Review Article: Significant Parameters in Building Energy Simulation
ตัวแปรสำคัญสำหรับการจำลองพลังงานในอาคาร

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Abstract

A simulation model has been widely used to investigate and predict the energy performance of buildings. However, to achieve more accurate energy result, the input data in the simulation model should be obtained from field measurements. Collecting field measurements is a very time intensive activity. With this limitation, in this work we summarized results of parameters most influential on energy results from 44 papers performing energy simulation model for determining the potential of energy saving and improving the model accuracy in various building types including offices, single rooms, homes, multi-family buildings, and other commercial buildings. It is found that the parameters with influence on energy performance were dissimilar to the parameter that the modelers used for adjusting the model accuracy and determining energy saving. Set point temperature had a large impact on energy results for office and home, while shading and occupancy schedule significantly impacted the energy results for multi-family building and other commercial buildings, respectively. At present, the number of sensitivity analysis related to building energy performance is limited. Future studies should increase a number of sensitivity analysis of building energy performance for different building types.

บทคัดย่อ

โปรแกรมการจำลองถูกใช้เพื่อสำรวจและคาดการณ์การใช้พลังงานสำหรับอาคารอย่างแพร่หลาย อย่างไรก็ตาม เพื่อที่จะได้ผลการจำลองพลังงานที่ถูกต้อง ตัวแปรตั้งต้นที่ใช้ในโปรแกรมการจำลองควรได้จากการวัดและเก็บข้อมูลในภาคสนาม การเก็บข้อมูลภาคสนามเป็นงานที่ละเอียดอ่อนและใช้เวลานาน ด้วยข้อจำกัดนี้ ผู้เขียนบทความได้สรุปตัวแปรสำคัญที่ส่งผลต่อการใช้พลังงานจาก 44 การศึกษาที่ใช้โปรแกรมจำลองพลังงานเพื่อศึกษาศักยภาพการประหยัดพลังงานในอาคารและเพิ่มความถูกต้องของผลจำลองพลังงาน อาคารกรณีศึกษาประกอบด้วย อาคารสำนักงาน ห้องเดี่ยว บ้านพักอาศัย บ้านพักอาศัยแบบหลายครอบครัว และอาคารสาธารณะประเภทต่างๆ จากการศึกษาพบว่า ตัวแปรที่ส่งผลต่อการใช้พลังงานในอาคารเป็นคนละตัวแปรกับที่ผู้ใช้โปรแกรมปรับเปลี่ยนค่าตั้งต้นเพื่อเพิ่มความถูกต้องของผลจำลองและเพื่อการประหยัดพลังงาน การตั้งค่าอุณหภูมิมีผลต่อค่าการใช้พลังงานมากที่สุดสำหรับอาคารสำนักงานและบ้านพักอาศัย ในขณะที่การบังเงาและตารางการใช้สอยของผู้ใช้อาคารส่งผลต่อการใช้พลังงานมากที่สุดสำหรับบ้านพักอาศัยแบบหลายครอบครัวและอาคารสาธารณะประเภทต่าง ๆ ตามลำดับ ปัจจุบันการศึกษาความไวของตัวแปรที่ส่งผลต่อการใช้พลังงานในอาคารมีจำนวนน้อยและจำกัด การศึกษาในอนาคตควรจะเพิ่มจำนวนการศึกษาความไวของตัวแปรที่ส่งผลต่อค่าการใช้พลังงานสำหรับอาคารหลาย ๆ ประเภท

Keywords (คำสำคัญ)

Energy Simulation Model (แบบจำลองด้านพลังงาน)
Input Parameter (ตัวแปร)
Sensitivity Analysis (การวิเคราะห์ความอ่อนไหวของข้อมูล)
Accuracy (ความเที่ยงตรง)
Energy Saving (การประหยัดพลังงาน)

Introduction

Energy simulation tools, namely EnergyPlus, DesignBuilder, eQuest, have been widely used for estimating building energy performance. The energy simulation model helps designers to design the physical characteristics of a building as well as make a decision for sizing applicants and ventilation components during the design phase. In addition, the simulation model also provides an understanding of energy demand, and is further used to improve overall efficiency performance of the existing buildings. At present, the accurate predicted energy simulation is becoming an essential requirement in the design document for owners and energy codes. The accurate simulation model provides well estimated the end used consumption and benefit for retrofit analysis. Typically, the energy model has been used during the design phase. There is the problem that the simulated energy results for the design phase could not represent the actual operational performance. Previous studies showed that the range of discrepancies between predicted and actual energy performance was 2%-30% (Soebarto & Williamson, 2001; Dell'Isola & Kirk, 2003; Turner & Frankle, 2008; Yudelson, 2010; Heo et al., 2012; Alangar et al., 2014; Pereira et al., 2014) and, in some case, the error was up to 100 percent (Azar & Menassa, 2012). One source of such error is due to model simplifications, especially occupancy schedule, ventilation system operation, and equipment load (Tuner & Frankel, 2008; Azar & Menassa, 2012; Alangar et al., 2014). In addition, air infiltration and natural ventilation influenced by outdoor conditions and mechanical ventilation system are usually assumed having constant operation even though these parameters vary with environmental temperature changes (Azar & Menassa, 2012; Yildiz et al., 2012). Besides the error caused from the model implications, the errors are possibly from the measurements and the error made by inexperienced modelers (American Society of Heating, Refrigeration and Air Conditioning Engineering [ASHRAE], 2009). An analysis of building energy performance is too complex since many parameters such as building information, system characteristics, plant description, and weather conditions, affect the building energy used and such information is required as input parameters in the energy simulation models (ASHRAE, 2009). Inaccuracy of modeled building information significantly results in unreliable predicted energy results as well as the estimated cost for building retrofit. To improve the accuracy of the simulated results, it is recommended using actual data measured during building operation rather than using the design data (Azar & Menassa, 2012; Heo et al., 2012; Alangar et al., 2014). However, collecting all field measurements for model input is very time intensive activity and requires field instrumentations. To achieve more accurate and reliable results using a simple energy model, this review of the literature addresses the following questions:

1) Are there any methods used to reduce the number of field measurements?

2) What parameters are typically modified for improving the model accuracy and evaluating energy saving potential?

3) What key parameters significantly affect the energy result?

This paper addresses these questions by summarizing: 1) the method used to determine an influence of significant parameters on energy results in the relevant literature, 2) the input parameters used in the energy model, and 3) the ranking of the top three parameters, which significantly influence the energy result in different building types. The objective of this review is to provide the significant parameters, which increase more accurate energy result and reduce large amount of energy consumption in different building types for future studies. The benefit of this review could save time effort for field-collected data used in the model inputs. In addition, future studies can pay attention to collecting accurate data in order to improve the quality of predicted energy result.

Sensitivity analysis and model validation

Sensitivity analysis is typically used to analyze how variables in inputs respond to model output (Saltelli, 2002; Saltelli et al., 2008). Sensitivity analysis has been widely used as a tool for model validation for determining the parameters most influential on model results and eliminating unimportant parameters (Hamby, 1994; 1995). Consequently, it can reduce the number of field measurements and guide the modelers to pay close attention to the quality of the measured data of such significant parameters. There are two types of sensitivity analysis typically used in the building performance analysis: local and global sensitivity analyses (Saltelli, 2002; Saltelli et al., 2008; Tian, 2013). Local sensitivity analysis is the simplest method, which is used to determine the impact of changes in single input parameters on the changes in outputs based on a base case (Saltelli et al., 2008; de Wilde & Tian, 2010). However, the local sensitivity analysis cannot explain the relation among input parameters if the model has more than one parameter varying at a time and there are nonlinear effects in the model. Global sensitivity analysis such as regression method (Yildiz et al., 2012), screening method (Garcia Sanchez et al., 2014), and variance-based method (Spitz et al., 2012), can examine the sensitivity for the entire parameter distribution. Therefore, the global approach is regarded as a more reliable method (Tian, 2013). However, Hamby (1995) compared several sensitivity analysis techniques and found that local and global methods provided similar rankings of the top sensitive parameters. The study suggested that sensitivity index (SI) was the easiest method, which required less knowledge of the parameter distribution and simulation time. The study showed that the SI method provided similar results as global sensitivity analysis does.

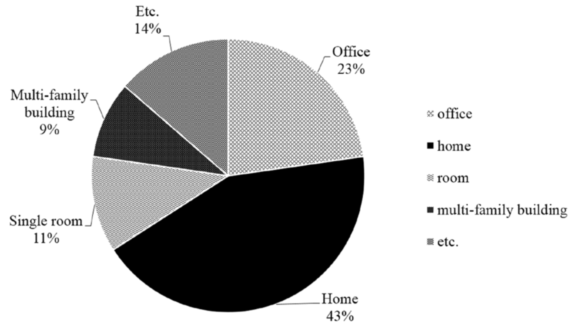
Model validation is the comparison between predicted and measured data while the model calibration is a fine-tuning method to reduce discrepancies between the simulated and measured values. To reduce time consumed by the calibration process, the significant input parameters obtained from the sensitivity analysis are then used for the fine-tuning model. At present, the model validation is required to ensure that the simulated results provide reliable information. ASHRAE Guideline 14-2002 (ASHRAE, 2002) provides the validation procedures using two statistical indices: 1) coefficient of variation of the root mean square error (CVRMSE), shown in Equation (1), and 2) normalized mean bias error (NMBE), shown in Equation (2). An acceptable error for monthly calibrated model between the predicted data, $\hat{y_i}$, and measured data, y_i, required in the Guideline 14 should be within 15% for CVRMSE and 5% for NMBE.

$$\text{CVRMSE} = 100\text{x}[\sum(y_i - \hat{y_i})^2/(n-p)]^{1/2}/\bar{y} \quad (1)$$

$$\text{NMBE} = \frac{\sum^{n}(y_i - \hat{y_i})}{(n-p)x\bar{y}}x100 \quad (2)$$

where n is the number of data points or periods in the baseline period. p is the number of parameters or terms in the baseline model, as developed by a mathematical analysis of the baseline data. $\bar{y}$ is the arithmetic mean of the sample of n observations.

The sensitivity analysis has been employed previously in the field of energy models in different building types, mostly 43% in single house and 23% in office building as shown in Figure 1. Sensitivity analysis in a single room has only been performed in 11% of the reported studies, multi-story residential building only 9%, and other building types such as institutional, commercial, and healthcare facility buildings 14%. Their purposes of using sensitivity analysis are to 1) reduce uncertainty in the simulation model (Capozzoli et al., 2009; Azar & Menassa, 2012; Aerts et al., 2014; Silva & Ghisi, 2014; Heo et al., 2015; Pereira et al., 2014; Song et al., 2014) 2) for decision making for energy saving potential and energy efficient retrofits (Carson, 1992; Lam & Hui, 1996; Westphal & Lamberts, 2005; de Almeida Ferreira Tavares and de Oliveira Gomes Martins, 2007; Capozzoli et al., 2009; Hemsath & Bandhosseini, 2015; Firth et al., 2009; Heiselberg et al., 2009; Murray & Sullivan, 2012; Masuda & Claridge, 2014; Alangar et al., 2014).



(Sources: Westphal & Lamberts, 2005; Azar & Menassa, 2012; Heiselberg et al., 2009; Capozzoli et al., 2009; Lam & Hui, 1996; Carson, 1992; de Almeida Ferreira Tavares & de Oliveira Gomes Martins, 2007; Heo et al., 2014; Hygh et al., 2012; Song et al., 2014; Masuda & Claridge, 2014; Wilde et al., 2009; Mechri et al., 2010; Murray & Sullivan, 2012; Alangar et al., 2014; Aert et al., 2014; Habara et al., 2013; Yasue et al., 2013; Malhotra & Haberl, 2006; Malhotra, 2006; Chulsukon et al., 2002; Spitz et al., 2012; Pereira et al., 2014; Blight & Coley, 2013; Guerra-Santin & Laure Itard, 2010; Silva & Ghisi, 2014; Hughes et al., 2014; Corrado & Mechri, 2009; On-ngam, 2011; Kittichanthira, 2010; Tabtimtong, 2010; Padunghus, 2007; Anonwattanakarn, 2006; Wimolwatvatee, 2004; Siribangkeadpol, 2000; Ballarini & Corrado, 2012; Yildiz et al., 2012; Chiewnantawong, 2004; Hemsath & Bandhosseini, 2015; Hopfe et al., 2011; Hoes et al., 2009; Petr et al., 2007; Taepipatpong, 2010; Malasri, 1996)

Figure 1. Percentage of implementation of sensitivity analysis in energy model categorized by building types.

Input parameters in energy model

Input parameters typically required in energy models compose of 6 categories: 1) architectural data, 2) mechanical data, 3) electrical data, 4) internal loads, 5) operations, and 6) economics (Hirsch, 2010). Table 1 provides the input parameters that the modelers in the existing studies typically adjusted for determining energy saving potential and model calibration classified by the required input parameters in energy models.

Figure 2 presents the percentages of the input parameter preferably used in the energy analyses regarding to model calibration and energy saving potential. Considering the input parameters typically adjusted in the energy model, most of the studies preferred modifying architectural data, except outer color, in the model for all building type (Westphal & Lamberts, 2005; Heiselberg et al., 2009; Capozzoli et al., 2009; Lam & Hui, 1996; de Almeida Ferreira Tavares & de Oliveira Gomes Martins, 2007; Heo et al., 2014; Song et al., 2014; Mechri et al., 2010; Murray & Sullivan, 2012; Alangar et al., 2014; Chulsukon et al., 2002; Spitz et al., 2012; Pereira et al., 2014; Corrado &

Table 1. Input parameters that the modelers typically used for modifying energy model.

Architectural data	Mechanical data	Electrical data	Internal load	Operations
- Climate and weather - Form and orientation - Roof characteristics - Ground floor characteristics - Wall characteristics - Window characteristics - Door characteristics - Window to wall ratio - Shading - Outer color - Air infiltration	- Heating and cooling equipment - Gas/ water heater and boiler - Airflow rate (mechanical)	- Lighting	- Occupancy schedule - Appliance and equipment	- Unoccupied set point temperature - After hour active HVAC operation - Lighting control - Set point temperature

(Sources: Westphal & Lamberts, 2005; Azar & Menassa, 2012; Heiselberg et al., 2009; Capozzoli et al., 2009; Lam & Hui, 1996; Carson, 1992; de Almeida Ferreira Tavares & de Oliveira Gomes Martins, 2007; Heo et al., 2014; Hygh et al., 2012; Song et al., 2014; Masuda & Claridge, 2014; Wilde et al., 2009; Mechri et al., 2010; Murray & Sullivan, 2012; Alangar et al., 2014; Aert et al., 2014; Habara et al., 2013; Yasue et al., 2013; Malhotra & Haberl, 2006; Malhotra, 2006; Chulsukon et al., 2002; Spitz et al., 2012; Pereira et al., 2014; Blight & Coley, 2013; Guerra-Santin & Laure Itard, 2010; Silva & Ghisi, 2014; Hughes et al., 2014; Corrado and Mechri, 2009; On-ngam, 2011; Kittichanthira, 2010; Tabtimtong, 2010; Padunghus, 2007; Anonwattanakarn, 2006; Wimolwatvatee, A., 2004; Siribangkeadpol, 2000; Ballarini & Corrado, 2012; Yildiz et al., 2012; Chiewnantawong, 2004; Hemsath & Bandhosseini, 2015; Hopfe et al., 2011; Hoes et al., 2009; Petr et al., 2007; Taepipatpong, 2010; Malasri, 1996)

Mechri, 2009; Kittichanthira, 2010; Tabtimtong, 2010; Ballarini & Corrado, 2012; Yildiz et al., 2012; Hemsath & Bandhosseini, 2015; Hoes et al., 2009; Taepipatpong, 2010). Few studies examined the impact of outer color on energy results for an office building (Capozzoli et al., 2009) and a single room (Malasri, 1996). For the mechanical parameters used as input data required in the energy model, most studies mainly adjusted on heating and cooling equipment regarding the system type and size. A few studies closely investigated the impact of gas/water heater and boiler on the energy results (Azar & Menassa, 2012; Wilde et al., 2009; Murray & Sullivan, 2012; Malhotra & Haberl, 2006; Malhotra, 2006 Hughes et al., 2014). The adjustment of lighting data was found in all studies (Westphal & Lamberts, 2005; Azar & Menassa, 2012; Heiselberg et al., 2009; Capozzoli et al., 2009; Lam & Hui, 1996; Carson, 1992; de Almeida Ferreira Tavares & de Oliveira Gomes Martins, 2007; Heo et al., 2014; Hygh et al., 2012; Song et al., 2014; Masuda & Claridge, 2014; Wilde et al., 2009; Mechri et al., 2010; Murray & Sullivan, 2012; Alangar et al., 2014; Aert et al., 2014; Habara et al., 2013; Yasue et al., 2013; Malhotra & Haberl, 2006; Malhotra 2006; Chulsukon et al., 2002; Spitz et al., 2012; Pereira et al., 2014; Blight & Coley, 2013; Guerra-Santin & Laure Itard, 2010; Silva & Ghisi, 2014; Hughes et al., 2014; Corrado & Mechri, 2009; On-ngam, 2011; Kittichanthira, 2010; Tabtimtong, 2010; Padunghus, 2007; Anonwattanakarn, 2006; Wimolwatvatee, 2004; Siribangkeadpol, 2000; Ballarini & Corrado, 2012; Yildiz et al., 2012; Chiewnantawong, 2004; Hemsath & Bandhosseini, 2015; Hopfe et al., 2011; Hoes et al., 2009; Petr et al., 2007; Taepipatpong, 2010; Malasri, 1996.). One of those studies additionally added an information of lighting control in the model (Heiselberg et al., 2009). The accuracy of occupancy schedule was expected the most influential parameter in the energy analyses (Westphal & Lamberts, 2005; Azar & Menassa, 2012; Heiselberg et al., 2009; Capozzoli et al., 2009; Lam & Hui, 1996; Carson, 1992; Heo et al., 2014; Alangar et al., 2014; Alert et al., 2014; Yasue et al., 2013; Spitz et al., 2012; Blight & Coley, 2013; Guerra-Santin & Laure Itard, 2010; Silva & Ghisi, 2014; Corrado & Mechri, 2009; On-ngam, 2011; Kittichanthira, 2010; Tabtimtong, 2010; Padunghus, 2007; Anonwattanakarn, 2006; Wimolwatvatee, 2004; Siribangkeadpol, 2000; Yildiz et al., 2012; Chiewnantawong, 2004; Hopfe et al., 2011; Hoes et al., 2009; Petr et al., 2007 Taepipatpong, 2010; Malasri, 1996). Besides the occupancy schedule, a few studies paid attention on the effects of unoccupied set point temperature and after hour active ventilation system on energy saving potential (Azar & Menassa, 2012; Carson, 1992; Habara et al., 2013).

Table 2 summarizes the top-three ranking for the parameters commonly used in the energy analyses, which are obtained from Figure 2. Overall, the top-three ranking for the parameters that the modelers modified in the energy model was wall characteristics, occupancy schedule, and shading, respectively. When considering specific building type, the top-three parameters, which were modified in the energy model for office building, were shading, lighting, and window characteristics, respectively. Unlike the energy analyses in home, a single room, and multi-family building, wall characteristics was the top parameter, which was adjusted in the energy model. Besides the architectural parameters discussed above, occupancy schedule was in the top-two rank for the parameters modified in the energy model for all building types, except multi-family building. Interestingly, air infiltration was expected being the most influential parameter on energy results for institutional, healthcare facility, and commercial buildings. From the paper reviews, however, it is not a guarantee that such expected parameters that the modelers modified in the energy model significantly either improve the model accuracy or increase energy saving. To ensure that such parameters certainly have a large impact on energy results, the sensitivity analysis of energy modeling input parameters for calibration model and energy saving potential should be reviewed.

Table 2. Summary of the top-three rank for the modified input parameters in the energy analyses.

Building types	1^{st} rank	2^{nd} rank	3^{rd} rank
Total	- Wall characteristics	- Occupancy schedule	- Shading
Office	- Shading - Lighting	- Set point temperature - Appliance and equipment - Occupancy schedule	- Air infiltration - Window to wall ratio
Home	- Wall characteristics	- Occupancy schedule	- Lighting control
Single room	- Wall characteristics - Occupancy schedule	- Lighting control	- Form and orientation - Climate and weather - Roof characteristics
Multi-family building	- Wall characteristics - Shading	- Roof characteristics - Window characteristics - Window to wall ratio	- Form and orientation - Air infiltration
Etc. such as institutional building, commercial building, healthcare facility	- Wall characteristics - Window characteristics - Air infiltration - Occupancy schedule	- Roof characteristics - Shading - Set point temperature - Heating and cooling equipment - Lighting	

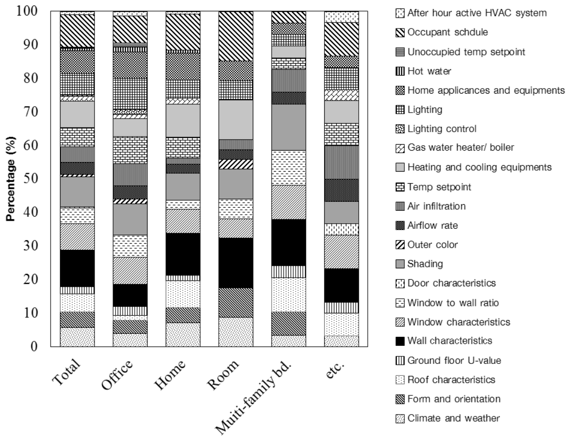


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Figure 2. Percentage of the studied parameters used in energy model input.

Most influential parameters in energy results

According to the literatures, twenty-three of the studies performed sensitivity analysis to determine the most influential parameters on building energy performance. (Westphal & Lamberts, 2005; Azar & Menassa, 2012; Heiselberg et al., 2009; Lam & Hui, 1996; Song et al., 2014; Wilde et al., 2009 Mechri et al., 2010; Malhotra & Haberl, 2006; Malhotra 2006; Spitz et al., 2012; Pereira et al., 2014; Blight & Coley, 2013; Silva & Ghisi, 2014; Hughes et al., 2014; Corrado & Mechri, 2009; Hoes et al., 2009; Petr et al., 2007; Ballarini & Corrado, 2012; Yildiz et al., 2012; Hemsath & Bandhosseini, 2015; Heo et al., 2014; Murray & Sullivan, 2012; Alangar et al., 2014). Table 3 presents the rank of most influential parameters on the energy results calculated using sensitivity analysis for each building type. According to the results from sensitivity analysis, the parameters with significantly influence energy results are diverse and dissimilar in each building type. The most significant parameters influencing the energy results for office building comprised of lighting (Westphal & Lamberts, 2005), set point temperature (Azar & Menassa, 2012; Lam & Hui, 1996), airflow rate (Heiselberg et al., 2009), occupancy schedule (Azar & Menassa, 2012), heating and cooling equipment (Song et al., 2014), shading (Song et al., 2014), window to wall ratio (Mechri et al., 2010), and air infiltration (Wilde et al., 2009). In contrast, heating and cooling equipment (Malhotra & Haberl, 2006; Malhotra 2006; Spitz et al., 2012), shading (Pereira et al., 2014), set point temperature (Blight & Coley, 2013; Corrado & Mechri, 2009), occupancy schedule (Silva & Ghisi, 2014) were the most influential parameter on home energy consumption. Window characteristics (Ballarini & Corrado, 2012), shading (Yildiz et al., 2012), and roof characteristics (Hemsath & Bandhosseini, 2015) significantly impacted on the energy used in multi-family building while occupancy schedule (Hoes et al., 2009), building form and orientation, and airflow rate (Petr et al., 2007) had a large impact on energy used in a single room. Based on this review, it is difficult to specify the most significant parameters, which impacts the energy results for specific building type. This variation may cause by 1) the sensitivity analysis performed in previous studies does not cover all parameters; 2) the case studies used in the analysis might be too specific, which cannot be a good representative for the whole building sector; 3) the number of sensitivity analysis of energy model in the existing studies is limited.

Table 3. A ranking of significant parameters influencing the energy result calculated using sensitivity analysis.

Rank	Office								Home							Single room		Multi-family building			Etc.		
	Westphal and Lamberts (2005)	Azar and Menassa (2012)	Heiselberg et al. (2009)	Lam and Hui (1996)	Song et al. (2014) (Heating)	Song et al. (2014) (Cooling)	Wilde et al. (2009)	Mechri et al. (2010)	Malhotra and Haberl (2006), Malhotra, 2006)	Spitz et al. (2012)	Pereira et al. (2014)	Blight and Coley (2013)	Silva and Ghisi (2014)	Hughes et al. (2014)	Corrado and Mechri (2009)	Hoes et al. (2009)	Petr et al. (2007)	Ballarini and Corrado (2012)	Yildiz et al. (2012)	Hemsath and Bandhosseini (2015)	Heo et al. (2014)	Murray and Sullivan (2012)	Alangar et al (2014)
1	p	l s	j	l	m	i	k	g	m	m	i	l	s	l	l	s	b j	f	i	c	p	l	s
2	f	q	o	p q	l f	l p q	p		i	f	e	q	e	m	j	m	e	j	g	e	s	n	
3	d	p	k	m			q		g	q s	f	k	i	a	s	g		g		f	k	c k	
4	c	t	s	s						i			c	b	q	i				b	m	d e f	
5	q		m	i						k			q	n		e							
f				i																			
6	s		f	j										r		p							
7	e		e i	g										e		a							
8														j									

Note: a - Climate and weather, b - Form and orientation, c - Roof characteristics, d - Ground floor characteristics, e - Wall characteristics, f - Window characteristics, g - Window to wall ratio, h - Door characteristics, i - Shading, j - Airflow rate, k - Air infiltration, l - Set point temperature, m - Heating and cooling equipment, n - Gas water heater/ boiler, o - Lighting control, p - Lighting, q - Home appliances and equipment, r - Hot water, s - Occupancy schedule, and t - After hour active HVAC system.

To simply determine the significant parameters in Table 2, this paper calculated a frequency distribution for the most influential parameters ranked in the top-two (Figure 3). The most influential parameters on building energy result for office and home was the set point temperature. Interestingly, the set point temperature was not in the top-three ranking that the modelers expectedly adjusted in the simulation model. From Table 2, shading, lighting, window, and wall characteristics were priority modified parameters in the energy model for home and office. For multi-family, commercial, institutional, and healthcare facility buildings, the significant parameters obtained from the sensitivity analyses were the same as the parameters that the modelers practically modified in the model. Shading significantly affected the energy result in multi-family building, and occupancy schedule was the most influential parameter on energy results for hotel, institutional healthcare facility buildings. Mechanical airflow, occupancy schedule, wall characteristics, building form and orientation, heating and cooling equipment equally affected the energy results for the single room.

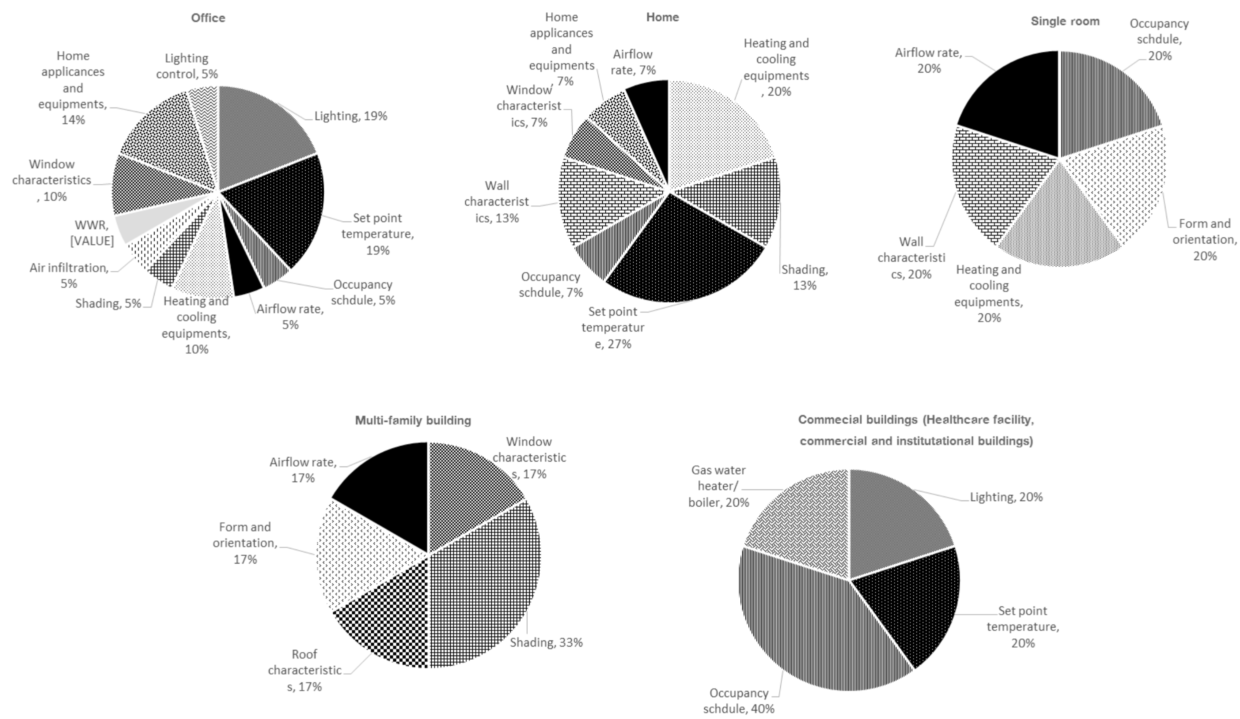

Figure 3. Percentage of significant parameters influencing building energy result in the first and second ranking categorized by building type.

This paper reviews the parameters used in the energy simulation model. There is a small number of implementation of sensitivity analysis regarding to building energy performance. Half of the studies performed sensitivity analysis to determine the most input parameters with significant influence on the building energy performance while half of the studies closely determined the impact change of few parameters on energy results. For commercial buildings, except office building, the sensitivity analysis of energy performance was found only in a study in healthcare facility (Alangar et al., 2014), commercial building (Heo et al., 2014), and institutional building (Murray & Sullivan, 2012). In addition, the set of input parameters performed in the sensitivity analysis for each study is not similar. Consequently, the significant parameters reviewed from the literatures are variable. With this limited existing studies and number of input parameters in the sensitivity analysis, it is difficult to clarify the most significant parameters which influence on energy results. Consequently, the results of significant parameters provided in this paper were determined from the top-two ranking for the most influential parameters on building performance. To get more reliable information on the most influential parameters on energy results, future studies should increase the number of studies in sensitivity analysis in different building types, especially in healthcare facility, institutional, and commercial buildings. Moreover, the set of parameters performed in the sensitivity analysis should be the same in each building type. This might reduce the variation of the significant parameter calculated using the sensitivity analysis.

It is noted that building energy performance might be susceptible to seasonal change and sensitivity analysis method. Song et al. (2014) did sensitivity analyses to investigate impact of input parameters on energy performance in winter and summer seasons. The study showed that the simulated energy result was most sensitive to heating equipment in winter and shading in summer. In addition, local and global sensitivity analyses might provide different results of the influential parameters. Hughes et al. (2014) showed that set-point temperature significantly made an impact on energy result when calculated by using local sensitivity analysis while wall characteristics was the most influential parameter when calculating using global method. Their results contrast with the study by Hamby (1995), which showed that local and global methods provided similar rankings of the top sensitive parameters. Consequently, future studies should do more reviews or works on the result comparison of different sensitivity analysis methods.

Conclusions

This paper presents a review of significant parameters for energy model. To determine most influential parameters on energy results, the implementations of sensitivity analysis with regard to building energy performance are reviewed. According to the reviews, the parameters that most influencial on energy results were not the same as the parameters that the modelers gravely modified in the model for improving the model accuracy and determining energy saving potential, especially for home and office building. According to the results obtained from the sensitivity analyses based on the limited number of existing studies, the set point temperature paid a significant contribution on energy results for office and home while shading and occupancy schedule significantly impacted the energy results for multi-family building and commercial buildings, respectively. To obtain more certain parameters, which significantly affect energy result, future studies should perform more sensitivity analysis regarding to energy performance. In addition, the case studies used in the analysis should be more general, which can be a good representative for a whole building in each sector.

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