Sensitivity Analysis of Designs of Row House Planning Influencing on Local Microclimate and Building’s Cooling Energy Consumption in A Tropical City

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Abstract. This study aims to investigate the impact of design characteristics of row house projects on outdoor thermal conditions and the building’s cooling energy consumption. The studied parameters comprise the design combinations of four street canyon orientations, building-two block shapes, four street canyon’s aspect ratios (H/W), and two window to wall ratios (WWR). The study firstly performs the simulations of air temperature and mean radiant temperature across the street canyons via using ENVI-net modeling. The simulated air temperature is used as input in energy modeling to calculate cooling energy consumption in a residential unit. The Standardized Regression Coefficient (SRC) obtained from the multiple regression analysis is used to determine the significant design parameters influencing on outdoor air temperature, mean radiant temperatures, and building’s cooling energy consumption. It is found that the increase of H/W has a positive effect on both outdoor conditions and building energy consumption. At the same time, the impact of street canyon’s orientation and building-block shape on those issues shows an invert direction. Future studies should investigate how to optimize the design for achieving better outdoor thermal conditions and building energy efficiency.

1. Introduction
Previous studies show that the design of urban morphology can lead to urban sustainability [1–2]. It can provide benefits for both a cooling living environment [3] and building energy efficiency [4]. Several design parameters such as street canyon’s aspect ratios (referred to a ratio of building height to street width), street canyon orientations, a relation of open space and building density, surface materials have been investigated in the climate-sensitive planning and building energy analysis [5–7]. However, the effects of urban planning and architectural designs on both studied issues are not well integrated. Some design parameters could considerably improve outdoor thermal conditions, but it has the worst building energy consumption. In addition, implementing all those parameters either in the simulation or design requires a significant time effort and construction cost. This study aims to understand and investigate whether the designs of the row house projects regarding planning, building geometry, and WWR can make a contribution to improving outdoor thermal conditions as well as promote energy-efficient...
buildings. The research results can help designers having a design strategy to create a more sustainable city.

2. Research methodology

2.1. Location selection and defined case studies

This study selects Pathumthani, located in northern Bangkok, the capital of Thailand, as a studied location. This area has the highest number of housing units owing to not only there are several significant facilities supporting people living, but it is also relatively easy to travel to Bangkok. The design characteristics of row house planning in Pathumthani, observed by previous work [6], are defined into four street canyon orientations (N–S, E–W, NE–SW, and NW–SE), four aspect ratios (0.5, 0.7, 0.9, and 1.1), and two building block shape (square and rectangular). The row house typically has two to five stories with a ratio of window to wall ratio (WWR) of 20 and 80 percent. In this study, the combination of those parameters can generate 16 design scenarios for microclimate simulation and 32 scenarios for building energy analysis.

2.2. Microclimate and energy analysis

The analysis in this study separates into two parts: 1) climate-sensitive analysis and 2) building energy consumption. The study performs the simulations of hourly outdoor air temperature ($T_{air}$) and mean radiant temperature ($T_{MRT}$) via using Envi-MET model [8]. Then air temperatures near the building surface of each design scenario are averaged and used to initiate the weather data for the energy analysis using the eQUEST model [9]. A peak cooling energy consumption in the unitary floor area (Wh/m$^2$/day) of a residential unit on April 26th, 2016, is calculated. The setting of the simulation model of microclimate analysis and building energy consumption are validated and compared with the field measurement and a case study from previous works [6,10].

2.3. Sensitivity analysis

For sensitivity analysis, the multiple linear regression analysis is used to examine the influential design parameters, which remarkably impact the peak cooling energy consumption. Initially, the discrete parameters, especially street canyon orientation and building block shape, have to transform into dummy variables with 0/1 coding. The study uses a standardized regression coefficient (SRC) to rank the significance of independent variables influencing independent variables. The SRC value ranges 0–1, which the value close to 1 represents the most substantial influential variables on the outputs. The SRC can be a negative value, which means the relationship between the variables has an invert direction. Finally, the influential design parameters considerably impacting on building cooling energy consumption, and outdoor thermal conditions are compared and discussed. Figure 1 summarizes the research framework of this study.

![Figure 1. Research framework](image)
3. Results and discussions

3.1. Simulations of outdoor thermal conditions

From the simulation results, the average $T_{air}$ in the street canyon with different design configurations has a similar performance (shown in figure 2(a)). Increasing the street canyon’s H/W improves the outdoor air condition slightly by up to 1%. With regards to the mean radiant temperature (in figure 2(b)), the average $T_{MRT}$ in the street canyons with a square block shape and that of the rectangular block shows a similar performance. For a square-shaped building, the maximum $T_{MRT}$ occurs in the N–S and E–W oriented canyons while the maximum $T_{MRT}$ of the rectangular-shape building happens in the E–W orientation. Design with a rectangular-shaped building can lessen $T_{MRT}$ in the N-S oriented canyons, in which the temperatures are lower than that of the canyons with a square-shaped one by 11–19 percent. Overall, an increase of street canyon aspect ratios from 0.5 to 1.1 significantly reduces the $T_{MRT}$ by approximately 19 percent in most orientations except the E–W oriented canyons.

![Outdoor Air Temperature](image1)

![Mean Radiant Temperature](image2)

**Note:** For the code for 4_0.5_20, the first number represents building block shape; 4 is a square shape, and 10 is a rectangular shape. The second letter represents H/W, and the third is the WWR.

**Figure 2.** The simulations of average outdoor air temperature (a) and mean radiant temperature (b) across the street canyons for various design configurations

![Peak Cooling Energy Consumption](image3)

**Figure 3.** The simulations of the peak cooling energy consumption in the row house unit for various street canyon configurations

3.2. Calculated cooling energy consumption in a residential unit
Figure 3 presents the simulation results of cooling energy consumption in a residential unit. The row houses in the N–S oriented canyons have the highest cooling energy, while those in the E–W oriented canyons consume the lowest cooling energy. The cooling energy consumption increases as the WWR increases. The decrease of WWR significantly reduces the cooling energy consumption more than that by the increase of H/W.

3.3. Sensitivity analysis

Figure 4 presents the rank of the SRC value of each design parameter. There is a high correlation among those design parameters with the output parameters. All models have the p-value below 0.05, and the adjusted R-square values range from 0.534–0.731. The priority ranking of the influential design parameters on the \( T_{air} \) shows similar to those of \( T_{MRT} \). The change in H/W has the highest correlation to the \( T_{air} \) and \( T_{MRT} \) (SRC = 0.619–0.759) followed by street canyon orientation (SRC = 0.282–0.330), and building-block shape (SRC = 0.196–0.230), respectively. In the climate-sensitive analysis, WWR is not accounted for as an independent design parameter according to this research scope.

![Standardized Regression Coefficients (SRC)](image.png)

**Figure 4.** The SRC values determining the influential design parameters on the outdoor air temperature, mean radiant temperature, and peak cooling energy consumption.

Regarding the building energy analysis, the change in WWR considerably impacts the residential cooling energy consumption with the SRC=0.567, followed by building-block shape (SRC=0.520), H/W (SRC=0.355), and street canyon orientation (SRC=0.185), respectively. The WWR shows a positive correlation with the building’s cooling energy consumption. It means that the building with higher WWR is more cooling energy consumption than that with lower WWR.

According to the sensitivity analysis, the increase of H/W could improve the outdoor thermal condition and reduce residential cooling energy consumption. However, the design of street canyon orientation and building-block shape show an invert effect on improving outdoor thermal conditions and building energy consumption. The N–S oriented canyons provide a better outdoor thermal condition than that of the E–W oriented canyons; however, the residential unit located in this orientation consumes the highest cooling energy. The energy consumption in the canyons with the rectangular block e is lower than that with the square block, while it has the worst outdoor thermal conditions.

4. Conclusion

In this study, a multiple regression method is used for assessing the set of design parameters, which make a significant contribution to cooling energy consumption in a residential unit and its impact on the outdoor air temperature and mean radiant temperature across a street canyon. Regarding the climate-sensitive analysis, the design of street canyon configurations has a significant effect on \( T_{MRT} \) across the street canyon, whereas those designs affect \( T_{air} \) slightly. The increase of H/W could provide the benefits for both outdoor thermal environment and residential energy efficiency while the design of street canyon’s orientation and building-block shape give opposite results. The most significant design parameter influencing the building cooling energy consumption is WWR, whereas the H/W has the most impact on the thermal condition. For future studies, those design effects on building energy use and cooler outdoor environments for more complex urban forms should be investigated. To find the design
solutions for a sustainable city, future studies should investigate and optimize the best solution enhancing both outdoor thermal condition and energy efficiency.

5. References

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