Journal of Building Performance Simulation

ISSN: 1940-1493 (Print) 1940-1507 (Online) Journal homepage: https://www.tandfonline.com/loi/tbps20

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To cite this article: Yiqun Pan , Mingming Zuo & Gang Wu (2011) Whole building energy simulation and energy saving potential analysis of a large public building, Journal of Building Performance Simulation, 4:1, 37-47, DOI: 10.1080/19401491003721301

To link to this article: https://doi.org/10.1080/19401491003721301

Published online: 15 Jun 2010.

Journal of Building Performance Simulation
Vol. 4, No. 1, March 2011, 37–47

Whole building energy simulation and energy saving potential analysis of a large public building

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(*Received 22 October 2009; final version received 22 February 2010*)

This article explores how to use EnergyPlus to construct models to accurately simulate complex building systems as well as the inter-relationships among sub-systems such as heating, ventilation and air conditioning (HVAC), lighting and service hot water systems. The energy consumption and cost of a large public building are simulated and calculated for Leadership in Energy and Environmental Design (LEED) certification using EnergyPlus. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) baseline model is constructed according to ASHRAE 90.1 standard and the comparison of annual energy consumption between ASHRAE baseline model and proposed model is carried out. Moreover, an energy efficiency (EE) model is built based on the design model. Meanwhile, other energy conservation measures (ECMs) such as daylighting dimming and occupant sensors are considered. The simulation results show 4.7% electricity consumption decrease but 6.9% gas consumption increase of the EE model compared to ASHRAE baseline model. In summary, the annual energy cost of the EE model is reduced by 7.75%.

Keywords: whole building energy simulation; large public building; ASHRAE baseline model; EnergyPlus

1. Introduction

In a public building, there exist many spaces with quite different functions and structures which will certainly lead to more complicated building systems such as heating, ventilation and air conditioning (HVAC) system, electric lighting system as well as service hot water system. Especially when more and more advanced building technologies become an important part of the composition of a large public building, it does show great difficulty in analysing and evaluating the whole building energy consumption. EnergyPlus, which is a new generation building energy analysis tool, bears many advantages when compared to its ancestors and is suited to analyse building performances with non-normal building systems especially for large office buildings. Griffith *et al.* (2003) employed EnergyPlus to study the influence of some advanced building technologies over the building performance of a public building in Teterboro airport and DOE-2.1E to analyse the effect of such common measures as optimized envelope system and schedules. Ellis and Torcellini (2005) carried out research on the reliability of EnergyPlus in simulating tall buildings and the outcomes from their research proved accuracy and reliability of EnergyPlus in simulating tall buildings. Pan *et al.* (2005) analysed a campus building equipped with a building cooling heating and power (BCHP) system based on the full understanding of corresponding features of EnergyPlus and also studied its whole building energy and operation performance (Hartkopf *et al.* 2003, Pan *et al.* 2005).

This article first describes a large public building located in Shanghai and its complex building systems and then compares EnergyPlus to DOE-2.1E and TRNSYS 16 over their capabilities in modelling buildings and their systems to find out the advantages of EnergyPlus as a whole building energy analysis tool. Then, the public building is simulated with EnergyPlus as an example to explore how to properly simulate building subsystems and their corresponding control strategies. The simulation results of this building are analysed.

2. Building description

2.1. General information

It is a public building located in Shanghai Expo Park with seven floors above ground and one floor underground. Figure 1 is its 3-D view generated with Design builder according to design documents. This building stretches 350 m from the west to the east, and 140 m from the north to the south, with the total floor area of 142,000 sq/m and the height of 40 m, located within riverside green areas. It will function mainly for conference; therefore, it contains various types of

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ISSN 1940-1493 print/ISSN 1940-1507 online

DOI: 10.1080/19401491003721301
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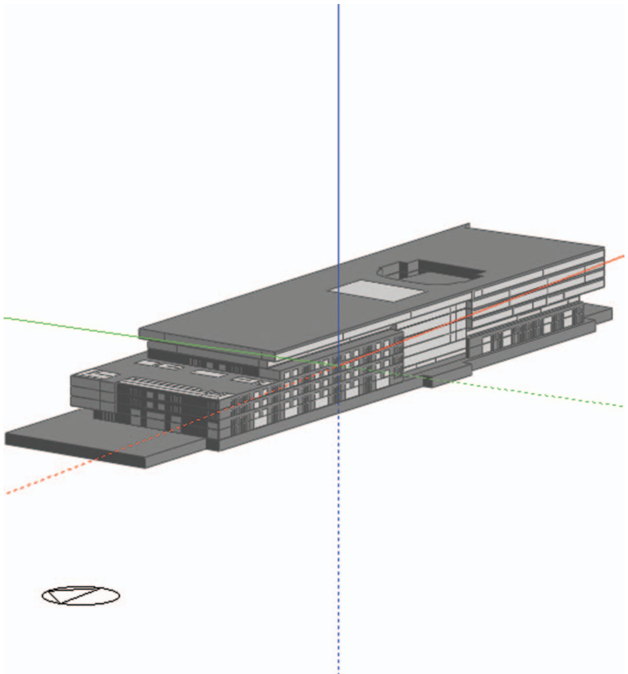

Figure 1. 3-D view of design model.

meeting rooms and auxiliary spaces such as restaurants, press room and offices, etc.

2.2. HVAC system

There are two types of all-air systems in this building, i.e. variable air volume (VAV) system and constant air volume (CAV) system; CAV systems mainly serve such spaces as main conference hall, multi-functional hall, banquet hall, lobby and entrance; VAV systems serve middle-size and small-size meeting rooms, office rooms and some small restaurants.

The cooling and heating source plants consist of two double-mode chillers, ice storage tanks, three water-source heat pumps using Huangpu River water as the heat source/sink, and two gas boilers. The chilled water system is a constant primary flow/variable secondary flow system, while the hot water system is a variable primary flow system.

In summer, the double-mode chillers, ice storage tanks and water-source heat pumps are operated to meet the cooling loads, while the gas boilers are operated to meet the heating loads of the building. During night, the double-mode chillers are operated in ice-making mode to charge ice storage tanks with the leaving coolant temperature of -5.6°C, where the coolant is 25% glycol solution. Whether the charging mode is completed or not depends on the leaving water temperature of ice storage tanks, i.e. once the temperature is below -4°C, the charging of ice storage tanks is completed and the double-mode chillers and corresponding pumps will stop running automatically. During the daytime, the ice storage tanks are discharged with warm water flowing through it and double-mode chillers are operated in normal chilled water mode. The operation priority sequence is ice storage tank – water source heat pump – double-mode chillers and the leaving temperature setpoints are 3.3, 6 and 6°C, respectively. In winter, only double-mode chillers and ice storage tanks are operated for cooling, while water-source heat pumps and gas boilers are operated for heating, with water-source heat pumps operating in priority concerning its high coefficient of performance (COP) in heating mode. The space heating system is coupled with the service hot water system, with the leaving hot water temperature of 50°C. Figures 2 and 3 illustrate schematics of chilled and hot water loop.

2.3. Lighting system and others

In the design scheme of this building, no lighting and daylighting dimming control is considered, but as there are big window to wall area ratios on all orientations of facades, daylighting dimming control is introduced into the energy efficiency (EE) model. In addition, photovoltaic (PV) system is also employed in this model to meet the electric power demand.

3. Comparison of energy simulation tools

Before constructing a whole energy model for the public building, a brief comparison of whole building energy simulation tools is carried out to demonstrate why EnergyPlus is selected in this article.

EnergyPlus is an energy simulation engine which employs a simultaneous load/system/plant simulation methodology and its timestep can be customized for an hourly or sub-hourly simulation. In load calculation, conduction transfer function (CTF) method is used to calculate heat conduction through envelopes and then a heat balance method for zone load (Crawley *et al.* 2001, 2005). Moreover, EnergyPlus makes use of a modular, loop-based method to simulate HVAC systems which helps to accelerate the model construction process (Strand and Pedersen 2001). Through the use of 'setpoint manager' and lately released module called 'energy management system' in EnergyPlus, many different kinds of variables such as supply air temperature and chilled water supply temperature can be controlled and this function facilitates the construction of modern advanced supervisory control system which is beyond the capability of DOE-2.1E and many other simulation tools.

Although TRNSYS and DOE-2 have been widely applied in evaluating the operation performance as

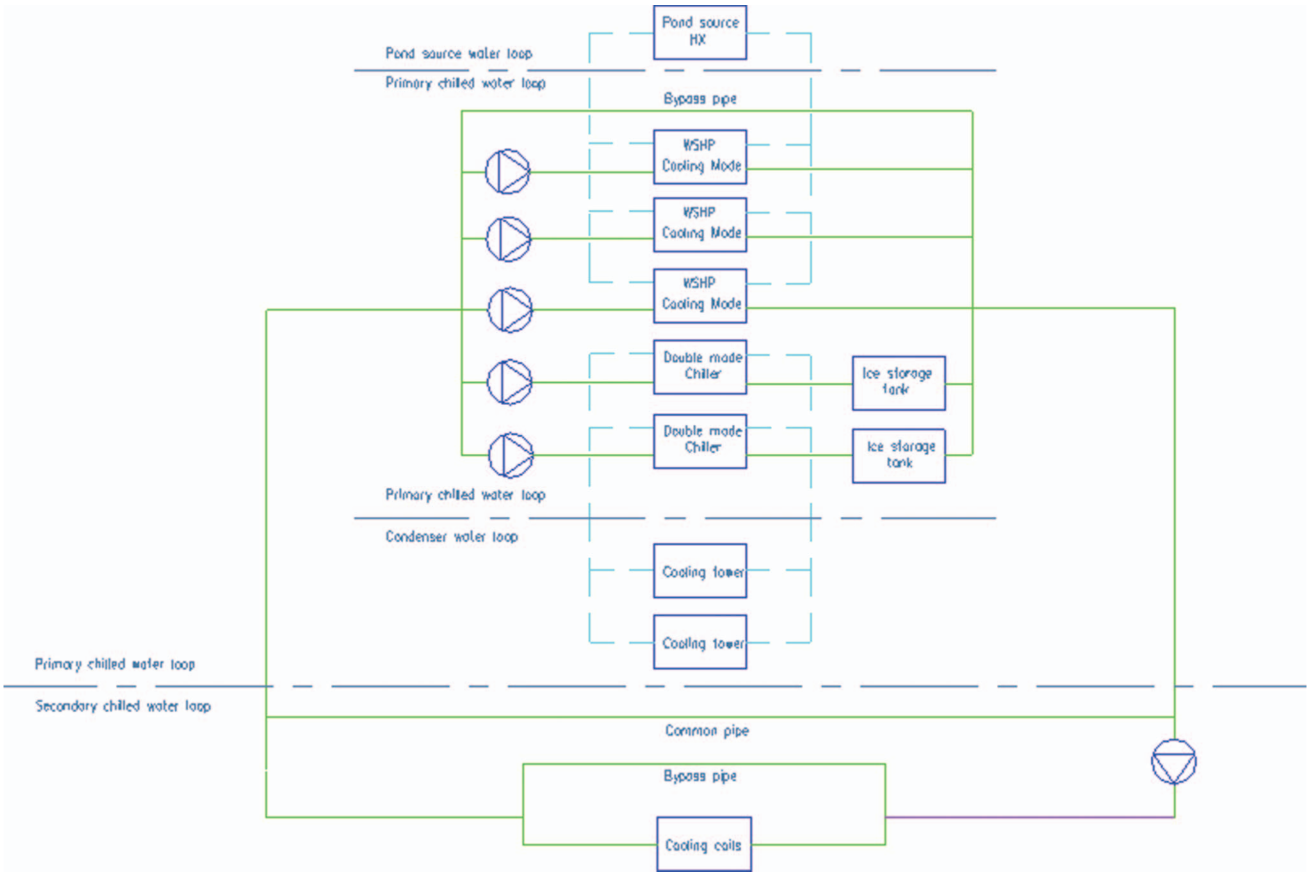

Figure 2. Schematic of chilled water loop.

well as the energy consumption of buildings, some drawbacks of these tools prevent them from further application in some large complex public buildings. For example, Type 56 in TRNSYS 16 can be used in constructing a multi-zone building but it is limited to conditions like not more than 25 zones and 999 surfaces. As far as many newly constructed public buildings in China are concerned, their sizes far exceed the capabilities of this type. Figure 4 is the zoning plan of ground floor of the public building described at the beginning of this article, in which an enclosed zone bounded by lines stands for a thermal zone and total thermal zone numbers are 36 on this floor. Though TRNSYS may be expanded to allow more thermal zones, it may require great expertise on its source code as well as the software structure. DOE-2.1E does not have so strict limitation on zone numbers and is also able to represent some related conventional HVAC systems, but its sequential simulation method cannot take the interactions among load, system and plant into consideration and the use of sequential simulation would lead to significant approximation of the following aspects of the design such as space air temperatures and thus many space temperature related parameters like system size, plant size as well as occupant comfort.

The complexity of the building and its system is a major factor in choosing EnergyPlus to conduct the simulation among various tools. EnergyPlus is capable of simulating the combination of multiple systems for one building and it allows the analyser to define the components in great detail, so as that most of the aspects of the design can be represented by the models. Moreover, it is very flexible and easy to switch between different seasonal states of the systems using schedules definition in EnergyPlus.

Although EnergyPlus has many excellent features, it still has some shortcomings. For example, there is no easy way to construct a complex system other than to use the template systems provided by the software. Sometimes we have to add related modules in a text IDF file, which is time-consuming and difficult due to the complex interconnections of various components and loops. In addition, a complex EnergyPlus model with many thermal zones normally requires a much longer simulation time than such software as DOE-2.1E.

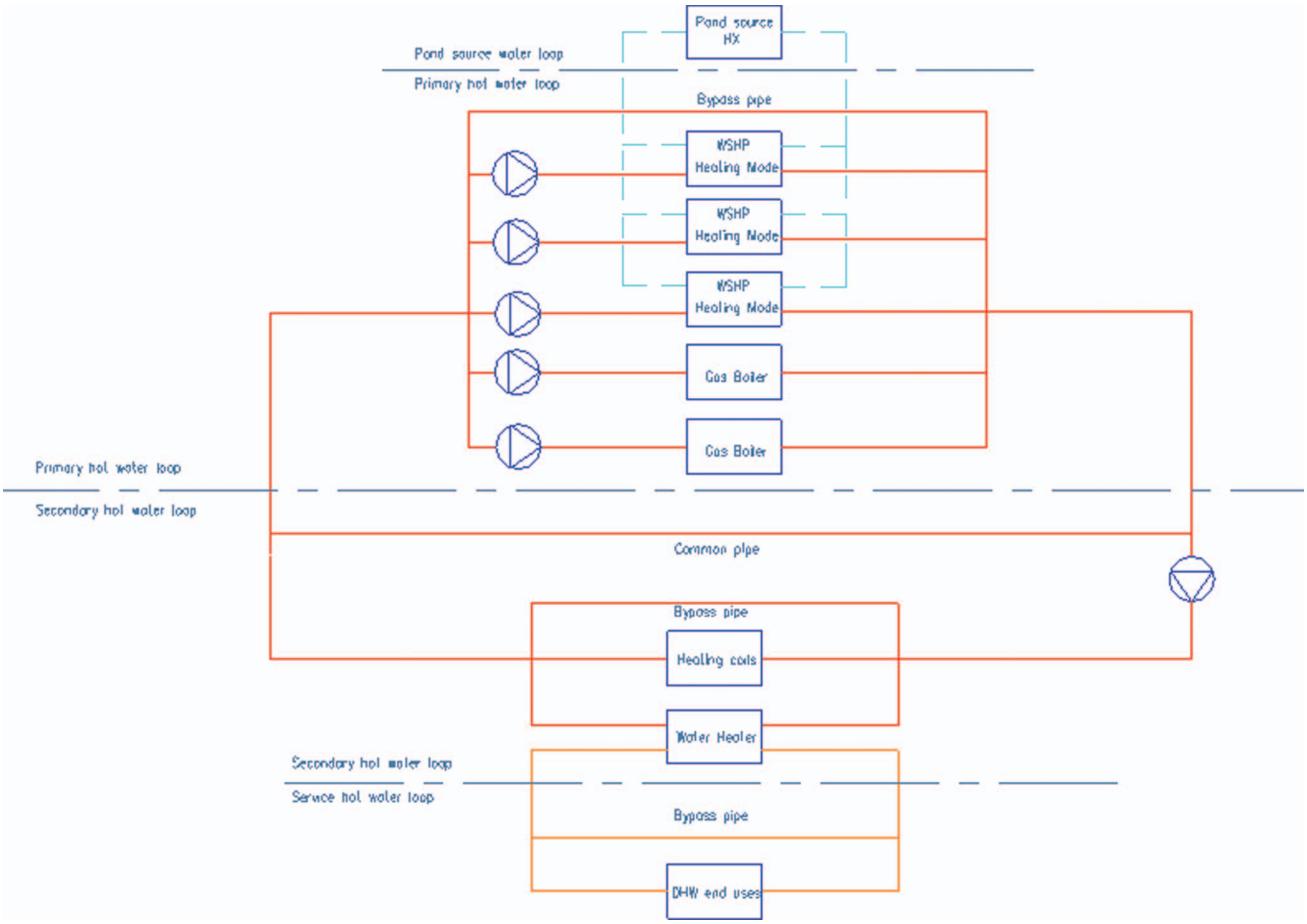

Figure 3. Schematic of hot water loop.

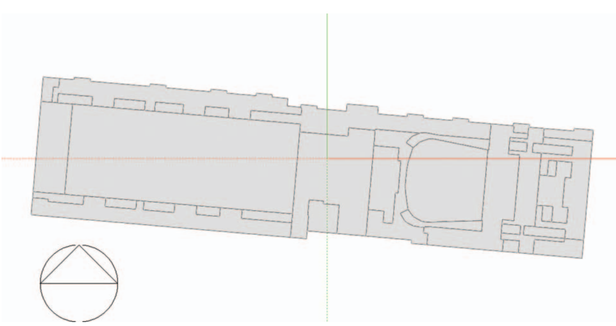

Figure 4. An example of zoning plan for the sample building.

4. Energy model construction

Before proceeding to specific model the methodologies employed for model input are described, such as zoning strategy, operation schedule, etc.

Considering the size and various space functions of such a public building, zoning of each floor has to be carefully carried out. In order to get an accurate estimation of the energy consumption, the zoning should correspond to HVAC design documents; in addition, thermal zones in different orientations may have quite different cooling and heating load profiles due to different solar heat gains; therefore, HVAC system and orientation are two main factors for zoning. For example, conditioned and unconditioned spaces are divided into different thermal zones; the zones served by VAV systems are divided into 4 m perimeter zones plus internal zones. An example zoning plan is shown in Figure 4.

As this building is primarily for conference, some assumptions on the operation schedules of conference rooms and meeting rooms are made. The conference rooms in this building are divided into three types according to their space sizes, i.e. large, medium and small. It is assumed that large conference rooms operate once every 3 weeks while medium conference rooms operate once every 2 weeks. Small conference rooms and meeting rooms are assumed to operate 3 days per week. Schedules for the other zones such as dining and banqueting rooms are defined according to the operation schedule of various conference rooms.

Three energy simulation models are constructed: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) baseline model, design model and EE model. The input data of envelopes, internal loads and HVAC systems of the three models are presented in Tables 1–5.

4.1. ASHRAE baseline model

ASHRAE baseline model is an ASHRAE 90.1-2007 compliant model based on the requirements outlined in Chapter 11 and Appendix G of the standard (ASHRAE 2007). The thermal performance of the envelopes is complied with the least requirement under climate like Shanghai which is categorized into climate zone 3A (refer to CDD and HDD), as listed in Tables 1 and 2. No shading devices are included in this model. Furthermore, VAV systems are applied to all conditioned zones and corresponding zoning is the same as that in the design model. Perimeter conditioned zones are served by VAV boxes with terminal reheat while internal conditioned zones are served by VAV boxes without terminal reheat.

In the baseline model, cooling and heating source plants are four 2691 kW centrifugal chillers with nominal COP of 6.1 and two 1170 kW gas boilers with efficiency of 75%. The loop supply water temperatures and loop supply-return temperature differences are 6.7/7.3°C, 29/5.6°C, 82/28°C, respectively for chilled water loop, condensed water loop and hot water loop. The efficiencies of pumps are 349 kW/1000 l/s, 310 kW/1000 l/s and 301 kW/1000 l/s for chilled water, condensed water and hot water, respectively.

In addition, water supply temperature reset based on outdoor dry bulb temperature (ODDB) is applied to both chilled water loops and hot water loops. Reset schedule for chilled water loop is 7°C at 27°C and above, 12°C at 16°C and below and ramped linearly between 7°C and 12°C at ODDB between 27°C and 16°C. Reset schedule for hot water loop is 82°C at −7°C and below, 66°C at 10°C and above and ramped linearly between 82°C and 66°C at ODDB between −7°C and 10°C.

According to ASHRAE 90.1 Appendix G Table G3.1–11 Service Hot Water System, ASHRAE baseline model should have the same power source as that in design model and since water-source heat pumps are the main heat source and operated in priority in design model, electric water heaters are used to provide service hot water in ASHRAE baseline model.

Table 1. Heat transfer coefficient of envelope components.

Envelope components	U-value (W/m^2K)		
	Design	EE	ASHRAE
Exterior wall	0.66	0.66	0.705
Underground wall	0.51	0.51	C-6.4731[a]
Roof	0.57	0.57	0.36
Interior wall	0.57	0.57	0.57
Window	1.8/2/2.3/2.42[b]	1.8/2/2.3/2.42	3.24

[a]Time rate of steady state heat flow through unit area of the underground wall, induced by a unit temperature difference between the body surfaces and this value excludes heat resistance of soil or air film.
[b]Nominal U-values of four different kinds of double skin facades.

4.2. Design model

The envelope parameters listed in Tables 1 and 2 are determined according to the design documentation and drawings. As the building system composition and its operation strategies have been described above, the method on how to construct the energy simulation model is discussed below and detailed information of HVAC system and equipment is further described.

4.2.1. Air side system

This building is of a great size plus complicated space types and distribution and many air handling units (AHUs) are installed to serve different spaces. However, it is unnecessary and also impossible to simulate every AHU, so the whole building is divided into 89 conditioned zones and many unconditioned zones according to their orientations, space types, operating schedules and HVAC systems. One VAV system, five CAV systems with variable frequency double fans (supply fan and return fan) and seven CAV systems with single fans are simulated to serve the 89 conditioned zones in the design model. The reason why only one VAV system is simulated is that the thermal zones served by VAV systems are mainly office rooms and small meeting rooms which share nearly the same operation schedule, in addition VAV terminals can be regulated to accommodate zone load changes, so the combination of several VAV systems into one will not make big difference in annual energy consumption.

Table 2. SHGC and window to wall ratios (WWR) and of windows and skylights.

Model		Design	EE	ASHRAE
SHGC	Window	0.4	0.279	0.25
	Skylight	0.4	0.279	0.19
WWR	East (%)	69	69	40
	South (%)	52	52	40
	West (%)	52.5	52.5	40
	North (%)	81	81	40
	Skylight (%)	6	6	5

4.2.2. Chilled water system

The cooling source plants equipped in this system are three 1758 kW water-source heat pumps with a nominal COP of 4.83, two 2426 kW double-mode chillers with COP of 4.83 under chilled water mode and 3.09 under ice-making mode and ice storage tanks with a total capacity of 9254 RTH.

The supply water temperature and loop supply-return temperature difference is 6°C and 7°C in chilled water system loop and 29.4°C and 5.6°C in condensing water loop. The efficiency of brine pumps of ice storage system is 595 kW/1000 l/s and that of primary chilled water pumps is 616 kW/1000 l/s that of secondary chilled water pumps is 349 kW/1000 l/s. The efficiency of all condensing water pumps is 349 kW/1000 l/s.

Table 3. Occupant density, outdoor air flow rate and equipment power density (EPD).

Space types	Occupant density (m^2/person)	Outdoor air flow rate per person (m^3/person per hour)	EPD (W/m^2)
Lobby	4.55	10	5
Atrium	15	10	5
VIP room	2.79	30	5
Multi-function hall	4.55	25	5
Conference hall with 2500 seats	6.3	25	5
Conference hall	6	25	5
Office	1.77	30	15
Meeting room	1.56	25	15
Banquet hall	4.55	30	5
Restaurant	20	25	5
Others	/	/	5

Table 4. Lighting power density (LPD).

Space types	Design model (W/m^2)	EE Model (W/m^2)	ASHRAE model (W/m^2)
Lobby	10	9	14
Atrium	10	9	14[a]
VIP room	14	14	14
Multi-function hall	14	14	14
Conference hall with 2500 seats	14	14	14
Conference hall	14	14	14
Office	12	12	12
Meeting room	11	14	14
Banquet hall	14	14	14
Restaurant/ dining area	15	14	14[b]
Others	5	5	5

[a]Atriums in this building function as entrances to conference rooms, so 14 W/m^2 for a lobby instead of 6 W/m^2 for an atrium is used here for ASHRAE model.
[b]As for restaurants, namely dining area, general application is 10 W/m^2. Considering the requirement of dining areas in this project is more close to that in a hotel, 14 W/m^2 is selected.

In order to realize the operation strategies described above in EnergyPlus modelling, 'Component setpoint based operation' in Plant-Condenser Control group is used to cooperate the operation of different heating and cooling source plants, through proper setting of leaving water temperatures. Moreover, proper loop supply water temperatures are also set in the object of 'setpoint manager'. The operation sequence will be properly simulated when node temperature setpoints are specified correctly and specific setpoints for each plant are the same as that given in the first part of this article. In addition, a pond source model from EnergyPlus is used to model the Huangpu River as heat source of the water-source heat pump in the design model, because of its capability in taking into account of the effects of the changes of weather, soil temperature and solar radiation (see Figure 2). The control logic of cooling source plant is presented in Figure 5.

4.2.3. Hot water system

Heating source plants installed in this system are two 2800 kW gas boilers with efficiency of 90% and three 1780 kW water-source heat pumps with nominal COP of 3.79.

For this hot water system, loop supply water temperature and loop supply-return temperature difference are 50°C and 10°C. The efficiency of hot water pumps serving this system is 557 kW/1000 l/s. Figure 6 presents the control logic of heating source plant.

The coupling between the space heating system and the service hot water system is realized by a hot water heater without any heating capacity as a connection component in EnergyPlus model (see Figure 3). The hot water heater draws makeup water from the municipal loop, and in order to properly evaluate the municipal makeup water temperature, the main water supply temperature is adjusted according to Shanghai IWEC (International Weather for Energy Calculations) weather data (US DOE EE and Renewable Energy, Website for EnergyPlus).

4.2.4. Photovoltaic system

The total area of PV panels installed is 5650 m^2 and its total efficiency is 0.15. In EnergyPlus, a simple PV model which only requires the location, area and total efficiency of PV panels is used for lacking detailed performance parameters of PV systems. The hourly electric power generated by the PV system is directly transmitted to the end users to meet the power demand

Table 5. HVAC system.

	Design model	EE model	ASHRAE model
Heating and cooling source plants	Water-source heat pump: 3 × 1758 kW, COP 4.83 Ice storage tanks: 9254RTH Double-mode chillers: 2 × 2426 kW, chilled water mode COP4.83, Ice making mode COP3.09	Water-source heat pump: 3 × 1758 kW, COP 4.83 Ice storage tanks: 9254RTH Double-mode chillers: 2 × 2426 kW, chilled water mode COP5.5, Ice making mode COP3.92	Chillers: 4 × 2691 kW, COP6.1
Chilled water supply temperature and loop DT	6/7°C	6/7°C	6.7/7.3°C
Chilled water supply temperature reset	none	none	ODDB ≤ 16°C, 12°C ODDB ≥ 27°C, 7°C 16°C < ODDB[1] < 27°C, linear change between 7 and 12°C
Cooling tower	Two speed cooling tower, water source heat exchangers	Two speed cooling tower, water source heat exchangers	Two speed cooling tower,
Condensed water supply temperature and loop DT	29.4/5.6°C	29.4/5.6°C	29/5.6°C
Chilled water loop primary pumps	Brine pumps: 595 kW/1000 l/s Other Pumps: 616 kW/1000 l/s	Brine pumps: 349 kW/1000 l/s Other pumps: 349kW/1000 l/s	349 kW/1000 l/s
Chilled water loop secondary pumps	349 kW/1000 l/s	349 kW/1000 l/s	349 kW/1000 l/s
Condenser water pumps	310 kW/1000 l/s	310 kW/1000 l/s	310 kW/1000 l/s
Heating source plants	Gas boilers: 2 × 2800 kW, efficiency 90%; Water source heat pump: 3 × 1780 kW, COP3.79	Gas boilers: 2 × 2800 kW, efficiency 90%; Water source heat pump: 3 × 1780 kW, COP3.79	Gas boilers: 2 × 1170 kW, efficiency75%
Hot water supply temperature and loop DT	50/10°C	50/10°C	82/28°C
Hot water supply temperature reset	None	None	ODDB ≤ −7°C, 82°C ODDB ≥ 10°C, 66°C −7°C < ODDB < 10°C, linear change between 66 and 88°C
Hot water pumps	557kW/1000 l/s	301 kW/1000 l/s	301 kW/1000 l/s

ODDB, outdoor dry bulb temperature.

of the building without storage devices; the extra electricity is not taken into account in the calculation, so based on an hourly IWEC weather data, usable hourly electricity generated by PV systems is obtained.

4.3. *Energy efficiency model*

EE model has the same configurations and operation strategies as large compared to design model, other than improving the performances of some components and employing additional energy conservation measures (ECMs), including:

(1) Improving the shading performance of fenestration system to gain a SHGC of 0.279.
(2) Applying occupancy sensors in corridors and other spaces which are intermittently occupied.
(3) Introducing daylighting dimming control to reduce lighting electricity consumption in perimeter zones, here a continuous dimming control is employed.
(4) Improving the COP of double-mode chillers up to 5.5 in chilled water mode and 3.92 in ice-making mode.
(5) Promoting the pump efficiency to the level of ASHRAE baseline model.

4.4. *Weather data*

International Weather for Energy Calculations (IWEC) of Shanghai is used in the simulation. The IWEC data files are typical weather files suitable for use with building energy simulation programmes for 2100 locations outside the USA and Canada.

4.5. *Room air setpoints*

In this public building, the room air setpoint for such zones as entrance hall and atriums is 25°C for cooling and 18°C for heating with dead band. For the other conditioned zones, room air setpoint

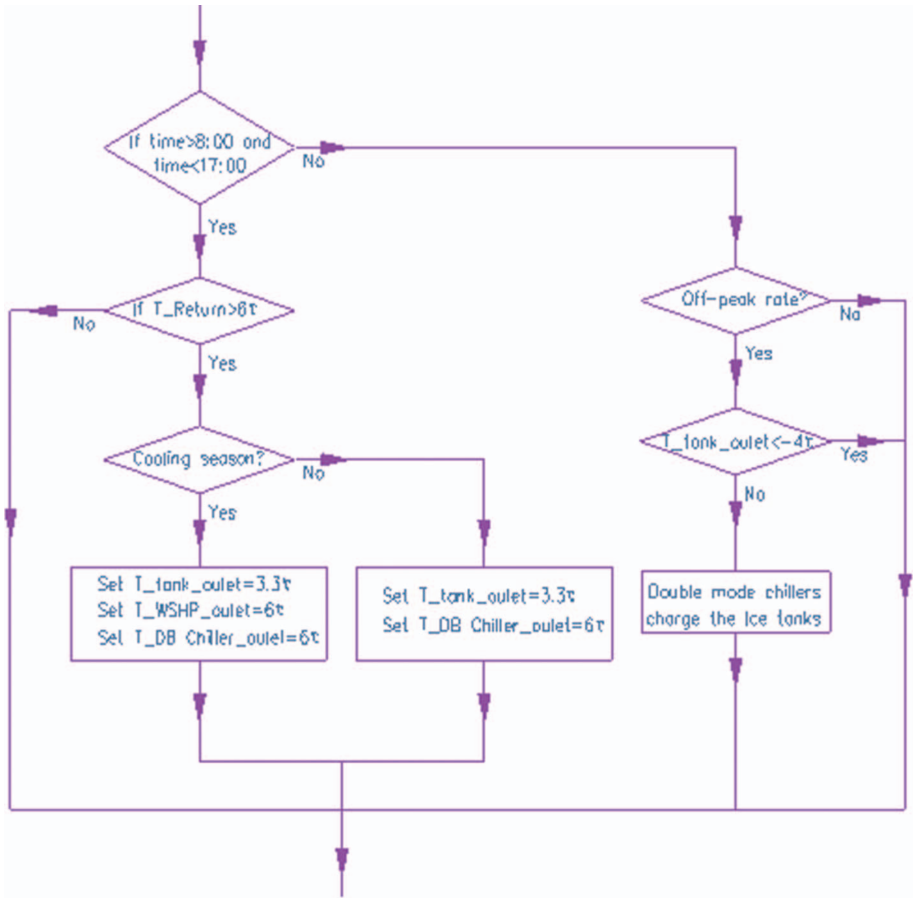

Figure 5. Control diagram of cooling source. Note: In simulation models, plants' setpoints are assigned in 'PlantEquipmentOperation:ComponentSetpoint' and with the sequence as in the diagram.

is 25°C for cooling and 20°C for heating with dead band.

4.6. *Energy and source rate*

The rate of electricity and gas for commercial buildings in Shanghai are listed in Table 6 and demand charge is 30 RMB per kW per month.

5. Annual energy consumption and energy cost analysis

5.1. *Annual energy consumption and energy cost*

Table 7 lists annual energy consumption and corresponding energy cost of ASHRAE baseline model, design model and EE model. The annual gas consumption of design model is reduced by 5282 Nm^3 compared to ASHRAE baseline model, while its electricity consumption is increased by 2164 MWh. Meanwhile, even ice storage system installed in design model could save some energy cost by shifting part of power demand from peak time to valley time; the energy cost is still 4% higher, because of its lower system efficiency, than ASHRAE baseline model. The annual energy cost of EE model is 12% lower than that of ASHRAE baseline model, attributed to additional ECMs employed.

Figures 7 and 8 illustrate monthly electricity and gas consumption of the three models.

Figure 7 shows that EE model consumes less electricity compared to ASHRAE baseline model nearly every month except September and October.

From Figure 8, in cooling season (from May to September) design model and EE model still consumes some amounts of gas while ASHRAE baseline model has no gas consumption in this period; this is mainly because gas boilers are used to provide service hot water in design model and EE model while ASHRAE baseline model employs electric water heaters for this purpose. During heating season from November to March, water-source heat pumps are operated in priority sequence in design model and EE model, therefore their monthly gas consumptions are less than those of ASHRAE baseline model. Moreover, as EE model has smaller internal heat gains due to the application of daylighting dimming and occupancy sensors, more heating is needed to meet building heating load and the gas consumptions of EE model in heating season are apparently larger than those of ASHRAE baseline model. But from the aspect of annual energy cost, ECMs added into EE model do reduce large amounts of electricity consumption as well as annual operation cost.

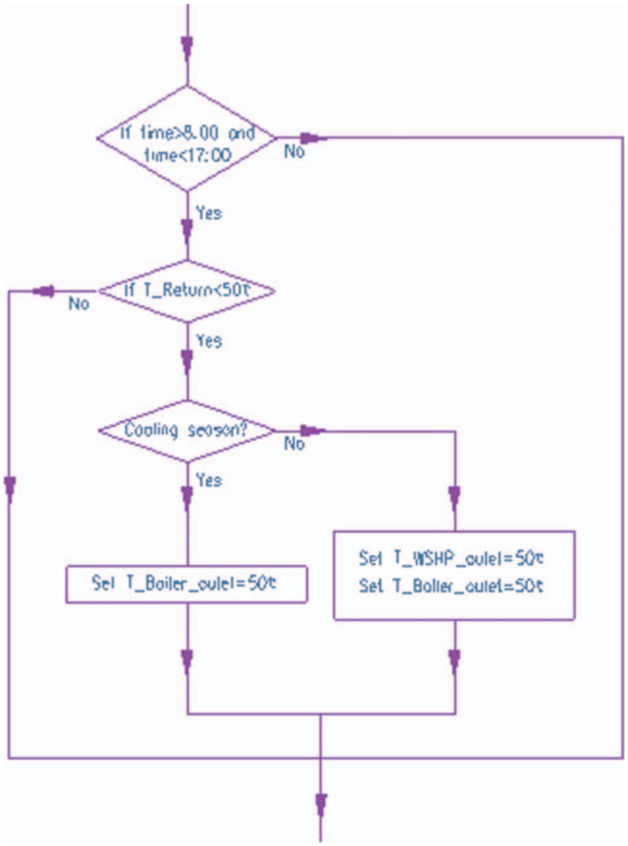

Figure 6. Control diagram of heating source. Note: In Simulation models, plants' setpoints are assigned with an annual setpoint schedule and plants are sequenced in 'PlantEquipmentOperation' with the sequence as in the diagram.

Table 6. Energy rates.

Periods	Electric rate (RMB/kWh)	Gas rate (RMB/Nm)^3
8:00–11:00 13:00–15:00 18:00–21:00	1.037	
6:00–8:00 11:00–13:00 15:00–18:00 21:00–22:00	0.706	2.3
22:00–6:00	0.234	

Figure 9 outlines annual electricity consumption breakdowns for the three models. Because of different compositions of heating and cooling source plants in the three models, the electricity consumptions of cooling plants and heating plants refer to those of centrifugal chillers and electric water heaters respectively for ASHRAE baseline model while referring to those of double-mode chillers and water-source heat pumps for cooling and water-source heat pumps for heating in design model and EE model.

According to annual electricity consumption breakdown, electricity consumption of lighting system in design model is less than that of ASHRAE baseline model and with the introduction of occupancy sensors and daylighting dimming control, lighting system electricity consumption is further reduced by nearly a quarter of the baseline model. Meanwhile, less heat gain caused by less average lighting power density makes cooling load lower which certainly leads to lower energy consumption for cooling.

Through the comparison between design model and ASHRAE baseline model, HVAC system compositing of fans, pumps and heating and cooling source plants and cooling towers of design model consumes much more energy than baseline model. There are several reasons for that. In ASHRAE baseline model, centrifugal chillers with a nominal COP of 6.1 is applied while in design model water-source heat pumps with COP of 4.83 under cooling mode and double-mode chillers with COP of 4.83 under chilled water mode and 3.09 under ice making mode are used. In addition, the pump efficiency of design model is nearly half of that in ASHRAE baseline model and brine pumps of ice storage systems have to run during night when no pumps are operating in ASHRAE baseline model. Higher fan energy consumptions of design model and EE model compared to ASHRAE baseline model are mainly because of continuous running of fans at a constant volume flow rate in CAV systems.

The electricity consumption of heating source plants is 38.61 MWh for design model and 40.77 MWh for EE model respectively but much higher for

Table 7. Annual energy consumption and cost.

Models	Electricity (MWh)	Gas (Nm_3)	Cost (RMB)	Cost saving
ASHRAE	14,478	55,583	14,860,000	–
Design	16,642	50,301	15,520,000	−4%
EE	13,887	59,428	13,090,000	12%

ASHRAE baseline model, arriving at 634 MWh. This is because ASHRAE baseline model employs electric water heaters for service hot water purpose certainly with a lower efficiency compared to water-source heat pumps installed in design model for the purpose. In addition, water-source heat pumps are only operating under heating mode in heating season while in cooling season gas boilers will take the place for heating.

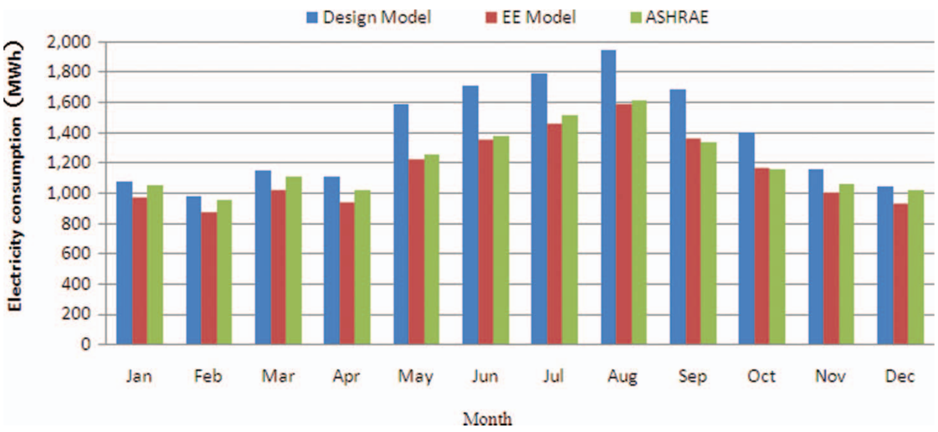

Figure 7. Monthly electricity consumption.

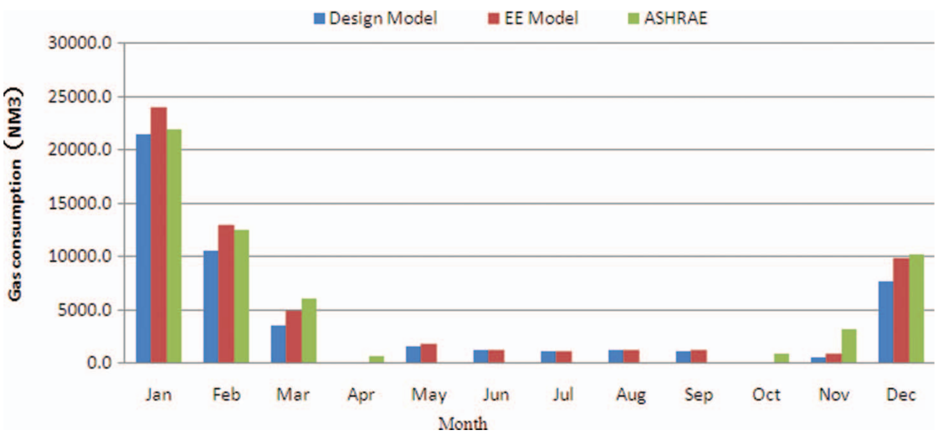

Figure 8. Monthly gas consumption.

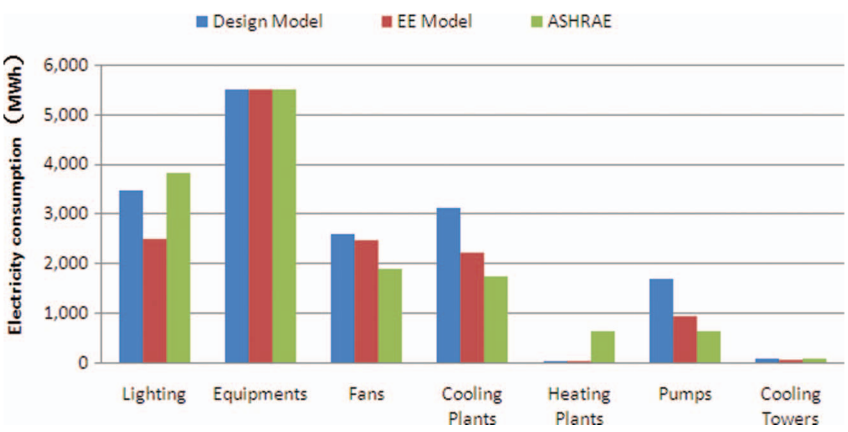

Figure 9. Annual electricity consumption breakdowns.

Table 8. Annual electricity consumption and cost with PV system.

Models	Electricity consumption (MWh)	Electricity cost (RMB)
ASHRAE	14,478	14,860,000
Design with PV	15,827	14,540,000
EE with PV	13,116	12,180,000

5.2. *Effect of PV system over annual energy consumption*

Annual energy consumption discussed above doesn't include the power generation of PV system and here the effect of PV system over annual energy consumption of design model and EE model will be taken into consideration. According to the simulation results of PV system, 1 MW PV system is able to generate 889,930 kWh electric power per year. Electricity rate for power from PV system is the same as that listed in Table 6. Table 8 lists annual electricity consumptions and related costs with PV system.

According to results listed in Table 8, after considering the effect of PV system, electricity consumption of design model is more than that of ASHRAE baseline model by 9.3% while EE model saves 9.4% of the annual electricity consumption of baseline model. Moreover, power from PV system not only reduces the power consumption but also reduces large amount of electricity cost because of its ability in reducing peak electricity demands, design model and EE model saves 2.1% and 18.1% of the annual electricity cost of baseline model, respectively.

6. Conclusions

This article compares the advantages and disadvantages of several different kinds of energy simulation tools in simulating large public buildings and discusses how to simulate large public buildings and its building systems plus specified operation strategies within the environment of EnergyPlus. Through the simulation of a large public building in Shanghai, conclusions can be drawn as followed:

- Due to the large size and multiple functions of various spaces contained, the energy modelling of large public buildings should take account of the complicated system composition and operation strategies in order to achieve an accurate evaluation of building performance. EnergyPlus as a new generation simulation tool has the capability for this kind of simulation.
- The electricity consumption of the public buildings discussed in this article is increased, because of its lower system efficiency, by 14.9% compared to ASHRAE baseline model and energy cost increases by 4% even though ice storage system is installed.
- Via additional ECMs such as higher equipment efficiency and better shading performance of fenestration systems, etc. EE model not only saves 4.1% electricity consumption but reduces 12% of annual electricity cost of baseline model.
- PV system has the potential of energy conservation under the solar radiation condition in Shanghai. The design model and the EE model save 2.1% and 18.1% respectively of annual electricity cost in baseline model.

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