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Utilization of building design performance simulation in the architectural design studio process

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ABSTRACT

Design is a unified system consists of parameters that influence each other, so design considerations must be careful. Building design performance is a measurable parameter, and integrating the planning and design process can make decision-making more focused and measurable. This paper describes the benefits and constraints of integrating building design performance simulations in the architectural studio design process using a design process of the Student Learning and Innovation Center. The study emphasizes cooling loads and daylighting using building design performance simulation to analyze the design form, layout, and building skin through shading study, UTCI, thermal comfort, wind, solar radiation, daylight, and cooling loads. Simulation using ladybug, honeybee, and sefaira software. The result is BPS utilization in the design process can assist designers in considering strategic design decisions when the problem is simple or aims to study climatic conditions. When the design problem is complex or requires detailed simulation, BPS utilization in the design process becomes more complicated so that the potential for simulation errors is more significant.

Introduction

Architecture is a discipline that poses several design challenges from the conception stage to the realization of the design. Architects must go through a systematic design process to solve design problems, which vary among individuals and groups (Oluwatayo et al. 2017). The existence of studio practice that involves students and facilitators can facilitate various design activities in the studio. Students learn with creative activities. They work together with their colleagues to find design solutions to solve problems (Hettithanthri and Hansen 2022). To achieve building performance, decision-making, in some cases, design at the conceptual stage can rely on experience and intuition. However, instinct can be invalid for complex issues (Brown 2019). In the context of a traditional design studio, students engage in an open, project-based problem, which allows students to solve problems in their way (Emam, Taha, and ElSayad 2019). To get a design solution, you can go through an iterative process by reviewing, assessing, and listening to comments by judges and colleagues (Ardington and Drury 2017).

Considering the complex interactions between energy performance, lighting, acoustics, and thermal comfort in contemporary designs, building performance simulation (BPS) will play a key role in addressing the technical decision-making processes and choices toward an optimized configuration during the entire design phase (Gaspari et al. 2017). However, its application is still limited in the early stages, where design decisions significantly impact the final performance and cost of the building. Integrating BPS in the design process is not easy because it is multi-objective and involves multidisciplinary science (Hernandez Neto 2019). The design process will become more complicated, and the task is computationally intensive (Wate et al. 2019). In addition, the experience of using BPS also determines the effectiveness and efficiency of the design process (Ianni and Sánchez de León 2013). The initial integration of simulation software faces several challenges, including time-consuming modeling, rapid design changes, conflicting requirements, input uncertainty, and extensive design variability (Østergård, Jensen, and Maagaard 2016).

Based on the existing issues regarding the conventional studio process and the studio process using building performance simulation (BPS), this study will review the effectiveness of using BPS for the studio process for undergraduate students and whether it is appropriate if used for undergraduate level students.

Method

This research uses the observation method. This method uses the case of an undergraduate student's final project with the project title Student Learning & Innovation Center (SLIC). This last project uses a building performance simulation (BPS) to complete. This observation looks at the effectiveness of using BPS on undergraduate students by identifying the stages of BPS, starting from the writing process or concept to the design process.

In figure 1. there is the workflow of utilizing BPS in the design process. The study emphasizes optimizing daylighting and cooling energy. Decision-making considers priority scales (Brown 2019), such as determining the priority of function, comfort, and beauty (Satwiko 2005).

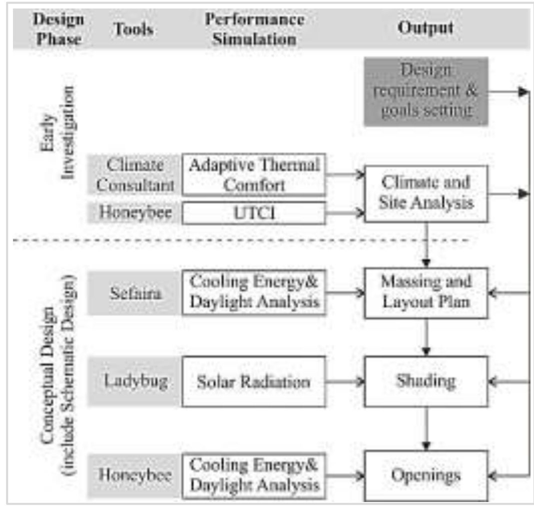


Figure 1. Workflow of utilizing BPS in design process in the study case

Result and discussion

In the Student Learning & Innovation Center (SLIC) design process, the use of Building Performance Simulation (BPS) is at the identification and concept stage. The identification process is communication between the subject and the architectural object. Architectural objects are affected by location, function, form, and aesthetics. The concept in architectural design is implementing a predetermined theme from the beginning of the planning and design process. It can implement the idea as a problem-solving synthesis in a plan such as forms of mass, space composition, color, material, aesthetics, and enrichment (Cardiah and Sudarisman 2018).

Identification

Identification for this project consists of three stages: design requirements, goal setting, and micro-macro climate analysis. At the stage of SLIC design requirements, there is visual connectivity between high spaces, flexible spaces, and the existence of communal areas. At the same time, the goal of SLIC is energy-efficient buildings by optimizing natural lighting and cooling energy. The passive design concept is considered an efficient strategy to reduce energy consumption in the building sector, where the most potent uses are for heating and cooling (Fernandez-Antolin et al. 2019).

The SLIC typology is an office with typing, reading, and discussing activities. Activity durations vary from short to long periods. Thus, the outside view is essential to reduce eye fatigue.

The exterior view is one of the criteria for indoor health quality (GBCI 2013). Providing outdoor viewing and daylight access can improve cognitive function performance (Jamrozik et al. 2019). Design that can adapt to the local climate will increase indoor comfort or avoid the need for cooling (PEEB 2020). Analysis of macro and microclimatic conditions is needed to determine the potential application of passive building principles (Jordan et al. 2021; Borrallo-Jiménez et al. 2022).

The site is in Yogyakarta (figure 3) with macro climatic conditions during operating hours based on EPW file data are:

1) Temperature 20.13 – 33.90ºC;
2) Relative humidity 41-94%;
3) Wind velocity 0.00 – 14.60m/s.

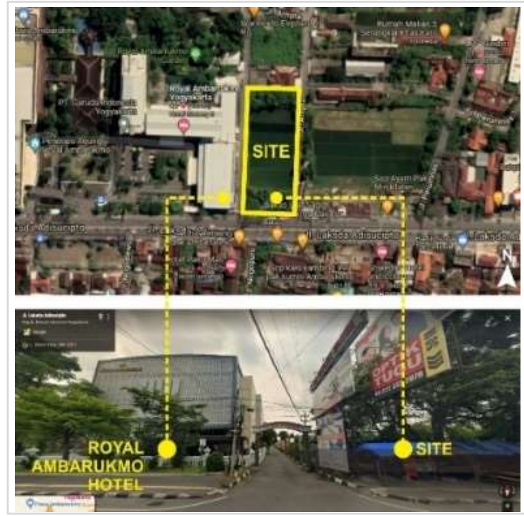


Figure 2. Site situation

When compared with SNI, the climatic conditions of Yogyakarta in one year do not always meet the standards, such as temperature 20.5-27.1ºC, relative humidity 40-60%, and air velocity 0-1.5m/s (SNI 2001). The adaptive thermal comfort strategy simulation using the climate consultant shows the percentage of met hours during building operating hours in one year is 59.3% (figure 4).

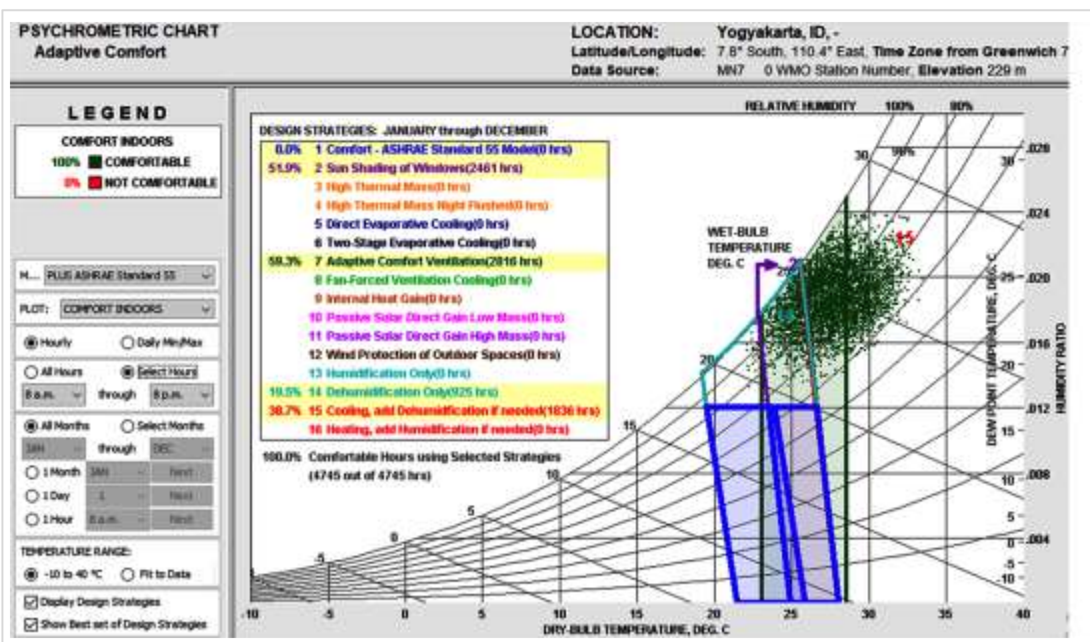


Figure 3. Psychrometric chart adaptive comfort based on Yogyakarta EPW file

This result shows that spaces with a short duration of use or rooms with service and circulation functions can still use natural ventilation. Thermal comfort in a room with natural ventilation increases through air movement caused by wind pressure, buoyancy, and mechanical forces (WHO 2009). It means that the designer needs consider planning the design and laying of openings looking at the wind. At a temperature of 30ºC, an airflow velocity of 0.25-1.5m/s can give a refreshing effect of around 0.5-2.2ºC (Frick, Ardiyanto, and Darmawan 2008).

Based on EPW data, Yogyakarta city wind Based on EPW data, the wind movement of Yogyakarta is dominated by the south, east, and north. While the wind from the west will hit the building and pass the site from the south with wind speeds less than 1.5 m/s.

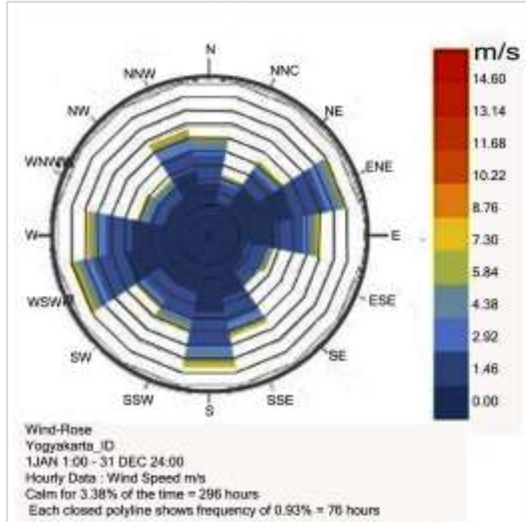


Figure 4. Wind rose based on Yogyakarta EPW file

The Universal Thermal Climate Index (UTCI) analysis reviewed the temperature mapping at the site. It used the simulation as consideration for determining the zone and the setting analysis using concrete material. The simulation results show that the location temperature ranges from 1-4ºC with the lowest temperature areas on the west and south sides (figure 6). The shading did not provide a significant temperature difference between the shaded and unshaded areas.

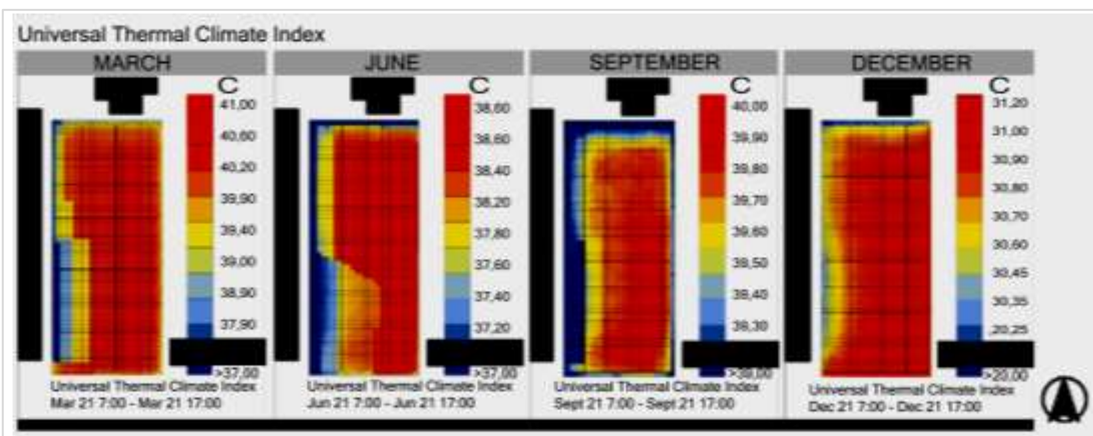


Figure 5. Universal Thermal Climate Index

Conceptual design

The conceptual design consists of mass study, plan layout and shading studies, and aperture study. The desired outcome is a strategy or design variable that meets the minimum standard of 55% for sDA (U.S. Green Building Council 2013) and the lowest cooling energy value.

A. Mass and layout planning

The shape of the mass will affect the condition of the project and vice versa. These two aspects are the criteria of the simulation tool for the conceptual stage (Massetti and Corgnati 2011).

Setting and material using default value from Sefaira, i.e., ASHRAE zone climate 2 (table 1).

Table 1. Properties setting in Sefaira

Model properties		Value
1	Wall insulation	0.86 W/m^2. K
2	Floor insultation	0.61 W/m^2. K
3	Roof insulatio	0.22 W/m^2. K
4	Glazing-u factor	2.27 W/m^2. K
5	Visible light transmittance	0.42
6	SHGC	0.25
7	Infiltration rate	7.34 m^3/m^2. h
8	Ventilation rate	15 L/s. person

After knowing the behavior of lighting and cooling on the shape of the building mass, the designer can do the development of the concept into a schematic pre-design.

B. Shading

The study uses simulations of annual solar radiation. The simulation aims to estimate the design and placement of shading devices—response data using a literature study.

C. Openings

The study sampled one zone using active ventilation on the 4th floor to study the shading effect. The simulation uses ladybug and honeybee for energy simulation and natural lighting. Workflow formula simulation consists of three groups: making models and test parameters, cooling energy analysis, and daylighting analysis (figure 6).

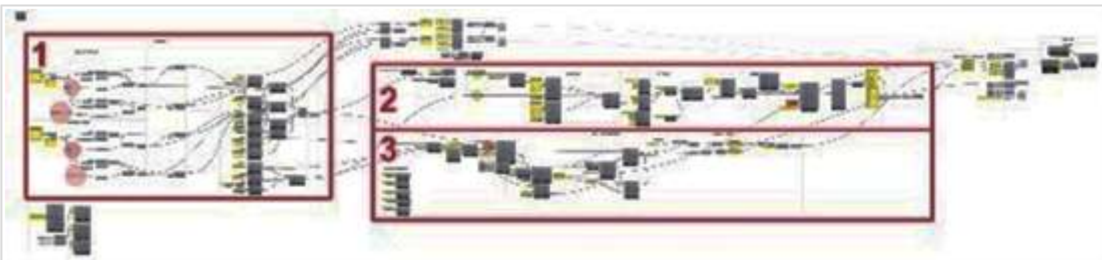


Figure 6. Formula in grasshopper canvas divided into three groups

Daylighting analysis to find sDA350/50% and ASE1000/250 value. Threshold 350lux from SNI for office typology workspaces (SNI 2011). Simulations are done at 08.00-18.00 in one year with the energy simulation setting in table 2.

Table 2. Energy simulation setting in honeybee

Input		Value
1	Cooling setpoint	27^o C
2	Cooling setback	29^o C
3	Infiltration rate	0.0003 m^3/s-m^2 @4Pa
4	Equipment	0 W/m^2. K
5	Lighting	0 W/m^2

Mass and layout plan

The site measures 130x55m and extends north-south, and the main entrance is on the south side. The building area is 6,358m^2, and the minimum floor area requirement is 8,112m^2. Therefore, the building shape follows the site shape to obtain optimal space. But the longest side of the building will face east-west. The multi-level period will increase the skin area of the east-west facing. It is contrary to the passive design principle.

Table 3. Mass form performance

Mass	Daylighting		Cooling energy (kWh/yr)
	SDA $_{300/50\%}$	ASE $_{1000/250}$	
1	64	21	376,6
2	61	19	375,0
3	72	22	399,7
4	72	21	391,3
5	68	19	389,1
6	61	15	367,0

The floor plan strategy is to minimize the number of layers of the room as much as possible to deepen the penetration of natural light (table 3). The recommended number of layers of the room is two to three layers divided by a glass partition (figures 7 and 8).

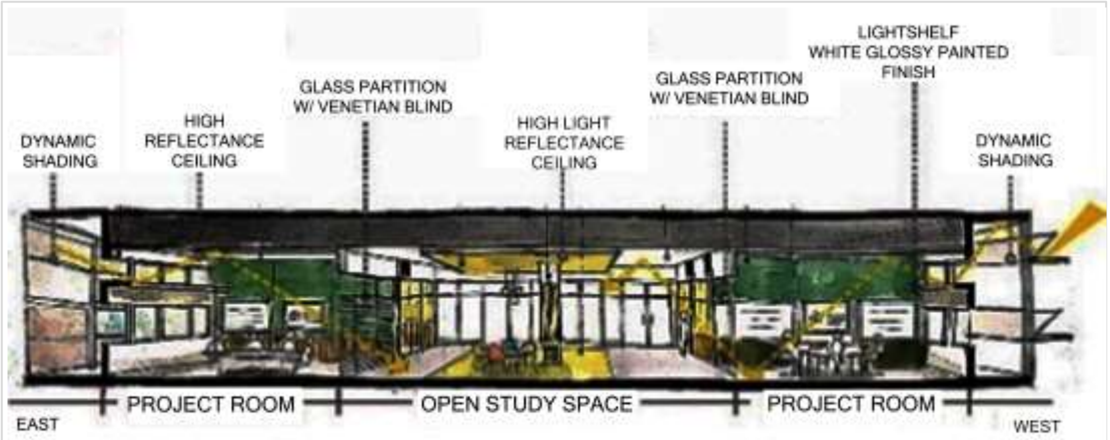


Figure 7. General workspace consists of three layers

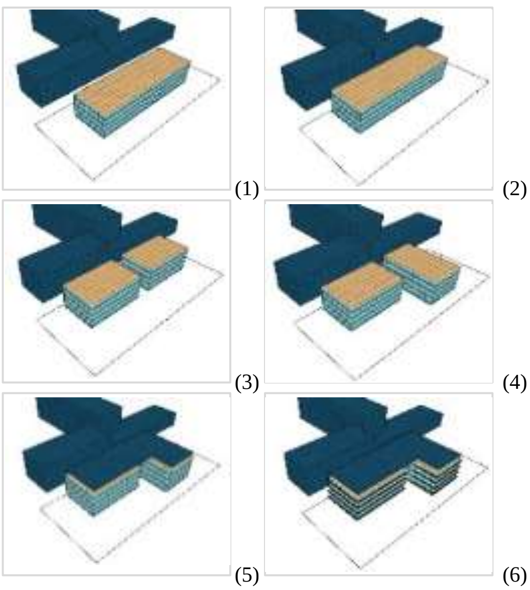


Figure 8. Mass form transformation

In figure 8, the transformation process uses simulation to find the form of mass that uses the lowest energy. In the picture, there are six experiments on the shape of the building—the second mass by moving the form forward and backward. The third form divides the building mass into two equal parts and increases one mass for the fourth. After that, the last one changes the shade's width on the facade (the fifth dan sixth mass). There is a difference in the decrease in energy use in each mass-made form (table 4).

Table 4. Mass form energy

Mass	Cooling energy	sDA300/50%	ASE1000/250
1	376,6 kWh/yr	64	21
2	Decreases 1 kWh/yr	Decrease 3%	Decrease 3%
3	Increased 24.7 kWh/yr	Increase 11%	Increase 3%
4	Decreased 8.4 kWh/yr	Constant	Decreased 2%
5	Decreased 2.2 kWh/yr	Decrease 4%	Decreased 2%
6	Decreased 22.1 kWh/yr	Decrease 4%	Decrease 4%

The shading effect can decrease cooling energy. This effect will be more significant in tropical climates (Han and Taylor 2015). Shading addition will decrease cooling energy consumption because it blocks solar radiation that will fall on building envelopes (Maleki 2011). A previous study has found that adding roof shading will decrease energy consumption (Macia et al. 2008).

From this mass study, sDA300/50% using WWR40 meets the standard for the entire strategy. The lowest sDA300/50% is 61%. It means cooling energy is still possible to optimize with changing WWR. It means that the best strategy is mass orientation and then shading openings. Using the mutual shading strategies does not significantly decrease cooling energy (Almutairi and Bourisli 2017).

In the design, placing the building on the west side can reduce the operative temperature on the 1st-3rd floors. The main building is "L" shaped with an auditorium on the north side. Separating the hall from the main building considers circulation efficiency and response to environmental noise. At the same time, the final mass form resembles a ladder north-facing. It aims to optimize PV panel utilization (figure 10).

Figure 9. SLIC roof shape

Use the gap between masses as an atrium, vertical circulation, utility, and toilet. The lobby area tends to be a circulation space and accommodate the short-term activity. These potentially increase cooling load due to air leaks and the need to condition huge volumes. Therefore, recommend these spaces for using natural ventilation coupled with mechanical ventilation. Thermal comfort is achieved by using voids on the third floor and opening the atrium's south, north, and east sides (figure 11).

Figure 10. Lobby and atrium using natural ventilation

Shading device

Simulation results showed annual solar radiation by the highest order are 1) roof, 2) east façade, 3) north façade, 4) western façade, and 5) south façade.

The base of shading device recommendations is solar radiation, and to reduce high solar radiation intensity, it can provide optimal shading.

Openings

The design variable is the height of the windows on the east and west sides (figure 14). Variable values will affect WWR. Range value 0.1-1.4m.

The design variable is the height of the windows on the east and west sides (figure 14). Variable values will affect WWR. Range value 0.1-1.4m.

Simulation results showed cooling energy values range from 20,920 - 30,098kWh. sDA350/50% value 49.6 - 64.2%. ASE1000/250 value 25.47 - 36.0%. It can obtain the highest cooling energy with minimum WWR and vice versa. Therefore, it is necessary to eliminate individuals using benchmarks.

Design solution selection is an individual with the lowest cooling energy value but meets the sDA350/50% value of at least 55%. The selected design is 21.6-24% for the west side WWR and

31.2-33.6% for the east side. However, this solution still needs to be modified to create an outside view.

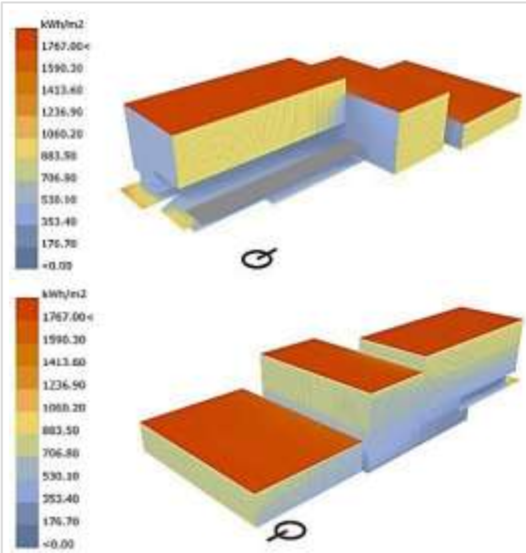


Figure 11. Annual solar radiation received by the mass form

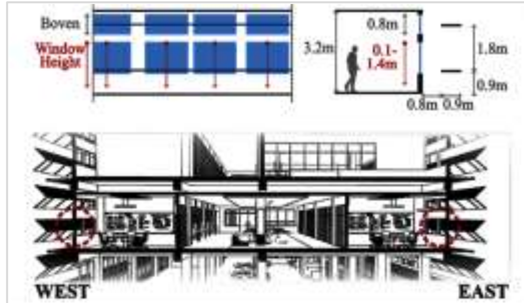
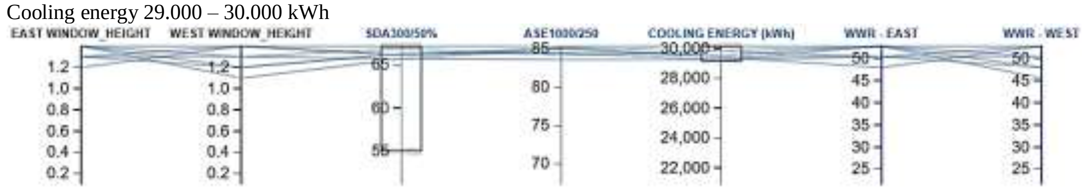


Figure 12. Design variable using window height on the east and west side of the 4th floor

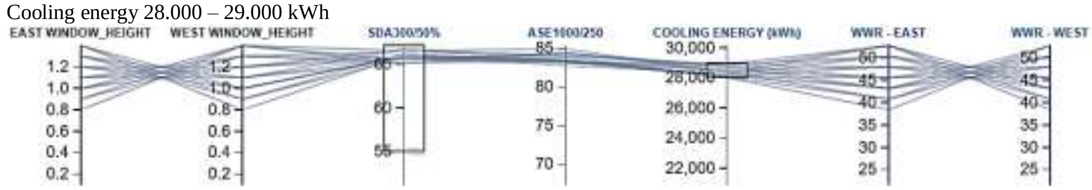
Sensitivity analysis (table 5) showed that mutual shading did not significantly lower cooling energy. The most significant factor was WWR values. Minimize the east side opening needs and vice versa to create a large opening on the west side. WWR recommendation is the west WWR smaller than the east side.

Table 5. Sensitivity analysis of WWR

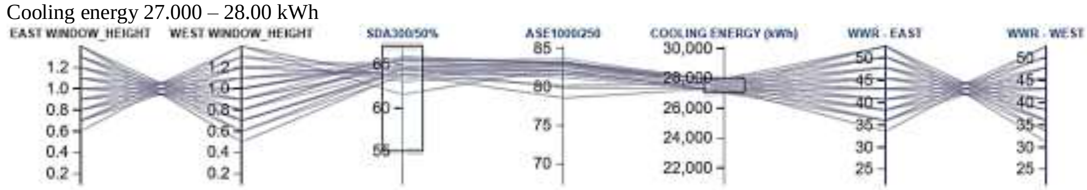
Cooling energy 29.000 – 30.000 kWh



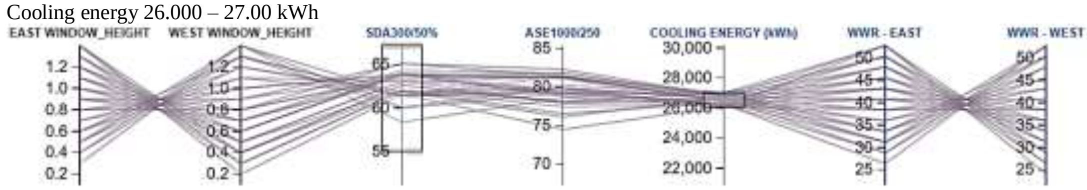
Cooling energy 28.000 – 29.000 kWh

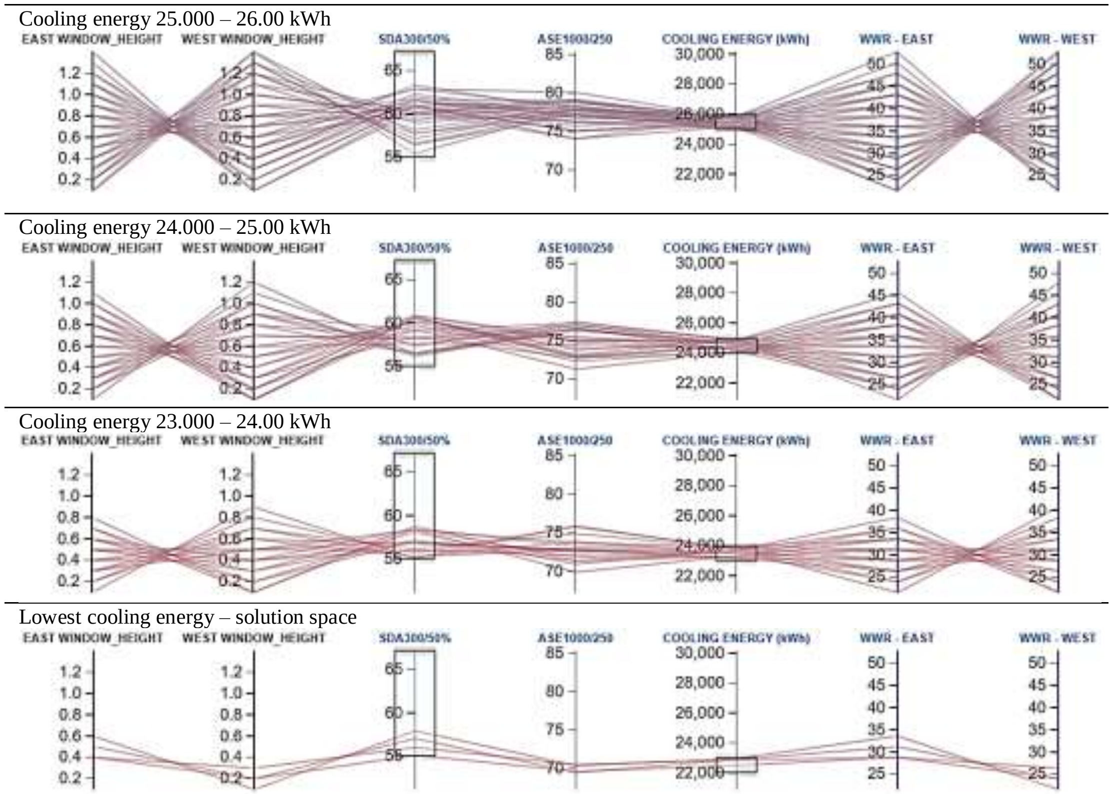


Cooling energy 27.000 – 28.00 kWh



Cooling energy 26.000 – 27.00 kWh





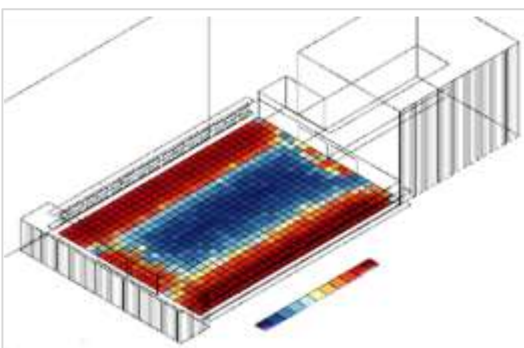


Figure 13. Performance of recommended WWR

Benefit and constraints of BPS integration

In the curriculum, the weight of architectural design learning is greater than the building performance system. Based on the BPS integration process, the benefit is improving the understanding of building performance behavior according to design variables. BPS utilization for undergraduate students can help in considering design decisions. So, it becomes more guided than not using BPS. However, this is with a note that should do the simulation process and methods correctly.

Figure 14 shows the understanding of building performance and the need for BPS from the initial stage to the end.

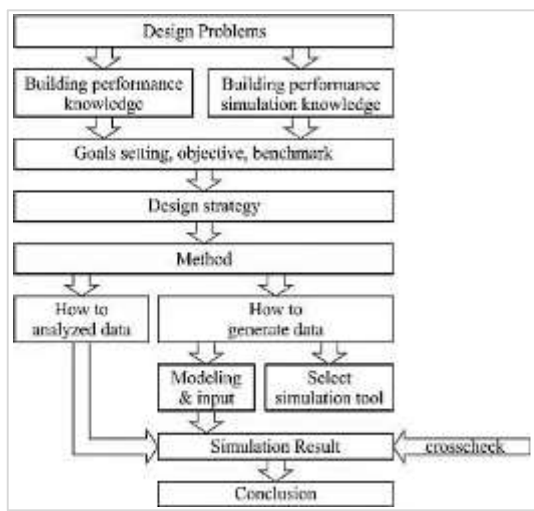


Figure 14. Workflow to utilize BPS

BPS is about modeling building systems that resemble actual conditions as much as possible. The simulation results cannot match the real conditions precisely due to modeling simplification. In addition, the misuse of building performance testing methods can result in incorrect understanding or conclusions. Therefore, experience building performance systems, testing methods, and simulation methods are essential to obtaining BPS benefits in the design process.

Building performance learning outcomes for undergraduate level architecture focuses on introducing the basic theory and general practical strategies. The student's knowledge and experience are insufficient to test building performance when design problems are already complex or require precision results. Enforcement of the use of BPS in the design process can waste time and lead to misunderstandings. However, BPS utilization can be helpful if used as a demonstration tool to help understand the basic theory of building performance, help understand macro-climatic conditions, and test simple problems. While the technique and the selection of simulation tools affect the ability of students to produce valid data.

Utilisation Sefaira can only apply one material to one type of surface. The parametric method using ladybug and honeybee plugins can perform more detailed simulations. However, the use of two different software can cause incoherent data input.

The obstacle to utilizing the parametric method is that users need to develop their formulas and requires a deep understanding of building performance and how simulation tools work—the more detailed the simulation tool, the more attention to the utilization procedure. Therefore, for the undergraduate level, it is better to use BPS, which is easy to use. However, it can still use parametric methods for simple cases like solar radiation simulations and daylighting simulations that do not require detailed input.

The obstacles encountered by the author in the case study design process were:

1. BPS utilization becomes challenging to implement for a complex problem.
2. Learning outcomes aim to teach the basic theory of building performance so that utilizing BPS to test complex design strategies becomes difficult.
3. Time availability will determine the simulation method and the level of detailed information generated.
4. The availability of valid data can affect the designer's confidence in the simulation results.
5. User-friendly software is more recommended.
6. The test method used needs to consider the scientific level of undergraduate students.

Conclusion

The finding of this paper is that BPS utilization in the design process can assist designers in considering strategic design decisions when the problem is simple or aims to study climatic conditions. When the design problem is complex or requires detailed simulation, BPS utilization in the design process becomes more complicated so that the potential for simulation errors is more significant. As a result, the simulation results cannot be used or can even give a wrong understanding of the designer are not checked the results.

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MD Krisna Adya Anindita contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

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