Environmental and Economic Benefits of Japanese *Koshi*-Inspired Mini-Louvres in Residential Buildings in Jakarta, Indonesia

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Abstract
The increase in energy consumption for cooling is a global problem, especially in hot regions, including Indonesia. It happens because of wealth, population growth, climate, building designs, and electronic appliances. Focusing on Jakarta, Indonesia's capital city, louvres in 18 different dimensions and overhangs in 2 different dimensions are simulated using Rhinoceros and Grasshopper with EnergyPlus to show their performance in reducing cooling energy. The design of the louvres is inspired by Japanese koshi. L-shaped aluminium profiles are used as mini-louvres. These mini-louvres can be placed on the outside surface of a glass window or can be attached to the window frame. The cost saving in electricity is obtained from the resulting reduction in cooling energy consumption, which utilises air-conditioning units that follow government regulations. The construction cost includes the price of aluminium profiles and attachment elements. The results show that the horizontal koshi mini-louvres are environmentally beneficial as they reduce the annual cooling energy by around 7-18% on average for all orientations. Moreover, all the proposed horizontal koshi types attached to the window frame are economically beneficial since they can achieve a simple payback period of less than a year when used in a westerly orientation.

Keywords
Cooling energy, simulation, shading, louvres, Japanese koshi

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1 INTRODUCTION

1.1 COOLING ENERGY CONSUMPTION

Energy used for cooling comprised only a small part of global energy consumption in the past. The International Energy Agency (2017c) noted that there are five factors that drive the growth of cooling energy. Wealth is the first factor. People want to achieve comfort by using air conditioning and can afford to do so. Population growth is the second factor. The population increases in countries with warmer temperatures, and people tend to migrate from colder to warmer areas. The third factor is climate. Global temperatures continue to rise, leading to higher average temperatures. The frequency of extremely high temperatures is increasing due to the urban heat island phenomenon and climate change. The fourth factor is building designs. Fewer new buildings utilise heavy materials such as brick, and there is a shift towards lighter materials with lower thermal mass. According to the International Energy Agency (IEA), the last factor leading to higher cooling energy consumption is electronic appliances. There has been an increase in the use of electronic tools, devices, and office machinery inside buildings, which produce heat as a by-product. The IEA (2018) noted that overall energy use worldwide, between 2000 and 2017, in buildings and appliances has increased by 21%, reaching 120 EJ. The IEA (2018) specifically noted that space cooling accounts for a large portion of energy demand, and residential buildings utilised three times more energy than is consumed by end-uses in non-residential buildings, in 2017. The expansion of usage of air-conditioning units increased the energy used for space cooling, causing it to almost double since 2000. According to the IEA (2018), cooling energy consumption is the fastest growing energy end-use in buildings; it increased from 3.6 EJ in 2000 to 7 EJ in 2017 globally. Global increase in energy use in buildings has been largely driven by six countries with major emerging economies: Brazil, China, India, Indonesia, Mexico, and South Africa, which account for one-third of global primary energy demand, equivalent to the energy demand of all Europe and the USA (the IEA, 2018). In Southeast Asia, energy use has increased by 60% in the past 15 years (the IEA, 2017b). The IEA (2019) reported that fewer than 10% of households in Indonesia used air conditioning, in comparison with around 80% of households in wealthier countries with less challenging climatic conditions. However, the IEA (2019) also noted that the use of air conditioning become higher because of the rise of income and urbanisation. Higher incomes make air conditioning units more affordable. Since temperatures tend to be higher in urban areas, the demand for cooling is intensified by urbanisation.

Indonesia is the country with the largest economy in Southeast Asia, and the tenth largest in the world in terms of purchasing power parity (the World Bank, 2019). Indonesia has shown an average economic growth rate consistently above 5% since the year 2010, accompanied by an increase gross national income increase per capita from USD $823 in the year 2000 to USD $3932 according to the World Bank (2019). An IEA special report on Indonesia`s energy efficiency (2017a) showed that Indonesia was accountable for 36% of the primary energy used in Southeast Asia, the largest energy consumption of any country in that region. Indonesia’s GDP growth doubled from 2000 to 2015 and electricity consumption increased by 150% (the IEA, 2017a). According to the World Bank (2020), Indonesia has a population of 267 million, of whom 55% live in cities, whereas 48% of the population lived in cities ten years previously. However, based the IEA data (2020), people in Indonesia consume only 900 kWh electricity per capita per year, just a quarter of the world average annual electricity consumption (3200 kWh) in 2017. 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, with a 41% share (Fig. 1).

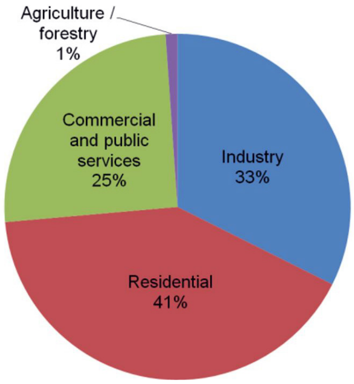

FIG. 1 Total final energy consumption in Indonesia by sector in 2017. Data from the International Energy Agency [2020]

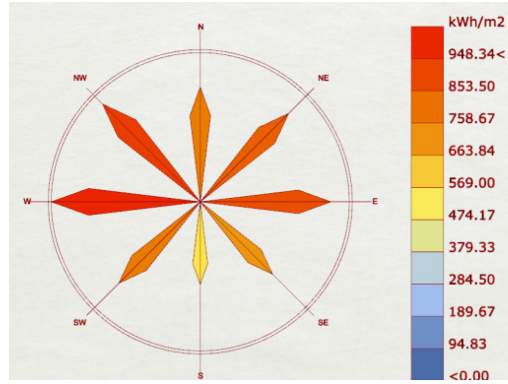

FIG. 2 Total solar radiation in a year in Jakarta. Data were extracted from the weather file for simulation, and the visualisation was created using Lady Bug. Image by Author

The IEA (2018) highlighted that indoor cooling represents a big portion of building energy demand and requires policy consideration to make energy consumption more efficient. The IEA (2018) noted that in hot climates, low-cost technologies, such as reflective roofs and walls, exterior shades and low-e window coatings and film can cut cooling energy consumption. The IEA (2018) suggested that national and local governments should 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) stated that energy-inefficient building materials, such as single, clear, glazed windows should be avoided, and existing materials should be replaced or upgraded with window attachments. Exterior shading is one of the possible window attachments that can be used in both new construction and older building retrofits. The IEA (2018) noted that available products, costs, climate, and energy prices at the local level have to be examined to meet the balance between envelopes and the equipment needed to apply the designs. They also highlighted that exterior shading is cost effective and is therefore becoming more prominent.

This research is done to provide one possible solution to reduce cooling energy consumption. Existing solutions are widely offered in other sectors, such as the office and commercial sectors, using advanced technology. This paper shows one alternative solution that is suitable for, but not limited to, end-users in the residential sector. The solution is a sun shading device utilising low technology that can be applied without requiring specific skills during the constructional and operational phase. The simulated computer model, followed by calculation based on the survey, is chosen for its ability to predict the effect of the application in a real situation. The objective of this paper is to determine the performance of Japanese *koshi*-inspired mini-louvres in terms of environmental and economic benefits. The results of this research can be used by end-users in the residential sector to contribute to cooling energy reduction, for design applications to other building sectors, and for expansion of further research on mini-louvres sun shading.

1.2 PREVIOUS RESEARCH

There has already been some previous research undertaken to find solutions to reduce the cooling energy using shading devices, especially louvres, while considering the economic feasibility. Ghosh and Neogi (2018) simulated south-oriented windows in Kolkata, India with horizontal overhangs, vertical fins, horizontal overhangs with triangular fins, four-sided fins, and a new shading design which consists of four partially overlapping fins below an overhang deflected downward at 65.77°.

A window with no shading devices was used for base case comparison. They concluded that the proposed new shading design performed best, by reducing annual cooling energy by around 4% in comparison with the base case, even though the size is smaller than horizontal overhang which cuts only around 2% of the annual cooling energy. Samaan, Farag, and Khalil (2018) simulated the cooling load of three drawing halls of the Faculty of Engineering, Mansoura University, using DesignBuilder with EnergyPlus. Using the same 0.5 metre overhang, side fin, and louvres, they found that the louvres performed best, reducing annual cooling energy by 10% in comparison with base case. The overhang cut around 7%, while the side fin reduced the annual cooling energy by around 2%. Darwish and Gomaa (2017) measured four retrofitting strategies of three existing buildings in Egypt by applying external wall insulation, changing windows glazing type, increasing airtightness, and adding 0.5 metre metal louvres, using computer simulation in Design Builder, incorporating EnergyPlus. The results of the study showed that the use of metal louvres was the most efficient of the strategies, reducing the energy consumption of the three buildings by up to 23%, on average.

Several studies explore the economical aspect of sun shading strategies. Huang, Niu, and Chung (2012) analysed a retrofitting strategy for existing school buildings in Hong Kong using overhangs to reduce cooling energy demand. The overhang consisted of a 38 mm fibreglass grating platform with aluminium cladding and supporting structure. They showed that the annual electricity saving was 55,700 kWh or 52,400 HKD. However, the lowest bidding price for the retrofitting project was 29,784,000 HKD, thus showing that the overhang system required a long payback period and the investment cost could not be recovered within the project life cycle. Cho, Yoo, and Kim (2014) conducted simulations of 48 exterior shading types using DOE-2.1 E to measure the cooling energy savings. Horizontal and vertical panels can reduce cooling energy demand by 19.7% and 17.3% respectively. The economic feasibility study showed a simple payback period of around 3.4 years for the horizontal overhang and 8.7 years for the vertical overhang. The authors noted that sun shading is expected to replace the use of expensive high-performance glass.

Research focusing on louvres has been undertaken to provide solutions for cooling energy reduction. Hariyadi, Fukuda, and Ma (2017) tested *"sudare"*, a traditional Japanese external blind, using Rhinoceros and Grasshopper as the modelling software and EnergyPlus as the simulation engine. They found that *sudare* with a diameter of 10.01 mm and 5 mm spacers reduced Overall Thermal Transfer Value (OTTV) by 5% and thermal energy use for cooling by 6% in comparison with the base line. Hernández, Cejudo López, Peña Suárez, González Muriano, and Rueda (2017) proposed horizontal and angled vertical louvres as an environmentally friendly solution to reduce cooling energy use for the south and east façades of buildings with a high window to wall ratio. They simulated the buildings in Málaga, Spain using TRNSYS for calculating cooling energy. They showed that the horizontal louvres reduce around 60% of cooling energy for south façades of buildings, while 60° facing north and south angled vertical louvres cut 68% and 64% respectively. Ralegaonkar and Gupta (2010) studied the criteria for passive solar strategies to develop recommendations for climate-responsive architecture. They found that one of the most significant design parameters to alter the building cooling and heating energy for passive-solar architecture is sun shading. They suggested small-scale modelling as one of the easiest and best methods to examine the effectiveness of specific systems. Simulations using computer software are the most suitable choice to predict real conditions. They mentioned that external static sun shading is the most efficient of all types of sun shading reviewed in their study. The efficiency of sun shading needs to be examined according to the location, following the sun paths in the particular geographic location.

1.3 CLIMATE CONDITION IN JAKARTA, INDONESIA

The problem of cooling energy consumption becomes greater in hot climate areas, especially in countries with increasing economic growth, high populations, and urbanisation, such as Indonesia. Jakarta, Indonesia's capital city, is chosen for this study. According to downloaded weather data used for the simulation in this study, the monthly average temperature ranges from a minimum of 26.87°C in January to a maximum of 29.1°C in October (OneBuilding, 2020a). The annual average temperature is 28.23°C.

Total diffuse and direct solar radiation for one year can be seen in Fig. 2, utilising the same weather data for simulation. The average annual total solar radiation per hour in 8 orientations is 762.14 kWh/m^2. The west direction suffers the highest annual total solar radiation of 948.34 kWh/m^2. The south direction gets the lowest annual total solar radiation of 525.02 kWh/m^2. The sun shading performance of reducing excessive solar gain is simulated to calculate the total annual cooling energy.

1.4 JAPANESE *KOSHI* LATTICEWORK

Koshi (格子)is traditional Japanese latticework which is commonly used for fences, doors, or parts of windows. The use of *koshi* as a window attachment was established after the Onin civil war in Kyoto (Tsushi-nikai, 2020). Traditional Japanese houses in Kyo-Machiya, which are protected by law as one of the most culturally significant and valuable types of architecture in Kyoto, usually have *koshi*. In another area in Uchiko, Ehime, all of the preserved houses and buildings in the village have *koshi*. One of *koshi's* functions is to allow sunlight into the buildings while also reducing the excessive heat from the sun. *Koshi* can be placed close to the outdoor surface of window (Fig. 3), or on the window frame. Traditional *koshi* are made of wood. However, some modern *koshi* use newer materials such as aluminium or PVC. The pattern is also varied, by placing the *koshi* members not only vertically but also horizontally (Fig. 4).

FIG. 3 *Koshi* placement close to the exterior window surface in a house, in Uchiko, Ehime

FIG. 4 Horizontal *koshi* in a commercial building in Kitakyushu, Fukuoka

Based on the weather data in Kyoto (OneBuilding, 2020b) and Matsuyama – a city close to Uchiko (OneBuilding, 2020c), the average solar radiation per hour in Kyoto and Uchiko from May to August is 234.08 Wh/m^2 and 257.82 Wh/m^2 respectively. There is the possibility to use Japanese *koshi* as a shading device in Jakarta, which has a slightly higher average solar radiation per hour value. The inspiration for the proposed design in this paper comes from *koshi* that utilises a small profile of sun shading device, which is attached close to the window's exterior surface. The proposed designs use aluminium with small L-shaped profiles, which can be placed close to the window, mimicking the idea of Japanese *koshi.*

1.5 L-SHAPED ALUMINIUM PROFILES

An L-shaped aluminium profile is a building material with a wide variety of uses. It can be used for structural or decoration purposes, such as bracing, framing, moulding, and edge protection. However, this research explores another opportunity to use it as a shading device. There are multiple reasons for proposing the use of these components as mini-louvres for shading devices. First, the L-shaped aluminium profile is widely available. It can be found in nearby building material stores. The second reason is its price, which is relatively low in Jakarta. A grey coloured L-shaped aluminium profile with dimension of 12 mm × 12 mm and a thickness of 0.08 mm costs USD $0.29 per metre. Third, many sizes are available, from as small as 8 mm to 30 mm. L-shaped aluminium profiles with different leg lengths are also available. The first three reasons are based on a market survey carried out in early 2019 in Jakarta, Indonesia. In general, the proposed raw materials for horizontal *koshi* can be easily found in any city in Indonesia. The fourth reason for its use is its high level of durability. Aluminium can be placed outdoors, last for years, and requires little maintenance. Stacey and Bayliss (2015) carried out a case study of 12 buildings using non-destructive tests to review the durability of aluminum used for windows. They noted that aluminium has a high durability and suggested a revision of standard life span of aluminium windows from 40 to 80 years. This was based on their finding that after 26 years, PVDF-coated aluminium looked very similar to its condition when first installed in 1988. Aluminium with polyester powder coating was still in use after 41 years. The fifth reason is the weight of the aluminium. Skejic, Boko, and Neno (2015) stated that aluminium is a low self-weight material that reduces the building load, reduces physical labour needs, and saves energy during construction. They noted that aluminium has a high corrosion resistance that lessens the maintenance costs and shows good performance in high corrosion environments. Sixth, aluminium is recyclable, making it environmentally friendly (Wondermetals, 2019). It can be recycled without losing its physical properties.

2 RESEARCH METHODOLOGY

2.1 RESEARCH WORKFLOW

Cooling energy is the main problem in this study. Based on the recent cooling energy consumption, and previous research, sun shading is chosen as one of the possible solutions. Suitable materials for the proposed types are determined based on a survey performed in the selected locations. Computer software is used to simulate the annual cooling energy according to the selected setting to resemble real world conditions, such as the building function, materials, and location-based weather data. The proposed designs are built parametrically in the Rhinoceros 3D with Grasshopper plug-in and simulated using Ladybug and Honeybee with the EnergyPlus engine (Ladybug tools, 2019). The results are used to calculate the economic benefits of the energy savings, based on the electricity price in Jakarta, Indonesia. The air-conditioning unit used in this research follows the regulations from the Ministry of Energy and Mineral Resources number 57/ 2017 (JDIH Kementrian ESDM, 2017). The price of materials and sun shading construction are used to determine the cost. A comparison between electrical savings and construction costs is calculated to show the simple payback period. The whole process of study in this paper is presented in Fig. 5.

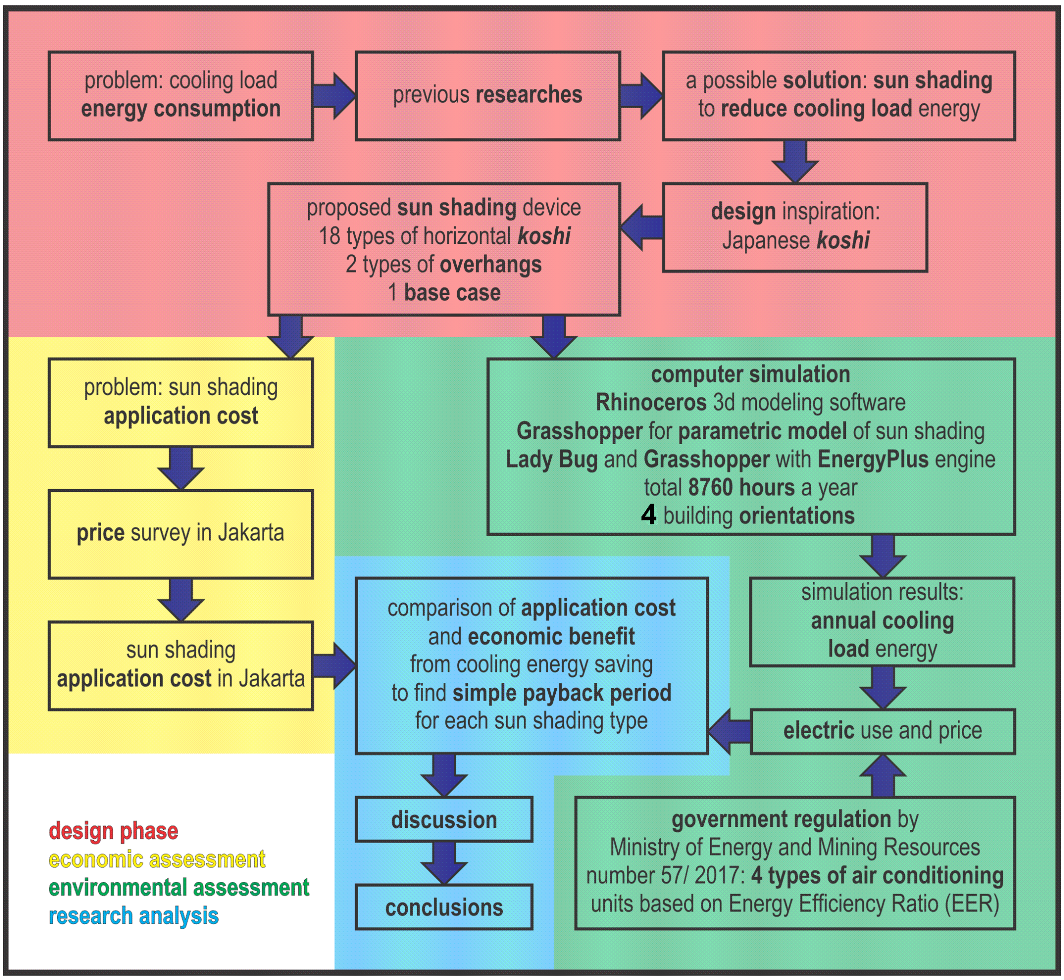

FIG. 5 Research workflow

2.2 SIMULATION SETTINGS

The simulations are all done in the Rhinoceros 3D software. Grasshopper is the main plugin for hosting LadyBug and HoneyBee. EnergyPlus is the simulation engine behind HoneyBee. First, a 3000 mm × 3000 mm box is created to represent a simple room, completed with a 2000 mm × 2000 mm window in the middle of one side of the wall. The roof construction consists of 100 mm thick lightweight concrete, ceiling air void, and acoustic tiles. Brick walls, with a total thickness of 150 mm, are constructed from 120 mm bricks with a 15 mm stucco finish to both the interior and exterior surfaces of the bricks. The floor construction consists 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 1. The window is made from a single pane of clear 3 mm glass. The glass properties are shown in Table 2. These are common building materials in Indonesia. The EnergyPlus shading object property for both diffuse solar and visible reflectance of the unglazed part of shading surface is 0.2.

TABLE 1 Properties of the opaque materials

MATERIAL TYPE	ROUGHNESS	THICKNESS (MM)	CONDUCTIVITY	DENSITY	SPECIFIC HEAT	THERMAL	SOLAR
			(W/m-K)	(kg/m^3)	(J/kg-K)	absorptance	absorptance
Lightweight concrete	Medium rough	101,6	0,53	1.280,00	840	0,9	0,5
Acoustic tile	Medium smooth	19,1	0,06	368	590	0,9	0,3
Stucco	Smooth	15	0,69	1.858,00	836,99	0,9	0,92
Brick	Medium rough	120	0,89	1.920,00	790	0,9	0,7
Insulation board	Medium rough	50,8	0,03	43	1.210,00	0,9	0,7
Heavyweight concrete	Medium rough	203,2	1,95	2.240,00	900	0,9	0,7

TABLE 2 Window properties of single clear 3mm glass panel

OPTICAL DATA TYPE	SPECTRAAL 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 is a simple box-shaped building with no shading device attached to the single glass pane window (Fig. 6). Eighteen models of horizontal *koshi* are made parametrically utilising the same script. The differences among horizontal *koshi* types are the size of the L-shaped aluminium mini-louvres, the gap between louvres, and their placement on the windows. Three sizes of L-shaped aluminium profiles: 12 mm × 12 mm, 15 mm × 15 mm, and 30 mm × 30 mm, are chosen to represent the different sizes of available materials. There are two possible options for attaching the horizontal *koshi* to the window. The first possibility is to directly attach the horizontal *koshi* to the exterior window surface using outdoor double-sided tape. A second possibility is to use screws to attach the horizontal *koshi* to the window frame. Both the outdoor double-sided tape and screws for attaching horizontal *koshi* are widely available. The performances of different shading types in reducing annual cooling energy are analysed in this study.

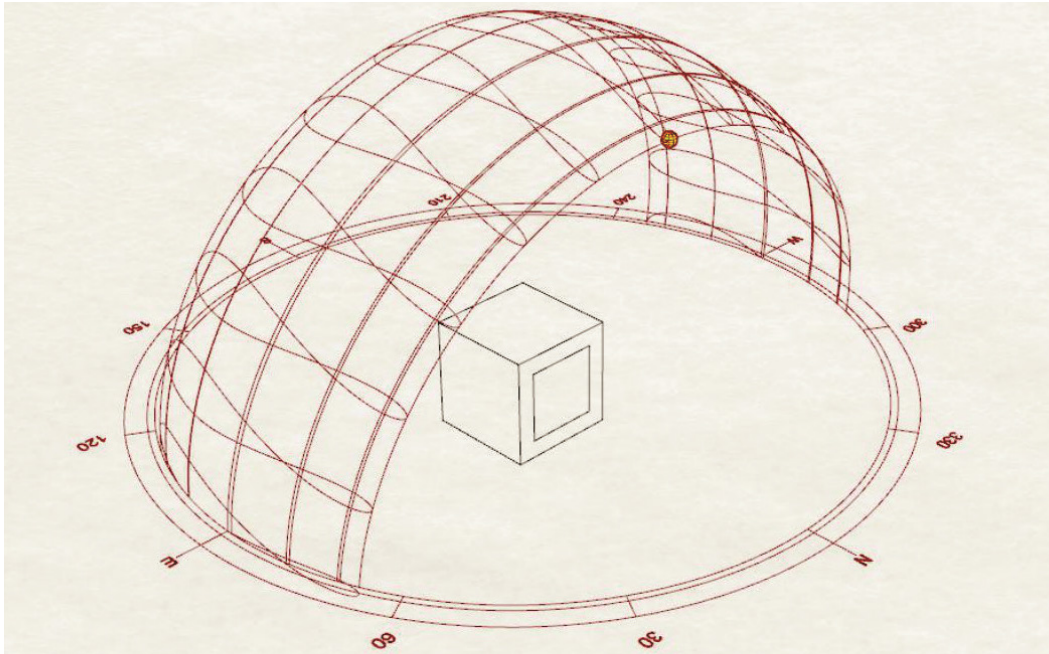

FIG. 6 Simulation setting. The picture shows the base case model without a shading device

Simulation model types A 1 to 9 are designed to mimic the condition of direct attachment by leaving only a millimetre gap between the horizontal *koshi* and the window's outer surface. Simulation model types B 1 to 9 are proposed to imitate the attachment of the horizontal *koshi* to the window frame with a 50 mm gap between the horizontal *koshi* and the window's exterior surface. Visualisation of horizontal *koshi* types A and B 1 to 9 can be seen in Fig. 7. There are three basic ratios between L-shaped mini-louvres and the gaps between them. The first is 1:1, meaning that the gaps are the same size as the L-shaped mini-louvres that form the horizontal *koshi*. The second ratio is 1:2, which means the gap size is twice the size of the L-shaped mini-louvres. The last ratio is 1:3, which gives a gap size three times larger than the size of the L-shaped mini louvres. An additional two horizontal overhang types, which are more common shading devices in the selected research location, are simulated for comparison with the performance of the horizontal *koshi*. These overhang models are types C1 and C2. Fig. 8 shows a schematic perspective view of the overhang type. Details of 21 buildings with detailed shading sizes and types for simulation are shown in Table 3.

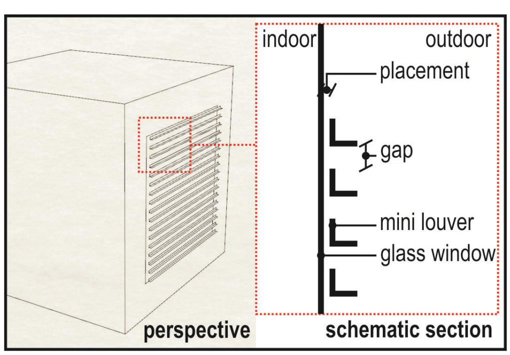

FIG. 7 Schematic of horizontal *koshi* mini-louvres design

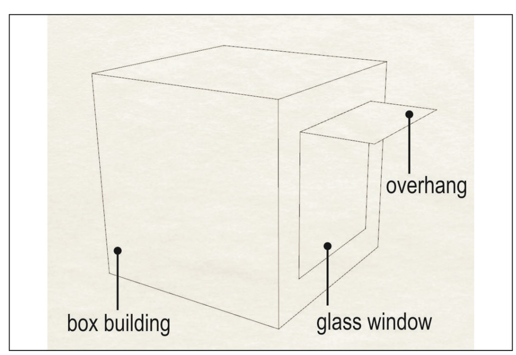

FIG. 8 Overhang type

TABLE 3 Simulated model types size parameters

MODEL NAME	SHADING TYPE	SIZE (MM)	GAP (MM)	PLACEMENT OUTSIDE WINDOW SURFACE (MM)
Base case	No shading	-	-	-
Type A1	Horizontal koshi mini-louvres	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	-	

TABLE 4 EnergyPlus settings for apartment zone program

APARTMENT	
Equipment load per area	3.875028 W/m^2
Infiltration load per area	0.000227 $m^3/s\text{-}m^2$ at 4Pa
Lighting density per area	11.840357 W/m^2
Number of people per area	0.028309 People/m^2
Ventilation per area	0
Ventilation per person	0
Honeybee zone schedule	default midrise apartment schedule
Ideal air load system	1
Heating set point	21.1°C
Cooling set point	23.9°C

The weather data for Jakarta, Indonesia are Typical Meteorological Year 3 (TMY3), downloaded directly using Ladybug from the OneBuilding website (2019). OneBuilding is a reputable website providing global weather data that are commonly used for simulation studies. The simulation scripts are made and executed in Grasshopper using Ladybug and Honeybee. There are various building programs in EnergyPlus, one of which is a midrise apartment with three schedules of rooms: apartment, office, and corridor. The target building type for the simulation is residential, so the building schedule for the apartment zone program is chosen to mimic a general residential room. The settings used for the midrise apartment zone programs are shown in Table 4. The equipment and infiltration load, lighting density, and the number of the people per area value are changed hourly according to the apartment program schedule in the simulation. The heating and cooling set point are constant through the year. However, this research focuses on cooling energy consumption since the temperature in Jakarta is high all year round.

3 RESULTS AND DISCUSSION

3.1 ANNUAL COOLING ENERGY SIMULATION RESULTS: ENVIRONMENTAL BENEFIT

All 21 buildings are tested in an hour-based simulation to obtain the cooling energy results for one year. There are 8760 hours of simulation per building in a year. Residential houses in Jakarta face a multitude of directions; however, in this research only 4 main orientations of the building are simulated. The results of simulations are defined as total cooling annual energy in Joules per hour, which then are converted to kilo British Thermal Units per hour. The unit conversion is necessary since the government of Indonesia uses the Energy Efficiency Ratio (EER) as standard for air-conditioning rating systems. The EER is used for showing the electricity consumption of selected air conditioning systems. The regulation on mandatory application of the star rating to air-conditioning systems was established in 2017 and also affects all air-conditioning devices in Indonesia, including those already in operation (JDIH Kementrian ESDM, 2017). These results are presented in Fig. 9.

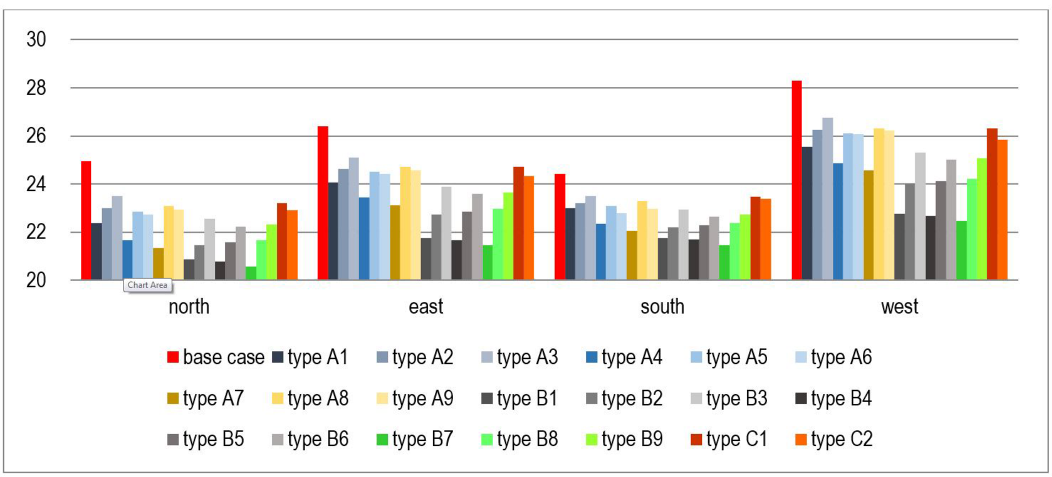

FIG. 9 Results of simulation of annual cooling energy (megaBtu/ h)

The base case shows the effect of the window on annual cooling energy for every orientation. The windows without sun shading on the west façade have an annual cooling energy of 28.29 mBtu/h, the highest among the orientations. In contrast, openings in the south require the minimum cooling energy of 24.43 mBtu/h, which amounts to 86% of the highest energy value. The difference between highest and lowest annual cooling energy is 3.86 mBtu/h.

The mini-louvres reduce the annual cooling energy, despite their small size. Denser mini-louvres give the lowest cooling energy in comparison to larger gaps between louvres, except for types A5 and A6, and types A8 and A9, which have louvre gap ratios of 1:2 to 1:3. On average, for all orientations, type A1 cuts the annual cooling energy by 2 percentage points compared to type A2. Type A2 cuts the annual cooling energy by 2 percentage points when compared to type A3. Type A4 cuts the annual cooling energy by 4 percentage points compared to type A5, while type A7 cuts it by 6 percentage points compared to type A8. However, changing mini-louvres' size to gap ratios to type A6 from type A5 and to type A9 from type A8 does not have a negative effect on the annual cooling energy. Rather than only considering direct sunlight, EnergyPlus also simulates reflective light and diffuse radiation (EnergyPlus Shading Calculations, 2019). A combination of a larger louvre size and a distance of only 1 mm from the window surface leads to a higher annual cooling energy, even though types A5 and A8 provide more shading than types A6 and A9, respectively. Significantly different results for annual cooling energy reduction occur even though types A1 to A9 have the same horizontal *koshi* design as types B1 to B9. On average, for all orientations, type A7, which is the best among the A types, consumes 88% of annual cooling energy compared to the base case, leaving a 5 percentage point difference in comparison with the amount consumed by type B7, 83%. Notably in the west façade, which requires the highest annual cooling energy, type A7 reduces consumption by around 13 percentage points in comparison to the base case but is inferior to type B7 which reduces it by around 21 percentage points. On average, for all orientations, types A1 to A9 reduce annual cooling energy by around 8 percentage points while types B1 to B9 reduce the annual cooling energy by 13 percentage points. There are two reasons for the higher annual cooling energy as a result of the sun shading being closer to the window's surface. First, closer sun shading makes the cooling energy higher because instead of only providing shading, the shading surface also reflects the direct sunlight onto the window's surface. The heat generated by the solar reflection has a negative impact on the cooling energy. The second reason is the heat radiation generated by the *koshi* mini-louvres themselves (EnergyPlus documentation, 2019). The small 1 mm distance between the horizontal *koshi* and the window allows the diffuse radiation to reach the window surface. . Placing the horizontal *koshi* mini-louvres further away from the surface, on the window frame, allowing a 50 mm distance from the window surface, reduces the annual cooling energy.

Increasing the gaps between mini-louvres in type B also increases the annual cooling energy. On average, for all orientations, increasing the louvre gap ratio from 1:1 to 1:2, from type B1 to B2, from type B4 to B5, and from type B7 to B8, increases the annual cooling energy by 3, 4, and 5 percentage points, respectively. On average, for all orientations, increasing the louvre gap ratio from 1:2 to 1:3, from type B2 to B3, from type B5 to B6, and from type B8 to B9, increases the annual cooling energy by 4, 3, and 2 percentage points, respectively. Type B7 shows the best performance among other sun shading devices by reducing the annual cooling energy by around 21 percentage points in the west, 19 in the east, 18 in the north, and 12 percentage points in the south orientation.

Common overhangs which are represented by types C1 and C2 show worse results than the proposed horizontal *koshi*, except for types A2 and A3, on average, for all orientation. Type C1 reduces the annual cooling energy by around 6 percentage points, while type C2 reduces it by around 7 percentage points. Type C1 reduces the annual cooling energy more than type A2 by around 1 percentage point and type A4, which is the worst sun shading device model in this study, by around 5 percentage points . Types C1 and A4 have a difference of 1.35 mBtu/ h. Types A2 and C2 cut the annual cooling energy by around 7 percentage points, but type C2 performs slightly better, by 0.15 mBtu/h. However, type C2 performs significantly worse than type B7, which can provide a reduction of around 17 percentage points , which is higher than the 7 percentage point reduction provided by type C2. This 10 percentage points, gap between types B7 and C2 equates to2.63 mBtu/h.

In summary, type B7 performs best among other sun shading types in this study of the annual cooling energy consumption. Type A4 is the best among all type A models, while type C2 is better than type C1. The results for each direction and average annual cooling energy saving of these models are presented in table 5.

TABLE 5 Annual cooling energy consumption of the best models (megaBtu/ h)

MODEL NAME	NORTH	EAST	SOUTH	WEST	AVERAGE
type A7	21,35	23,13	22,04	24,57	22,77
type B7	20,57	21,47	21,47	22,47	21,5
type C2	22,92	24,34	23,39	25,86	24,12

Based on the simulation results of annual cooling energy, the differences between the base case and all 20 types of sun shading are calculated to show the annual cooling energy saving. Since west-facing buildings in Jakarta have the highest annual cooling energy compared to other orientations, the energy savings are also highest for this façade. The annual cooling energy savings are used to calculate electricity consumption.

3.2 ELECTRICITY CONSUMPTION

There is a rating system for specific air-conditioning units based on the government regulation issued by the Ministry of Energy and Mineral Resources No. 57, 2017 (JDIH Kementrian ESDM, 2017) concerning the minimum energy performance standard. The air-conditioning unit is a single split wall mounted inverter and non-inverter type with a capacity of 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. One star, which is the lowest rating, is used for air-conditioning units which have an EER from 8.53 to less than 9.01. The highest rating, four stars, can only be obtained if the air-conditioning units have EER values equal to or more than 10.41. The simulation results from Fig. 9 are used for calculating the electricity consumption of four-star air-conditioning units. An EER 10.41 is used for the electricity consumption calculation to show that even using the best air-conditioning units, the proposed design of the mini-louvres has significant environmental and economic benefits. The electrical power consumption savings using the four-star air-conditioning unit are presented in Fig. 10.

For the west façade, which requires the highest electrical power to maintain the indoor conditions, type B7, which is the best model, can reduce the annual electricity consumption by 559.82 kWh. Type B8 reduces the annual electricity consumption by 391.28 kWh, while type B9 reduces it by 308.93 kWh, around 95% and 93% respectively in comparison with type B7. Type B7's horizontal *koshi* louvre size of 30 mm × 30 mm and gap ratio of 1:1 leads to greater savings than those given by type B4's 15 mm × 15 mm and B1's 12 mm ×12mm. Type B4 consumes 96% while type B1 consumes 95% of the annual electric in comparison with type B7's.The horizontal *koshi* louvre size and gap ratio of 1:2 of type B8 give the lowest saving of 367.62 kWh, while B5 saves 377.08 kWh and B2 saves 386.28 kWh of annual electricity consumption. Type B6's horizontal *koshi* louvre size and gap ratio of 1:3 shows the best reduction in annual electricity consumption, at 315.70 kWh, followed by type B9 with 308.93 kWh and type B3 with 285.99 kWh. This result shows that a mini-louvre size of 30 mm × 30 mm with a 1:1 gap works best in type B7, but adding larger gaps by changing the ratio does not lead to better results. For the 1:2 ratio, the mini-louvres size of 12 mm × 12 mm is better than the other sizes, while for the 1:3 ratio, the size of 15 mm × 15 mm performs slightly better. For example, in the west orientation, types B6 and B9 have a difference of 6.76 kWh of the annual electricity consumption saving.

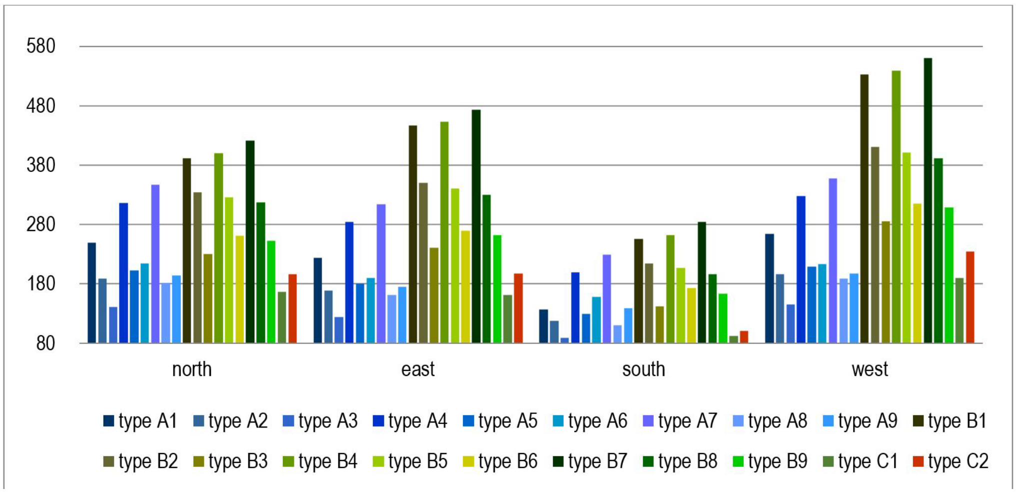

FIG. 10 Annual electricity consumption saving of four-stars air-conditioning unit (kWh)

3.3 COST OF PROPOSED HORIZONTAL *KOSHI* APPLICATION

The materials and construction price of the proposed sun shading are calculated to obtain the cost of the horizontal *koshi* application. A comparison between the energy savings and the application cost of the proposed sun shading can be shown to determine the economic benefits of each design by checking the simple payback period of each sun shading type. The L-shaped aluminium profiles are used for making horizontal *koshi*. The double-faced tape is used to directly attach the horizontal *koshi* to the outdoor glass window surface. A quarter of a metre of double-sided tape is used to attach each metre of L-shaped aluminium profile. Galvanized screws are used to attach the L-shaped aluminium profile forming the horizontal *koshi* to the window frame. Two screws are used per metre of L-shaped aluminium profile. For overhang sun shading, the material commonly used is reinforced concrete.

The price of the L-shaped aluminium profile with dimensions of 12 mm × 12mm, 15 mm × 15 mm, 30 mm × 30 mm are USD$ 0.29, $0.32, and $0.72 respectively. All three L-shaped aluminium profile sizes used in this study have the same thickness of 0.8 mm. The price of reinforced concrete for the overhang is USD$ 759.41/m^3. Outdoor double-sided tape costs USD$ 1.43/m while the galvanized screws cost USD$ 0.005 per piece. There is no special skill requirement to apply the proposed horizontal *koshi* so there is no labour cost for these types of sun shading. In this study, the price of the structural support for types C1 and C2 is excluded. The calculations of the total application costs of the proposed design types are presented in Fig. 11. The application cost of type C2 is USD$ 121.51, which is the most expensive type of sun shading of all the types proposed in this study. Type B6 is the cheapest, costing only USD$ 21.45. Even without considering the price of the structural support, the cost of applying the reinforced concrete overhang is higher than the cost of applying the horizontal *koshi*, except for type A1.

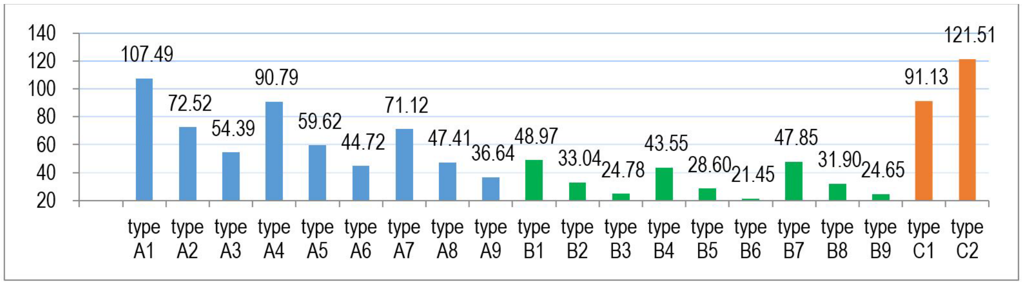

FIG. 11 Aun shading application cost (USD)

3.4 COMPARISON BETWEEN ELECTRICAL PRICE AND APPLICATION COST: ECONOMIC BENEFIT

The electricity price in Indonesia is Rp. 1,428.67/ kWh, or around $0.1 USD/ kWh, based on the March 2017 price, which is still in use as of the beginning of 2020 (Perusahaan Listrik Negara, 2020). The annual electricity price is calculated by multiplying the annual electricity consumption by the electricity price per kilowatt hour for all types of sun shadings, in all eight façades, using four-star air-conditioning units. The annual economic benefits from the energy saving are shown in Table 6 for every orientation of all sun shading types.

TABLE 6 Annual electricity payment saving (USD)

MODEL NAME	NORTH	EAST	SOUTH	WEST
type A1	24,93	22,4	13,69	26,42
type A2	18,93	16,86	11,77	19,65
type A3	14,13	12,47	8,93	14,59
type A4	31,66	28,48	19,95	32,79
type A5	20,26	18,03	13	20,88
type A6	21,4	19	15,8	21,37
type A7	34,69	31,38	22,97	35,79
type A8	18,11	16,14	11	18,86
type A9	19,42	17,49	13,96	19,77
type B1	39,2	44,66	25,56	53,22
type B2	33,47	35,03	21,5	41,1
type B3	23,03	24,06	14,26	28,6
type B4	40,04	45,31	26,2	53,93
type B5	32,59	34,1	20,71	40,14
type B6	26,12	26,95	17,29	31,57
type B7	42,18	47,3	28,44	55,98
type B8	31,69	33,01	19,65	39,13
type B9	25,26	26,24	16,35	30,89
type C1	16,69	16,11	9,29	19
type C2	19,62	19,75	10,08	23,42

The annual economic benefits from the total application cost (Fig. 11) and annual electricity payment saving (Table 5) of the proposed shading types are calculated to determine the payback period of each sun shading type. A faster payback period is better since the sun shading can still be used on the building. The simple payback periods of all sun shading types in all orientations are shown in Fig. 12.

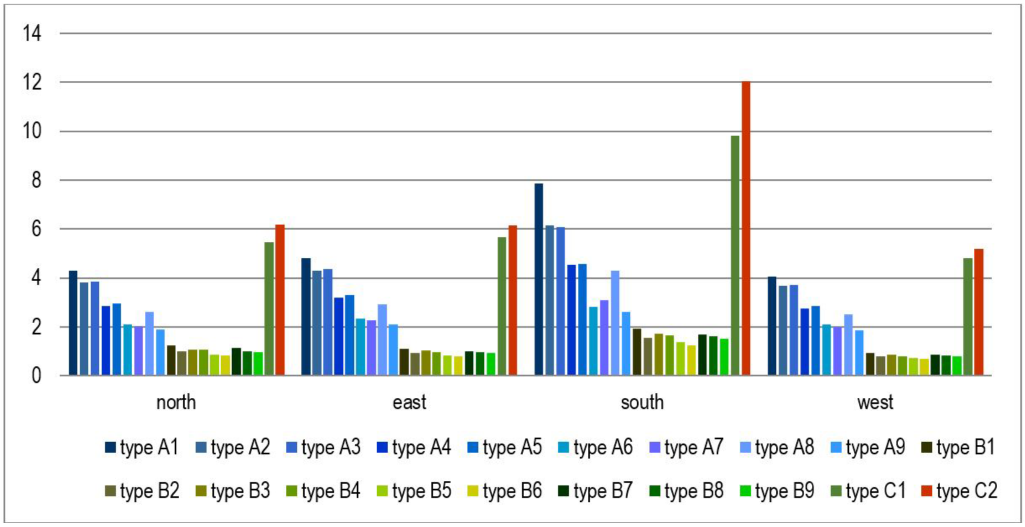

FIG. 12 Simple payback period of sun shading devices using four-star rated air-conditioning units (year)

The west orientation, which has the highest annual cooling energy has the fastest payback period of the sun shading applications. Type B6 shows the best performance, achieving a simple payback period of 0.68 years (around 8 months and 4 days), followed by type B5 with 0.71 years, and then types B2 and B9 with 0.8 years. All type B horizontal *koshi* can achieve simple payback periods of less than one year, and even the worst one, type B1, achieves a simple payback period of 0.92 years (around 11 months). Type A9 is the best of the type A sun shadings, having a simple payback period of 1.85 years (around 1 year, 10 months and 5 days). However, type A1, the worst of the A types has a payback period of 4.07 years (around 4 years and 21 days) although this is still faster than the type C1 overhang's payback period of 4.8 years (around 4 years 9 months and 16 days).

An opening in the south orientation has the lowest annual cooling energy consumption. This gives it the longest payback period among all of the orientations. Overhang type C2, which is the worst, has a payback period of 12.06 years (around 12 years 16 days). However, all type B applications have payback periods of less than two years. Type B6 is the best, with a payback period of 1.24 years (around 1 year 2 months and 26 days).

The results for other orientations fall between the results for west and south. Overall, the proposed horizontal *koshi* performs better than overhangs. Even though the same designs are used, the simple payback period of A types is longer than that of B types. The performance of A types in terms of annual cooling energy reduction is not as high as that of B types. Moreover, the application cost of A types is higher than B types.

4 CONCLUSION

Horizontal *koshi* mini-louvres have the effect of reducing the annual cooling energy in Jakarta, Indonesia, despite their small size. On average, in four orientations, horizontal *koshi* placed at the exterior surface of the window cut the annual cooling energy by around 5-12 percentage points in comparison with the base case. The cooling energy saved by the horizontal *koshi* on the window's exterior surface is similar to that saved by traditional overhangs, which can cut annual cooling energy consumption by around 6-7 percentage points in comparison with the base case. Placing horizontal *koshi* at the window frame improves the performance in terms of reducing the annual cooling energy. *Koshi* performs significantly better than overhangs, since around 10-17 percentage points reduction in the annual cooling energy can be achieved, depending on the type of horizontal *koshi*. All sun shading types in this study show their best performance in the west direction. Type B7, which is the best sun shading in this study, reduces around 21 percentage points of annual cooling energy in the west façade in comparison with the base case. On average, all of the proposed sun shading types cut the annual cooling energy in the west orientation by 12 percentage points in comparison with the base case. They perform worst for the south orientation, reducing the annual cooling energy by only around 7 percentage points of the average. Type B7 is the best sun shading among other tested models in this research, reducing annual cooling energy by 17 percentage points on average for all orientations. However, the construction cost is a consideration when applying the design to real buildings.

The double-sided tape price for attaching horizontal *koshi* is more expensive than the L-shaped aluminium profile in Jakarta. This makes the application cost of types A1 to 9 more expensive than those of types B1 to 9, even though they use the same designs. However, attaching horizontal *koshi* directly to the window's exterior surface gives a faster payback period than overhangs. Type A1, which is the worst among the A types has a payback period of 5.16 years, faster than that of type C1 which is 6.29 years. Type A9 is the best among other type A mini-louvres, with a simple payback period of 2.12 years. On the other hand, rather than just being environmentally friendly, placing horizontal *koshi* on the window frame is economically beneficial. Types B1 to 9 horizontal *koshi* can achieve a simple payback period of less than a year, even when using the highest rated, most effective four-star air-conditioning units in the west façade. Type B6 performs best, achieving a payback period of 0.68 years, when using the four-star air-conditioning unit. This means that horizontal *koshi* is economically beneficial during the building's operational period since it requires no maintenance. Horizontal *koshi* uses low technology. Its application does not require specific skills. The materials required to make horizontal *koshi* are widely available and relatively cheap. Horizontal *koshi* can be applied to new constructions as well as to old buildings as retrofits. The L-shaped aluminium profile does not occupy a lot of space in comparison to traditional overhangs due to its small size. It can be applied in space-limited area. It can also be applied to high rise buildings

Many further researches are possible following this study. The consideration of daylighting as well as privacy issues following the application of horizontal *koshi* mini-louvres can be researched. User acceptance of the proposed design can be studied to predict the probability that the application horizontal *koshi* will be successful. Location-based research is another possibility. As mentioned in the introduction to this paper, many tropical countries will demand a significantly higher cooling energy, such as India and Brazil. The results of this study show the possibility of applying such designs in other locations with conditions similar to those of Jakarta, Indonesia. Since the proposed design is simple, everyone can participate in reducing the need for cooling energy while saving money on electricity costs.

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