019). *Southeast Asia energy outlook 2019*. https://webstore.iea.org/southeast-asia-energy-outlook-2019

The International Energy Agency (2017). *Space Cooling Energy Insight Brief.* https://www.iea.org/publications/freepublications/publication/SpaceCoolingEnergyEfficiencyInsightsBrief.pdf

The International Energy Agency (2013) *Technology roadmap: energy efficient building envelopes*. https://www.iea.org/reports/technology-roadmap-energy-efficient-building-envelopes

The International Energy Agency (2018). *The Future of cooling.* https://www.iea.org/reports/the-future-of-cooling

The Onebuilding (n.d.). *Jakarta Halim Perdanakusuma International Airport.* http://climate.onebuilding.org/WMO_Region_5_Southwest_Pacific/IDN_Indonesia/JW_Jawa/IDN_JW_Jakarta-Halim.Perdanakusuma.Intl.AP.967470_TMYx.zip

The Onebuilding (n.d.). *Jakarta Indonesia TMY3.* http://climate.onebuilding.org/WMO_Region_5_Southwest_Pacific/IDN_Indonesia/JW_Jawa/IDN_JW_Jakarta.Obs.967450_TMYx.zip

The United Nations. (2018). *68% of the world population projected to live in urban areas by 2050, says UN.* https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

The World Bank. (2019). *Indonesia overview.* https://www.worldbank.org/en/country/indonesia/overview#1

The World Bank. (2019). *Urban population: Indonesia.* https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=ID&view=chart

UNESCO. (2009). *Indonesian Batik*. https://ich.unesco.org/en/RL/indonesian-batik-00170

UNESCO. (2008). *Wayang puppet theatre*. https://ich.unesco.org/en/RL/wayang-puppet-theatre-00063

US Green Building Council. (1996). *Sustainable building technical manual.* Public technology, Inc.

Waterson, R. (1998a). *Common Features: Raised Pile Foundations*. In Gunawan Tjahjono (ed), *Indonesian Heritage Volume 6: Architecture* (pp.12 - 13). Archipelago Press.

Waterson, R. (1998b). *Common Features: Extended Roof Ridges*. In Gunawan Tjahjono (ed), *Indonesian Heritage Volume 6: Architecture* (pp.14 - 15). Archipelago Press.

Wonder Metals. (2012). *The many benefits of aluminum louvers*. http://wondermetals.com/benefits-of-aluminum-louvers/

Woolley, T., Kimmins, S., Harrison, P., Harrison, R. (1997). *The Green Building Handbook vol 1*. Spon Press

Zielinski, S. (2014). *Why the city is (usually) hotter than the countryside.* https://www.smithsonianmag.com/science-nature/city-hotter-countryside-urban-heat-island-science-180951985/

Zomorodian, Z., S., Tahsildoost, M. (2019). Assessing the effectiveness of dynamic metrics in predicting daylight availability and visual comfort in classrooms. *Renewable Energy 134*. 669-680

[photograph of *Irori*] (n.d.) https://www.trekearth.com/gallery/Asia/Japan/Chubu/Gifu/Shirakawago/photo1574768.htm

[photograph of *Koshi*] (n.d.) https://www.japan-architecture.org/latticework/

[photograph of The exterior elements of a traditional Japanese House] (n.d.)https://manabi-japan.jp/en/art-design/20200401_20235/