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DEVELOPMENT OF A SIMULATION TOOLKIT FOR THE SELECTION OF HIGH-PERFORMANCE SYSTEMS FOR OFFICE BUILDINGS IN HOT AND HUMID CLIMATES

(Phase I: Calibrated Simulation of the Case Study Building)

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ABSTRACT

This paper reports on the development of an easy-to-use tool for the selection of high-performance systems in office buildings in hot and humid climates. In this paper, the preliminary results of a calibrated simulation of a typical large office building are presented for the John Connally building (124,000 sq-ft) in College Station, TX. To calibrate the DOE-2 simulation model, measured data were retrieved from permanently installed data loggers in the building, which measured whole-building electricity use and sub-metered cooling electricity use, lighting and miscellaneous equipment use, as well as thermal energy measurements for chilled water and hot water use. Also used in the calibration process were portable data loggers for comparing the performance of the building's air-handling units with the simulated performance. For the calibration of the DOE-2 model, several calibration methodologies were used, including manual & iterative calibrations, graphical & statistical analysis, and signature analysis. This calibrated simulation model will be used as a base-case model for the development of a easy-to-use simulation tool for the selection of high-performance systems in office buildings in hot and humid climates. This paper presents the calibrated simulation results of the office building and outlines the additional steps for the development of the high-performance systems selection tool.

INTRODUCTION

Currently, there is a lot of discussion about sustainability, green buildings, high-performance buildings, and/or energy efficient buildings. Although these terms are different, the main concepts are the same. In general, high-performance buildings are substantially more efficient buildings than conventional buildings in terms of energy, economic, and environmental performance (EERE, 2006), yet provide the same comfort and environmental conditions as conventional buildings. A number of buildings already have been publicly reported as high-performance buildings in many different publications. However, it was revealed from a detailed literature survey (Cho and Haberl, 2006) that the reported high-performance buildings included only partial descriptions of the characteristics of high-performance systems. Also, there were only a few high-performance buildings identified and reported in hot and humid climates. Consequently, it is important to continue to study the design and construction of high-performance buildings, using high-performance environmental systems and components, for hot and humid climates. In addition, even for the technologies applicable in hot and humid climates, the demonstration and analysis of systems is needed for designers and engineers to learn from, so they can implement the successful features into their buildings with confidence. To date, there are a lack of tools that can be used to quickly evaluate the energy performance of office buildings using high-performance and renewable energy systems. The development of such tools is necessary for high-performance building designers and engineers who do not have the budget or expertise to run complex simulation programs. In this paper, a calibrated simulation for the case study building is presented as the first step for the development of the systems selection tool.

CALIBRATED SIMULATION MEHODS

Calibrated simulation methodologies can be categorized into three groups, including manual and iterative calibrations, graphical and statistical analysis, and signature analysis.

In general, the manual and iterative calibration procedure has been the most popular approach. This method involves a utility data comparison, walk-through audits, and short-term monitoring. To obtain a calibrated simulation model, the procedure is applied in an iterative fashion using heuristics or rules-of-thumb. Diamond and Hunn (1981) summarized several reports written in late 1970's about the calibration of detailed building simulation programs. The procedure gathered monthly utility bills for an entire year, obtained information about the buildings, HVAC information and operating schedules, and then calibrated the DOE-2 simulation models to the buildings. Haberl et al. (1995) showed the impact of using measured weather data in a DOE-2 simulation. They compared the simulation results of using the Typical Meteorological Year (TMY) weather data with those of using measured data or Test Reference Year (TRY) weather data. They found that the simulation using the TRY weather data considerably improved the cooling energy simulation for their case study building. Abushakra et al. (2001) developed procedures to derive the diversity factors and conventional load shapes of office buildings' lighting and equipment loads. In their study, a percentile analysis method was used to develop load shapes and diversity factors. In 2006, Pan et al. (2006) summarized the method of calibrated simulation using procedures from ASHRAE Guideline 14 (ASHRAE, 2002), IPMVP (IPMVP, 2002), and FEMP (FEMP, 2000). They used the method to develop DOE-2 simulation models for two commercial buildings in Shanghai, China. In summary, the manual and iterative calibration procedures were identified from the previous studies. These calibration procedures were utilized for the calibration of the case study building in this study.

Second, procedures were identified that used graphical and statistical analysis to highlight differences between measured and simulated results with certain types of visual graphs. These can be very useful techniques to help decide which parameters need to be calibrated for the next iteration. In addition to graphical techniques, Kreider and Haberl (1994a & 1994b) and Haberl and Thamilseran (1996) developed statistical methods such as percent difference, Mean Biased Error (MBE), and Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) to assist with quantifying the progress of the calibration. In these reports, it was shown that the best achievable hourly CV(RMSE) was in the range between 10% and 20%. In 1998, Haberl and Bou-Saada presented new hourly calibration methods with graphical procedures and statistical goodness-of-fit parameters. Also included were methods using a monthly mean difference, hourly MBE for each month, and an hourly CV(RMSE) for each month. The allowable tolerance of the MBE and CV(RMSE) using hourly data has been published in several places (FEMP, 2000; IPMVP, 2002; and ASHRAE, 2002); e.g., CV(RMSE) of +-30% (ASHRAE), +-20% (IPMVP), and +-25% (FEMP). Therefore, it was decided that graphical and statistical methods would be used for the calibration of the case-study building model along with the satistical MBE and CV(RMSE) guidelines published in the ASHRAE literature.

Third, a signature analysis has been developed as an approach for calibrated simulation. Calibration signatures, which represent graphical deviations between measured and simulated energy use as a function of average dry bulb temperature, were shown to be useful to calibrate a simulation model. Wei et al. (1998) developed the calibration signatures based on the previous efforts from Liu and Claridge (1998) and Katipamula and Claridge (1993). Liu et al. (2003 & 2004) added characteristic signatures, which represent a sensitivity analysis in each parameter for a building and system level. The characteristic signatures provide a predictable shape according to changes of an input parameter by a certain amount based on the calibration signatures. In 2006, Song extended the signature analysis method for the calibration of the case study building in his Ph.D. dissertation (Song, 2006), and added a statistical signature to the previous graphical signatures that allowed for the quantification of the progress of the calibration across multiple characteristic signatures.

In summary, three different calibrated simulation methodologies were shown for this analysis, which include manual and iterative calibrations, graphical and statistical analysis, and statistical signature analysis.

CASE STUDY BUILDING DESCRIPTION

Case Study Building: John B. Connally Building

In this paper, a calibrated DOE-2 simulation model of a case study building, the John B. Connally Building in College Station, TX was developed. The John B. Connally (JBC) building is one of the Texas A&M University facilities in College Station, Texas. The building picture and DrawBDL output of DOE-2 input file for the case study building are shown in Figure 1. This building consists of 124,000 square feet of conditioned space with seven stories and a thermal plant, which is detached from the building. This building is used for offices and conference rooms. The JBC building has window-to-wall ratio of 40%.

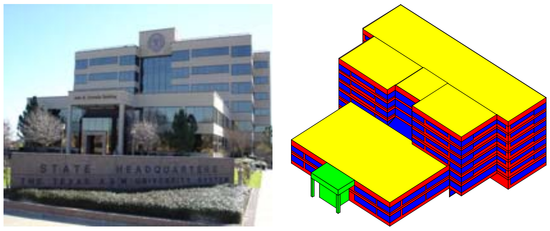


Figure 1. Case Study Building: John B. Connally Building

JCB Building's AHU Systems

There are a total of nineteen (19) Air Handling Units (AHUs) of which seventeen are Single-Duct, Variable Air Volume (SDVAV) AHUs with Variable Frequency Drives (VFDs) and two (2) AHUs are SDVAV 100% outside AHUs, which provide the seventeen SDVAV AHUs with fresh outdoor air. The two outside air AHUs are located on the roof of the building. The SDVAVs, as shown in Figure 2, are equipped with a cooling coil and a draw-through supply air fan. The mechanical rooms are used as mixing chambers. Return air comes through plenums on each floor, which are connected to the mechanical rooms. The return air is mixed with the outside air, which comes into the mechanical room through ducts from the OAHUs on the roof. The mixed air in the mechanical rooms comes into the AHUs and passes through the cooling coils.

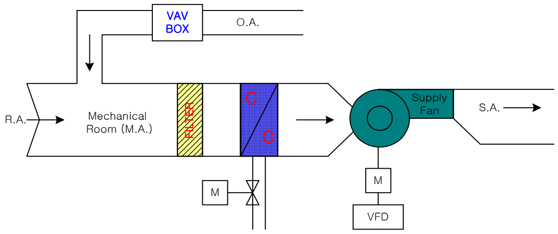


Figure 2. AHU System Diagram in the JBC Building

In the building, there are 230 terminal VAV boxes, which have hot water reheat coils and supply air dampers that are run by Direct Digital Control (DDCs) systems. Also, there are nine (9) cooling fan coil units in several places such as the electrical room and the mechanical penthouses. Table 1 specifies the design conditions of the seventeen (17) SDVAV AHUs and two (2) 100% Outside AHUs (OAHUs) in each service area, which was obtained from the JBC building drawings.

JCB Building's Thermal Plant

The thermal plant has two chillers proving chilled water for space cooling, two boilers proving hot water for space heating, and one water heater for service water heating. The two centrifugal chillers have a capacity of 280-ton each. The JBC building only needs one 280-ton chiller to meet the building's maximum cooling loads during occupied hours. The chillers are sequenced to allow both to run equal amounts each year. There are two 20 HP constant speed chilled water pumps. These pumps operate only when their corresponding chillers are running. Two cooling towers are located right next to the thermal plant, which have a condensing water flow of 840 gallons per minute each. Each cooling tower has a 15 HP fan, which is a draw through fan installed on the top of the cooling tower and is controlled by a VFD system. In a similar fashion as the chilled water pumps operate, these cooling towers also work when their associated chillers are running. The plant also contains two hot water boilers, which are gas-fired (80% efficiency) boilers with an input capacity of 2,000 MBH. Table 2 summarizes the JBC building's plant information with design conditions for chillers, boilers, cooling towers, pumps, and service water heater.

Table 1. Design Conditions of 17 SDVAV AHUs and 2 100% OAHUs

AHU Schedule								
#	AHU ID	Total CFM	SP (inWG)	HP	Fan Eff.	Unit Location	Area Served	Air Flow
1	AHU 1-1	7610	2.5	7.5	40%	1st Floor	1st FL North	VAV
2	AHU 1-2	10445	2.5	7.5	55%		1st FL South	
3	AHU 1-3	9385	2.5	7.5	49%		1st FL West	
4	AHU 2-1	8000	2.5	7.5	42%	2nd Floor	2nd FL North	VAV
5	AHU 2-2	8535	2.5	7.5	45%		2nd FL South	
6	AHU 2-3	12170	2.5	10.0	48%		2nd FL West	
7	AHU 3-1	6855	2.5	7.5	36%	3rd Floor	3rd FL North	VAV
8	AHU 3-2	10775	2.5	10.0	42%		3rd FL South	
9	AHU 3-3	8935	2.5	7.5	47%		3rd FL West	
10	AHU 4-1	9520	2.5	7.5	50%	4th Floor	4th FL North	VAV
11	AHU 4-2	9850	2.5	10.0	39%		4th FL South	
12	AHU 5-1	9520	2.5	7.5	50%	5th Floor	5th FL North	VAV
13	AHU 5-2	9850	2.5	10.0	39%		5th FL South	
14	AHU 6-1	9520	2.5	7.5	50%	6th Floor	6th FL North	VAV
15	AHU 6-2	9850	2.5	10.0	39%		6th FL South	
16	AHU 7-1	10560	2.5	10.0	42%	7th Floor	7th FL North	VAV
17	AHU 7-2	10620	2.5	10.0	42%		7th FL South	
18	OA AHU-1	4215	1.0	3.0	22%	Roof (Weather proof Construction)	Outside Air	VAV
19	OA AHU-2	5075	1.0	3.0	27%		Outside Air	

Table 2. Thermal Plant Summary of the JBC Building

Boilers	Fuel Type	GPM	EWT (F)	LWT (F)	HP	Input (MMBtu)	Output (MMBtu)	Remarks
B-1	N.G.	80	150	190	1	2,000	1,600	460V, 3Phase Blower Motor
B-2	N.G.	80	150	190	1	2,000	1,600	Cleaver Brooks Model M4W-2000
Chillers	Tons	Chiller Data				Input	Eff.	Remarks
		GPM	EWT (F)	LWT (F)	Delta-P	(kW)	(kW/ton)	
CH-1	280	560	54	42	15	190	0.68	York Centrifugal Chiller
CH-2	280	560	54	42	15	190	0.68	Model: YT E1 E3 C1-CK FS
Cooling Towers	Condenser Data			Amb. Twb	Fan data			Remarks
	GPM	EWT (F)	LWT (F)	(F)	HP	Volts	Phase	
CT-1	840	96	86	80	15	460	3	VFD
CT-2	840	96	86	80	15	460	3	
Pumps	GPM	Head Ft.	Min. Eff.	HP	Volts	Phase	RPM	Remarks
CHWP-1	560	90	75	20	460	3	1750	Aurora Series 410
CHWP-2	560	90	75	20	460	3	1750	Aurora Series 410
CTWP-1	840	40	81	15	460	3	1750	Aurora Series 1110
CTWP-2	840	40	81	15	460	3	1750	Aurora Series 1110
HWP-1	80	80	60	5	460	3	1750	Aurora Series 360
HWP-2	80	80	60	5	460	3	1750	Aurora Series 360

MEASURED ENERGY USE

Whole-Building Electricity (WBE) Consumption

The electricity consumption data were retrieved from the logger installed in the JBC building. The electric data points are Whole-Building Electricity (WBE), Lighting & Equipment (L&E), Motor Control Center (MCC), Chiller, and CHW Pump. To verify the metered electric data, utility bills were obtained from the College Station Utility Services. Figure 3 shows daily electric use for WBE, L&E, and Chiller, which was created by summing and averaging the collected hourly data.

Natural Gas Consumption

The Natural Gas (N.G.) consumption of the JBC building was obtained from the utility provider. Unfortunately, there was no hourly N.G. metering equipment installed for this study, so the gas meter on site was manually read for the period from June 2006 to October 2006. The total N.G. consumption of the JBC building was 8,171 therms in 2006.

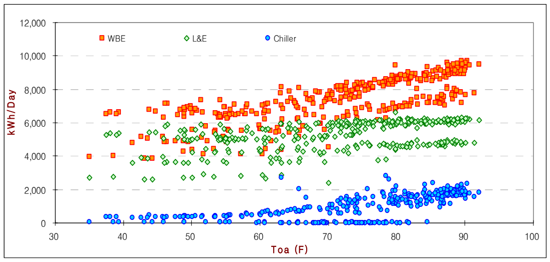


Figure 3. Measured Electric Use of WBE, L&E, and Chiller in 2006

Energy Use Indices (EUIs) Comparison

The JBC building consumed 2,676 MWh of electricity (EUI of 21.58 kWh/sqft-yr) and 8,171 therms of N.G. (EUI of 6.59 kBtu/sqft-yr) in 2006. This total energy use is divided by the total building's conditioned space of 124,000 sq-ft. The EUI of the JCB building is 80.2 kBtu/sqft-yr. To have a snap shot of the JBC building's energy performance, the EUI of the JBC building was compared with ones from other similar buildings. As indicated in Figure 4, there are six other buildings picked from Austin, Texas (Haberl et al., 2001), which are same building types (office) and have similar building areas (120,000 – 183,000 sq-ft).

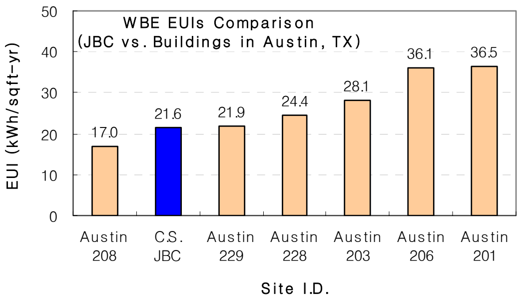
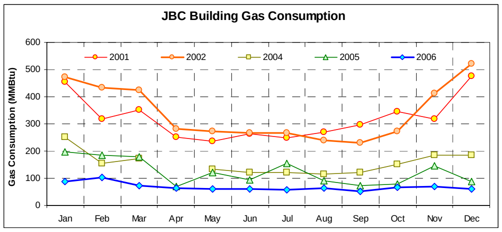


Figure 4. Comparison of EUIs (JBC Bldg. vs. Other Bldgs. in Austin, TX) – (Source: Haberl et al., 2001)

It shows that the JBC building's energy performance is better than average in terms of total electric consumption (WBE + Cooling Energy) compared to other buildings. One thing that needs to be mentioned is that the JBC building went through a commissioning process in 2003 by engineers in the Energy Systems Laboratory at Texas A&M. Before the commissioning, the building consumed electricity of 2,879 MWh (EUI of 23.22 kWh/sqft-yr) and 40,960 therms (EUI of 33.03 kBtu/sqft-yr). After the commissioning process, the JBC building's electric consumption dropped by 10%. However, as shown in Figure 5, the N.G. use dropped to less than half of the 2004 use. Additional changes were made in 2005 and 2006 that reduced this further. One major change during the commissioning on the boilers was a reset of the constant boiler temperature, which was 180F year round.



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2001	454	317	351	253	236	264	247	269	297	345	318	477	3,828
2002	474	432	424	283	273	267	267	239	231	274	412	520	4,096
2003	Commissioning												
2004	212	252	156	173	153	133	121	122	115	122	151	186	1,896
2005	186	196	186	180	70	120	93	155	92	72	79	147	1,576
2006	87	103	74	63	62	60	58	63	51	66	69	61	817

Figure 5. N.G. Consumption Changes of the JBC Building Before and After Commissioning

MEASURED DATA ANALYSIS FOR CALIBRATED SIMULATION

Weather Data

The 2006 TRY weather file was packed using data from the NOAA (National Oceanic and Atmospheric Administration) website (NOAA, 2007) for College Station, TX and NREL (National Renewable Energy Laboratory) solar data (ESL, 2007) available also for the city of College Station, TX.

Lighting & Equipment Data

To develop typical load shapes of lighting and equipment loads, the ASHRAE RP-1093 (Abushakra et al., 2001) method was used. This method uses 10th, 25th, 75th, and 90th percentiles for each hour of the day by daytype such as weekday and weekend. The 50th percentiles are recommended to be used for the diversity factors for lighting and equipment. And the 90th percentile values are used for the peak load calculation. The maximum W/sqft values are calculated, and then these values are used to normalize the hourly data, which is expressed as values between 0 and 1. DOE-2 input schedules are compatible with these values.

AHUs Data

Thermal data for the AHUs was retrieved from portable data loggers (HOBO loggers) that were installed in two mechanical rooms and two offices in the 5th floor for the period from September 2006 to February 2007. The temperature measurement points were: return air (Tra), outside air (Toa), mixed air (Tma), and cooling coil leaving air (Tcc) in the mechanical rooms; and room supply air (Trs) and room return air (Trr). All these measurements were conducted for both interior and exterior areas. Figure 6 is an example from the measured data of the return air from both south and north interior zones. These measured data were then used for the calibrated simulation of the case study building.

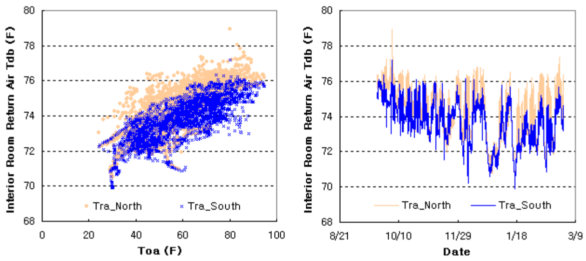


Figure 6. Return Air Measurement from Interior Zones

Chiller Data

Thermal data were also retrieved from the permanently installed water flow and temperature meters. The data points included water flow and supply and return water temperatures for both chilled water and condenser water sides. Figure 7 shows the performance of the chillers calculated using metered data. The chiller performance was compared against the manufacturer's curve for the chiller (Peraza, 2006).

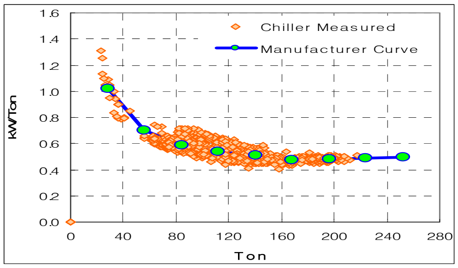


Figure 7. Chiller Performance (Measured vs. Manufacture data)

SIMULATION MODEL DEVELOPMENT

LOADS/SYSTEMS/PLANT Input Summary

Followings are DOE-2 key words and input values used for the LOADS, SYSTEMS, and PLANT simulations of the case study building. Table 3 shows general inputs and building envelope U-values. Table 4 shows the glazing property from the manufacturer. Table 5 shows the space conditions. Table 6 and Table 7 show the SYSTEMS inputs and PLANT inputs, respectively.

Initial Simulation Results

The initial simulation was performed using design data available from the building drawings and TMY2 Houston weather data. The hourly simulation results from HVAC systems, lightings, equipment, and other building energy systems were summed up to the daily energy consumption. These daily energy use data were divided into cooling, heating, and whole building energy sections to compare these with measured energy consumption. Figure 8 shows the initial simulation results and comparison with measured data. The uncertainties of the simulation were CV(RMSE) of 15.3% (WBE) and 26.3% (CHW), and MBE of 4.4% (WBE) and 4.7% (CHW). The discrepancies between measured and simulated energy uses can easily be seen in the figures.

Table 3. Building General Inputs and U-Values

DOE-2 Keywords	DOE-2 Values	Description
LATITUDE	30.35 N	From NOAA
LONGITUDE	96.22 W	From NOAA
ALTITUDE	326 ft	From NOAA
AZIMUTH	90 Degree	Facing West
WALL-EXTERIOR	0.105	Btu/hr-sf-F (U-Value)
WALL-INTERIOR	0.339	Btu/hr-sf-F (U-Value)
ROOF	0.034	Btu/hr-sf-F (U-Value)
FLOOR-INTERNAL	0.230	Btu/hr-sf-F (U-Value)
UNDERGROUND	0.011	Btu/hr-sf-F (U-Value)
CEILING	0.562	Btu/hr-sf-F (U-Value)

Table 4. Glazing Properties

Properties	Value	Description
LAYER	Exterier Lite	1/4" PPG Solarcool Bronze
	1/2" Cavity	1/2" Air
	Interior Lite	1/4" Clear Glass
U-VALUES	0.50/0.48	Summer/Winter (Btu/hr-sf-F)
SHGC	0.34	Solar Heat Gain Coefficient
SC	0.40	Shading Coefficient

Table 5. Space Conditions Input for DOE-2 Simulation

DOE2 Key Words	Inputs	Descriptions
TEMP	71 F	Avg. Measured Value
AREA/PERSON	492 sq-ft/person	124,000 sqft / 252 people
PEOPLE-HG-SENS	245 Btu/hr	ASHRAE Fundamental
PEOPLE-HG-LAT	155 Btu/hr	ASHRAE Fundamental
LIGHTING-TYPE	REC-FLUOR-RV	Recessed Fluorescent Vented to Return Air
LIGHTING-W/SQFT	1.90 W/sq-ft	Measured (RP-1093)
LIGHT-TO-SPACE	0.80 (80%)	REC-FLUOR-RV
EQUIPMENT-W/SQFT	1.07 W/sq-ft	Measured (RP-1093)
FLOOR-WEIGHT	70 lb/sq-ft	DOE2 default (Medium)

Table 6. SYSTEMS Input Summary

Item	DOE2 Key Words	DOE2 Model	Descriptions
ZONE-CONTROL	HEAT-TEMP-SCHEDULE	HEAT-SCHED	74 F
	COOL-TEMP-SCHEDULE	COOL-SCHED	74 F
SYSTEM	SYSTEM-TYPE	VAVS	
	RTN-AIR-PATH	PLENUM	
SYSTEM-CONTROL	MIN-SUPP-TEMP	55F	Measured
	COOL-SET-TEMP	55F	
	HEAT-SET-TEMP	105F	Default
SYSTEM-AIR	MIN-OUTSIDE-AIR	0.02	7% of Total
	OA-CONTROL	FIXED	
SYSTEM-FAN	SUPPLY-STATIC	2 in H2O	
	FAN-CONTROL	SPEED	
SYSTEM-TERMINAL	MIN-CFM-RATIO	0.3	
	REHEAT-DELTA-T	48F	

Table 7. PLANT Input Summary

	Items	DOE2 Model	Descriptions
HW-BOILER	SIZE	2 x 1.2	1.2 MBtu/Hr
CENT-CHILLER	SIZE	2 x 280 TON	3.4MBtu/Hr
COOLING TOWER (OPEN)	SIZE	2 x 4.2	Mbtu/Hr
	TWR-CAP-CTRL	Variable Speed	
PUMPS	PUMP-TYPE	Variable Speed	

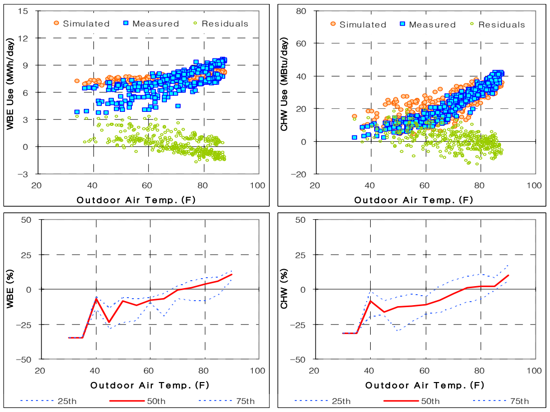


Figure 8. Initial Simulation Results vs. Measured WBE and Chiller Electric Use (Upper) and Calibration Signature (Lower) for WBE and CHW

Calibration 1: Weather File (TMY2 to TRY)

In this step the TMY2 Houston, TX weather file was replaced with the packed 2006 TRY file for College Station, TX. As shown in Figure 9, after changing the weather file, the simulated cooling energy improved significantly, so that the CV(RMSE) of the cooling energy reduced to 14.1% from 26.3%, while the other error values improved about 2%.

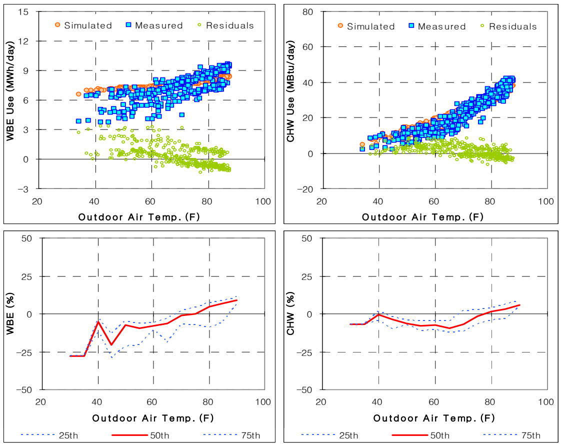


Figure 9. First Calibration vs. Measured WBE and Chiller Electric Use and Chiller Electric Use (Upper) and Calibration Signature (Lower) for WBE and CHW

Calibration 2: Diversity Factor for L&E

In this step the total measured Lighting & Equipment (L&E) power density of 1.76 W/sq-ft was further refined using daytype profiles. As shown in Figure 10, the hourly measured L&E electric data were rearranged for weekday and weekend profiles using the ASHRAE RP-1093 method (Abushakra et al., 2001).

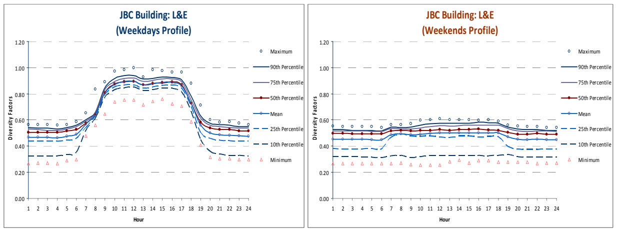


Figure 10. JBC Building L&E Weekday and Weekend Profile

The resultant weekday and weekend diversity factors were incorporated in the simulation and the results are depicted in Figure 11. Due to the different schedules for weekday and weekend, the residuals in the figure show in a narrower range. Statistical analysis showed that the CV(RMSE) of WBE was improved from 14.6% to 10.9%. However, the cooling energy had a relatively small change since the power density did not change but only the schedule changed.

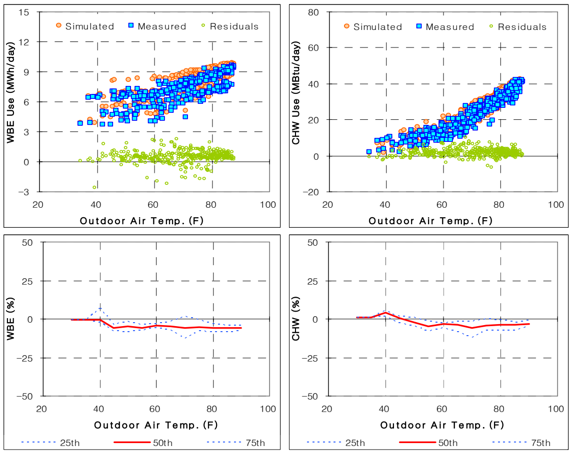


Figure 10. Second Calibration Results vs. Measured WBE and Chiller Electric Use (Upper) and Calibration Signature (Lower) for WBE and CHW

Calibration 3: AHU Supply Air Temperature Reset

In this step the cold deck temperature was changed from constant set temperature of 55 F to scheduled temperature based on the outside air temperature. From the measured data, it was observed that when the outdoor air temperature was 65 F or lower, the cold deck temperature was set to 62 F, and when the outdoor temperature was 80 F or higher, it reset to 55 F. The cold deck temperature linearly decreases from 62 F to 55 F as the outside sir temperature increases from 65 F to 80 F. In this simulation, as shown in Figure 11, there are almost no changes made from this calibration, so that the CV(RMSE) just changed within 1%.

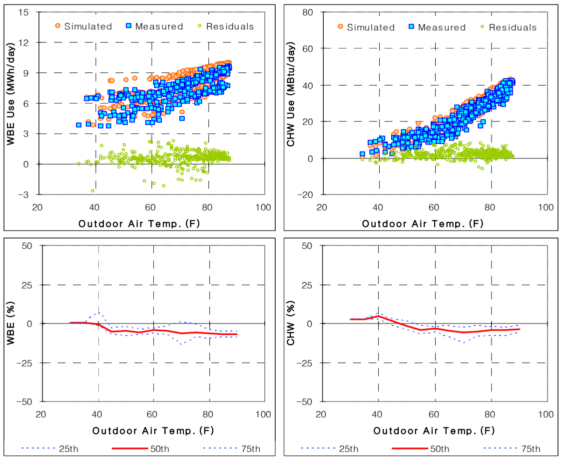


Figure 11. Third Calibration Results vs. Measured WBE and Chiller Electric Use (Upper) and Calibration Signature (Lower) for WBE and CHW

Calibration 4: Room Air Temperature Reset

The room air temperature was changed from 71F to 74F based on the observation of the data from the portable data loggers. Figure 12 shows the results of simulation. Although a visual inspection of the figure shows a little change, the CV(RMSE) value CHW improved from 12.6 to 9.8.

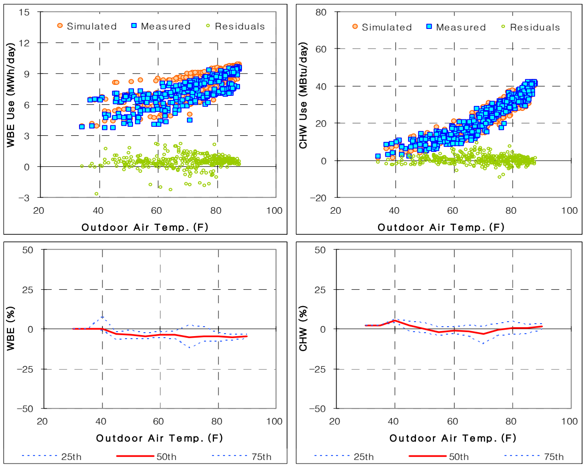


Figure 12. Fourth Calibration Results vs. Measured WBE and Chiller Electric Use (Upper) and Calibration Signature (Lower) for WBE and CHW

Calibration 5: Chiller Efficiency (COP from 4.8 to 6.9)

The final calibration was made on the chiller data. The chiller COP changed from the DOE-2 default, which is COP 4.8, to measured chiller COP of 6.9. Figure 13 shows the simulation results and comparison with the measured data.

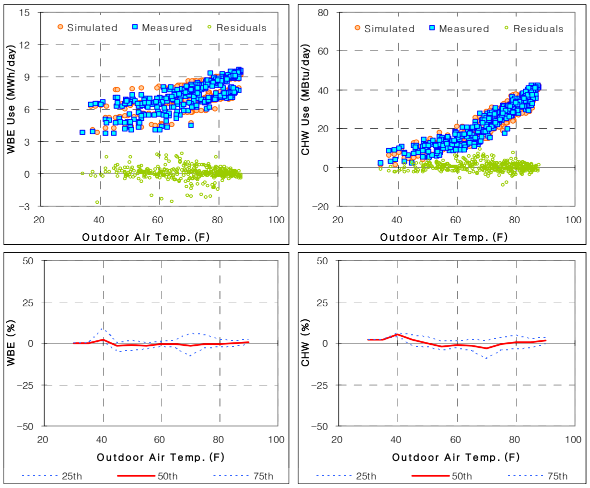


Figure 13. Fifth Calibration Results vs. Measured WBE and Chiller Electric Use (Upper) and Calibration Signature (Lower) for WBE and CHW

The final uncertainties of the simulation were CV(RMSE) of 8.4% (WBE) and 9.8% (CHW). These error values are well below the tolerance range that ASHRAE published (ASHRAE, 2002), which is 30% (CV(RMSE)).

Calibration Summary

Figure 14 shows the CV(RMSE) errors for the basecase and the five calibrations. The chilled water consumption changed the most by changing the weather file from TMY2 to TRY for 2006, although the WBE did not change much. In the WBE calibration, the use of diversity factors for internal heat gain schedule was the largest impact as shown in the graph (Calibration1 to Calibration2). The final errors for both WBE and CHW were all in the tolerance ranges that ASHRAE published.

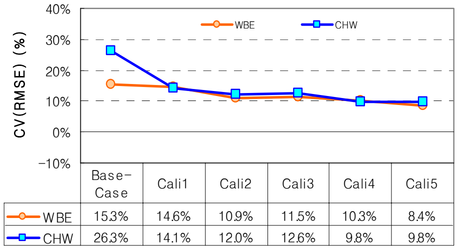


Figure 14. Summary of CV(RMSE) Changes

SUMMARY

This paper presented the calibrated simulation of a typical commercial office building in hot and humid climates. This was the first of three phases for developing a simulation toolkit for the high-performance systems selections in hot and humid climates. In this analysis measured and metered electric and thermal data were analyzed and used for the calibrated simulation. The resultant simulated energy use matched well within the ASHRAE tolerance range of 30% CV(RMSE).

FUTURE WORK

To develop a simulation toolkit for the selection of high-performance systems for office buildings in hot and humid climates, several steps will be followed as noted below.

- Develop a Simplified Building Geometry Model
- Develop a High-Performance Modified DOE-2 Model
- Perform An Energy Savings Assessment
- Demonstrate the Energy Performance Evaluation Tool

Finally, procedures to integrate the modified DOE-2, F-Chart, and PV F-Chart into a web-based tool will be developed to include renewable energy. This tool will include the energy savings potential obtained from implementing individual or combined high-performance features in office buildings in hot and humid climates. Several different climate conditions in

Texas will be used to show how the performance of the individual building components will change by different climate conditions. Methods to integrate the F-Chart (Beckman et al., 1977) and PV F-Chart (Klein and Beckman, 1983) will be identified to represent the impact of integrating solar energy analysis. It is the intention that such a tool will help users to select the best selection of building components when they design high-performance office buildings in hot and humid climates.

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