MULTI-OBJECTIVE OPTIMISATION OF ENERGY RETROFIT IN HOT-HUMID CLIMATES' OFFICE BUILDING

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Abstract

Globally, buildings are responsible for significant amounts of energy consumption and greenhouse gas emissions. Although new buildings can be constructed to higher energy performance standards, around 75% of today's buildings will still be in use in 2050. Therefore, energy retrofitting the existing stock offers significant opportunities to reduce global energy consumption and greenhouse gas emissions. Although building retrofit projects have already been applied in many developed countries, studies in hot-humid climates, like that of Indonesia, are still sparse. Indonesia's hot-humid climate makes developing the right energy retrofit strategies more challenging than in other climates.

This research investigated the multi-objective optimisation of energy retrofitting in Indonesian office buildings using environmental and social criteria to apply the most optimum retrofit strategies. The research methodology utilised environmental monitoring, a questionnaire, and thermal simulation modelling for an office building in Jakarta, Indonesia' that had received a Green Building Council Indonesia (GBCI) Platinum rating.

A post-occupancy evaluation (POE) was carried out to understand the occupants' thermal comfort, actual energy consumption, and the effect of recent retrofitting measures on the occupants' thermal comfort. In addition, the existing building was modelled in a dynamic thermal simulation modelling software, Design Builder (DB) and successful model calibration was achieved using on-site measured data. The calibrated model parametrically tested the suitability of some retrofit strategies for the office building. The results from this and future work will hopefully help Indonesian stakeholders identify the most appropriate retrofit measures based on environmental and social criteria.

Keywords: Multi-objective optimisation, Building retrofit, Energy efficiency, Thermal comfort, hot-humid climate

Nomenclature

NZEB	Net zero energy building	MBE	Mean bias error
ZEB	Zero energy building	N-MBE	Normalised bias error
GA	Genetic algorithm	RMSE	Root mean square error
NSGA	Non-dominated sorting genetic algorithm	CV(RMSE)	Coefficient of the variation of the root mean square error
MOO	Multi-objective optimization		
CFD	Computational fluid dynamic	HVAC	Heating, Ventilation and Air Conditioning
OTTV	Overall thermal transfer value	Low-E	Low Emissivity
BIM	Building information modelling	WWR	Window wall ratio
RBIM	Retrofitting building information modelling	FCU	Fan coil unit
GBCI	Green Building Council Indonesia	VAV	Variable Air Volume
POE	Post-occupancy evaluation	VRF	Variable refrigerant flow
DTSM	Dynamic thermal simulation modelling	BIPV	Building Integrated Photovoltaic
DB	Design Builder	HR	Heat recovery
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers	DOAS	Dedicated Outdoor Air System
		PUPR	Pekerjaan Umum dan Perumahan Rakyat
SHGC	Solar heat gain coefficient		

1 Introduction

Buildings consume significant amounts of energy and are responsible for high levels of carbon emissions worldwide, and so it is essential to formulate sustainable development strategies for buildings [1]. In Indonesia, the building sector (commercial and residential) represented 20% of the average final energy consumption from 2013 to 2019 [2]. It was reported that more than 60% of the total electricity consumption in commercial buildings in Indonesia was used mainly to achieve indoor thermal comfort through air conditioning [3]. According to the Paris Agreement in 2016, the Indonesian government set a target to reduce greenhouse emissions by 26% by 2030. Retrofitting existing buildings offers significant opportunities to reduce global energy consumption and greenhouse gas emissions. Additionally, retrofitting buildings provides excellent opportunities to improve energy efficiency, increase occupants' productivity, reduce maintenance costs, and provide thermal comfort [4].

Building retrofit projects have already been applied over the past decade in many developed countries. Yet, the case studies in hot-humid climates, especially in Indonesia, are minimal. Rating system tools for sustainable building in Indonesia have focused on new buildings and not yet on existing ones. Thus, retrofit could be an opportunity and challenge for Indonesia in the building sector to develop suitable energy retrofit strategies based on geographic location, which is a hot-humid climate. As evidence, a review of Net Zero Energy Buildings (NZEB) in hot and humid climates [5] found that from 34 case studies, only 5 were retrofit projects. Hence, surveys about NZEB in tropical climates with retrofit projects are still limited. Multi-objective optimisation is one of the most robust approaches to assessing different retrofit options because it generates solutions from trade-offs between two or more conflicting sustainable design objectives (i.e. social, environmental, economic) [6].

The recent review recommended a comprehensive and comparative analysis of effective energy-efficient measures in building energy retrofitting by considering different climate conditions for future studies. Developing decision-making tools for improving existing buildings' energy efficiency was also suggested [7]. Furthermore, a study about multi-objective optimisation of energy retrofit recommended future studies on different types of buildings and climates (i.e. hot-humid climate) [8]. A systematic review of the genetic algorithm (GA)-based multi-objective optimisation of building retrofit strategies also highlighted that future studies on this topic could be divided into two groups, which are related to methods or tools, as well as research gaps that need to be explored more including the expansion of objective function concerning occupants behaviour and indoor environmental quality [9].

This study aimed to investigate and test a multi-objective optimisation of energy retrofit in a hot-humid climate office building using environmental and social criteria to apply the optimum retrofit strategies. Hence, the objectives of this study were to investigate a multi-objective optimisation framework for retrofitting office buildings in Indonesia, analyse the most optimum solutions for energy retrofit in hot-humid climates' office buildings based on environmental criteria (minimise energy consumption) and social criteria (maximise thermal comfort), and provide recommendations for energy retrofit projects for office buildings in Indonesia.

2 Building retrofit in hot-humid climates

A study in a hot-humid climate revealed that an electrochromic glazing system with no shading was the most effective and efficient intervention for building retrofit, reducing heat gain by 53%-59% in winter and summer [8]. Several retrofit studies in hot and humid climates use residential buildings as case studies [8-10]. There are also studies about glazing in hot-humid climates [11, 12], shading devices [13] and daylighting [14], as well as radiant cooling or natural ventilation [15, 16]. The relationship between materials and retrofit strategies has also been explored [17]. Many papers discuss retrofit strategies in general [18-20].

A study proposed an optimisation method for retrofitting building information modelling (RBIM) to find the optimum building envelope of an office building in Malaysia with two objectives - minimising OTTV value and minimising retrofit cost. The method required three different software, Autodesk Revit for BIM authoring tools, Dynamo for visual scripting, and MATLAB, to customise a non-dominated sorting genetic algorithm (NSGA-II) for optimisation [21]. Both passive and active state-of-art energy-efficient technologies were implemented in Singapore's Zero Energy Building (ZEB) retrofit demonstration project. The results revealed that active strategies such as energy-efficient lighting and high-performance air-conditioning system were the most energy-efficient retrofit measure for buildings in hot-humid climates. On the other hand, they also concluded that passive design strategies were not preferable because they were not cost-effective and had a more extended payback period [20].

From these previous studies, four different building types were used for multi-objective optimisation case studies: residential buildings [22-25], school or university buildings [20, 26], heritage buildings [15] and office building [21], with office buildings being the least widely. Hence, the author found this as a research gap that should be explored.

3 Methodology

The methodology in this research used a quantitative analysis including a field survey, questionnaire, and software simulation. The selected case study building was the 9th floor of the Main Building of the Ministry of Public Works and Housing, Republic of Indonesia (Pekerjaan Umum dan Perumahan Rakyat - PUPR). The building has received Platinum green certification from the Green Building Council Indonesia. Figure 1 shows the location of the PUPR building, while Figure 2 shows the east view of the PUPR building.

Figure 1. Location of PUPR building in Jakarta

Figure 2. Picture of PUPR building

3.1 Data collection

Data collection was performed to gather building drawings (Figure 3), construction data, materials, occupants' schedules, electricity consumptions, appliances, and HVAC and lighting system details. These were used as resources to make a dynamic thermal simulation digital twin-building model using Design Builder software. A building survey was also conducted to measure indoor temperatures and humidity. HOBO UX100-003 and HOBO MX1101 data loggers were used and installed in several rooms on the 4th, 9th, and 17th floors. The location of the logger installation was decided based on the building manager's approval.

Typical 2nd, 3rd, 4th, 15th, 16th floor

Typical 5th – 14th floor

Figure 3. Typical floor plan of PUPR building

Figure 4 shows the location of several loggers installed on the 9th floor. However, in this paper, the simulation will focus on the office rooms where logger number 2 was installed for one month in October 2022. Based on the building manager's information, the building form and orientation were modified to respond to the sun's direction, which can affect thermal comfort. The material of the building uses thermal resistant glass for windows to support the energy efficiency program, which is super silver dark blue 8 mm glass with a U-value of 5.739 W/m^{2}K and a solar heat gain coefficient (SHGC) of 0.423.

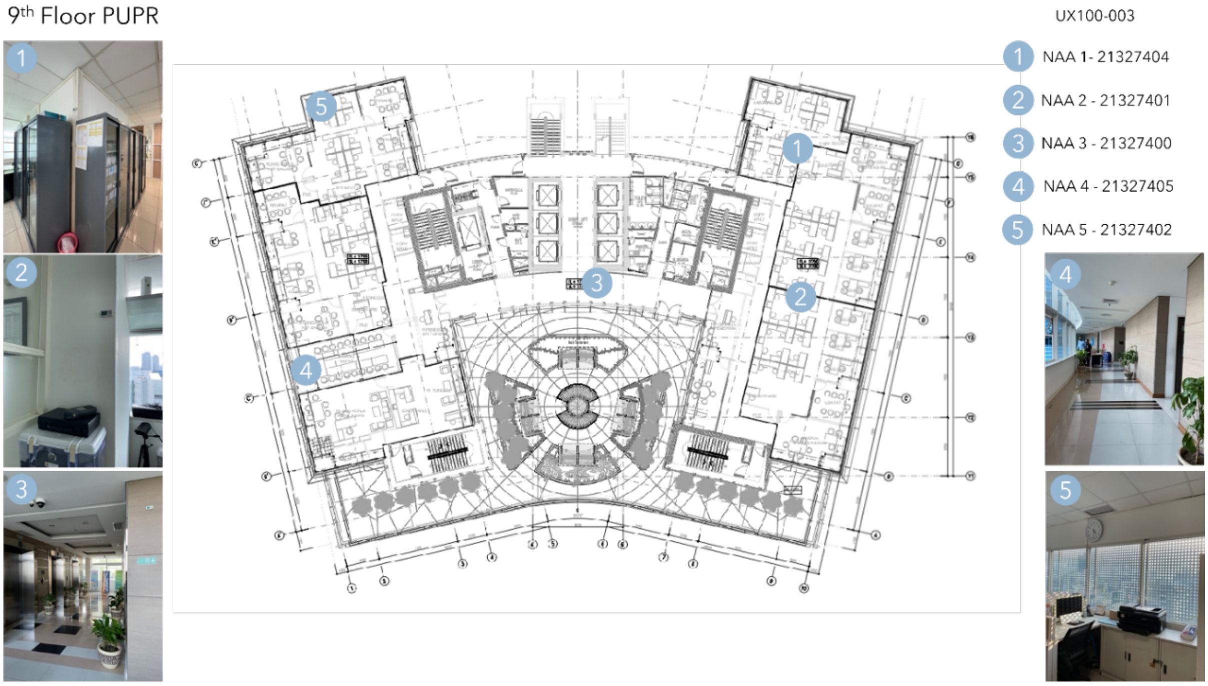

Figure 4. Temperature and humidity data loggers' installation

Insulation was also added on the wall with the configuration of external surface film, cladding aluminium (thermal conductivity k= 211 W/mK), calcium silicate/gypsum (k=0.170 W/mK), and fibreglass insulation internal surface film (k= 0.035 W/mK). Other passive design architecture, such as sun shading on the windows and double skin façade with perforated material on the west side, were installed to decrease solar gain and increase natural lighting.

The temperature in the office area is maintained at 25°C with relative humidity between 60-65%. The office spaces at the PUPR building use a central air conditioning system VAV dual duct water-cooled chiller with refrigerant R-134a. Interestingly, the seventeen-storey building uses natural ventilation in its circulation area, including corridors, the lift's lobby, staircases, and toilets. Types of artificial lighting installed in this building are T5 (52%), LED (4%), PLC (34%), and TL (10%). Illumination is maintained at 350 lux to correspond to the Indonesian National Standard. Furthermore, some strategies related to artificial lighting, such as lux sensors, motion sensors, and scheduling, are applied to obtain energy efficiency.

3.2 Simulation of existing building and model validation

In this study, Dynamic Thermal Simulation Modelling (DTSM) was performed using Design Builder (DB). The building performance analysis process is shown in Figure 5.

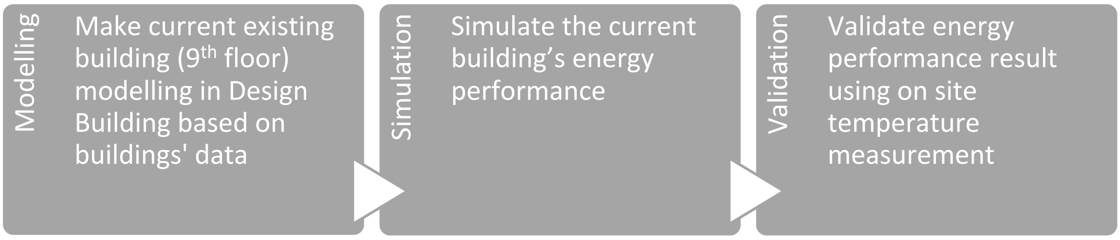

Figure 5. Building Performance Analysis process

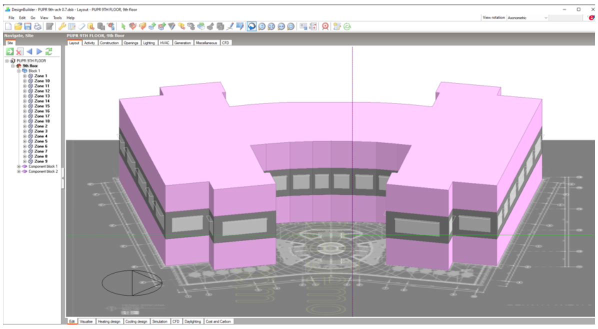

Figure 6. Model of the middle floor of the building

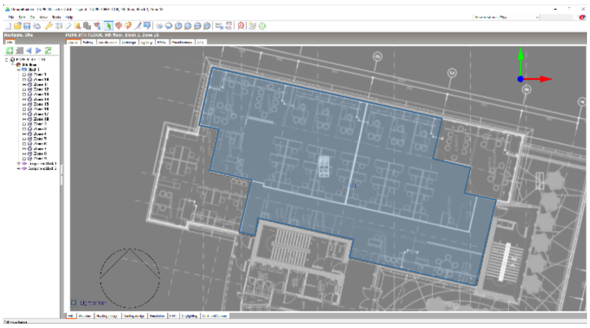

Figure 7. Model of office room as zone

The existing building model was built in DesignBuilder (DB) and based on the as-built drawing provided by the building manager. Figure 6 above shows the DB model of the 9th-floor PUPR building with its upper and lower floor as a component. Figure 7 shows the office room used as the zone for the simulation. The 9th floor was selected because the logger was installed for a whole month without interruption, and the floor itself can be represented as the typical office layout in the PUPR building. The model in DB was then validated using the formula of Normalised Mean Bias Error (NMBE) and Coefficient of the Variation of the Root Mean Square Error (CVRMSE) below:

$$MBE\ (\%) = \frac{\sum_{k=1}^{n} (Y_k - \widehat{Y_k})}{\mathrm{n}} \tag{1}$$

$$Normalised\ MBE\ (\%) = \frac{\sum_{k=1}^{n} (Y_k - \widehat{Y_k})}{(\mathrm{n}-\mathrm{p}) \times \mu} \times 100 \tag{2}$$

p for engineering models to be p=1

$$RMSE = \sqrt{\frac{\sum_{k=1}^{n} (Y_k - \widehat{Y_k})^2}{\mathrm{n}-\mathrm{p}-1}} \tag{3}$$

p= number of variables, in engineering models (Option D) p=0

$$CVRMSE\ (\%) = \frac{\mathrm{RMSE}}{\mu} \times 100 = \frac{\sqrt{\frac{\sum_{k=1}^{n} (Y_k - \widehat{Y_k})^2}{\mathrm{n}-\mathrm{p}-1}}}{\mu} \times 100 \tag{4}$$

According to ASHRAE [48], if using hourly data, the validation accuracy of the model should be +/- 10% for NMBE and <30% for CV(RMSE). The validation results with these formulae are presented in Table 2.

3.3 Multi-objective optimisation of retrofit strategies

This study's multi-objective optimisation process with different retrofit objectives and variables used the Non-dominated Sorting Genetic Algorithm II (NSGA-II) available in the optimisation option built-in DesignBuilder software, as shown in Figure 8. Table 1 shows the selected objectives and variables as the parameter for the optimum retrofit strategies. NSGA-II obtains the optimum result with many parameters that usually contrast with each other. This study’s optimisation objectives were to increase thermal comfort (minimise discomfort hours) and minimise the energy needed for cooling. Additionally, six variables were added to the calculation: glazing type, cooling set point temperature (^{o}C), local shading type, window wall ratio (WWR), façade type, and HVAC template.

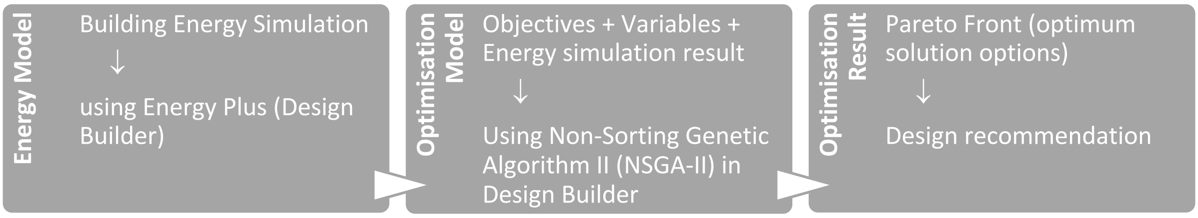

Figure 8. Multi-objective optimisation process

Table 1. Objectives and variables for the optimisation process in DesignBuilder

Objectives		**Variables**					
1	**2**	**Glazing type**	**Cooling setpoint temperature (°C)**	**Local shading type**	**Window Wall Ratio (WWR)**	**Facade type**	**HVAC template**
Discomfort (All Clothing) (hr)	**Cooling (Electric) (kWh)**	Double Clear 6mm/13mm Air	Min 24 Max 27.5 Step (parametric)2 Step (optimisation) 0.2	0.5m projection Louvre	Min 20 Max 80 Step (parametric) 20 Step (optimisation) 2	Horizontal Strip, 100% glazed	Chilled Ceiling, Air-cooled Chiller
							FCU 4-pipe, Air-cooled Chiller
				1.0m projection Louvre			FCU 4-pipe, Air-cooled Chiller, Parallel Chilled Water Storage
		Double Clear 6mm/13mm Argon				Horizontal Strip, 90% glazed	FCU 4-pipe, Water-cooled Chiller, Parallel Ice Thermal Storage
				1.5m projection Louvre			FCU 4-pipe, Water-cooled Chiller, Waterside Economiser
							FCU with DOAS, Air-cooled Chiller
		Dbl LoE (e2=.1) Clr 6mm/13mm Air		0.5m Overhang		Horizontal Strip, 80% glazed	Fluid Cooler, Generator Heat Recovery
							VAV Reheat, Air-cooled Chiller
				1.0m Overhang			VAV Reheat, Chiller Cooled by Fluid Cooler
		Dbl LoE (e2=.1) Clr 6mm/13mm Argon				Horizontal Strip, 70% glazed	VAV Reheat, Water-cooled Chiller
				1.5m Overhang			VAV Reheat, Water-cooled Chiller with Chilled Water Storage
							VAV Reheat, Water-cooled Chiller, Full Humidity Control
		Project BIPV Window		2.0m Overhang		Horizontal Strip, 60% glazed	VAV with Powered Induction Units
							VAV, Dual Duct, Water-cooled Chiller
		Sgl LoE (e2=.2) Clr 6mm		No Shading		Horizontal Strip, 50% glazed	VRF with HR and DOAS

4 Result and Discussion

The selected zone represents the office room in DesignBuilder and had several setting changes, including the activity schedule, construction details and materials, opening, lighting, and HVAC system. The model in DB was then simulated in fifteen scenarios with infiltration and temperature setting changes to determine the smallest values of N-MBE and CV(RMSE) according to the ASHRAE 14 standard. Table 2 presents the validation result by comparing Jakarta's measured, modelled, and outdoor temperatures from the commercial weather generation software Meteonorm. The results show that the model with an infiltration rate of 3 ac/h and a cooling set point temperature of 20-24°C was closely similar to the temperature the data logger installed in the same room recorded.

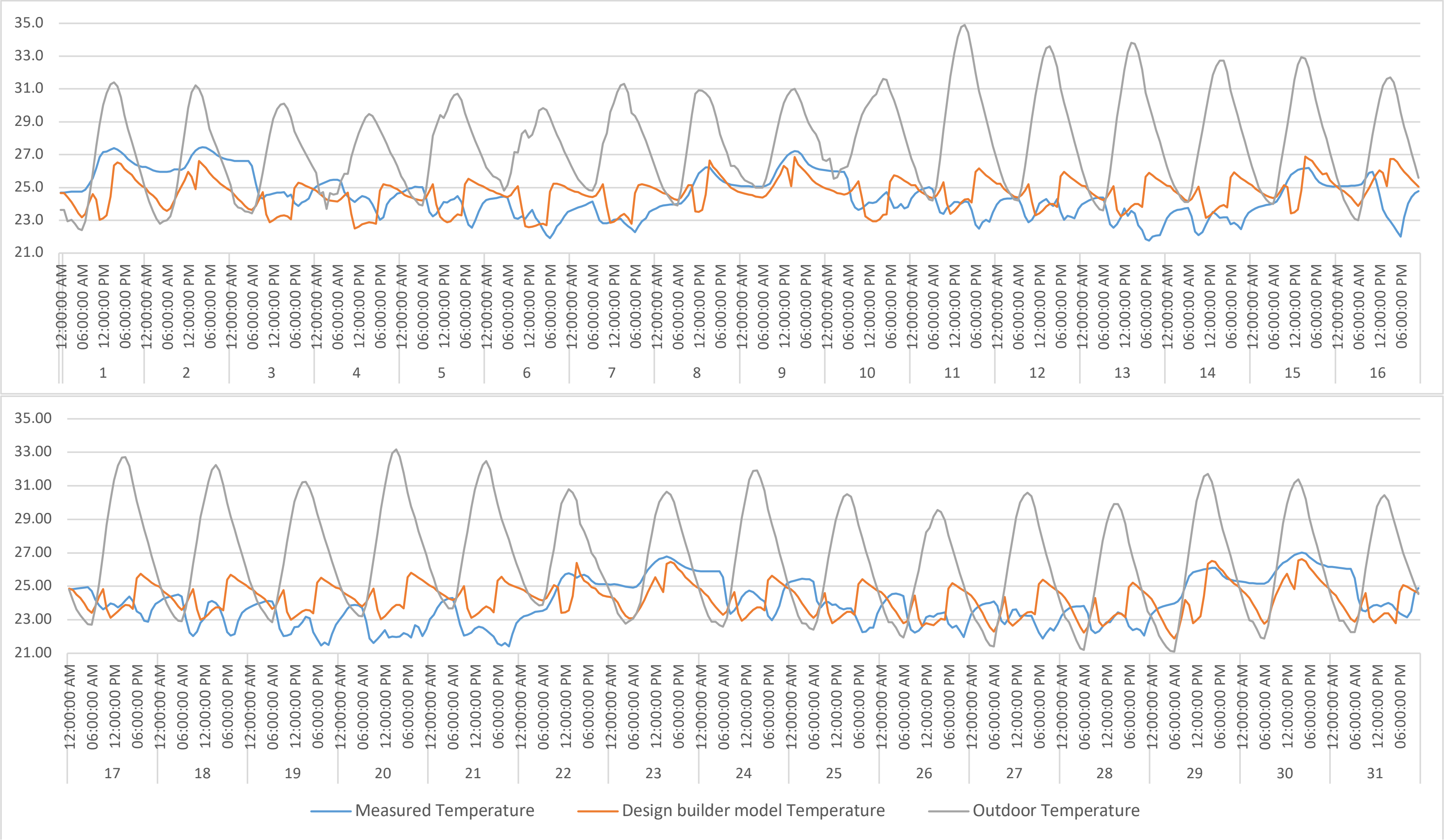

Figure 9. Temperature comparison in 1-16 October 2022 (top) and 17-31 October 2022 (below)

It is shown in Figure 9 that both measured and modelled temperatures inside the office room during office hours in October 2022 were mainly below 25°C, while the outdoor temperature reached more than 30°C in the afternoon. The measured temperatures also showed that on most days in October 2022, the temperature peaked early in the morning before 08.00 and reached its lowest after 17.00 in the afternoon. Meanwhile, the simulation results in DB showed that higher temperatures occurred in the evening and reached the lowest point during working hours. The DB model simulation results shown in Figure 10 indicated discomfort during working hours each day when the temperature was below 24°C because it might be considered uncomfortable or cold.

Table 2. Validation result

Infiltration rate	***Temperature setting***	***MBE***	***N_MBE***	***RMSE***	***CV(RMSE)***
ACH 0.7	T 20-23°C	0.30	1.25	1.46	6.01
	T 20-24°C	-0.23	-0.93	1.50	6.21
	T 20-25°C	-0.70	-2.88	1.77	7.29
ACH 1.5	T 20-23°C	0.30	1.26	1.46	6.03
	T 20-24°C	-0.21	-0.88	1.52	6.25
	T 20-25°C	-0.66	-2.74	1.78	7.33
ACH 2	T 20-23°C	0.31	1.27	1.46	6.04
	T 20-24°C	0.28	1.16	1.43	5.92
	T 20-25°C	-0.65	-2.67	1.78	7.35
ACH 2.5	T 20-23°C	0.31	1.28	1.47	6.05
	T 20-24°C	-0.20	-0.83	1.53	6.29
	T 20-25°C	-0.63	-2.62	1.78	7.36
ACH 3	T 20-23°C	0.31	1.28	1.47	6.06
	T 20-24°C	-0.19	-0.80	1.53	6.30
	T 20-25°C	-0.62	-2.58	1.79	7.37

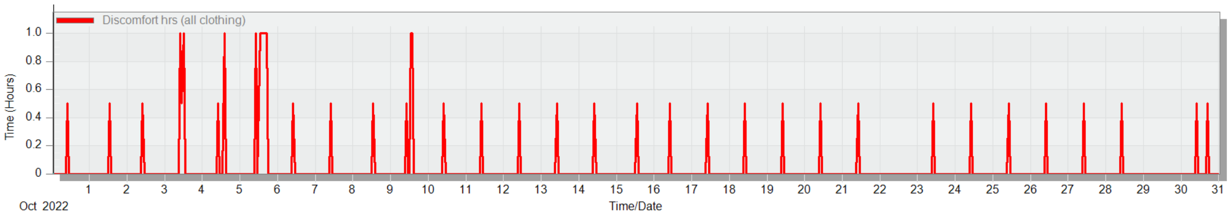

Figure 10. Discomfort hours during October 2022

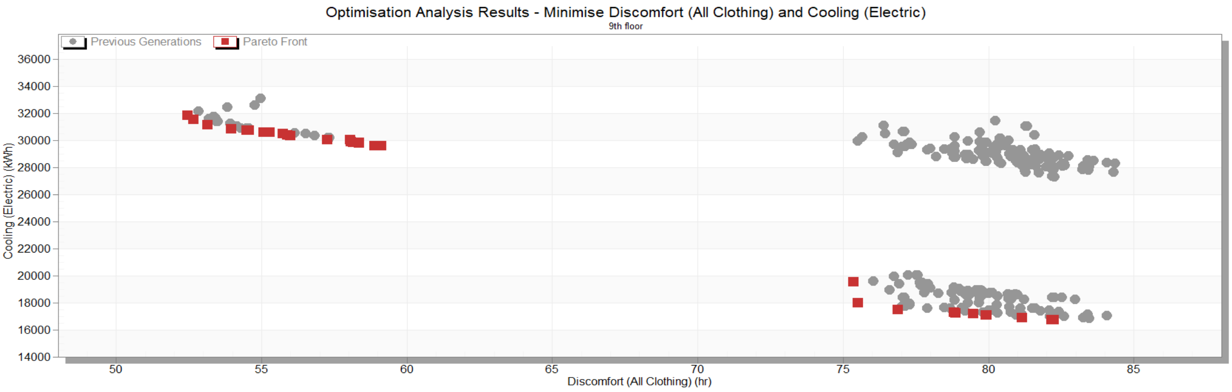

Figure 11. Optimisation analysis results with two objectives

In the optimisation analysis, the setting of maximum generation was 200, while generation for convergence and initial population size were both 20. The results can be seen in Figure 10 and Table 3. In Figure 10, the red points are the Pareto front or the optimum configuration to achieve both objectives with the variables applied. DesignBuilder calculated 1404 iterations with 70 generations until it converged. There are 31 optimal design solutions with a different sets of variables. The configuration with the lowest cooling demand has the most extended discomfort hours. This option uses double low emissivity clear 6mm glass and a cavity filled with Argon, a cooling set temperature of 16.4°C, a 1.5m projection louvre, a window-to-wall ratio (WWR) of 32%, a façade type as a horizontal strip 100% glazed, and an HVAC template VRF with HR and DOAS.

In contrast, the configuration with the lowest discomfort hours but higher cooling demand used single low emissivity clear 6mm glass, a cooling set temperature of 28.6°C, a 0.5m projection Louvre, a window-to-wall ratio of 50%, a façade type as a horizontal strip, 60% glazed, and VAV Reheat, water-cooled chiller, full humidity control. From the list of optimum design solutions, double low emissivity glass gave a lower cooling demand than single low emissivity glass. The optimum cooling set temperature was between 20.6-29.2°C. Shading systems were needed, either a projection louvre or overhang with a range of 0.5-2.0m. A lower WWR was also preferably combined with a horizontal strip façade. As for the HVAC system, the VAV reheat and water-cooled chiller performed well with the other variables, with full humidity control.

5 Conclusions

From the result of the building measurement, simulation, and optimisation in DesignBuilder, it can be concluded that there are 31 sets of optimal retrofit design solutions for the PUPR building in Jakarta, Indonesia. Recommendation of configurations with the lowest cooling demand is using double low emissivity clear 6mm glass and cavity filled with Argon, cooling set temperatures of 16.4°C, 1.5m projection louvre, window wall ratio (WWR) of 32%, façade type as horizontal strip 100% glazed, and HVAC template VRF with HR and DOAS. Meanwhile, the recommendation of configuration to get the least discomfort hours is using single low emissivity clear 6mm glass, cooling set temperatures of 28.6°C, 0.5m projection Louvre, window wall ratio (WWR) of 50%, façade type as horizontal strip, 60% glazed, and VAV Reheat, water-cooled chiller, full humidity control. For future studies, testing the performance in other zones and the whole building will be beneficial to see if the solutions are similar. Then further research will apply the exact solutions to the different types of buildings in hot-humid climates.

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Appendix

Table 3. Optimization result from Design Builder

Iteration	Generation	Objectives		Variables					
		Discomfort (All Clothing) (hr)	Cooling (Electric) (kWh)	Glazing type	Cooling setpoint temperature (°C)	Local shading type	Window Wall Ratio (WWR)	Facade type	HVAC template (Detailed HVAC)
2	0	58.08	29898.49	Dbl LoE (e2=.1) Clr 6mm/13mm Air	26.6	1.0m projection Louvre	24	Horizontal strip, 60% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
22	1	55.73	30488.21	Dbl Clr 6mm/13mm Arg	29	2.0m Overhang	72	Horizontal strip, 90% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
24	1	75.35	19555.88	Sgl LoE (e2=.2) Clr 6mm	28.6	0.5m projection Louvre	58	Horizontal strip, 90% glazed	Fluid Cooler, Generator Heat Recovery
44	2	55.27	30606.75	Dbl LoE (e2=.1) Clr 6mm/13mm Arg	24	0.5m projection Louvre	76	Horizontal strip, 70% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
67	3	75.51	17990.18	Sgl LoE (e2=.2) Clr 6mm	28.8	0.5m projection Louvre	54	Horizontal strip, 80% glazed	VRF with HR and DOAS
78	4	79.92	17078.16	Dbl Clr 6mm/13mm Arg	24	1.5 m projection Louvre	36	Horizontal strip, 70% glazed	VRF with HR and DOAS
86	4	81.16	16905.21	Dbl LoE (e2=.1) Clr 6mm/13mm Air	26.6	1.0m projection Louvre	34	Horizontal strip, 100% glazed	VRF with HR and DOAS
94	4	55.09	30627.60	Project BIPV Window	23.8	1.5m Overhang	24	Horizontal strip, 60% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
97	5	58.37	29822.87	Dbl LoE (e2=.1) Clr 6mm/13mm Arg	25.2	2.0m Overhang	54	Horizontal strip, 90% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
114	5	58.34	29856.62	Dbl LoE (e2=.1) Clr 6mm/13mm Air	20.8	2.0m Overhang	58	Horizontal strip, 90% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
142	7	55.07	30629.71	Dbl LoE (e2=.1) Clr 6mm/13mm Air	21.4	0.5m projection Louvre	42	Horizontal strip, 60% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
147	7	53.15	31160.07	Sgl LoE (e2=.2) Clr 6mm	27.8	1.5m Overhang	34	Horizontal strip, 100% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
149	7	53.95	30871.24	Sgl LoE (e2=.2) Clr 6mm	22.2	2.0m Overhang	30	Horizontal strip, 100% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
160	8	59.12	29585.00	Dbl LoE (e2=.1) Clr 6mm/13mm Arg	23.2	1.5 m projection Louvre	22	Horizontal strip, 60% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
167	8	55.98	30358.17	Project BIPV Window	28.2	2.0m Overhang	22	Horizontal strip, 50% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
194	10	54.49	30766.26	Dbl Clr 6mm/13mm Air	26.4	1.5m Overhang	32	Horizontal strip, 80% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control

198	10	54.58	30762.62	Dbl Clr 6mm/13mm Arg	25.8	1.5m Overhang	28	Horizontal strip, 80% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
203	10	57.28	30057.16	Dbl LoE (e2=.1) Clr 6mm/13mm Arg	21.4	1.5m Overhang	64	Horizontal strip, 50% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
205	10	82.25	16724.07	Dbl LoE (e2=.1) Clr 6mm/13mm Arg	26.4	1.5 m projection Louvre	32	Horizontal strip, 100% glazed	VRF with HR and DOAS
226	11	52.45	31866.06	Sgl LoE (e2=.2) Clr 6mm	28.6	0.5m projection Louvre	50	Horizontal strip, 60% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
257	13	52.66	31573.24	Sgl LoE (e2=.2) Clr 6mm	23.2	1.0m Overhang	22	Horizontal strip, 70% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
276	14	58.89	29626.30	Dbl LoE (e2=.1) Clr 6mm/13mm Air	26.4	1.5 m projection Louvre	52	Horizontal strip, 100% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
295	15	58.16	29859.63	Dbl LoE (e2=.1) Clr 6mm/13mm Arg	25.4	1.0m projection Louvre	34	Horizontal strip, 70% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
326	16	58.05	30046.05	Project BIPV Window	29.2	1.5 m projection Louvre	60	Horizontal strip, 100% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
411	21	78.87	17253.27	Dbl Clr 6mm/13mm Arg	22	1.0m projection Louvre	60	Horizontal strip, 100% glazed	VRF with HR and DOAS
580	29	79.46	17171.76	Project BIPV Window	28.2	1.0m projection Louvre	60	Horizontal strip, 100% glazed	VRF with HR and DOAS
683	34	82.16	16752.87	Dbl LoE (e2=.1) Clr 6mm/13mm Air	23.8	1.5 m projection Louvre	32	Horizontal strip, 100% glazed	VRF with HR and DOAS
698	35	76.89	17468.47	Sgl LoE (e2=.2) Clr 6mm	26	1.0m projection Louvre	34	Horizontal strip, 100% glazed	VRF with HR and DOAS
714	36	55.89	30427.32	Dbl LoE (e2=.1) Clr 6mm/13mm Air	22.2	1.0m Overhang	50	Horizontal strip, 100% glazed	VAV Reheat, Water-cooled Chiller, Full Humidity Control
886	45	78.82	17259.48	Dbl Clr 6mm/13mm Air	29	1.0m projection Louvre	30	Horizontal strip, 100% glazed	VRF with HR and DOAS
989	50	79.91	17085.45	Dbl Clr 6mm/13mm Air	20.6	1.5 m projection Louvre	62	Horizontal strip, 80% glazed	VRF with HR and DOAS