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COOLING LOADS PREDICTION OF 2010 SHANGHAI WORLD EXPO

Yiqun Pan
Tongji University
Shanghai, China

Yan Qu
Tongji University
Shanghai, China

Yuming Li
Tongji University
Shanghai, China

ABSTRACT

The paper predicts and studies on the cooling loads of the pavilions in 2010 Shanghai World Expo based on the general planning of the expo. The simulation models are established using DOE-2, for the various pavilions: 5 permanent pavilions, national pavilions, international organization pavilions, corporate pavilions, and temporary exhibition pavilions. The modularization method is used to simplify the simulation models of the temporary exhibition pavilions. The cooling loads of the various pavilions from May 1st to Oct 31st 2010 are simulated and analyzed, including hourly cooling loads, monthly cooling loads and hourly cooling loads on summer design day.Lastly, three factors – weather, visitor flow rate and outdoor air supplying mode, are selected to conduct the uncertainty analysis on their impact on the cooling loads.

1. INTRODUCTION

2010 Shanghai World Expo is a very good chance for urban development of Shanghai. However on the contrary, it is a very big challenge for the designers and planers. The expo will be held from May 1 to October 31 in 2010, which is just the summer period of Shanghai; therefore space cooling is essential for all pavilions. In order to make successful cooling system design for the pavilions and energy planning for the expo, the cooling loads have to be calculated accurately. Several researchers in China and from abroad conducted research work on the cooling load estimation and energy planning of the expo. Ojima Toshio (2005) and Fan Cunyang (2003) estimated peak cooling loads during expo opening period and post-expo period, based on the experiences and technical data of energy planning of Japan expos. Yang Jie (2006) studied the main factors that have impact on the cooling loads of the buildings in Shanghai expo and drew the conclusion that the energy consumption of air conditioning system in Shanghai expo depends mainly on visitor flow rates and heat transfer characteristics of the envelopes. However these researchers have not calculated the hour-by-hour cooling loads throughout the entire opening period of Shanghai expo for each pavilions in the expo area and the estimations of cooling loads done by them are not accuate enough due to lack of information.

This paper presents part of the research results of “Research and demonstration of clean energy utilization technology and system – sub-project 3: Research on distributed energy system and district cooling and heating technology in 2010 Shanghai Expo” – cooling loads prediction – as the basic of further research on distributed energy system planning and central cooling and heating plants sizing in the project.

In this paper, energy analysis software DOE2.1e is employed to conduct hour-by-hour simulation on the pavilions in 2010 Shanghai Expo and the cooling loads of the entire expo are calcuated. DOE2.1e is one of the simulation softwares based on forward modeling approach – modeling for building and HVAC system design and associated design optimization (ASHRAE Handbook – Fundamentals, Chapter 32, 2005). Forward modeling of building energy use begins with a physical description of the building system or component of interest. For example, building geometry, geographical location, physical characteristics (e.g., wall material and thickness), type of equipment and operating schedules, type of HVAC system, building operating schedules, plant equipment, etc., are specified. The peak and average energy use of such a building can then be predicted or simulated by the forward simulation model. The models in DOE2.1e have three basic elements: (1) space load calculation; (2) secondary equipment load calculation (3) primary equipment energy requirments calculation. The first step is to determine space load, which is the amount of energy that must be added to or extracted from a space to maintain thermal comfort. The space load calculation in DOE2.1e is not the same as the the simple heating and cooling load calculations used to size equipment during design process, since it utilize much more sophisticated proceduures based on hourly profiles for climate conditions and operational characteristics for a number of typical days of the year on 8760 h of operation per year. Since the hourly load of various pavilions are very important for the further research on energy planning, design and analysis, DOE2.1e was selected to conduct the cooling load calculation.

2. OVERVIEW OF PAVILIONS IN 2010 SHANGHAI EXPO

The site of Expo 2010 Shanghai, an area of 5.28 square kilometres, is in the waterfront area on both sides of the Huangpu River, mostly between Nanpu Bridge and Lupu Bridge. The eastern part of the site covers 3.93 square kilometers and the western part 1.35 square kilometres. The core area (into which an admission ticket will be required) is 3.22 square kilometers (2010 Shanghai Expo Bureau, 2006).

The paper predicts the cooling loads of the pavilions located in the core area, including China Pavilion, Theme Pavilion, World Expo Museum, Public Activity Center, Performing Arts Center, national pavilions, international organization pavilions, and corporate pavilions (see Figure 1). The Urban Best Practices Area and public services facility in the core area are not included.

The total number of the pavilions is 163, with total building area of 863,000m^2. As shown in Figure 2, the core area is divided into Zone A, Zone B, Zone C, Zone D and Zone E. Zones A, B and C are located in Pudong Area, while Zones D and E are located in Puxi Area. Among them, Zone A is mainly for Asia national pavilions, with building area of 84,000m^2; Zone B, the center of expo, composites of Southeast Asia/Australia national pavilions, international organization pavilions, China Pavilion, Theme Pavilion, Performing Arts Center and Public Activity Center, with total building area of 310,500m^2; Zone C is mainly for Europe/America/Africa national pavilions, with building area of 208,000m^2; Zone D is the area of corporate pavilions, with building area of 110,000m^2, among them, future pavilions accounting for 50,000m^2, and industrial pavilions accounting for 60,000m^2; Zone E composites of 30,000m^2 corporate pavilions and 120,000m^2 World Expo Museum, with total building area of 150,000m^2 (2010 Shanghai Expo Bureau, 2006; Wu Zhiqiang 2004; Wu Zhiqiang, Feng Fan, 2004). Among the 163 pavilions, China Pavilion, Theme Pavilion, Performing Arts Center, Public Activity Center and Would Expo Museum are five permenant buildings, which will be used for exhibition, arts performing, conference, etc, after the expo. The permenant buildings has the total building area of 355,000m^2, accounted for 41% of total building area in expo; while the rest temporary buildings, which will be pulled down after the expo, account for 59% of total building area.

3. MODEL DEVELOPMENT

The expo pavilions can be mainly classified into three categories according to their functions: pavilions for exhibition, pavilions of museum and pavilions for performance. By reviewing relative literatures and understanding the initial planning and design, the profiles of the three types of buildings are analyzed and the factors that have impact on building loads are defined. Furthermore, the cooling load simulation models of these buildings are developed.

The factors influencing building loads include mainly building geometry, weather data and internal loads. Building geometry refers to building area, building envelope, building north axis, floor-to-floor height, window-to-wall ratio and building shape, etc. Internal loads include the loads due to occupants, lighting, plug, as well as outdoor air.

Building models are developed for all 163 pavilions, among them, 131 stand-alone national pavilions and international organization pavilions are simplified by modularization into 7 categories and 21 types, which can reduce the simulation work greatly without sacrificing the accuracy.

3.1 Building Geometry

The building areas are listed in Table 1. National pavilions and international organization pavilions has totally 140 pavilions, including 131 stand-alone pavilions and 9 joint pavilions. The stand-alone pavilions are built into 2 units to 12 units (i.e. 1,000 m^2 to 6,000 m^2), as listed in Table 2.

The characteristics of the building envelop are set referring to GB50189-2005, Public Building Energy Saving Design Standard, as listed in Table 3.

The window-to-wall ratio is predicted as 0.4 for World Expo Museum, but 0.5 for the other pavilions, according to statistics of historical world expos (Fan Cunyang 1991).

The building north axis is determined based on initial design and planning of Shanghai expo for all pavilions (2010 Shanghai Expo Bureau, 2006).

The floor-to-floor height is determined based on the building area, the ratio of building area to land area, specification index of codes etc, referring to statistics of similar types of buildings for the pavilions(Fan Cunyang 1991, Ojima Toshio etc 2005).

The shapes as well as the zonings in buildings of the five permanent pavilions – China Pavilion, Theme Pavilion, World Expo Museum, Public Activity Center, and Performing Arts Center are specified according to the initial design and planning, referring to relative literatures and surveying on a great amount of exhibition pavilions, museums and performing arts buildings. Model for each permanent pavilion is built based on the specified shape and zoning.

For national pavilions, international organization pavilions, and corporate pavilions, prototype models are developed. Through the surveying and statistics on the building shape, height and volume of the pavilions in 1970 Japan Osaka Expo (Fan Cunyang 1991, Ojima Toshio etc 2005), it is summarized that 38% pavilions are in rectangular shape, 27% in cylinder shape, 11% in prism shape, 9% in sphere shape, and the others are in random shapes. If replacing cylinder with prism, due to the similarity of the two shapes, then the percentage of pavilions in rectangular shape and in prism shape are equal, i.e. 38%. Therefore both rectangular model and prism model are developed and simulated, and the simulation results present little impact of the two different shapes on the cooling loads, the rectangular shape is finally determined as the prototype model of the units of national pavilions, international organization pavilions and corporate pavilions.

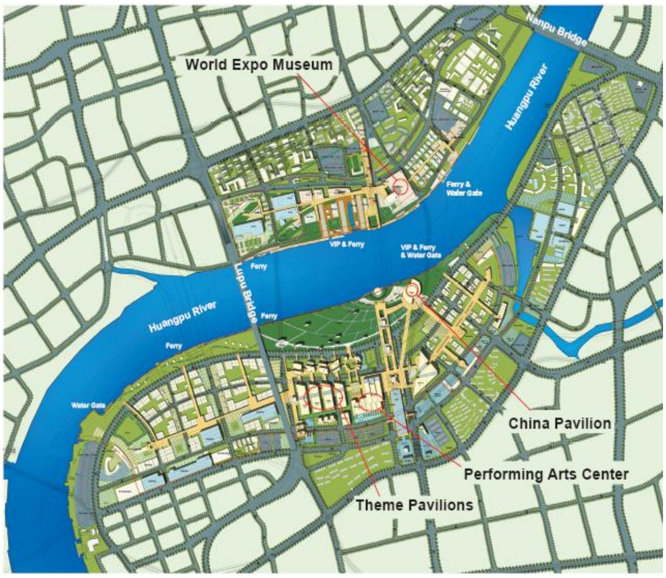

FIGURE 1 Expo Site Plan

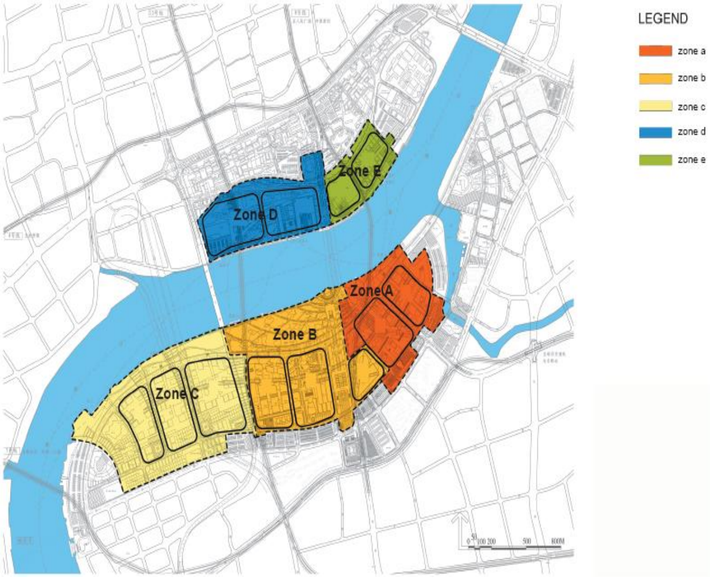

FIGURE 2 Expo Site Framework

TABLE 1 Building Area of Pavilions

Item				Sum	Zone				
					A	B	C	D	E
Area of Land (ha.)				328.0	43.18	95.17	101.37	50.19	38.09
National Pavilions	Stand -alone	Built by participants	Nations	68	18	8	42		
			Units	418	130	44	244		
			Building Area（10^4m^2）	20.9	6.5	2.2	12.2		
		Rented to participants	Nations	47	16	4	27		
			Units	104	34	16	54	——	
			Building Area（10^4m^2）	5.2	1.7	0.8	2.7		
		Sum	Units	522	164	60	298		
			Building Area（10^4m^2）	26.1	8.2	3.0	14.9		
	Joint		Nations	77	2	14	61		
			Building Area（10^4m^2）	7.5	0.2	1.4	5.9		
	Sum		Building Area（10^4m^2）	33.6	8.4	4.4	20.8		
Interna -tional Organiza- tion Pavilions	Stand -alone	Built by participants	Organizations	8		8			
			Units	23		23			
			Building Area（10^4m^2）	1.2		1.2			
		Rented to participants	Organizations	8		8			
			Units	24		24			
			Building Area（10^4m^2）	1.2	——	1.2	——	——	
		Sum	Building Area（10^4m^2）	2.4		2.4			
	Joint		Organizations	8		8			
			Building Area（10^4m^2）	0.8		0.8			
	Sum		Building Area（10^4m^2）	3.2		3.2			
Corporate Pavilions	Stand-alone		Units	16				10	6
			Building Area（10^4m^2）	8.0		——		5.0	3.0
	Joint		Building Area（10^4m^2）	6.0				6.0	——
	Sum		Building Area（10^4m^2）	14.0				11.0	3.0
China Pavilion			Building Area（10^4m^2）	4.5	——	4.5	——	——	
Theme Pavilion			Building Area（10^4m^2）	4.5		4.5			
World Expo Museum			Building Area（10^4m^2）	12.0		——		——	12.0
Performing Arts Center			Building Area（10^4m^2）	4.5		4.5			
Public Activity Center			Building Area（10^4m^2）	10.0		10.0			
Sum			Building Area（10^4m^2）	86.3		60.3		41.0	

3.2 Weather Data

The outdoor climate weather data uses the Typical

TABLE 2 Units of national pavilions and international organization pavilions

Stand-alone pavilions \ Units	12b	10b	9b	8b	6b	4b	2b	Sum
Asia national pavilions	3	/	/	5	7	4	15	34
South Asia national pavilions/Australia national pavilions	/	1	/	/	3	8	/	12
Europe national pavilions	6	/	/	/	2	21	13	42
America national pavilions	2	/	/	/	1	3	8	14
Africa national pavilions	/	/	/	2	/	4	7	13
International organization pavilions	/	/	1	/	/	4	11	16
Sum	131							

TABLE 3 Characteristics of building envelope

Components	U-value (W/m²℃)	
Roof	0.7	
Exterior Wall	1.0	
Window	U-value (W/m²℃)	SC
Window-to-wall ratio: 0.4~0.5	2.8	0.45 (North façade: 0.55)
Skylight	3.0	0.4

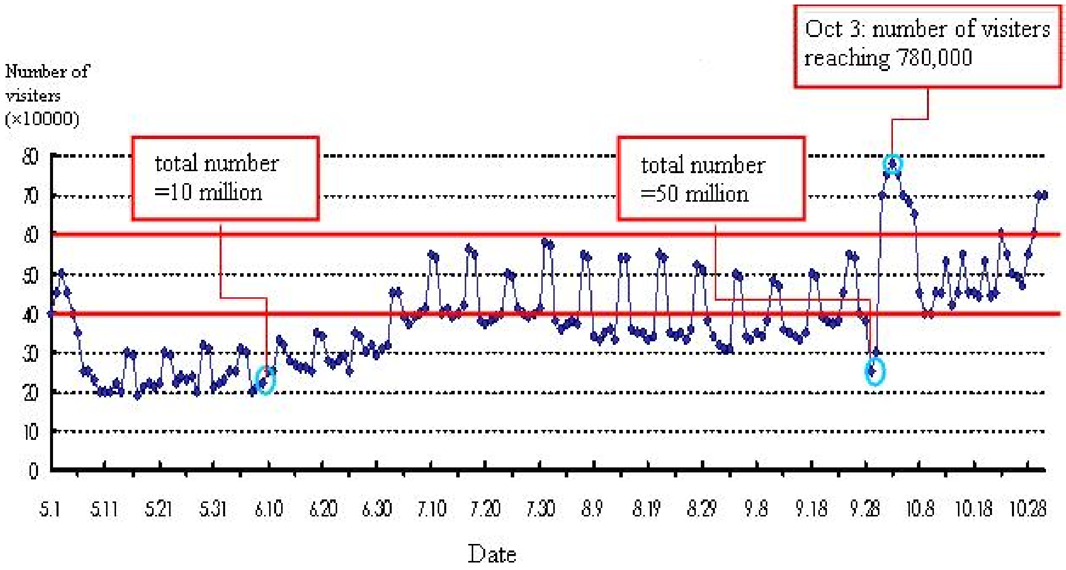

FIGURE 3 Prediction of visitor flow rates of 2010 Shanghai Expo
(total number: total accumulative number of visitors)

TABLE 4 Percentage of visitors entering and leaving expo

Period \ Scenario	Long Holiday		Weekdays		Weekends		Summer Holiday	
	Percent of entering visitors	Percent of leaving visitors	Percent of entering visitors	Percent of leaving visitors	Percent of entering visitors	Percent of leaving visitors	Percent of entering visitors	Percent of leaving visitors
10:00-12:00	45%	2%	35%	2%	40%	2%	50%	2%
12:00-14:00	6%	3%	8%	3%	7%	3%	5%	3%
14:00-15:00	6%	8%	9%	8%	8%	8%	5%	8%
15:00-16:00	7%	15%	10%	15%	8%	15%	5%	15%
16:00-17:00	6%	32%	8%	32%	7%	32%	5%	32%
17:00-20:00	25%	5%	25%	5%	25%	5%	25%	5%
20:00-21:00	3%	10%	3%	10%	3%	10%	3%	10%
21:00-22:00	2%	25%	2%	25%	2%	25%	2%	25%

Meteorological Year (TMY2) developed by NREL based on the hourly weather data of Shanghai from 1961 to 1990. Cooling degree hours (Base 26℃·hour) of TMY of Shanghai is 4600 and total solar radiation throughout the year is 5780MJ/m^2.

3.3 Internal loads

The occupants in pavilions are determined through estimating the visitor flow rates and the ratios of people entering and leaving the pavilions as well as the distribution of the visitors in the expo area.

The visitor flow rates are influenced by many factors, e.g., seasons, outdoor climate, etc. The visitor flow rates will increase dramatically in holidays, especially two long holidays – Labor Day (May 1 to May 7) and National Day (Oct 1 to Oct 7). Figure 3 presents the daily visitor flow rates during the period from May 1 to Oct 31 (184 days), which is estimated by the general planning group based on the statistics of historical expos, population of Shanghai and the economic development until 2010 (2010 Shanghai Expo Bereau, 2006). The total number of visitors will be 71.4 million. If the 400,000/day is defined as the baseline visitor flow rate, then there will be 75 days exceeding the baseline. The peak visitor flow rate will be 780,000/day on Oct 3.

According to the experiences of historical world expos and concerning various factors and possibilities, it is predicted that one day will be divided into two visiting periods: daytime and nighttime. Daytime is from 10 am to 5 pm, while nighttime is from 5 pm to 10 pm. Different visiting coupons will be sold for the two periods. Through surveying and analysis, four scenarios are set: Long Holiday (May 1 to May 7, Oct 1 to Oct 7), weekdays, weekends and summer holiday (July 1 to Aug 31). The percentages of visitors entering and leaving expo during various periods are predicted for each scenario (Table 4).

Based on the daily visitor flow rates (Figure 3) and the percentages of entering and leaving visitors in 4 scenarios (Table 5), the hourly visitor flow rates for 4416 hours during expo are predicted as Figure 3. The peak visitor flow rate appears around 10 am to 11 am and 1pm to 3pm during each visiting day and the average flow rate is about 64% to 68% of the peak flow rate.

The visitors will spread not only in the pavilions but also the outdoor spaces and service facilities in the expo area. Only the visitors in the pavilions will affect the cooling loads. Therefore the authors predicted the visitor densities in most pavilions which are influenced directly by the total visitor flow rates for different spaces with various functions referring to relative literatures and codes (GB50189-2005, JGJ 66-91, JGJ-57-2000, GB50019-2003, JGJ 67-89) (see Table 5). The schedules of the visitor densities in the pavilions are also defined according to the hourly visitor flow rates.

However the occupancy in Performing Arts Center and Public Activity Center is different from the other pavilions and has no direct relationship with the total visitor flow rates but is influenced by the using percentages. According to the planning of performing and activities of expo, it is estimated that around 1000 entertainment performing programs, international symposiums and seminars will be held during the expo period. Therefore the using percentages of the two pavilions are predicted (Figure 5) and the occupant densities in spaces are distributed.

The lighting and plug densities in various spaces in pavilions are determined referring to relative national standards, codes and literatures (GB50189-2005, JGJ 66-91, JGJ-57-2000, GB50019-2003, JGJ 67-89) (See Table 5). The schedules of lighting and plug densities are set based on the prediction of the using conditions of various spaces.

3.4 Infiltration

Concerning most exterior doors of the pavilions are wide-open for continuous visitors entering and leaving, the infiltration is set as 0.5ACH for perimeter spaces in the pavilions, which is higher than normal office buildings.

3.5 Outdoor Air

The outdoor air flow rates for various spaces in pavilions are determined based on relative codes and standards (GB50189-2005, JGJ 66-91, JGJ-57-2000, GB50019-2003, JGJ 67-89) (See Table 5). Moreover it is supposed that demand control ventilation will be employed in all pavilions, meaning the hourly outdoor air flow rates change with the visitor flow rates in pavilions.

3.6 Modularization of Models

Since it was still during the period of initial planning when the authors did the simulation, there was no detailed information and data of each pavilion. In order to ensure the accuracy of simulation and reduce simulation work, the 131 stand-alone national pavilions and international organization pavilions are simplified by modularization into 7 categories and 21 types. 7 categories are defined according to the units of the pavilions (refer to Table 2). Then the 7 categories are divided into 21 types with different shape, north axis and floor-to-floor height, based on the site and building planning (2010 Shanghai Expo Bureau, 2006). Figure 6 illustrates the locations of the modules. Table 6 presents the area, shape, north axis and floor-to-floor height of the 21 types of modules.

4. ANALYSIS OF COOLING LOADS

The cooling loads of all pavilions are simulated from May 1 to Oct 31 using the models and summed up hour-by-hour. Cooling loads include not only building loads due to heat gain from outdoor climate and internal heat gain but also the loads due to outdoor air.

4.1 Hourly Cooling Loads

The total cooling loads of all pavilions are presented in Figure 7. The peak total cooling load is 159162.5 kW at 12 pm on July 13.

The cooling loads of the pavilions in 5 zones are calculated respectively. Table 7 gives the exact values of peak cooling loads and their appearing times for the 5 zones. The peak cooling loads for 5 zones all appear around noon on July 13. Figure 8 presents the hourly cooling loads of 5 zones on July 13

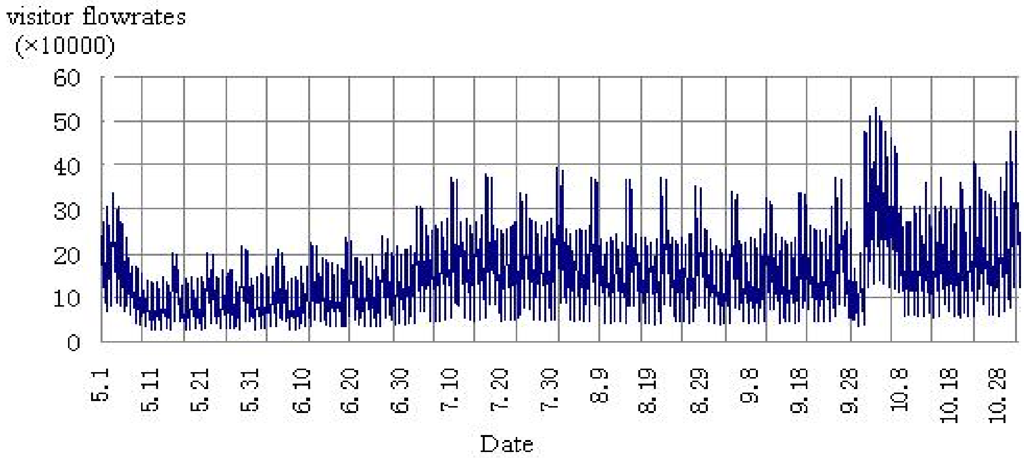

FIGURE 4 Hourly visitor flow rates from May 1 to Oct 31 in Shanghai Expo

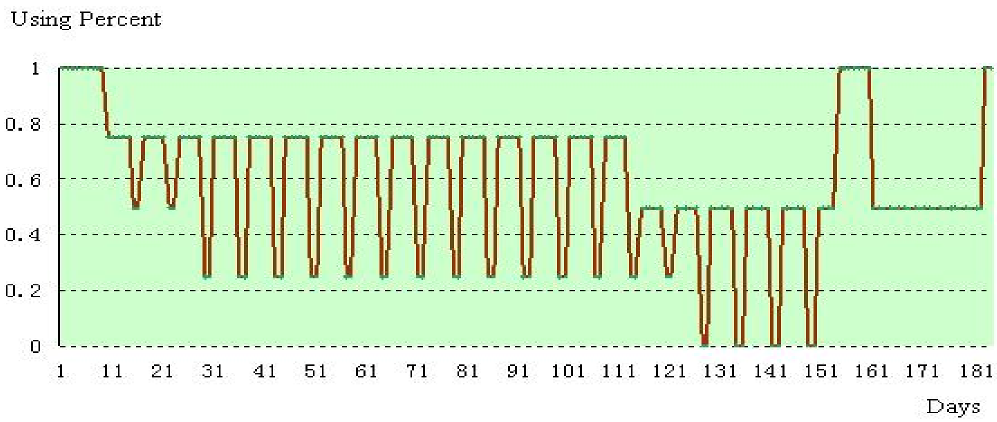

FIGURE 5 Using percentages of Performing Arts Center and Public Activity Center

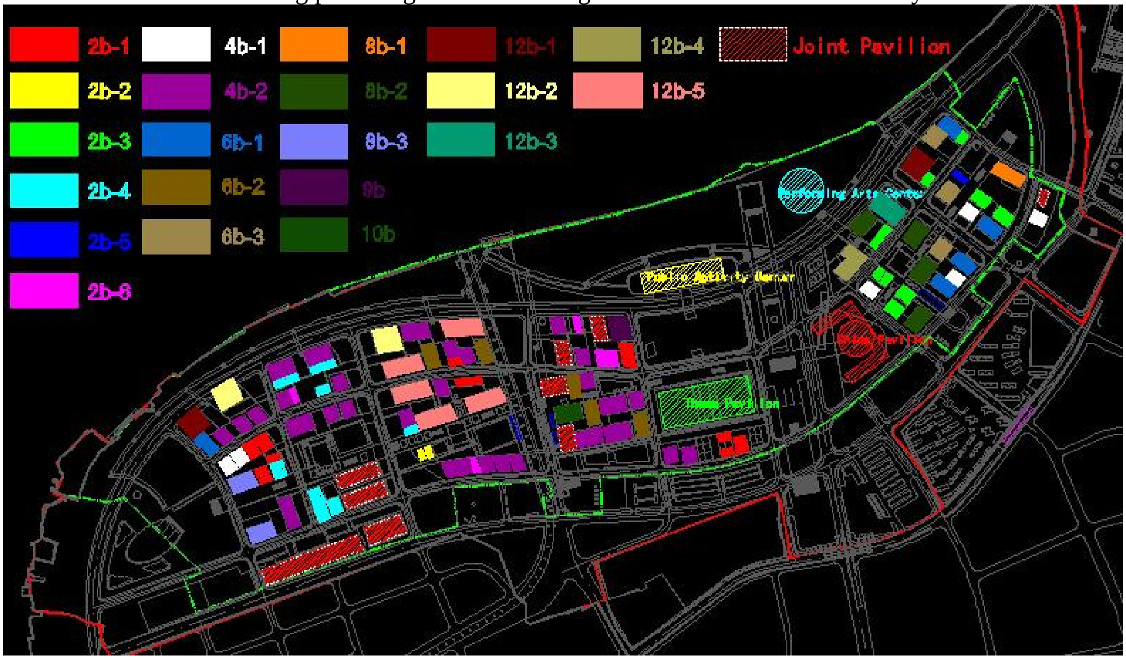

FIGURE 6 Locations of the modules

TABLE 5 Densities of occupant, lighting and plug in three types of pavilions

	Zones	Occupant Density (Person/ m^2)	Lighting Density (W/m2)	Plug Density (W/m2)	Outdoor Air (m3/h·person)
Exhibition	Exhibition Hall	0.33	35	30	20
	Meeting room	0.40	11	5	20
	Auditorium	0.50	11	5	20
	Multi-function room	0.25	18	10	20
	VIP room	0.05	30	25	30
	Banqueting hall	0.30	20	15	20
	Press center	0.30	20	20	20
	Office	0.10	18	20	30
	Lounge	0.20	15	20	15
	Dinning room	0.50	13	25	20
	Lobby	0.20	15	10	10
	Corridor	0.03	5	0	10
Museum	Exposition room	0.33	35	25	20
	Showroom	0.33	45	25	20
	Video room	0.50	10	20	20
	Acoustics room	0.50	15	20	20
	Reception room	0.20	20	10	15
	Lounge	0.20	15	20	30
	Office	0.10	18	20	30
	VIP room	0.05	11	25	30
	Multi-function room	0.25	30	10	20
	Lecture room	0.40	18	10	20
	Seminar room	0.10	15	10	20
	Lobby	0.20	15	10	10
	Corridor	0.03	5	0	10
Performance	Auditoria	1.5	10	10	15
	Stage	0.2	60	30	30
	Dressing room	0.3	30	15	30
	Rehearing hall	0.3	20	10	30
	Press Center	0.3	20	20	20
	Meeting room	0.4	11	5	20
	Western restaurant	0.5	13	25	20
	Banqueting hall	0.3	20	15	20
	VIP room	0.05	30	25	30
	Office	0.1	18	20	30
	Lobby	0.2	15	10	10
	Corridor	0.02	5	0	10

Table 6 Building area, shape, and building north axis and floor-to-floor height of modules

Types of models		Area (m2)	Shape	North Axis	Floor-to-floor height
12b	12b-1	6000	Rectangular: 80m×75m	-52^o	15
	12b-2	6000	Rectangular: 80m×75m	-15^o	15
	12b-3	6000	Rectangular: 100m×60m	-51^o	15
	12b-4	6000	L Shape	-46^o	15
	12b-5	6000	Rectangular: 120m×50m	-15^o	15
10b		5000	Rectangular: 100m×50m	-11^o	15
9b		4500	Rectangular: 75m×60m	79^o	15
8b	8b-1	4000	Rectangular: 100m×40m	38^o	10
	8b-2	4000	Rectangular: 80m×50m	-52^o	10
	8b-3	4000	Rectangular: 80m×50m	-20^o	10
6b	6b-1	3000	Rectangular: 75m×40m	45^o	10
	6b-2	3000	Rectangular: 75m×40m	75^o	10
	6b-3	3000	Rectangular: 60m×50m	-52^o	10
4b	4b-1	2000	Rectangular: 50m×40m	45^o	10
	4b-2	2000	Rectangular: 50m×40m	75^o	10
2b	2b-1	1000	Rectangular: 40m×25m	-15^o	10
	2b-2	1000	Rectangular: 40m×25m	85^o	10
	2b-3	1000	Rectangular: 40m×25m	-45^o	10
	2b-4	1000	Rectangular: 40m×25m	-30^o	10
	2b-5	1000	Rectangular: 50m×20m	38^o	10
	2b-6	1000	Rectangular: 40m×25m	84^o	10

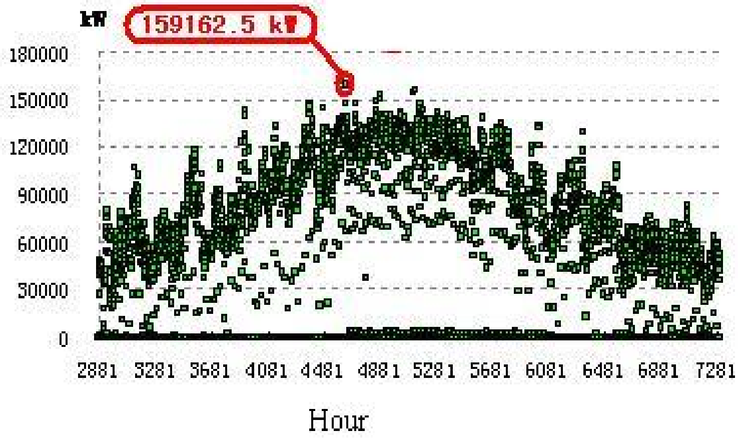

FIGURE 7 Hourly total cooling loads

TABLE 7 Peak cooling load, appearing time and total cooling load during the day when peak cooling load appears

Zones	Peak cooling load (kW)	Peak load appearing time	Total cooling load on July 13 (kWh)
A	17932	12 pm July 13	162788
B	66815	12 pm July 13	718142
C	46788	12 pm July 13	426071
D	17306	11 pm July 13	162073
E	20155	11 pm July 13	177431

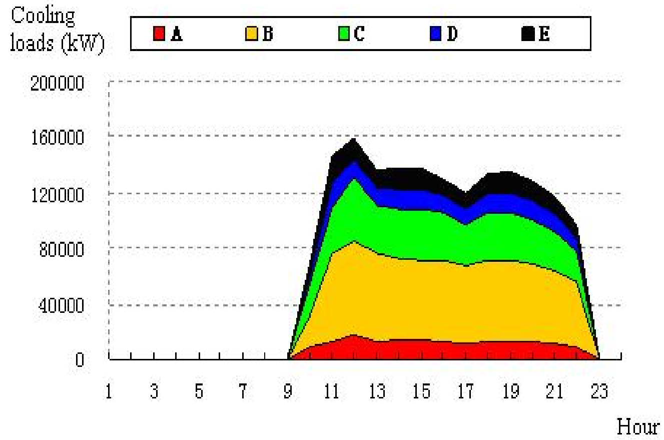

FIGURE 8 Cooling loads of 5 zones on July 13

4.2 Frequency of Cooling Loads

The frequency of total cooling loads is calculated as shown in Figure 9. Table 8 presents the frequency of cooling loads for 5 zones respectively. Frequency of cooling loads means the percentage of hourly cooling to peak cooling load, while frequency of hours means the percentage of the appearing hours within the corresponding range of cooling loads to the total cooling hours (from 10am to 10pm every day during the opening period of expo).

TABLE 8 Frequency of cooling loads of 5 zones

Frequency of cooling loads		**0%-25%**	**25%-50%**	**50%-75%**	**75%-100%**
Frequency of hours	A	10%	44%	35%	10%
	B	15%	40%	32%	12%
	C	9%	45%	36%	11%
	D	6%	40%	39%	14%
	E	17%	42%	34%	6%

4.3 Monthly Cooling Loads

The monthly cooling loads are calculated for 5 zones and shown in Table 9. The total monthly cooling loads in July and August are the highest among the 6 months.

The cooling loads on summer design day are simulated and calculated for all pavilions as well as pavilions in 5 zones. The design day peak load appears at 11 am with the value of 177,890kW for all pavilions (as shown in Figure 10). The total cooling load from 10am to 10pm for design day is 2,050,422 kWh. The dry bulb air temperature is 34℃ and welt bulb air temperature is 28.2℃ on summer design day.

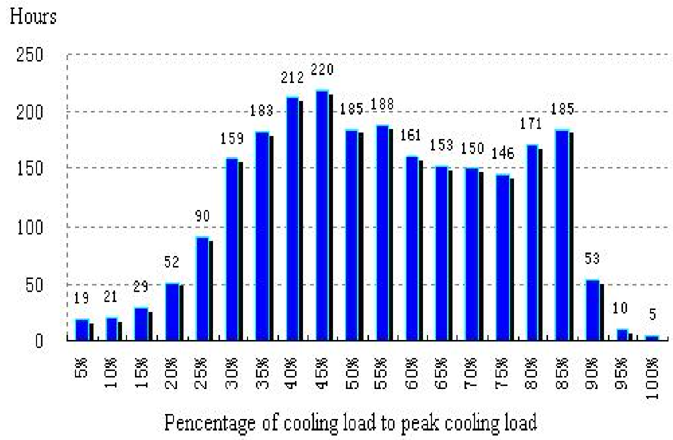

FIGURE 9 Frequency of total cooling loads

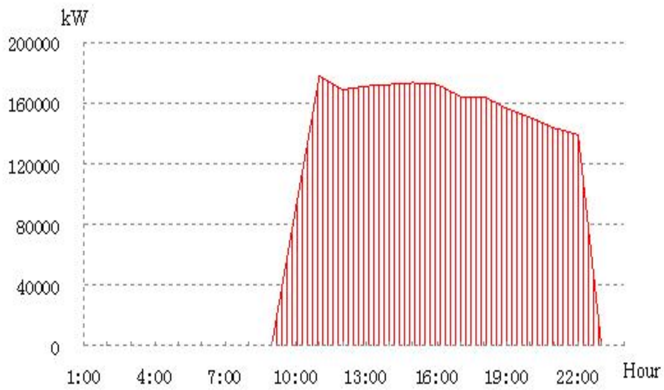

FIGURE 10 Cooling load on summer design day

TABLE 9 Monthly cooling loads

Cooling Load (MWh)	**May**	**June**	**July**	**August**	**September**	**October**	**Sum**
A	2635	3314	4844	4754	3224	2160	20931
B	8426	12601	18877	18115	11352	7355	76726
C	6931	8723	12734	12495	8528	5747	55158
D	2842	3463	4859	4766	3399	2440	21769
E	2515	3405	5202	5088	3255	1984	21449
Sum	23349	31506	46516	45218	29758	19686	196033

Table 10 lists the peak loads, their appearing time and total cooling loads on design day for 5 zones. Comparing Table 10 and Table 5, it is found that the peak cooling load on summer design day is higher than the peak load on July 13, which is simulated using TMY weather data. The peak load for all pavilions on summer design day is 18727.5kW and 12% higher than the peak load on July 13. The total cooling load of summer design day is 403917 kWh and 24.5% higher than the total cooling load of July 13.

The cooling loads of the pavilions in 2010 Shanghai Expo will be influenced by the uncertainties of various factors, e.g., weather, thermal transfer performance of building envelope, internal loads, outdoor air supplying mode, etc. This paper selects three factors – weather, visitor flow rate and outdoor air supplying mode – and conducts uncertainty analyses on their impact on the cooling loads of the buildings in expo.

The models described above use Typical Meteorological Year as the weather input data, however the real weather in 2010 will be different from TMY, e.g., probably hotter due to global warming effect. In order to study the impact of the uncertainty of weather data on the cooling loads, the real weather data in year 2004 and 2005 are input into the model to conduct the same simulation to compare with TMY. Table 11 presents the cooling degree hours and total solar radiation of the year 2004, 2005 and TMY, showing that the two real years are hotter than typical weather, and the cooling degree hours in 2005 is more than 2004 while the total solar radiation in 2004 is higher than 2005.

TABLE 10 Peak load, appearing time and total load on design day

Zones	Peak cooling load (kW)	Appearing time	Total cooling load on design day (kWh)
A	18533	11 am	209488
B	72376	3 pm	856674
C	47887	11 am	541138
D	17766	11 am	203178
E	21736	11 am	239943

TABLE 11 Cooling degree hours and total solar radiation of TMY and year 2004, 2005

Weather data	Cooling degree hours (Base 26℃/hour)	Total solar radiation ($MJ/m^2 \cdot a$)
TMY	4600	5780
2004	6354	5913
2005	8703	5761

TABLE 12 Peak cooling load, appearing time and total cooling load of three meteorological years

Weather	Peak cooling load (kW)	Peak load appearing time	Total cooling load on the day when peak cooling load appears (kWh)	Total cooling load from May 1st to Oct 31st (MWh)
TMY	159163	12 pm, July 13th	1646505	196032
2004	180504	4 pm, Aug1st	1827129	204192
2005	167959	12 pm, Aug 3rd	1791562	209920

Table 12 lists the simulation results of three weather data. The peak cooling load in year 2004 is higher than that in year 2005 and the peak cooling loads in the two real years are both higher than the typical meteorological year, while the appearing times of the peak loads in the two real years are later than TMY. The total cooling load on the day when peak load appears is the highest in year 2004, the second highest in year 2005 and the lowest in TMY. However the total cooling load during expo opening (from May 1st to Oct 31st) is highest in year 2005 and lowest in TMY. The peak cooling load in 2004 is 13.4% higher than that in TMY. The total cooling load in year 2005 is 7.1% higher than that in TMY. Comparing Table 11 and Table 12, cooling degree hours have bigger impact on peak cooling load than total solar radiation does, and vice versa.

In order to analyze the impact of the uncertainty of visitor flow rate on the cooling loads, two scenarios – high visitor flow rate and low visitor flow rate – are simulated in addition to the middle visitor flow rate described above. High visitor flow rate is about 50% higher than the middle flow rate and the same for occupant densities in various spaces; low visitor flow rate is about 50% lower than the middle flow rate and the same for occupant densities. Table 13 gives the simulation results of the three visitor flow rates. The peak cooling load under high visitor flow rate is 11% higher than that under low visitor flow rate and total cooling load during the expo opening period under high visitor flow rate is also 11% higher than that under low visitor flow rate.

In order to analyze the impact of uncertainty of outdoor air supplying mode on the cooling loads, another outdoor air supplying mode – constant outdoor air flow rate – other than demand control ventilation is simulated. Table 14 gives the simulation results. The peak cooling load under constant outdoor air flow rate is 10% higher than that under demand controlling outdoor air supplying mode and the total cooling load during the expo opening period under constant outdoor air flow rate is 15% higher than that under demand control mode.

TABLE 13 Peak cooling load, appearing time and total cooling load of three visitor flow rates

Visitor flow rate	Peak cooling load (kW)	Peak load appearing time	Total cooling load on the day when peak cooling load appears (kWh)	Total cooling load from May 1st to Oct 31st (MWh)
Low	151425	12 pm, July 13th	1563590	187013
Middle	159163	12 pm, July 13th	1646505	196033
High	168660	12 pm, July 13th	1745014	206659

TABLE 14 Peak cooling load, appearing time and total cooling load of two outdoor air supplying modes

Outdoor air flow rate	Peak cooling load (kW)	Peak load appearing time	Total cooling load on the day when peak cooling load appears (kWh)	Total cooling load from May 1st to Oct 31st (MWh)
Constant	174450.5	3 pm July 13th	1841535	225680
Demand control	159162.5	12 pm July 13th	1646505	196033

5. SUMMARY

Overview of the 163 pavilions in 2010 Shanghai Expo is given and the factors that have impact on the cooling loads of the pavilions are analyzed and then models are developed with DOE-2 for the pavilions. Among the 163 pavilions, 131 stand-alone national pavilions and international organization pavilions are simplified by modularization into 7 categories and 21 types to reduce the model development and simulation work. The cooling loads of the pavilions are calculated through hour-by-hour simulation with models. The uncertainty analysis is conducted with three weather data, three visitor flow rates and two outdoor air supplying modes.

- ✧ The peak cooling load of all pavilions in expo is predicted as 159,163 kW, appearing at 12 pm on July 13. The total cooling load from 10 am to 10 pm on July 13 is 1,646,505 kWh.
- ✧ The total cooling load of all pavilions from May 1 to October 31 is predicted as 196,033 MWh.
- ✧ The peak cooling load of all pavilions in expo is 177,890 kW at 11 am and total cooling load is 2,050,422 kWh on summer design day.
- ✧ Concerning the buildings in 2010 expo, especially the permament pavlions, will probably use higher performance evenlopes and lighting systems than code requirements, the cooling loads will be lower than those presented in the paper.
- ✧ Uncertainty analysis shows that hotter weather, higher visitor flow rate and constant outdoor air supplying mode will all increase the cooling loads.

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