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DEVELOPMENT OF A BASELINE BUILDING MODEL OF AUTO SERVICE AND REPAIR SHOP

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ABSTRACT

To support the ASHRAE Building Energy Quotient (bEQ) standard, the ASHRAE Research 1771 is trying to identify baseline building energy models for major commercial buildings so that the modeled source EUI is close to the median source EUI of the same type of buildings in the 2003 CBECS data. This paper introduces the procedure of creating a baseline model for the auto service and repair shops as they account for 2% quantity, 0.3% total floor area, and 0.2% energy consumption among the commercial buildings. First, we introduced a method to create the geometry model using the data collected from the 2003 CBECS data, reports, and existing building samples. Then a systematic approach is developed to identify the model inputs unrelated to geometry. Ultimately, the baseline model of auto service and repair shop is validated by using the median source EUI from the 2003 CBECS data. The results indicate that the relative errors between the source EUI of the new model and the median EUI from the 2003 CBECS data is 12.33%.

INTRODUCTION

The ASHRAE Building Energy Quotient (bEQ) standard is a building energy rating program that provides information on a building's energy use. The tool assists owners and operators searching for ways to understand their buildings' energy use and to select the suitable plans for improvement (Jarnagin 2009). Energy performance indicators (EPIs) are used to analyze and evaluate energy performance of commercial buildings. ASHRAE bEQ adopts energy use intensity (EUI) as the EPI. EUI is defined as the energy use per square foot in a year. Depending on the rating methods, the baseline EUI can be either empirical or modeled. The ASHRAE bEQ uses the empirical approach with the baseline EUI based on existing building performance data. It hopes that the rating results are matchable to the results based on the modeled baseline EUI.

To support the ASHRAE bEQ, the ASHRAE TRP-1771 aims to match the modeled source EUIs of the 18 main building types to the median source EUIs from the 2003 Commercial Buildings Energy Consumption Survey (CBECS) (EIA 2006). The auto service and repair shops, as one of the main building types in CBECS 2003, are employed as the research object. Overall, the auto service and repair shop account for 2% quantity, 0.3% total floor area, and 0.2% energy consumption of the 2003 CBECS building samples. To calculate the modeled source EUI of the auto service and repair shop, its baseline building model is required.

The U.S. Department of Energy (DOE) provides two baseline model sets, called DOE's Commercial Reference Building Models (DOE 2011) and DOE's Commercial Prototype Building Models (DOE 2015). The baseline models serve the researchers in assessing new technologies, optimizing designs, analyzing advanced controls, and developing energy codes and standards (Deru et al. 2011). To develop these baseline models, researchers selected model inputs from a rich set of data sources. The 2003 CBECS database is one of the data sources. However, survey data have limitations. For example, the accurate data of system characteristics and operational patterns are usually not provided by surveys (Huang and Franconi 1999). Thus, data are also collected from the standards, reports, and papers. For instance, the DOE's Commercial Prototype Building Models set the U-factors of the models' exterior walls from the ASHRAE Standard 90.1 (ASHRAE 2004). Moreover, for the geometry of the models, the new surveys are required to make the baseline models reflect the real situation.

The DOE's Commercial Prototype Building Models provide models of the 14 main building types in the ASHRAE TRP-1771. However, the baseline model of auto service and repair shop is not included. Thus, the ASHRAE TRP-1771 develops a new baseline building model of auto service and repair shop. The paper introduce the proceduce to develop the new baseline building model and the energy results of the model. First, a method is introduced to create the geometry model using the data collected from the 2003 CBECS data and existing building samples. Then a systematic approach is developed to identify the model inputs unrelated to geometry. Ultimately, the baseline model of auto service and repair shop is validated by using the median source EUI from the 2003 CBECS data.

MODEL CREATION

The baseline model of auto repair and service shop is developed by using SketchUp (Trimble 2017) and OpenStudio (NREL et al. 2017). The geometry of the model is created in SketchUp and the inputs unrelated to geometry are inserted in OpenStudio. To develop the model of auto service and repair shop, hundreds of model inputs are required. It is crucial to determine the values of the model inputs which are sensitive to the EUI. These inputs are called sensitive model inputs.

Sensitive Model Inputs

Model inputs are classified into non-sensitive ones and sensitive ones. Non-sensitive model inputs are the variables that only have weak or no impacts on the EUI of a model. Since the energy model aims to predict EUI, it is inessential to determine the values of these inputs. The default or empirical values are used for these inputs. Sensitive model inputs are in the other classification, and have great impacts to the modeled EUI. Sensitive model inputs make model unique, and the model with sensitive model inputs can simulate the energy performance of a specific building type. Thus, the values of sensitive model inputs need to be determined carefully.

Due to requirements of sensitive model inputs to create models, several papers and reports list the sensitive model inputs. For example, Wang et al. (2016) listed 35 variables, and identified that all these inputs are sensitive to EUI based on the results of sensitivity analysis. Glazer (2016) summarized the energy efficiency measures from other literatures. Also, Eisenhower et al. (2012) conducted uncertainty and sensitivity analysis, and quantify contributions of the model inputs to energy usages of building models. The sensitive model inputs of the new baseline model of auto service and repair shop are collected from these papers and reports. Since the sensitive model inputs serve for creating SketchUp model and OpenStudio model, the sensitive model inputs are classified into sensitive inputs of the SketchUp model and sensitive inputs of the OpenStudio model.

SketchUp Model

SketchUp model describes the geometry of the auto service and repair shop, and is the basis of the OpenStudio model. This paper identifies nine sensitive model inputs of the SketchUp model, and they are:

- Total floor area;
- Number of floors;
- Buiding shape;
- Window-to-wall ratio;
- Aspect ratio;
- Floor-to-ceiling height;
- Shape of roof;
- Space type;
- Location of the windows.

The objective is to match the modeled source EUI to the empricial source EUI from the 2003 CBECS. Thus, the 2003 CBECS is the first choice of the data source. The three sensitive model inputs, total floor area, number of floors, and building shape, can be collected from the 2003 CBECS directly. The median values or the highest frequent categories of the 2003 CBECS samples are selected to develop the SketchUp model of the auto service and repair shop.

Window-to-wall ratio and aspect ratio are not included in the 2003 CBECS data. The 2003 CBECS only provides the categories of percents of exterior glass of the building samples. Winiarski et al. (2007) provide the assumed window-to-wall ratio based on the reported percent exterior glass. Also, they provide the aspect ratio for each building type. The values of these two sensitive model inputs are collected from the report.

The 2003 CBECS does not collect the accurate data that can identify the floor-to-ceiling height, shape of roof, arrangement of each function area, and location of the windows. Also, from the reports and papers, it is also difficult to determine these values of auto service and repair shops. To identify these values, 26 samples of auto service and repair shops are selected. The procedures to select the samples are:

1. Identify the main brands of auto service and repair shops in the U.S. Based on the survey results, Jiffy Lube and Midas are the two most popular brands in the U.S., and these two brands are included in the samples.
2. Select samples from the typical cities of the ASHRAE climate zones in the U.S., and the samples cover all the ASHRAE climate zones in the U.S.
3. Randomly select the samples, and get the values of the four sensitive model inputs based on the geometry of the buildings shown in the Google Maps and their websites.

By using the workflow to determine the values of the sensitive model inputs of the SketchUp model, the values of all the nine sensitive model inputs of SketchUp model are selected from the 2003 CBECS, the report, and the 26 samples,. Table 1 lists the values and sources of the nine sensitive model inputs. The auto service and repair shops usually have offices and repair shop. Due to the different energy use behaviors of the office and repair shop, the two space types are created. It is benefits when the OpenStudio model is developed since the different schedules, temperature setpoint, and internal loads are used in different space types.

After collecting all the sensitive model inputs of the SketchUp model, the model of auto service and repair shop is created by using SketchUp. Figure 1 shows the geometry of the auto service and repair shop model. In Figure 1, left part is the office, and right part is the repair shop.

Table 1 Sensitive model inputs of geometry model

NO.	SENSITIVE MODEL INPUT	VALUE	SOURCE
1	Total Floor Area	5,850 ft^2	2003 CBECS
2	Number of Floors	1	2003 CBECS
3	Building Shape	Wide Rectangle	2003 CBECS
4	Window-to-wall Ratio	5%	Report
5	Aspect Ratio	1.93	Report
6	Floor-to-ceiling Height	15 ft	Sample Data
7	Shape of Roof	Flat Roof	Sample Data
8	Space Type	Office, Repair Shop	Sample Data
9	Location of the Windows	Two Exterior Walls of Office	Sample Data

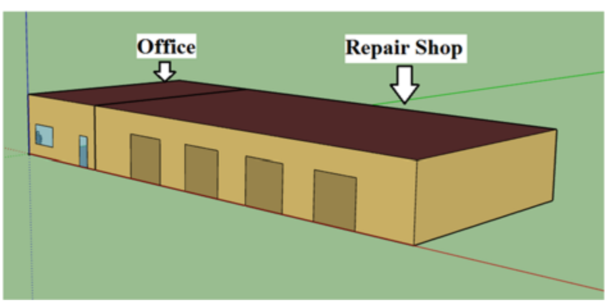

Figure 1 Geometry of Auto Service and Repair Shop Model

OpenStudio Model

OpenStudio model needs hundreds of model inputs. These model inputs describe the schedules, envelopes, and systems. To sum up, the sensitive model inputs of the OpenStudio model of the auto service and repair shop are:

- Schedule (People, Lighting, Electric Equipment, Heating, Cooling, Service Hot Water, Infiltration);
- People Density;
- Lighting Power Density;
- Electricity Power Density;
- Materials of Envelopes (Exterior Walls, Roof, Windows);
- R-value of Exterior Walls;
- R-value of Roof;
- U-factor of Windows;
- Solar Heat Gain Coefficient (SHGC) of Windows;
- System Types (Heating, Cooling, Service Water Heater, Fan, Pump);
- System Efficiency (Heating, Cooling, Service Water Heater, Fan, Pump);
- Economizer;
- Daylighting Control.

After identifying the sensitive model inputs of the energy model, the values of these inputs need to be determined. Due to the objective of the ASHRAE TRP-1771, the 2003 CBECS is the first choice to select the values of the sensitive model inputs of the energy model. However, as Huang and Franconi (1999) mentioned, the survey data are difficult to collect the accurate system information and operating information. For example, the 2003 CBECS provides the working hours per week, and whether they work on workday or weekend (Table 2), but OpenStudio needs hourly schedules as the model inputs. Thus, other data sources are needed to complement the 2003 CBECS data.

Table 2 Information of schedule in the 2003 CBECS

NO.	VARIABLE DESCRIPTION	MEDIAN/HIGHEST FREQUENT VALUE
1	Open 24 hours a day?	No
2	Open during week?	Open all five days (Mon-Fri)
3	Open on weekend?	Yes
4	Total weekly operating hours	50 hr

The reports and ASHRAE Standard provide information of energy model which can complement the deficient data in the 2003 CBECS. For instance, COMNET (2010) provides the hourly schedules for people, lighting, electric equipment, heating, cooling, hot water, and infiltration. These schedules are used for model development. For example, for the office room in the auto service and repair shop, the workday and weekend schedules of occupancy in COMNET are provided as the fraction of the maximum people density in each hour. Figure 2 shows the hourly schedules, and the OpenStudio can use the schedules directly to create the model. For the information of envelope, the 2003 CBECS only provides the types of envelope, but does not show the detailed information of the envelope like the R-values of the exterior walls and roof. The ASHRAE Standard 90.1 (ASHRAE 2004) gives the detailed information. Winiarski et al. (2007) link the envelope's types in the 2003 CBECS to the types listed in the ASHRAE Standard 90.1. Thus, the types of envelope are selected from the 2003 CBECS and the detailed information of the envelope are determined by using the ASHRAE Standard 90.1.

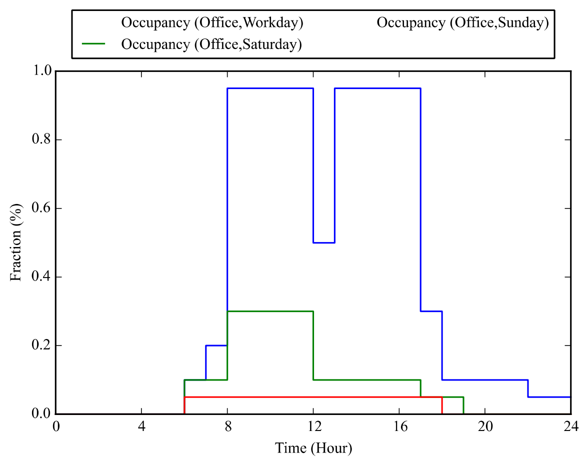

Figure 2 Schedule of occupancy in office room

For some values of sensitive model inputs that cannot be determined from these data sources, the statistical analysis is used to determine the values of the sensitive model inputs. The statistical analysis method used here is called Bayesian classifier. For example, the 2003 CBECS provides some information related to the HVAC systems like cooling system types and heating system types. However, the system efficiency is not provided. The information like cooling system types and heating system types is called, related known inputs. All the related known inputs are the sensitive model inputs of the OpenStudio model. Based on the related known inputs, Bayesian classifier can identify which building type has the most similar HVAC systems compared with the auto service and repair shops. Then the values of unknown sensitive model inputs can be collected from the existing building model of the building type from the DOE's Commercial Prototype Building Models (DOE 2015). Ultimately, expert knowledge is used to adjust the values to suit the new model's situation.

Figure 3 shows the schematic chart of Bayesian Classifier. For example, there are two samples belonging two building types, and three related known inputs (Input 1~3) for each building. The shape and color are used to represent the values of the sensitive model inputs. If input i in the two samples have the same shape or color, the values of the input i in the two samples are similar; if they have both the same shape and color, the input i in the two samples have the same value. The Bayesian Classifier needs to identify which building is more similar to the auto service and repair shop. In Figure 3, the auto service and repair shop has the same values of the two inputs compared with Building Type 1 (Input 1 and 2). However, there is no same value compared with Building Type 2. Thus, the auto service and repair shop is more similar to Building Type 1. Then the value of Input 4 in Building Type 1 is selected and used as the value of Input 4 of the auto service and repair shop.

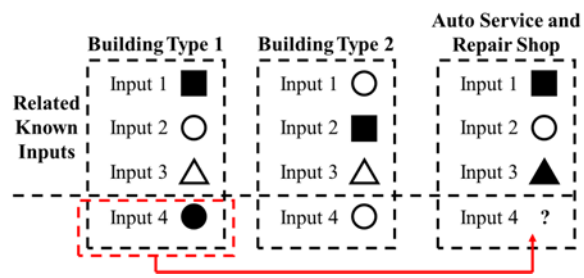

Figure 3. Schematic chart of Bayesian Classifier

Because there are a rich set of samples for each building types in the 2003 CBECS, the similiarity between all the samples belonging two building types need to be considered. The conditional probability is used to show the similarity between the two building types. Because 14 building types like large office and primary school have the existing baseline building models provided by the DOE's Commercial Prototype Building Models, these building types are used, and conditional probability is used to identify the similarity between these 14 building types and the auto service and repair shop. The similarity between the ith building type and the auto service and repair shop is calculated by using the equation:

$$P(c_j|\boldsymbol{x}) = \frac{P(c_j)\cdot\prod_{i=1}^{n}P(x_i|c_j)}{\prod_{i=1}^{n}P(x_i)} \qquad (1)$$

where P is probability; x_i is the ith related known inputs, and $i = 1,2,\dots,n$; $\boldsymbol{x}$ is the list of all the related known inputs; c_j is the jth building type, and $j = 1,2,\dots,14$.

After that, the building type which has the maximum of the conditional probability is the most similar type to the auto repair and service shop. Its inputs are used as the inputs of the auto repair and service shop. Based on the data from the reports, standard, and existing baseline models, the values of all the sensitive model inputs of the energy model can be determined. Figure 4 shows the workflow to determine the values of the sensitive model inputs.

Based on the workflow shown in Figure 4, the values of the sensitive model inputs of the energy model are summarized. A rich set of sensitive model inputs have many values. For example, all the schedules are the hourly data, and there are 24 values for each day. In another example, ASHRAE (2004) identified 15 climate zones in the U.S., and the 15 baseline building models need to be developed. Building models in different climate zones need different values of envelope. Thus, it is impossible to list all the values of the sensitive model inputs of the energy model in a short table. The data sources are important, and can be listed in a short table. Thus, Table 3 lists the data sources of the main sensitive model inputs of the energy model. Besides, it is also important to provide the information of the main model inputs like construction materials and system types. Therefore, Table 4 shows the main description of the building models.

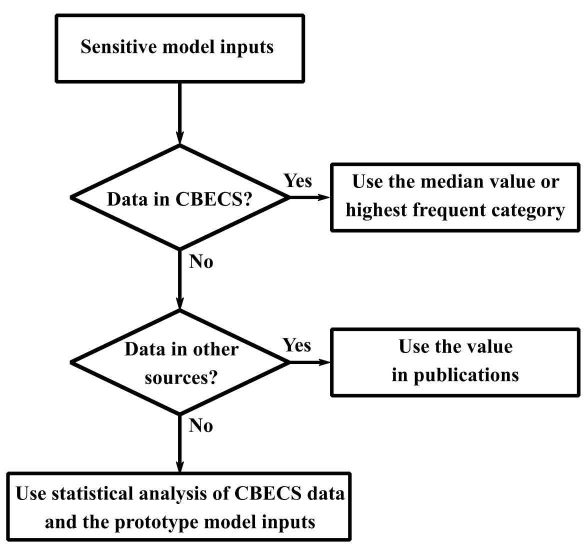

Figure 4 Workflow to determine the sensitive model inputs

Table 3 Sensitive model inputs of energy model

NO.	SENSITIVE MODEL INPUT	SOURCE
1	Schedule (People, Lighting, Electric Equipment, Heating, Cooling, Service Hot Water, Infiltration)	COMNET
2	People Density	COMNET
3	Lighting Power Density	COMNET
4	Electricity Power Density	COMNET
5	Materials of Envelopes (Exterior Walls, Roof, Windows)	2003 CBECS, Report
6	R-value of Exterior Walls	ASHRAE 90.1
7	R-value of Roof	ASHRAE 90.1
8	U-factor of Windows	ASHRAE 90.1
9	Solar Heat Gain Coefficient of Windows	ASHRAE 90.1
10	System Types (Heating, Cooling, Service Water Heater, Fan, Pump)	2003 CBECS, Existing Models
11	System Efficiency (Heating, Cooling, Service Water Heater, Fan, Pump)	Existing Models
12	Economizer	2003 CBECS
13	Daylighting Control	Existing Models

Table 4 Main description of the energy model

NO.	SENSITIVE MODEL INPUT	VALUE
1	Material of Exterior Walls	Metal Building Wall
2	Material of Roof	Metal Building Roof
3	Type of Windows	Single-Glazed Window
4	Cooling System Type	Packaged A/C Units
5	Heating System Type	Furnaces That Heat Air Directly
6	Service Hot Water System Type	Centralized Gas Heater

MODEL VALIDATION

After completing the model creation, it is necessary to validate the new model. Based on the objective of the ASHRAE RP-1771, the source EUI of the models needs to match with the median source EUI from the 2003 CBECS data. Thus, the 2003 CBECS data are used to validate the baseline model of auto service and repair shop.

Energy Performance Indicators (EPIs)

Energy performance indicators (EPIs) are usually used to analyze and evaluate energy performance of buildings. Source energy use intensity (EUI) is one of the most common EPIs. Source energy is the total primary energy consumption, which means the site energy plus all the delivery and production losses (EPA 2017). This paper compares modeled source EUIs and source EUIs from the 2003 CBECS samples to validate the model of auto service and repair shop. When the number of data is large, the median value can reflect the features of the data. Thus, median source EUI is used during the comparison.

Method of Model Validation

The baseline model's envelopes and weather files are adjusted based on the different climates. The DOE's Commercial Prototype Building Models use the ASHRAE Climate Zones introduced in the ASHRAE Standard 90.1 (ASHRAE 2004). The new models of auto service and repair shops are also used from the ASHRAE Climate Zones. The U.S. includes 15 ASHRAE Climate Zones, and thus, 15 new models are generated. However, the 2003 CBECS provides its own climate zones. The 2003 CBECS divides the U.S. into five Climate Zones. To compare the modeled source EUIs and empirical soruce EUIs in each climate, we need to match the ASHRAE Climate Zones to the 2003 CBECS Climate Zones. Based on their comparison, Table 5 shows a relation between them. Then the 2003 CBECS Climate Zones are used as the climate zones when comparing the modeled source EUIs to the empirical source EUIs. To conduct validation, first, the median source EUI of the models in all the climate zones need to be matched to the median source EUI of the 2003 CBECS samples of auto service and repair shops. This paper defines that the difference between these two median source EUI needs no more than 20%. The difference can be expressed as:

$$\Delta = \frac{\left|EUI_{med,emp} - EUI_{med,mod}\right|}{EUI_{med,emp}} \times 100\% \leq 20\% \quad (2)$$

where $EUI_{med,emp}$ is the median empricial source EUI calculated by the 2003 CBECS samples in all the climate zones; $EUI_{med,mod}$ is the median modeled source EUI in all the climate zones.

Table 5 Connection between the two types of climate zones

ASHRAE CLIMATE ZONE	2003 CBECS CLIMATE ZONE
1A	Zone 5
2A	
2B	
3A	Zone 4
3B	
3C	
4A	Zone 3
4B	
4C	
5A	Zone 2
5B	Zone 1
6A	
6B	
7	
8	

Then, because the number of models in each 2003 CBECS Climate Zone is small, the average source EUIs of each Zone is calculated. After that, the average modeled source EUI is compared with the median empirical source EUI in each 2003 CBECS Climate Zone. Because the number of samples in each zone is not great, some individual features of the samples may cause the strong fluctuation of the median source EUI. The low percentage of difference between source EUIs from the two sources may cause overfitting. Thus, the criteria provides the high percentage of difference to avoid overfitting. This paper defines that the difference between the average modeled source EUI and the median empirical source EUI in each 2003 CBECS Climate Zone should be no higher than 60%. The difference can be expressed as:

$$\Delta_{max} = \max_{i \in S}\left(\frac{\left|EUI_{med,mes,i} - EUI_{aver,mod,i}\right|}{EUI_{med,mes,i}} \times 100\%\right) \leq 60\%, S = 1,2,3,4,5 \quad (3)$$

where $EUI_{med,mes,i}$ is the median empirical source EUI in Zone i, i =1,2,3,4,5; $EUI_{aver,mod,i}$ is the average modeled source EUI in the 2003 CBECS Climate Zone i, i =1,2,3,4,5.

Results of Model Validation

There are 15 ASHRAE Climate Zones in the U.S., and each ASHRAE Climate Zone has one model developed based on the baseline model of auto service and repair shop. The 2003 CBECS provides 124 samples of auto service and repair shops. Table 6 lists the number of models and CBECS samples in each climate zone.

Table 6 Number of models and CBECS samples in each climate zone

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5
Model	5	1	3	3	3
CBECS	20	40	21	30	13

Then the 15 models are run, and source EUI of each model is collected. Figure 5 shows the distribution of the empirical source EUIs and modeled source EUIs.

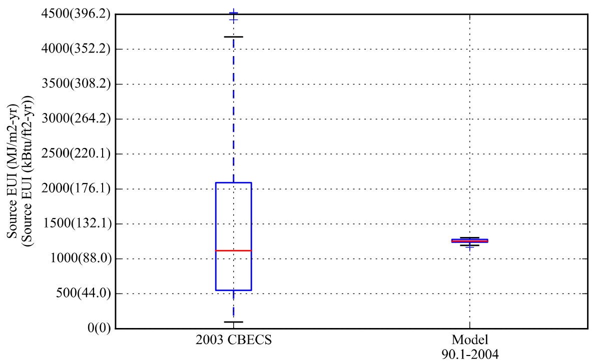

Figure 5 Distribution of the source EUIs from the models and the 2003 CBECS

Figure 5 shows that the empirical source EUIs have larger range than the modeled source EUIs, but both of the data sources have similar median values. The large range of the empirical source EUIs is due to different schedules, different characteristics and measured errors. There are 124 samples while only 15 building models are included. Thus, it is reasonable that the empirical source EUIs have larger range. Then the median source EUIs are calculated. The median empricial source EUI in all the climate zones is 1,115.55 MJ/m^2-yr (98.23 kBtu/ft^2-yr), and the median modeled source EUI in all the cliamte zones is 1,253.11 MJ/m2-yr (110.34 kBtu/ft^2-yr). The difference between these two median source EUI is 12.33%, which meets the requirement of the first criterion.

Then the modeled source EUIs and empirical source EUIs in each 2003 CBECS Climate Zone are summarized. Figure 6 shows the distribution of the modeled source EUIs and empirical source EUIs in each 2003 CBECS Climate Zone.

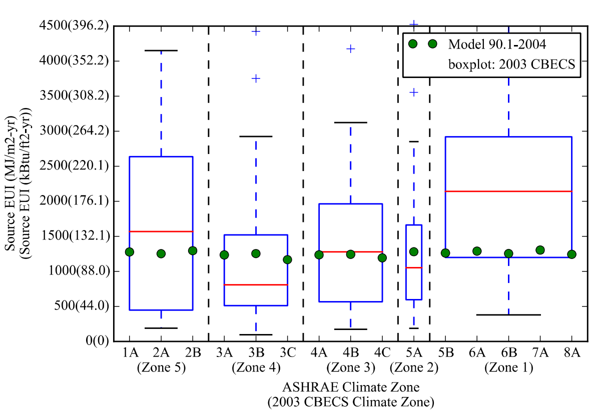

Figure 6 Distribution of the source EUIs from the models and the 2003 CBECS in each climate zone

Figure 6 shows that the median empirical source EUIs are varied in different climate zones while the modeled source EUIs are only changed in a small range in different climate zones. One of the main reasons is that the samples are from different locations with different schedules and characteristics while one model needs to represent the average performance of exisitng buildings in one cliamte zone. Also, the models use 2003 weather file of the typical cities, but the survey years may not be 2003. The third reason is that the number of samples is not enough, and the survey results are not precise. These are the reasons why the criteria to validate the building models are not strict. Based on the results shown in Figure 6, the maximum difference between the average modeled source EUI in each 2003 CBECS Climate Zone and the median empirical source EUI in each 2003 CBECS Climate Zone is appeared in the 2003 CBECS Climate Zone 5. The percentage of the difference is 51%, which meets the requirement of the second criterion.

In all, the baseline model of the auto service and repair shop meets the criteria, and will be used in the ASHRAE TRP-1771. In ASHRAE TRP-1771, large scale modeling will be used to auto-tune the baseline model, and the baseline model will match the 2003 CBECS data better.

CONCLUSION

To support the ASHRAE bEQ, the ASHRAE TRP-1771 aims to match the modeled source EUIs of the 18 main building types to the median source EUIs from the 2003, and auto service and repair shop is one of the main building types. Thus, the new baseline model of auto service and repair shop is created. To develop the model, this paper identifies the senstive model inputs of geometry model and energy model, and introduces the method to determine their values. After that, the criteria to validate the model are provided. Based on the criteria, the baseline model of auto service and repair shop meets the requirements, and will be used in ASHRAE TRP-1771 as a baseline model.

In ASHRAE TRP-1771, the large scale modeling will be conducted, and the baseline model of auto service and repair shop will be auto-tuned. After that, the model will be matched the 2003 CBECS data better.

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