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Efficient Envelope Designs to Maximize Cooling Energy Savings in Housing Complexes in Bangkok Neighborhoods

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ABSTRACT

Architectural design can significantly improve home energy-efficiency. New energy-saving techniques are regularly proposed; however, integrating all design parameters into the energy simulation specific knowledge and is time-consuming, making it difficult for non-experts in building energy analysis. This present study investigates the impact of envelope designs on household cooling energy consumption in housing complexes located in Bangkok neighborhood areas. The study selects a representative house and identifies a range of envelope designs, including thermal properties of exterior walls and roof, painted color, length of roof eaves, and window-to-wall ratio (WWR). The Latin hypercube method randomly generates two hundred sets of design scenarios based on those design parameters. The eQuest model is used to perform analysis of household cooling energy consumption for four orientations, and the simulation results are validated. The standardized regression coefficient (SRC) is used to determine a strong correlation between design parameters and cooling energy consumption in detached houses. The results reveal that improving a window’s solar heat gain coefficient (SHGC), wall painted color, wall u-value, and length of roof eaves could reduce energy consumption by up to 19.7 percent. The WWR and building orientation were found to have only a small impact on household cooling energy consumption, especially for a square-shaped house. The results provide designers and non-professional a simple design guideline to improve the energy efficiency of their home designs.

Keywords: multiple regression analysis, sensitivity analysis, building energy simulation, cooling load, detached house

INTRODUCTION

Electricity is an essential service in our daily living and national economy. The Intergovernmental Panel on Climate Change, IPCC (IPCC, 2007) stated that electricity consumption in buildings accounts for 40 percent of the world's total energy consumption. According to the national energy report (Energy Policy & Planning Office, 2019), Thai households accounts for 24 percent of electricity consumption, ranking in the top three of primary energy consumers. Electricity consumption in Bangkok metropolitan areas rapidly increases every year (Chaisinboon, 2014). This increment positively correlates with the increase in single-family houses in housing complexes, which grew by 2.3 – 2.7 percent from 2010 to 2013 due to urbanization (Chaisinboon, 2014; Cox, 2017). Air conditioning units for cooling the living environment are necessary for most Thai houses, especially in big cities. Household cooling accounts for 16.9 to 70 percent of the total energy consumed (Arifwidodo & Chandrasiri, 2015; Chungrakkiat & Clarke, 2011; Sudprasert, 2019; Katili, Boukhanouf, & Wilson, 2015). The Department of Alternative Energy Development and Efficiency, DEDE (2019) reported that household energy consumption had increased 5 percent annually due to air conditioning overuse. Higher energy consumption in Bangkok results in increased outdoor air temperature associated with climate change. In line with this concern, DEDE (2019) has drafted new energy-saving targets for new residential buildings constructed between 2020 and 2024. That target aims to limit energy use to less than 25 kWh/m^2-year in single-family houses, and 54 kWh/m^2-year for row houses and semi-detached houses. Several design techniques and highly energy-efficient appliances are recommended, such as: 1) the roof eaves of at least 2m. in length to shade the building envelope from direct solar radiation, 2) high-sloped roofs (30-35 degree) with insulation installed above the ceiling, 3) high performance glazed windows, 4) increased cross natural ventilation, and 5) highly energy-efficient home appliances.

With respect to the design of energy-efficient buildings, several design techniques, including providing shade, lowering the WWR, insulating building envelopes, and building orientation have been investigated in building energy analysis. According to the reviews, the proposed significant contributions to home energy consumption vary depending on climate conditions, building characteristics, and types of studied parameters. Previous studies performed sensitivity analysis and found that shading effect and WWR are significant contributors to reduction of home energy consumption (Zhao, Künzel, & Antretter, 2015; Hou, Liu, Yang, Lui, & Qiao, 2017). However, other studies have shown that adding wall insulation could make a significant impact on reducing energy consumption (Zhao et al., 2015; Hou et al., 2017; Delgarm, Sajadi, Azarbad, & Delgarm, 2018; Pathirana, Rodrigo, & Halwatura, 2019; Spitz, Mora, Wurtz, Jay, 2012). Weather condition and air infiltration were found to be dominant parameters on household heating energy demand in a Mediterranean city (Rodríguez, Andres, Muñoz, López, & Zhang, 2013), and these factors have significant influence on cooling energy consumption in buildings with thermally massive structures (Al-Saadi & Al-Jabri, 2020). Furthermore, Silva & Ghisi (2014) reported that the specific heat of wall materials greatly influences cooling and heating energy in different seasons.

Regarding household energy analysis in Thailand, energy simulation is typically performed with one or two specific building case studies. Envelope design, especially wall materials and window characteristics, have been widely investigated (On-ngam, 2011; Taepipatpong, 2010; Tubtimthong, 2010; Sudprasert, 2018; 2019). Studies on the effect of building orientation and painted wall colors on the energy savings are few (Sudprasert, 2018; Taepipatpong, 2010). Sudprasert (2018) discussed methods for improving envelope thermal properties to prevent heat gain through the building envelope of two detached houses in housing complexes. The study showed that adding roof insulation could significantly reduce cooling energy consumption compared to reductions from an increment of wall thermal resistance. However, investigations in previous studies have suggested that higher performance of window materials is the most dominant factor in household energy consumption, followed by insulated exterior walls and ceilings (Sethabutra & Chindavanik, 2007; Sudprasert &

Sakdawattananon, 2018; Taepipatpong, 2010). These results deliver similar findings to those from previous studies (Zhao et al., 2015; Hou et al., 2017; Shabunko, Lim, & Mathew, 2018). Based on the literature review, it is clear that the recommended designs for achieving maximum energy savings propose different savings results. This may be because the building characteristics accounted for in studied design parameters and variations were limited. The representative buildings and variation in architectural designs of single-detached houses should be investigated to reduce the uncertainty that currently exists about the impact of specific design features on energy efficiency.

Regarding the impact of Thai homeowners' activities on energy savings, they were found to be based on people's experiences and understanding (Jareemit & Limmeechokchai, 2017, p. 247–252; Yoshida, Manomivibool, Tasaki, & Unroj, 2020). Most Thai homeowners lack even a background knowledge of heat transfer and have no experience in building simulation analysis; for this reason, an evaluation of energy savings performance requires an energy modeling specialist. As a result, it is difficult for most homeowners to understand how to achieve maximum savings without technical assistance. Jareemit & Limmeechokchai (2019, p. 328–335) made it clear that homeowners were interested in improving their homes to reduce cooling energy consumption. However, their investigation found that the savings performance from those improvements was less than what the homeowners expected. Previous studies (Wolfe, & Hendrick, 2012; Thampanishvong, 2015; Khan, 2019; Laicane, Blumberga, Blumberga, & Rosa, 2015) had shown that household energy savings can significantly improve after homeowners are trained and learn about energy efficiency. Given their concerns, identifying dominant savings approaches should help homeowners considerably decrease household energy consumption with low investment.

This research investigates the priority ranking of influential design parameters on household cooling energy consumption in Bangkok. The study selects a housing complex as the studied location. The resulting proposed design guidelines should assist homeowners in making the best decisions about designs to improve their homes' energy efficiency. The research findings should significantly contribute to cooling energy reductions and cost savings in Thai households.

RESEARCH METHODOLOGY

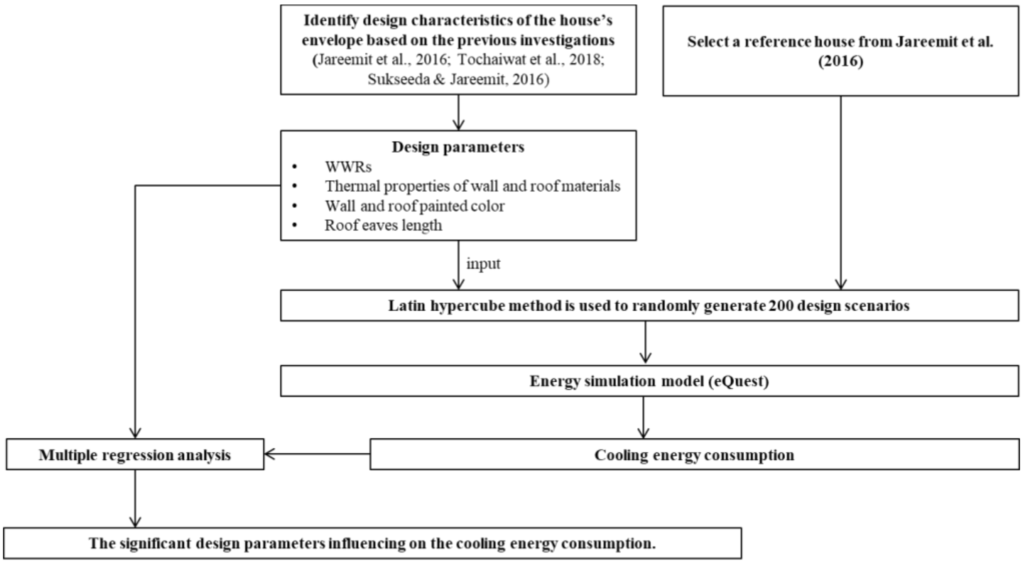
This study's methodology was to first select a reference building from the previous work (Jareemit, Inprom, & Sukseeda, 2016) for use in the cooling energy simulation. The study's research framework of the impact of the significant design parameters on the household cooling energy consumption is presented in Figure 1. Detailed information on the defined representative building, setting design scenarios, building energy simulation, and sensitivity analysis is described in this part.

Building case study

In this study, the representative house from the previous work Jareemit et al. (2016) is used for the building case study. Jareemit et al. (2016) investigated the building design characteristics of detached houses from 167 housing complexes constructed from 2013 to 2015. Those houses are in Bangkok neighborhood areas that include Pathum Thani, Samutprakarn, Bangbauthong, Bangna, Nontaburi, and Nakornnayok. In that study, the house areas ranged from 96 - 297 m^{2,} with an average value of 145 m^2 (s.d. = 36.8). The houses' width ranged from 7.8 – 8.0 m., and length from 9.0 - 9.2 m. From that investigation, two house layouts, comprising three bedrooms and three bathrooms, were found in 328 houses, accounting for 68 percent of the investigated houses. The design characteristics of those houses, including room area, room dimension, WWR on each building façade, air infiltration, building materials, and length of roof eaves, were measured and compared. These design parameters varied depending on the architectural design concept and image of the housing complex. Finally, the study provided the mode values and distribution ranges of the architectural designs observed from the detached houses in Bangkok neighborhood. Detailed information on the building design and defined design parameters for this study is presented below.

Figure 1

Framework of investigating the significant design parameters on the building's cooling energy consumption.

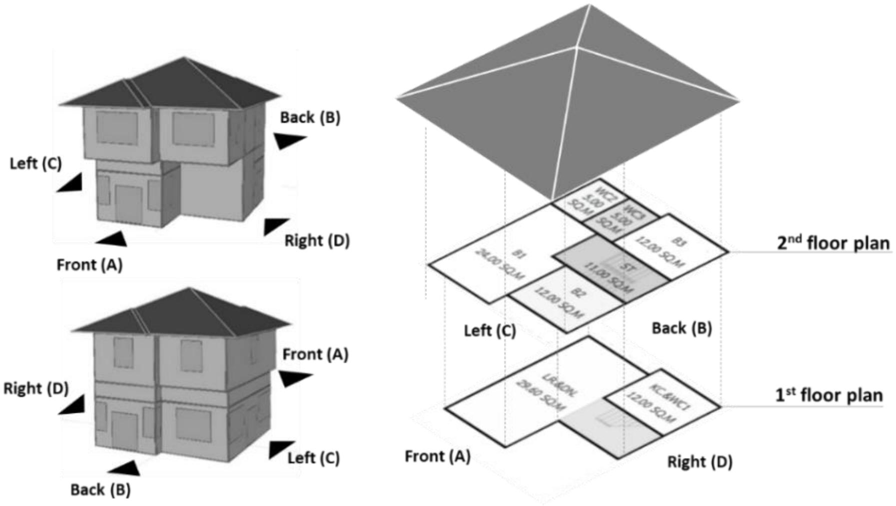


Building design

Figure 2 presents the studied house, and its layout, used in the energy analysis. The house has a square shape with two stories comprising a living room, dining room, and kitchen on the first floor, while the second floor has three bedrooms and two toilets. The mode values of the room areas and dimensions (shown in Table 1) from the investigation by Jareemit et al. (2016) were used to establish the studied house. This building design is typical of roughly half of the detached houses in housing complexes in Bangkok neighborhood areas.

Figure 2

The model of the studied house and typical floor plans of the house (Number of surveys N=328)



Note. (A) Front façade; B) Back façade; C) Left façade; D) Right façade.

Table 1

Type of rooms and the room areas of the studied house (Number of surveys N=328)

1st floor plan			2nd floor plan		
Room	Area (m^2)	Dimension W(m) x L(m)	Room	Area (m^2)	Dimension W(m) x L(m)
Living room	17.6	6 x 2.9	Master bedroom	24	4 x 6
Dining room	12	4 x 3	Bedroom 1	12	3 x 4
Kitchen	8	4 x 3	Bedroom 2	12	3 x 4
Toilet	4	2 x 2	Toilet	10	2.5 x 4

Sensitivity analysis

Sensitivity analysis has been widely applied in building energy analysis to identify the influential variables affecting building energy consumption (Saltelli, 2002). To perform sensitivity analysis, four steps should be followed: 1) identifying input variations, 2) setting the energy model and running the simulation, 3) performing sensitivity analysis (determining the effect of input variations on the simulation results), and 4) reporting sensitivity analysis results (Tian, 2012). Two approaches -- local and global analysis -- are typically used in the sensitivity analysis. The global analysis can provide more reliable results than the local method due to the large number of sampling iterations. The steps towards sensitivity analysis described below.

Sets of input parameters in energy simulations

A range of input variables is required to assess the impact of design parameters on cooling energy consumption via sensitivity analysis. Table 2 presents the distribution ranges of WWR on each building façade, architectural design parameters, and thermal properties of building materials of the investigated houses (Jareemit et al., 2016; Tochaiwat, Kulintonpraserb, Jiraprasertkun, & Yang, 2018; Sukseeda & Jareemit, 2019). The WWRs on the front façade are relatively larger than those of the other sides; the WWR ranges from 5 to 60 percent, with an average value of 33 percent. The back façade of the house has the smallest WWR range (average value of 18 percent). The length of the roof eaves of investigated houses ranges from 0.8 to 1.2 m. The WWR and eaves length have a continuous distribution with small multiple numbers. Consequently, in this study, the maximum, minimum, and average values of WWR and roof eaves length are calculated.

Examining the distribution range of materials' thermal properties in housing complexes is based in a different concept. Since the data set comprises a noncontinuous distribution, the mode value is used to define the range. The building materials -- brick, lightweight cement blocks, and pre-cast concrete (u-value varying from 2.60 to 5.07 W/m^2.K) -- are commonly used for the wall construction system in housing complexes, as observed from Tochaiwat et al. (2018) and Sukseeda & Jareemit (2019). The wall construction for the internal zone is a masonry system (u-value = 2.6 W/m^2.K). The roof materials are clay roof tiles with installed thermal insulation (u-values ranging from 0.16 to 0.49 W/m^2.K). The exterior walls are painted with light earth tone (ex. Ivory, Pearl, and Cove Blue) to dark grey color, representing high solar absorptance, ranging from 0.4–0.9 (Dornelles, Roriz, & Roriz, 2007). The SHGC values of glazed windows commonly found in the houses are 0.28, 0.62, 0.70, and 0.8.

Table 2

Uncertainty distribution of design parameters used in the sensitivity analysis

Parameters		Unit	Distribution range			Sources
			Max	Min	Average	
WWR (Number of surveys N=328)	A1	percent	39.0	27.0	33.0	Jareemit et al. (2016)
	A2	percent	42.1	24.1	33.1	
	B1	percent	28.6	15.6	22.1	
	B2	percent	19.2	7.2	13.2	
	C1	percent	12.3	4.3	8	
	C2	percent	29.3	15.1	22.2	
	D1	percent	41.9	26.7	34.3	
	D2	percent	17.2	6.2	11.7	
Roof eaves lengths		m	0.8, 1.0, 1.2			Tochaiwat et al., (2018) and Sukseeda & Jareemit (2019)
Wall color		solar absorptance	0.4, 0.6, 0.9			
Roof color		solar absorptance	0.4, 0.6, 0.9			
U-value of wall		W/m^2.K	2.60, 4.31, 5.07			
SHGC of glass window		-	0.28, 0.62, 0.70, 0.81			
U-value of roof		W/m^2.K	0.16, 0.26, 0.49			
Orientation		degrees	0, 90, 180, 270			

Note. For the code of WWR, A, B, C, and D represent the front, back, left, and right of the building façade, respectively. Numbers 1 and 2 after the letters A, B, C, D represent the 1st and 2nd floor of the house.

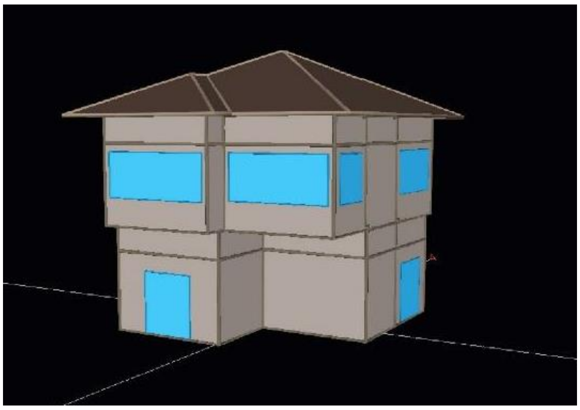
All combinations of design parameters used to perform cooling energy consumption simulation show a total of 8,748 cases for each orientation; this much analysis requires a great deal of simulation time. Therefore, in this study, a random sampling technique, namely Monte Carlo sampling, is used to reduce the large sample size in the simulation runs. The Monte Carlo is a traditional technique widely used to randomize variables based on probability distribution. It requires enough iterations to create input distribution through sampling since small sampling iterations could present errors (Goeury et al., 2015; Vorechovsky, 2010).

Latin hypercube sampling was developed from the Monte Carlo sampling; it better covers the distribution with a small sampling iteration. It could provide more accurate results as compared to those of the Monte Carlo method (Silva & Ghisi, 2014). Rodríguez et al. (2013) investigated the proper size of the sample for the Latin Hypercube and found that the sample size of 200 is big enough to produce consistent results for analysis of things like annual energy consumption (kWh). In this study, the distribution ranges of design parameters (shown in Table 1) are used to randomly generate 200 sets of model inputs using the Latin hypercube sampling via Simlab software (Simulation Environment for uncertainty and sensitivity analysis) (Tarantola & Becker, 2016). Accounting for all building orientations, 800 simulation runs of household cooling energy consumption were carried out.

This study uses eQuest modeling to perform cooling energy simulation (Hirsch, 2010). This energy simulation tool is widely used, and it provides acceptable, accurate energy results. The simulation model is performed under Bangkok weather data (National Renewable Energy Laboratory, 2016). The modeled building is stand-alone and does not have a shading effect from surrounded trees or adjacent buildings, as shown in Figure 3.

Figure 3

Setting a modeled house in the energy simulation



Operation of air-conditioning units

The total conditioned area of the studied house, including a living room, dining room, and bedrooms, is 76.6 m^2. The air conditioning unit in the living room is operated during the hours of 6 pm–10 pm on weekdays, and 8 am–9 pm on weekends and holidays. The air conditioning unit in the bedrooms is in operation from 10 pm–6 am on weekdays, and 9 pm–7 am on weekends and holidays. The air conditioners use a single zone with a DX coil split-type system. The energy efficiency rating (EER) of the air conditioners is 11, which is consistent with surveys of houses in 2015-2016.

Internal load

This study utilizes data about the number of home appliances and electric devices in detached houses in 2015-2016. It was found then that a house typically has four air conditioning units and electric fans, two televisions, and two personal computers. The internal heat sources from the home appliances and electric devices shown in Table 3 are used as energy modeling inputs. In this study, it is assumed that three people are living in the house.

Table 3

Types and number of home appliances and electric devices in a household

Type	Number	Type	Number
Air-conditioning unit	4	Television	2
Fan	4	Refrigerator	1
Laundry	1	Computer/ laptop	2
Stove/ oven	1	Microwave	1

The accuracy of simulation results is examined using Equation (1). The Mean Bias Error (MBE) is calculated to access the magnitude error between monthly cooling energy consumption from the simulation result and actual condition identified by Sudprasert (2018). The model validation of energy modeling is based on compliance with statistic criteria defined in ASHRAE guideline 14 (2002).

$$MBE = \frac{\sum_{i=1}^{n}(Actual\ energy\ consumption - Simulation)}{n} \qquad (1)$$

Sensitivity analysis simulation

Regarding the global approach, a multiple linear regression analysis is used to examine the impact of design parameters on household cooling energy consumption. The calculated cooling energy consumptions are then used to establish the regression model, as shown in Equation (2).

$$CLE = \beta_0 + \sum_{j=1}^{n} \beta_j x_j \qquad (2)$$

where CLE is the annual cooling consumption (kWh/m^2-year). β_o represents the constant value (dimensionless). β_j is the regression coefficient (dimensionless), and x_j is the design variable (dimensionless). The regression models are then validated with the energy simulation results. The R^2 is used as a statistical measure of the goodness-of-fit between the results calculated using the regression model and the energy simulation results. The order of the significant design parameters is ranked using the SRC value. The SRC values range from 0 to 1, and are obtained from the multiple linear regression analysis. The highest value shows the most substantial influence on the outputs. The coefficients can be positive or negative values: positive values indicate positive changes in the dependent variable, while negative values show an inverse relationship.

RESULTS

This study presents two significant findings: 1) the distribution range of the cooling energy consumption in Thai households, and 2) the influential architectural design parameters that achieve the highest cooling energy savings in detached houses.

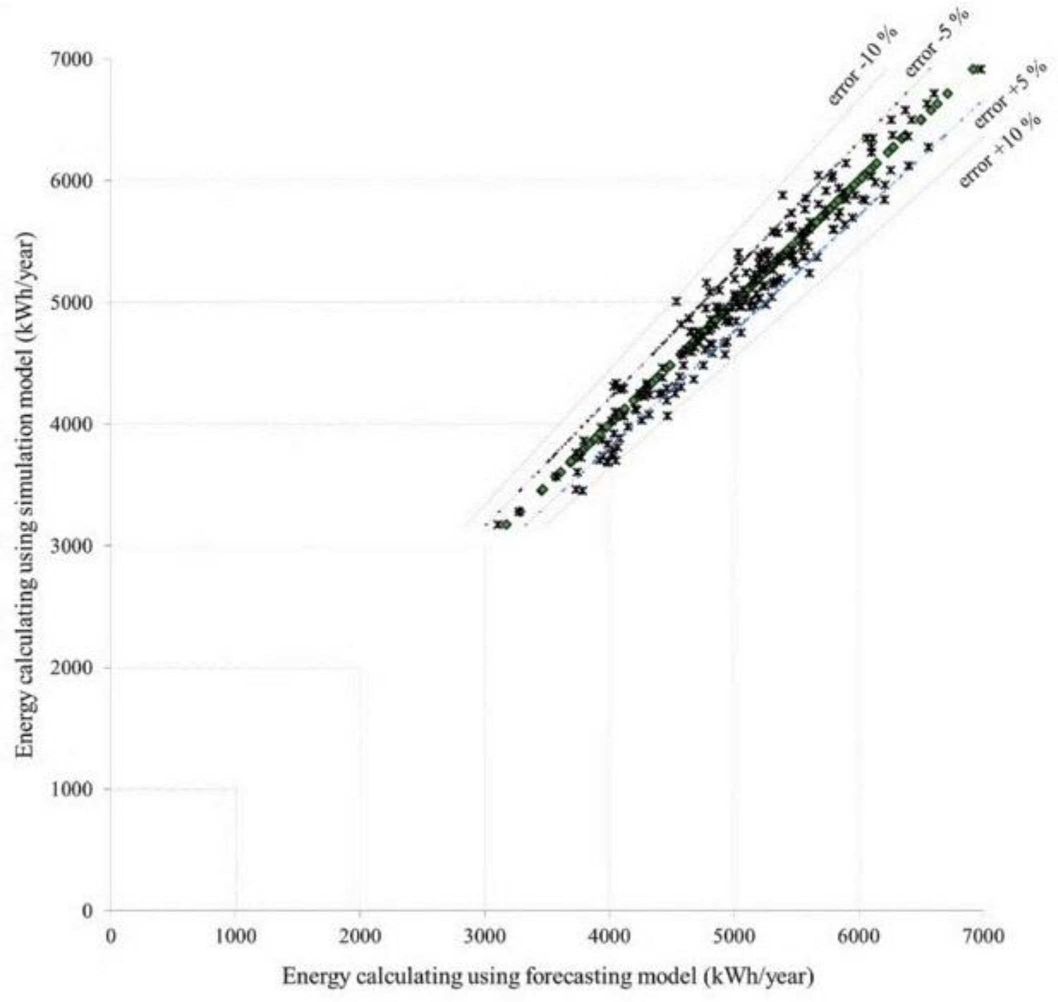
Distribution of cooling energy consumption in detached houses in neighborhoods

In determining the accuracy of energy simulation, the simulation of cooling energy consumption is compared to those of the actual operations of the selected house (Sudprasert, 2018) using Mean Bias Error (MBE). In this study, the calculated error is 14.7 percent, which is considered unacceptably high for the ASHRAE guideline 14 (2002). However, it is less than 20 percent error, defined by the International Performance

Measurement and Verification Protocol, IPMVP (Tanguay, 2021). Consequently, the simulation results are considered to be acceptable, accurate results. Regarding the model verification, the magnitude of errors of the predicted regression model and energy simulation model were examined. The calculated errors between the simulated and regression models occur within 5-10 percent, as shown in Figure 4.

Figure 4

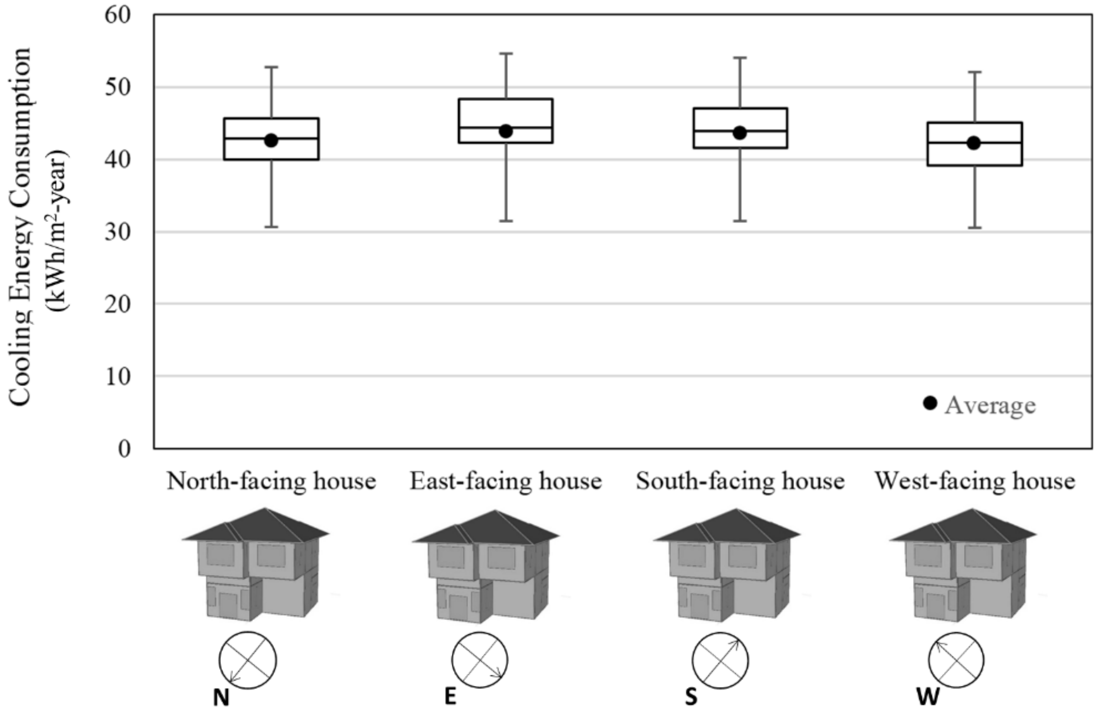
The validation of calculated results using the regression models and energy simulation results



According to the energy simulations, the household cooling energy consumption ranges from 30.7–55 kWh/m^2-year (shown in figure 5). The cooling energy consumption varies depending on building orientations, with 3.2–4.8 percent difference. The maximum cooling energy consumption, ranging from 31 to 55 kWh/m^2-year, occurs in those houses with the front façade oriented to the east, followed by those in the south-facing houses. West-facing houses consume the lowest cooling energy, with a range of 30.7–51.7 kWh/m^2-year.

Figure 5

Distributions of the calculation of household cooling energy consumptions by four building orientations



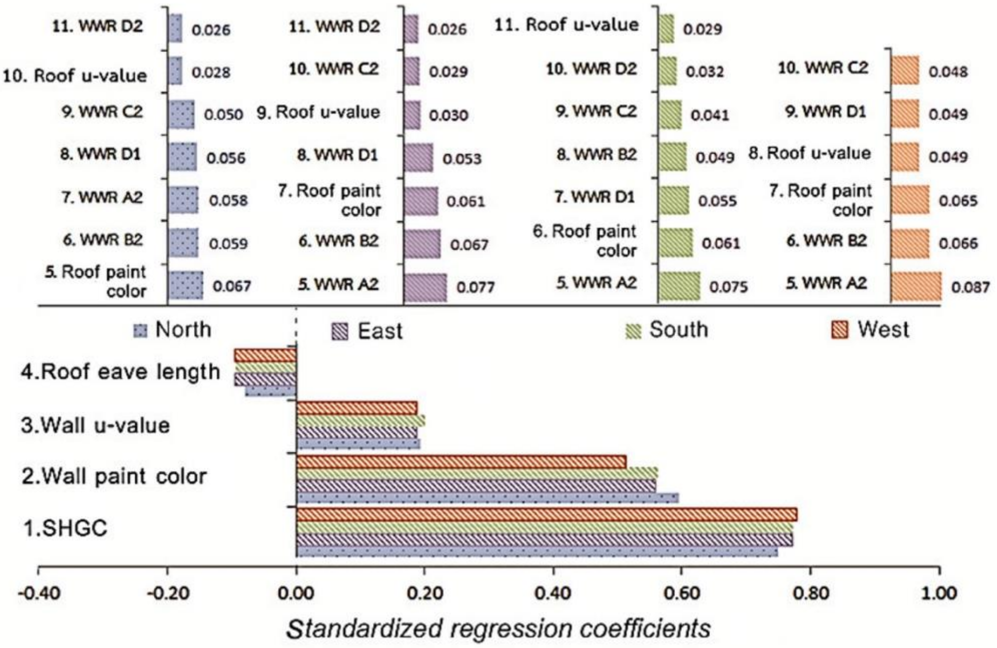
As a design to promote building energy efficiency, the long sides of the buildings should face the N-S orientation to avoid long exposure to the sunlight (Raji, Tenpierik, & Van den Dobbelsteen, 2017, p.623). As a result, the building orientation of rectangular houses has a higher impact on cooling energy consumption than square shapes. However, in this study, the building orientations had only a slight impact on cooling energy savings for detached houses because the shape of the studied house is almost square.

Influence of design parameters on cooling energy consumption

The cooling energy consumption calculated from the 200 design scenarios is ranked in order of importance using the SRC value in each orientation. Eleven design parameters of 14 input parameters are chosen as making the most significant contributions to the household cooling energy consumption. The coefficient of determination R^2 of the forecasting models ranges from 0.592–0.978 (p-value < 0.05), which shows an excellent fit to the energy simulation results. Figure 6 presents the order of the SRC values of 10–11 design parameters for each building orientation. The four most influential design parameters are the same for all building. The most influential design parameter is the SHGC, followed by wall-paint color, wall u-value, and roof eaves length.

Figure 6

Priority ranking of the calculated SRCs for design parameters by different building orientations



Note. The codes for WWR, A, B, C, and D represent the front, back, left, and right of the building façade, respectively. Numbers 1 and 2 after the letters A, B, C, D represent the 1st or 2nd floor of the house.

In this study, the SHGC is the most influential parameter for cooling energy consumption in detached houses (SRC range is 0.78–0.79). Improving window performance through lower SHGC values could considerably reduce the cooling energy consumption by 18.6 to 19.7 percent. The results are similar to those of previous studies (On-ngam, 2011; Sang et al., 2014). A lower SHGC prevents heat gain through the windows during the daytime and reduces the cooling load from removing the heat stored in the interior space during the night time (Taepipatpong, 2010).

The solar absorptance of paint color is ranked as the second most influential parameter (SRC range is 0.5–0.59). Painting the walls with a bright color (low solar absorptance value) could decrease the cooling energy consumption by 11.5–13.6 percent. This result is well-aligned with that of the previous study (Taepipatpong, 2010), showing that high reflectance of light color potentially reduces electricity consumption by 9–11 percent. The most significant reduction effect occurs in the buildings with lower WWR. Notably, the solar absorptance of the roof color becomes more influential in the north-facing houses (5th rank).

Lower u-value materials (high thermal resistance) is more effective at preventing heat transmission through building envelopes than higher u-value materials. According to the simulation results, lightweight brick as a wall material can reduce energy consumption by 4.1–4.5 percent compared to the use of mortar brick (SRC range is 0.18–0.19). In this study, the u-value of the roof materials is not ranked in the order of influential parameters. By contrast, another study revealed that adding roof insulation could provide more energy savings than adding wall insulation (Sudprasert, 2018).

According to the regression analysis, the studied house's cooling energy consumption is more sensitive to sunshade than a change of WWR. Increasing the length of roof eaves from 0.8 m to 1.2 m could reduce the cooling energy consumption by 1.86 to 2.20 percent (SRC ranging from –0.09 to –0.1). An increase in the length of roof eaves can shield against the transmission of solar radiation into the building. A previous study suggested that an overhang length of greater than 1 m. could reduce energy consumption by approximately 1.2 percent (Kittichanteera, 2010). In this study, the influence of WWR on energy consumption in different building orientations varied, depending on the amount of solar heat penetrating through the opening areas. However, it was found to have a small impact on household cooling energy use.

DISCUSSION

Based on the sensitivity analysis, architects and engineers should take protection against heat gain through design of the building envelope into consideration when planning construction of single-family houses. In this study, four significant design features such as increased SHGC values, high thermal resistance in wall materials, length of roof eaves, and light paint color on external walls were found to considerably reduce the cooling energy consumption in detached houses in housing complexes. Sudprasert (2018) revealed that heat transfer through the roof significantly contributes to cooling energy consumption in housing complexes. Adding roof insulation has been found to save more energy than installing wall insulation by 10-11 percent. However, the study's result agrees well with the findings of other studies (Sethabutra & Chindavanik, 2007; Taepipatpong, 2010). Using a high-performance window is the most significant factor in reducing cooling energy use, followed by installation of wall insulation.

Regarding the effect of variations in WWR, in this study, WWR has a slight effect on cooling energy consumption compared to SHGC, light paint color on external walls, u-value of wall building materials, and length of roof eaves. These findings provide different conclusions compared to previous studies (Hou et al., 2017; Spitz et al., 2012; Pereira et al., 2014). They revealed that decreasing WWR could lead to a considerable savings in a building's energy consumption. It might be that the distribution of WWRs on each building façade in this study has a small and similar range. When performing the energy simulation, a slight change in WWR was found to have little effect on cooling energy use. A larger distribution of WWR values might possibly prove a more significant effect.

Furthermore, the impact of orientation on building energy consumption is a major consideration in the previous analysis (Raji et al., 2017, p.623). However, it is small when the detached house has an almost square shape combined with a similar range of WWR on each façade. A rectangular-shaped building with a large WWR on the large façade could show a significant impact.

The distribution range of input variables and initial setting values in the energy model considerably impacts significant parameters on building energy efficiency. Significant savings occur in some design parameters such as u-value and paint color owing to the fact that these parameters have large differentials between the maximum and minimum values. In this study, improving roof insulation has a small impact because high-performance insulation is used in the model setting. Making improvements to a house that has a similar layout and design variables as defined in Table 2 should provide the maximum benefit of this research, while results could vary significantly if these approaches are implemented in houses with different designs.

In this study, the calculated cooling energy consumption from the studied houses was higher than 25 kWh/m^2-year as required for an energy-efficient house (DEDE, 2019). Notably, Tantasavasdi and Inprom's investigation (2019) revealed that façades of detached houses could dramatically change in the near future with larger glazed windows and darker colored walls. This design trend could result in an increase in cooling energy use. Better design integrated with high-performance systems, such as high EER of air conditioning unit and energy-efficient appliance, might reduce household cooling energy consumption and achieve that new saving target.

CONCLUSION

Understanding and learning how to use an energy simulation model is difficult for people without technical expertise. With this limitation, homeowners can easily make a misguided decision for home improvement, leading to less energy efficiency. Simple techniques that can provide people with knowledge of efficient envelope designs for maximum energy savings need to be investigated. This paper investigates the influence of envelope design parameters on cooling energy consumption in 328 detached houses in 167 housing complexes located in Bangkok neighborhood areas. The representative house and design variation of building components are identified from those existing conditions. The sensitivity analysis is used to assess the most influential design parameters on household cooling energy consumption. It is found that cooling energy consumption in detached houses ranges from 30.7 to 55 kWh/m^2-year. The parameters that result in a variation in household energy use in different orientations are few. East-facing houses consume more cooling energy than other orientations, whereas west-facing houses consume the least cooling energy. In order to achieve maximum savings of up to 19.7 percent, glazed windows need to be upgraded with a lower SHGC value. Furthermore, painting the exterior wall with light colors can reduce energy use by 13.6 percent. Finally, changing the WWR has a small impact on the cooling energy consumption owing that the distribution of design variation is small compared to those of other parameters.

In this study, the analysis of household energy performance does not account for the shading effect from adjacent buildings and trees. However, those factors have been mentioned as being responsible for a significant reduction of heat gain through the building envelope. These factors need further investigation. In addition, the information of representative house and thermal properties of materials used in the sensitivity analysis was collected from houses built in 2013–2015. At present, materials with improved thermal properties have been developed for better performance than those used in this study. Significant design parameters on energy consumption and its potential savings for newly constructed houses require further analysis and updating.

The research results can provide non-expert people and homeowners an effective design approach for improving home energy efficiency. Of course, improving building energy efficiency through the design of building envelopes results in high construction costs. For this reason, the government should identify and initiate campaigns or promotions that encourage people to utilize these recommended guidelines to achieve maximum energy-saving benefits.

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