BUILDING CLASSIFICATION BASED ON SIMULATED ANNUAL RESULTS: TOWARDS REALISTIC BUILDING PERFORMANCE EXPECTATIONS

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ABSTRACT

This study reviews typical assumptions for days of operation, sub-space type receptacle and other unregulated process loads, and occupancy rates to propose a risk evaluation for energy simulation accuracy of office buildings. Office building simulations entail low-, medium-, or high- risk of being inaccurate based on the variation of key energy simulation parameters from typical values used in office buildings. The three parameters and associated risk should indicate a potential difference between projected design and actual energy use for high performance office buildings. Overall, the risk assessment provides a way to determine whether a building energy simulation is likely to produce realistic building energy performance expectations.

INTRODUCTION

Energy software tools have been widely used in the design stage of buildings to size the HVAC systems (Yoon et al. 2003, Reddy 2006). Researchers have shown calibrated energy simulation models can provide reliable energy simulation results close to the actual energy use of the building (Reddy et al. 2007). Calibration is possible when energy bills or measured data are available. There has not been a unifying procedure for building energy modellers to use the same energy model throughout design, construction, and building operation. Designer, commissioner, and engineer typically create a building energy simulation to predict building energy consumption. Typically, these models do not use the same inputs since they are created in different building stage and there is no unifying procedure to keep record of the inputs. This lack of unifying procedure sometimes results in unrealistic expectations from the energy simulation tools.

Various short-term and long-term remedies exist to improve accuracy of currently used energy simulation tools. One remedy is to review inputs used in the energy models through the building design stage and classify energy simulation models based on associated deviation from the typical used inputs. The proposed classification in this study correlates associated deviation from typical inputs to associated risk level. This study reviews three existing assumptions used in building energy simulations and recommends classifying these assumptions into three categories: (1) low-risk, (2) medium-risk, and (3) high-risk assumptions.

RESEARCH METHODLOGY

134 office buildings certified under the U.S. Green Building Council (USGBC) Leadership in Energy Efficient Design for New Construction & Major Renovations (LEED NC) located in the U.S. are analysed (USGBC 2012). These office buildings span 13 American Society of Heating, Refrigeration, and Air-conditioning Engineers, Inc. (ASHRAE) climate zones in the U.S. Figure 1 illustrates average Heating Ventilating and Air Conditioning (HVAC) related and non-HVAC related Energy Utilization Index (EUI) based on Conditioned Floor Area (CFA) and Gross Floor Area (GFA) for the selected office buildings excluding on-site renewable energy production. Various design and consulting firms used different design methodologies, assumptions, and energy simulation tools to model these office buildings. Details of the capability of the common energy simulation tools are available in the existing literature (Crawley et al. 2005). The selected office buildings vary from small office buildings 1991 ft^2 (~185 m^2) area to large office buildings with 199,999 ft^2 (~18,580 m^2).

Energy models breakdown annual energy use of a building into specific end-uses. This study separates different components of the energy end-uses into 17 energy use parameters that comprise HVAC and non-HVAC related energy use. HVAC related energy end-use includes space heating, space cooling, pumps, and fans. Non-HVAC related energy end-use contains interior lighting, service water heating, process, receptacle, computer servers, refrigeration, cooking, unregulated interior task lighting, and other unregulated process or equipment loads. Each end-use is normalized by gross floor area and weather to account for the building size and geographic location. This study used the Typical Meteorological Year (TMY3) files (Wilcox and Marion 2008). Heating and Cooling Degree Days (HDD) and (CDD) were calculated from the TMY3 files. Further, the identification of the ASHRAE climate zones used the methodology recommended in the ASHRAE Standard 169 (ASHRAE 2006). Finally, HDD65 and CDD50 were calculated with 65ºF (18.3ºC) and 50ºF

(10ºC) as the balance point temperatures, respectively. Once energy end-uses normalized, several buildings were excluded as outliers using the recommended methodology in the literature (Gaitani et al. 2010).

LEED requires that buildings achieve a minimum energy reduction compared to a building that complies with minimum energy standards set forth in ASHRAE 90.1 or California Title 24. These standards are used as guides for parameter input into energy simulations.

Energy simulation input parameters can be classified based on how far they deviate from the typical value used by engineering design teams. A large deviation from a typical value incurs risk that the building energy model output will not match that of an energy model of the exact same building using typical parameters. Values for three building parameters: (1) days of operation, (2) sub-space type receptacle and other unregulated process loads, and (3) occupancy rates – are classified as low-risk, medium-risk, and high-risk, based on how far they deviate from typical values. Risk does not necessarily reflect incorrect inputs, nor significant variation in modelling accuracy, rather it provides a measure for how far the parameter deviates from typically used values in state-of-the-art design practice of high performance buildings. The three risk levels are:

(1) **Low-risk:** Building parameters are within 95% confidence interval of typical input values; the value is typical for an office building energy simulation.

(2) **Medium-risk:** Building parameters are within the range of median and lower endpoint of the 95% confidence interval of typical input values; the value is atypical for an office building energy simulation, but still used within industry.

(3) **High-risk:** Building parameters are greater than upper endpoint of the 95% confidence interval or lower than the 95% confidence interval lower endpoint of typical input values; the value is rare for an office building energy simulation, and should be used only if known accurately to prevent significant variation from other energy model results of the same building.

Equations (1) and (2) define the lower endpoint and upper endpoint for the confidence interval used in this study.

$$\overline{X} - 1.96 \times \frac{\sigma}{\sqrt{n}} \qquad (1)$$

$$\overline{X} + 1.96 \times \frac{\sigma}{\sqrt{n}} \qquad (2)$$

Where $\overline{X}$, σ, and n are mean, standard deviation, and number of office buildings used in this study.

This study evaluates three critical input variables, shown in Table 1, because they strongly affect the

energy simulation results and are difficult to obtain. Equation 3 shows the energy end-uses that are used in the sub-space type receptacle and other unregulated process loads definition. Nevertheless, these correlations are specific for published case studies, while more general guidelines and recommendations still need to be developed.

Table 1 Critical input variables

VARIABLE NUMBER	(I)	(II)	(III)
VARIABLE	Days of operation	Sub-space type receptacle and other unregulated process loads	Occupancy rate

Sub-space type receptacle and other unregulated process loads = Process + Receptacle + Computer Services + Task Lighting + Other unregulated process or equipment loads (3)

Interestingly, original design input estimates for these critical variables should be updated during building operation because a change in building function or occupancy type can significantly change the energy use patterns of a building (Martani et al. 2012). In addition, occupancy rate can lead to major difference between the energy simulation results and the actual energy use of the building (Fabi et al. 2011, Davis III and Nutter 2010). The proposed office building classification is a starting point to develop a dynamic prediction model for the energy use of these buildings.

DISCUSSION AND RESULT ANALYSIS

Days of Operation

Days of operation defines the operation schedule, and consequently directly influences building energy consumption. In the sample of office buildings, days of operation varies from 156 days to 365 days. The results show 36%, 25%, and 11% of the buildings used 250, 260, and 365 days of operation in the energy simulation models, respectively. Figure 2 illustrates selected assumptions for the days of operation. More than 73% of office building energy simulations assume 250-260 days of operation per year.

Table 2 shows ranges of these three categories based on the days of operation in the office buildings. Low-risk office buildings use the common practice of design in the energy simulation tools. The common practice in the energy simulation tools are usually between 5 to 6 days per week (DesignBuilder 2012, CBECS 2003). 20% of the designers used 280 to 365 days of operation. Based on the CBECS data, mean hours of operation for the office buildings vary from 50 hours per week for government offices to 61 hours

of operation per week for mixed-used office buildings. The mean hours of operation are 55 hours per week. Therefore, assuming hours of operation for a building is between 10 to 11 hours per day, lead to an realistic assumption for the low-risk input. The lower endpoint and upper endpoint of the 95% confidence interval are 263 and 277, respectively. The median for the days of operation is 255 days of operation. Therefore, offices modelled for 263-277 days of operation are low-risk. Offices with days of operation between 255 to 262 and more than 277 are medium-risk. The later conclusion is based on the engineering judgement. Finally, this study assumes less than 255 to be high-risk inputs. Offices are high risk if they operate for fewer than 5 days of operation. It is important to note that there are office buildings that operate with the same days of operation used in the design documents and have inaccurate energy simulation models due to other inaccurate input assumptions. The purpose of this low-risk, medium-risk, and high-risk classification is to inform the facility managers what kind of assumptions were used in the design stage of office buildings.

Table 2 categorizes office buildings based on their days of operation. Office buildings with 263-277 days of operation have low-risk. Office buildings with 255-263 and more than 277 days are categorized as medium-risk office buildings. Buildings with less than 255 days of operation are categorized as high-risk because they need to meet the energy simulation model inputs; otherwise, the energy model for the building needs to be modified.

Table 2 Categorize office buildings based on their days of operation

	LOW-RISK	MEDIUM-RISK	HIGH-RISK
Days	263 - 277	255 – 262 Or More than 277	Less than 255

Table 3 revisits the days of operation based on the office principal building activity. The office sub types include (1) administrative/professional, (2) government, (3) financial, (4) mixed-use, and (5) other (USGBC 2012). The prevalence of each sub-space types of office buildings for the studied buildings is shown in Table 3. In addition, Figure 3 illustrates distribution of the principal building activity for the office buildings.

Table 3 Categorize principal activity of the office buildings based on their days of operation for the selected office buildings

OFFICE TYPE	LOW-RISK	MEDIUM-RISK	HIGH-RISK
Administrative / Professional	0.0%	19.4%	20.1%
Government	0.0%	11.9%	12.7%
Financial	0.0%	0.0%	1.5%
Mixed-Use	0.0%	13.4%	11.9%

Sub-Space Type Receptacle and Unregulated Process Loads

Reference Buildings developed by National Renewable Energy Laboratory (NREL) is guideline for designers to compare the building EUI (Deru et al. 2011). However, if the office building comprises a data server, sub-spaces with residents, retail, or industrial work the building does not perform similar to the benchmark values. Figure 4 shows energy use for two types of office buildings. The first type of office building has typical receptacle and other unregulated process loads, represented by a square symbol in the figure. The second building type is office buildings that contain a data centre, industrial work, or other special processes that results in intense thermal loads. These loads dominate energy use, even if they occupy only a small portion of the CFA. The second type is dissimilar to energy simulations and actual energy use of typical office buildings, and therefore is not appropriately categorized as an office building from an energy use perspective. Therefore, office buildings need to be benchmarked by their energy use pattern, rather than the by the space type that accounts for most of the area.

This study considers only other unregulated process and receptacle energy use in the analyses to find particular energy intense end-use office buildings that usually are 24/7, the HVAC systems need to run 168 hours/week. Table 4 summarizes the low-, medium-, and high-risk office buildings threshold ranges. There is more chance to find discrepancies between the energy simulation results and the actual energy use of the building for the medium- and high-risk office buildings.

Table 4 Categorize office buildings based on their receptacle and other unregulated process energy use patterns

	RECEPTACLE + OTHER UNREGULATED PROCESS OR EQUIPMENT LOADS EUI THRESHOLD RANGE		
	LOW-RISK	MEDIUM-RISK	HIGH-RISK
Receptacle + Other unregulated process or equipment loads EUI	18.8 – 29.1	16.2 – 18.8	Less than 16.2 Or More than 29.1

Office buildings tend to be internally-load dominated (Al-Homoud 1997). Although typical office buildings with low- and medium- risk do not have intense non-HVAC energy end-use, their cooling and heating energy use are not solely a function of outdoor environmental indicators such as CDD50 and HDD65. Figure 5 shows cooling EUI versus CDD50 for the typical office buildings. With coefficient of determination, R^2, 0.44, typical office buildings can be categorized as internally-load dominated space type.

Occupancy Rate

The occupancy rate used in an energy simulation model can create huge discrepancies between the simulation results and actual energy use of the buildings (Hoes et al. 2009). Therefore, this paper analyses occupancy rates used in energy simulation The USGBC database contains average and peak occupancy rates for four types of occupants: (1) Full/part-time employees (FTE), (2) visitors (VISIT), (3) transients (TRANS), and (4) residents (RES), summarized in Table 6 and 7. Occupant behaviour varies for these different types of occupants, but at present, typical energy simulation tools cannot quantify the effect of different occupancy behaviour and associated uncertainties on energy simulation results. Although quantification of occupants' behaviour is beyond scope of this paper, this paper recommends considering various building occupancy types in their analyses to indicate different occupant behaviours.

Table 6 Typical occupancy rates per CFA (Note: six occupancy intense offices that do not represent typical office buildings dominate the mean, stDev, and max) (People/1000 ft^2)

	FTE	RES	TRANS	VISIT
Min	0.1	0.0	0.0	0.0
Mean	4.0	1.2	0.8	2.8
Median	3.1	0.0	0.0	0.4
StDev	6.0	14.2	4.6	14.6
Max	65.7	164.0	50.1	164.0

Table 7 Peak occupancy rates per CFA (Note: five occupancy intense offices that do not represent typical office buildings dominate the mean, stDev, and max) (People/1000 ft^2)

	FTE	RES	TRANS	VISIT
Min	0.0	0.0	0.0	0.0
Mean	2.4	1.2	0.6	4.0
Median	2.2	0.0	0.0	0.2
StDev	2.2	14.3	3.2	19.1
Max	11.0	164.0	33.7	198.3

Total occupancy per CFA, accounts for the summation of FTE, RES, TRANS, VISIT, and other (USGBC 2012). Table 8 shows the statistics of average operating rates for the collection of office buildings. For typical occupancy rates, the median is 4.3 people/1,000 ft^2. The occupancy rate for the office sub-space is recommended to be 5 people/1,000 ft^2 (Deru et al. 2011). A comparison between the typical occupancy per CFA with the reference buildings shows that the total occupancy is less than the recommended one. It is important to note that five office buildings are excluded from Table 6 and 7 to Table 8 since there is no exact formula to add FTE, RES, TRANS, and VISIT together.

Table 8 Typical total occupancy rates (People/1000 ft^2) (Note: five office buildings with very high occupancy rate are excluded)

	TYPICAL
Min	0.4
Mean	5.1
Median	4.3
StDev	3.3
Max	20.4

Table 9 shows the low-risk, medium risk, and high-risk ranges based on the total occupancy.

Table 9 Typical and peak total occupancy rates (People/1000 ft^2)

	TOTAL OCCUPANCY		
	LOW-RISK	MEDIUM-RISK	HIGH-RISK
Occupants	4.6 – 5.7	4.3 – 4.6	Less than 4.3 Or More than 5.7

Table 10 summarizes the results low-risk, medium-risk, and high-risk input parameters for the three analysed variables. The results show for most office buildings there is one assumption that may lead to classify the building as high-risk building. To avoid any unrealistic expectations, the designers need to inform the facility managers about the assumptions

that were used in the design stage of office buildings. It is important to note that there are office buildings that operate within reasonable agreement of the energy model results with high-risk, medium-risk, or low-risk assumptions. The main reason of this study to classify buildings based on the risk level is to inform facility manger about the assumptions.

Table 10 Summarize low-risk, medium-risk, and high-risk office buildings that lead to unrealistic expectations from the reviewed energy simulations

	LOW-RISK	MEDIUM-RISK	HIGH-RISK
Days of operation	0.0%	44.8%	46.3%
Sub-space Energy use (receptacle + other unregulated process or equipment loads EUI)	18.7%	11.2%	70.1%
Occupancy rate	25.4%	5.2%	69.4%

CONCLUSION

This paper reviews typical values days of operation, sub-space type receptacle and other unregulated process loads, and occupancy rate used in energy simulations of 134 LEED NC certified office buildings from the USGBC databse. These results cover a range of building sizes, design strategies, and energy simulation softwares. Building simulation models are classified as high-, medium- or low- risk, dependning on whether the three variables vary significantly from typical values used to model office buildings. Significant variation from typical values can yield inaccurate energy simulation results. This risk classification provides a means for checking whether energy models assume typical values, and to highlight when a choosen parameter may significantly differ from other office buildings. Further studies are needed to more precisely correlate days of operation, receptacle and other loads, and occupancy rates with actual energy use to improve accuracy of energy simulation tools.

NOMENCLATURE

ASHRAE = American Society of Heating, Refrigeration, and Air-conditioning Engineers, Inc.
CFA = Conditioned Floor Area
CDD = Cooling Degree Days
GFA = Gross Floor Area
HDD = Heating Degree Days
EUI = Energy Utilization Index
FTE = Full-time Employee
HVAC = Heating, Ventilation, and Air-conditioning
LEED NC = Leadership in Energy Efficient Design for New Construction & Major Renovations
RES = Resident Occupants
StDev = Standard Deviation
TRANS = Transient Occupants
USGBC = the U.S. Green Building Council
VISIT = Visitor Occupants

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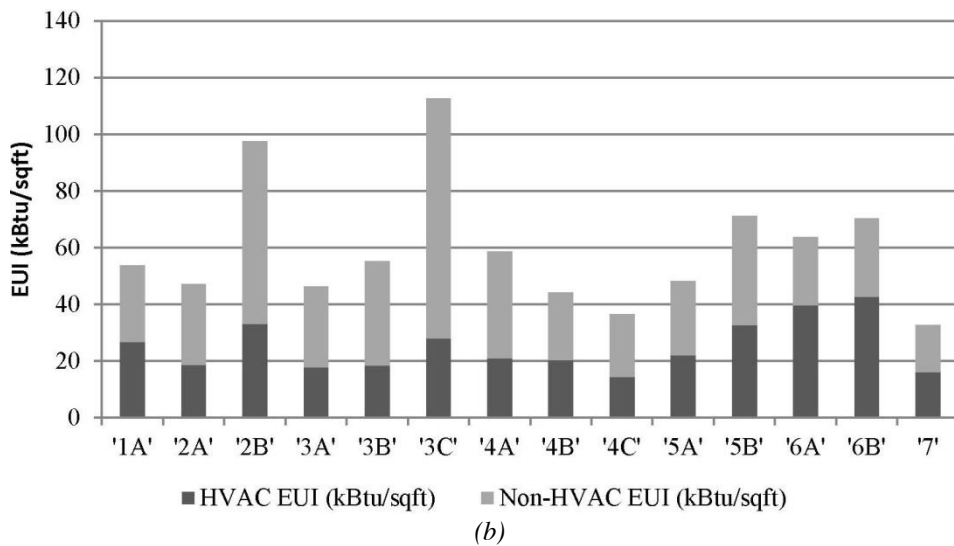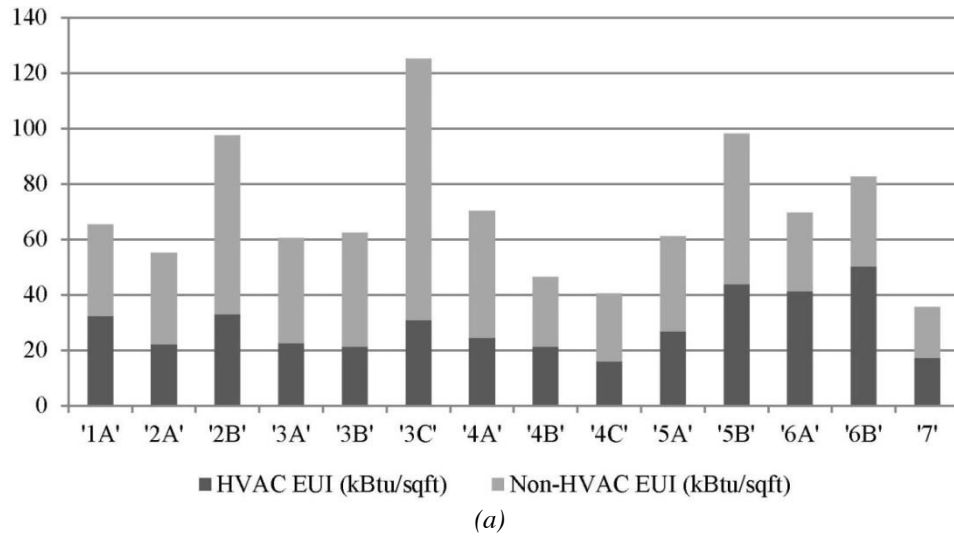
(a)

(b)

Figure 1 Representation of selected office buildings in this study (note: less than five buildings are included for climate zone 2B, 3C, 4B and 4C); (a) EUI calculated based on CFA, (b) EUI calculated based on GFA
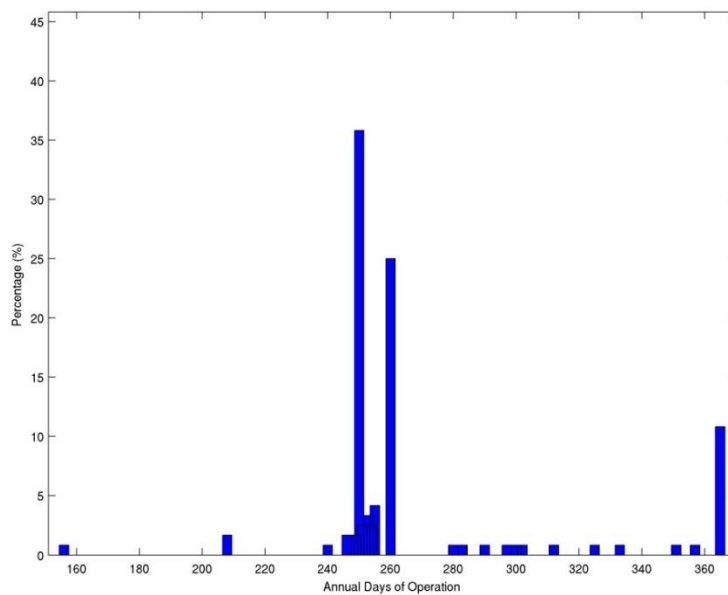

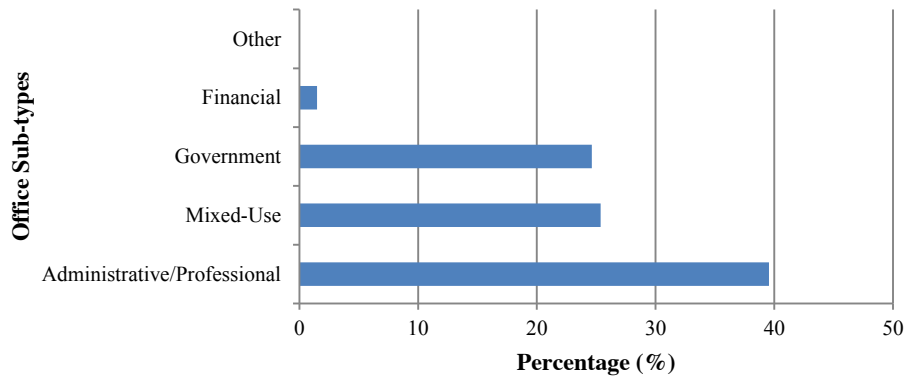*Figure 2 Days of operation in the energy simulations*

Figure 3 Principal activity distribution of office buildings in the studied office buildings (note: there not sufficient number of financial and other buildings to make a conclusion)

△ High Receptacle and Other Unregulated process or equipment energy end-uses
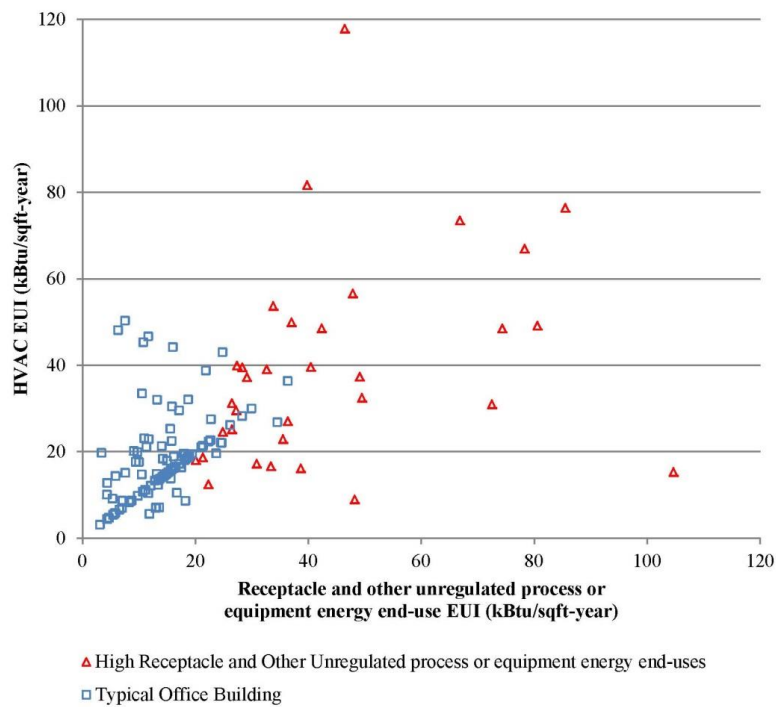
☐ Typical Office Building

Figure 4 Two types of office buildings; (Type one): office buildings with typical receptacle and other unregulated process or equipment energy end-uses (blue squares), (Type two): office buildings with energy intense receptacle and other unregulated process or equipment energy end-use
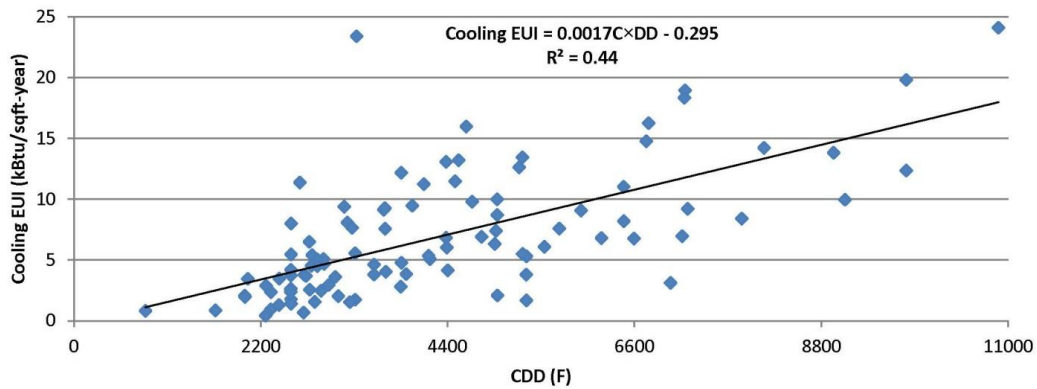

Figure 5 Building cooling EUI with the CDD for the typical office buildings with low- and medium- risk receptacle and other unregulated process or equipment loads EUI