DESIGN OF A GREEN DEMO BUILDING IN A HOT AND HUMID CITY IN CHINA

Yi Jiang
Sebesta Blomberg & Associates
Woburn, MA

Ana Bacall
Sebesta Blomberg & Associates
Woburn, MA

Brad Jones
Sebesta Blomberg & Associates
Woburn, MA

William Hammer
HKT Architects
Somerville, MA

Eric Kluz
HKT Architects
Somerville, MA

Andrea Sonan
HKT Architects
Somerville, MA

ABSTRACT

A sustainable demonstration building has been designed in Shanghai, China. The local climate in terms of temperature, humidity, and wind are analyzed to identify the effective strategies for heating, cooling, and ventilation. Advanced green design practice and technologies are introduced into the design. In terms of design standards, the proposed design complies with the relevant standards and building regulations in China, in conjunction with the best design practices in the USA. An integrated design process is followed through close collaborations between architects and engineering consultants. For example, to improve ventilation effects and avoid excessive solar heat gains, the architectural design is modified by introducing a ventilation well, upper-lower window placement, bioclimatic facades, light shelf, and wing walls. In addition, many green features are incorporated into the design, such as geothermal heat pump, hybrid ventilation, daylighting dimmer, green roof, and composting toilets, etc.

INTRODUCTION

The building industry in China has grown rapidly in recent years. According to the World Bank, by 2015, approximately half of world's new building construction will take place in China. However, over the last few years, environmental degradation has become so severe that it threatens to undermine the industrial growth in China. People in China have realized the problems and seek to develop energy-efficient and sustainable buildings. Required by a developer in China, two US design firms team together to design a sustainable demo building in Shanghai, China.

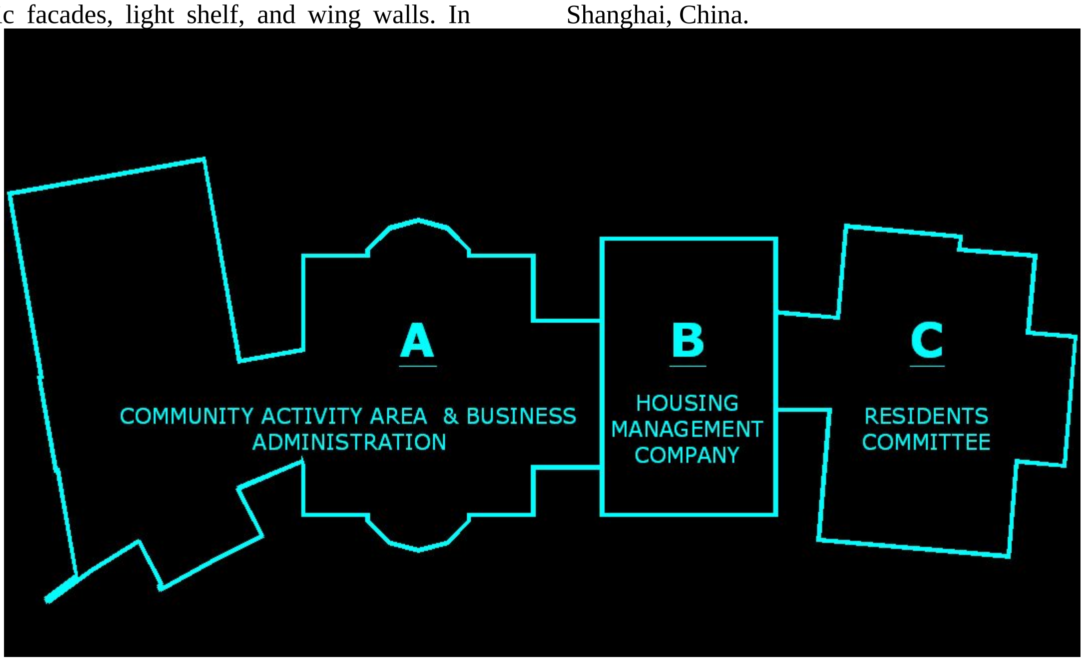


Figure 1. Building plan.

The demo building, Ailu Community Center, is located in Minhang District in Shanghai. The total area of the building is about 21,000 ft^2. Figure 1 shows the building plan. This building system design is focusing on the BLOCK A: Community Activity and Business Administration Areas. BLOCK B will be provided with local air conditioning systems, and BLOCK C will not be provided with any mechanical HVAC. The goal of the design is to meet with the local climate and customs, to introduce advanced green design practice and technologies to reduce energy consumption and improve comfort, and to achieve sustainable demonstration.

CODE INVESTIGATION

The design needs to comply with the relevant standards and building regulations in China, in conjunction with the best design practice in the USA. To recommend building parameters for the building, the local regulations on building envelope were compared with ASHRAE 90.1 (ASHRAE, 2004). ASHRAE 90.1 divided US territories into different climate zones. It is found that the climate in Washington DC is similar to the climate in Shanghai. Figure 2 illustrates the monthly average temperatures during a typical meteorological year for Shanghai and Washington DC.

The comparison of the envelope requirements between Shanghai standards and ASHRAE 90.1-2004 for Washington DC is summarized in Attachment A. The highlighted parameters are the more stringent, and therefore, designed for this project.

ANALYTICAL TOOLS TO ASSIST DESIGN

Climate and Site Analysis

The analysis of the climate is the starting point for a design that maximizes comfort and minimizes the energy consumption for both heating and cooling.

Figure 3 illustrate the comfort level from January to December in Shanghai (MIT China Housing Study, 1998). In Figure 3, the dark-green colored zone shows the comfort range based on the study by Givoni (1998). Over a typical meteorological year, there are four types of seasons: a cold winter with the need for heating, a summer with the need for cooling and dehumidification, a comfort season, and a warm season with need for natural ventilation.

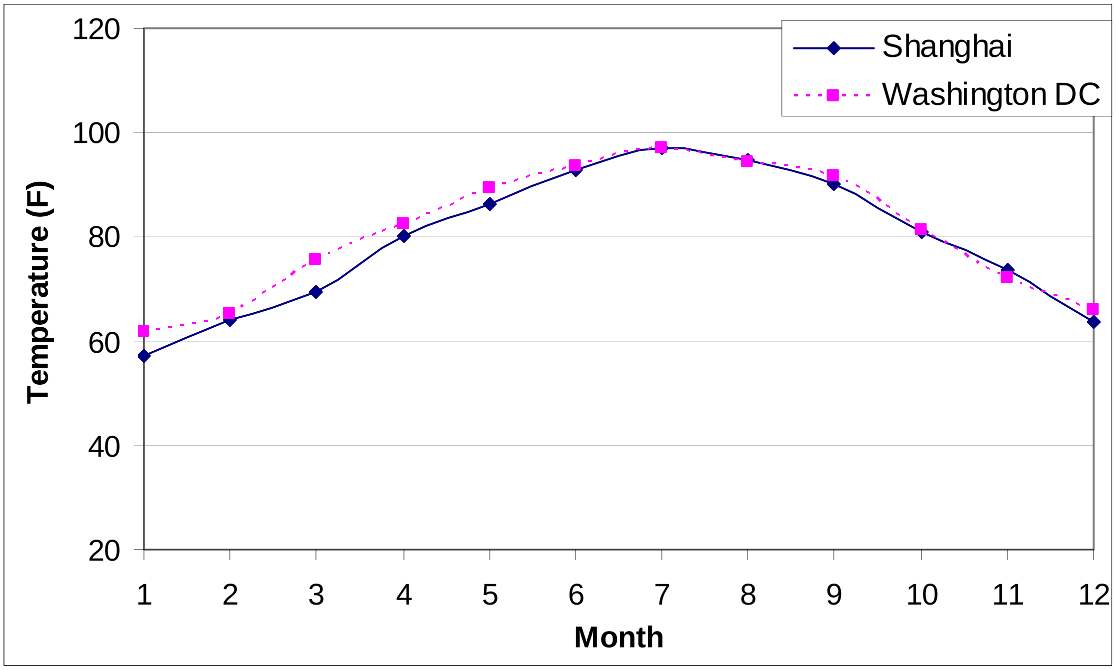


Figure 2. Comparison of Monthly Dry Bulb Temperature Between Shanghai and Washington, DC.

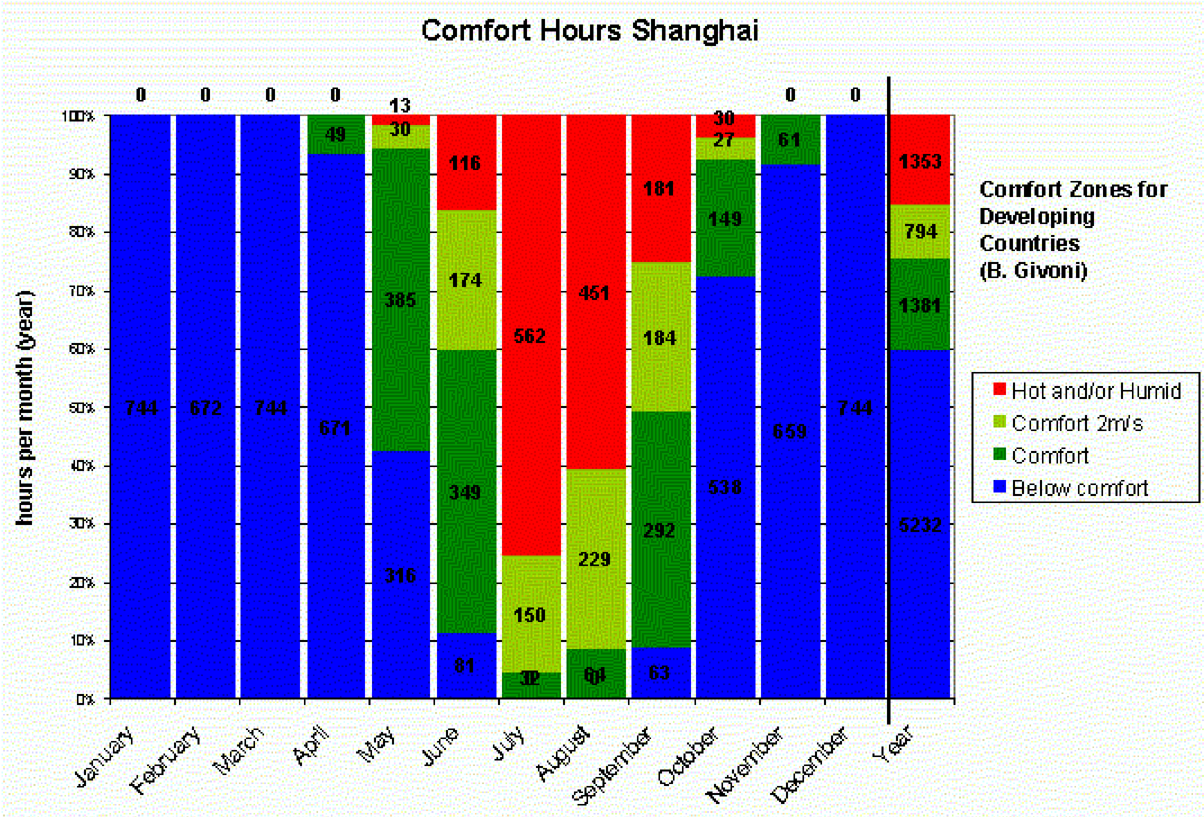


Figure 3. Investigation of Comfort Hours in Shanghai (MIT, 1998)

Figure 3 shows that In May, June, September and October, there are many hours where no cooling or heating is necessary, which corresponds to 1381 comfortable hours at outdoor conditions. By increasing the velocity of the air of the surroundings, people still feel comfortable at higher indoor air temperatures and humidity. The comfort zone is then extended to light green, which occurs mainly from June to September for a total of 794 hours. Therefore, natural ventilation can be applied to eliminate mechanical cooling during those hours. The climate is hot and/or humid during 1353 hours of the year. For this time, mechanical cooling and/or dehumidification is necessary to provide a comfortable indoor climate. During the remaining time of the year, the temperatures are below 68°F and above 80% relative humidity simultaneously (blue zone). This does not necessarily mean that there is a need for heating. Internal and solar heat gains can provide enough heat to create an acceptable indoor climate during many of these hours.

Determination of Outdoor Design Conditions

ASHRAE Fundamentals (2005) provides the design conditions for Shanghai, China (Table 1 based on 99% for heating and 1% for cooling). The HVAC system is sized to meet the maximum heating and cooling loads under these conditions.

Table 1. Outdoor Design Conditions for Shanghai.

	Dry Bulb		Wet Bulb	
	°F	°C	°F	°C
Summer	92.2	33.4	81.5	27.5
Winter	28.7	-1.8	-	-

Determination of Indoor Design Conditions

The factors that affect thermal comfort of building occupants include:

a. Clothing levels
b. Indoor temperature and humidity
c. Air velocity
d. Activity levels

Clothing Level. An analysis of the activity and clothing insulation levels has been conducted for different building spaces in the new Ailu community center. In general, the activity level is equivalent to slow walking or office work, and the clothing insulation levels are similar throughout the building spaces. Therefore, the indoor design conditions should be similar for different building spaces. A formula has been developed to evaluate thermal insulation of clothing ensemble conditions: Clothing

Insulation Level or Clothing level (ASHRAE Fundamentals, 2005). For example, trousers and short-sleeved shirt corresponds to a clothing level of 0.57, and trousers and long-sleeved shirt with suit jacket corresponds to a clothing level of 0.96.

Indoor Design Parameters. To determine the indoor design conditions, a bioclimatic chart (Arens, *et al.*, 1980) is used to show the impact of climate variables on thermal comfort (Figure 4). With the combination of temperature and relative humidity, one can determine if the resulting condition is comfortable (within the comfort zone), too hot (above the top of the comfort zone), or too cold (below the bottom of the comfort zone). Figure 4 also shows that the introduction of wind helps to expand the comfort zone. For example, without wind, people would feel hot under 80°F and 50% relative humidity (above the top of the comfort zone). By introducing 1 mph (0.5 m/s) wind, people feel comfortable under the same temperature and humidity. The bioclimatic chart assumes a 0.8 clothing level, and an activity level of 1.3 Met (Metabolic Rate) that is equivalent to slow walking or office work.

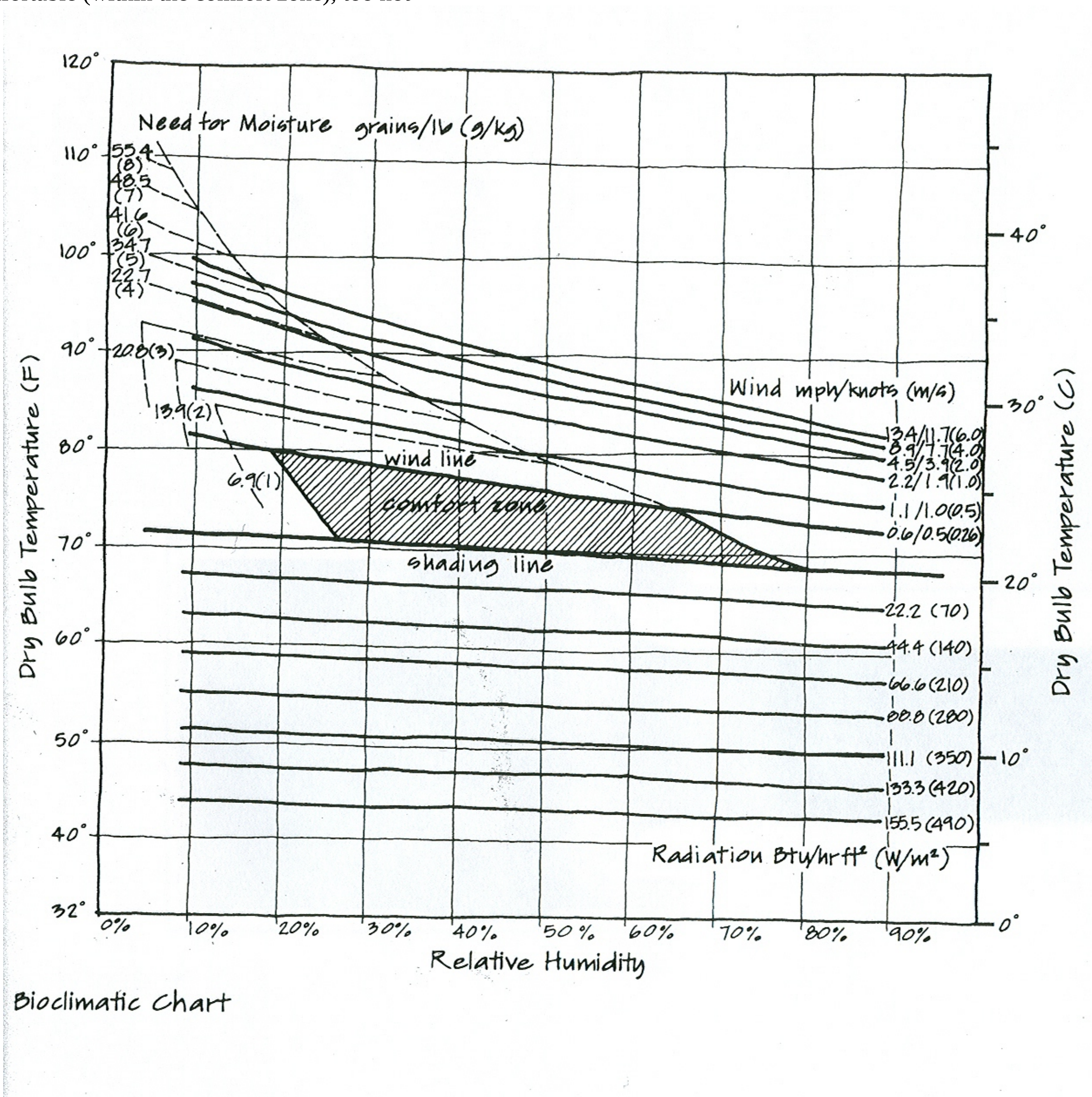


Figure 4. Bioclimatic chart (Arens, *et al.*, 1980)

Table 2. Indoor Design Conditions.

Room Type	Temperature						Humidity (%RH)			Ventilation
	Natural Ventilation		Summer Cooling		Winter		Natural Ventilation	Summer Cooling	Winter Heating	
	°F	°C	°F	°C	°F	°C				
Offices	75 ± 5	24 ± 2.8	75 ± 4	24 ± 2	70 ± 4	21 ± 2	50% ± 10%	NA	NA	NA (Operable Windows)
Multi-purpose Room	75 ± 5	24 ± 2.8	75 ± 4	24 ± 2	70 ± 4	21 ± 2	50% ± 10%	NA	NA	Same
Activity Room	75 ± 5	24 ± 2.8	75 ± 4	24 ± 2	70 ± 4	21 ± 2	50% ± 10%	NA	NA	Same
Card and Board Room	75 ± 5	24 ± 2.8	75 ± 4	24 ± 2	70 ± 4	21 ± 2	50% ± 10%	NA	NA	Same
Reading Room	75 ± 5	24 ± 2.8	75 ± 4	24 ± 2	70 ± 4	21 ± 2	50% ± 10%	NA	NA	Same
Kitchen	75 ± 5	24 ± 2.8	75 ± 4	24 ± 2	70 ± 4	21 ± 2	50% ± 10%	NA	NA	Same
Toilet	NA	NA	NA	NA	NA	NA	NA	NA	NA	10 ACH

Based on the analysis of the bioclimatic chart, the indoor design conditions are developed (Table 2). There are three different modes for indoor environment control: natural ventilation, mechanical cooling, and heating. The system and control strategies will be discussed in the system design section.

Load and Energy Study

To size the mechanical systems correctly and optimize cost-effective energy efficiency measures, both load and energy consumption for Block A are calculated with Trace 700. The recommended building envelope parameters in previous sections are used in the simulation. Table 3 provides a brief summary of the building information.

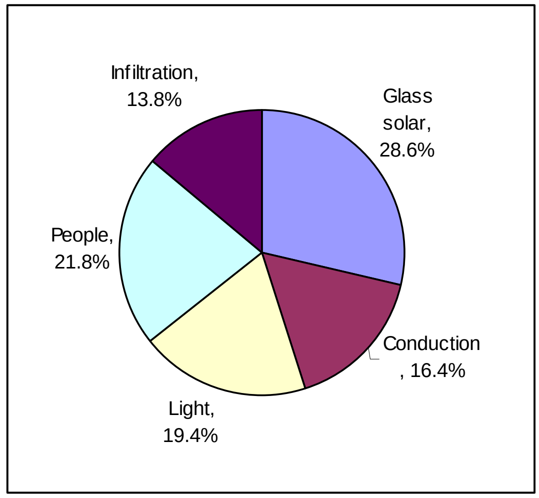
Table 3. Building Design Parameters.

Total Floor Area	12,500	ft^2
Exterior Wall Area	9,180	ft^2
Window (%)	29%	
Infiltration & Exhaust	0.5	ACH

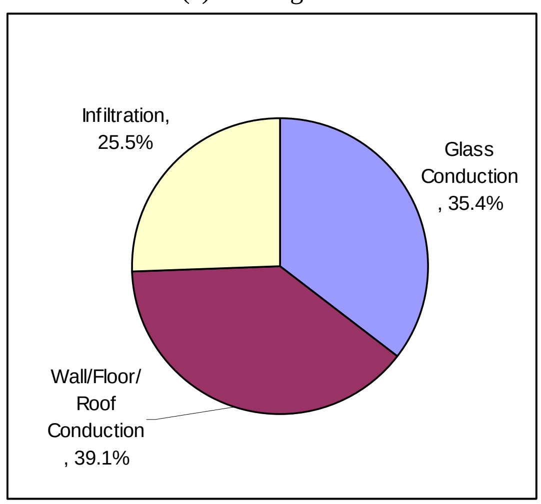
The calculated cooling and heating loads for Block A are:

- Whole Cooling Load: 41.4 Tons
- Whole Heating Load: 194 MBh (1,000 Btu/hr)

Figure 4 illustrates the building cooling and heating loads affected by different envelope elements and internal loads. Figure 4 (a) shows that the solar heat gain constitutes nearly 30% of total cooling loads. Therefore, proposed sustainable design strategies should address reduction of the solar heat gain. Some of the methods proposed are: orienting windows to north/south facing, reducing shading coefficients of the windows, and providing proper shading devices.



(a) Cooling Load



(b) Heating Load

Figure 4. Pie Chart of Building Loads Affected By Different Envelop Elements

Table 4. Building Annual Energy Consumption for Different Components

Items	Primary Heating	Primary Cooling	Lighting	Plug Loads	Total
kWh	11,709	43,698	60,984	40,656	157,047
% of Total	7.5%	27.8%	38.8%	25.9%	100.0%

The annual energy consumption of the building Block A was also calculated (Table 4). The results show that lighting constitutes nearly 40% of total energy consumption. Therefore, some lighting efficiency measures, such as daylighting dimmer and occupancy sensors, are proposed to help reducing lighting consumption as well as cooling costs.

BUILDING ENVELOP DESIGN

When conducting the building envelop design, an integrate design process has been followed through close collaborations between architects and engineering consultants. To improve ventilation effects, avoid excessive solar heat gains, and utilize daylighting, the architectural design has been modified by introducing ventilation well, upper-lower window placement, bioclimatic facades, light shelf, and wing walls.

Bioclimatic facades

Bioclimatic façade consist of horizontal trellis and planters located on every story on the outside of the façade. The planters are located a few inches away from the façade to let the air wash vertically upward the exterior surface of the façade and remove the heat. Some of the recycled water is used to water the plants. Plants assist in shading from the sun, avoiding glare and heat spots, and filter the ventilation air when opening windows.

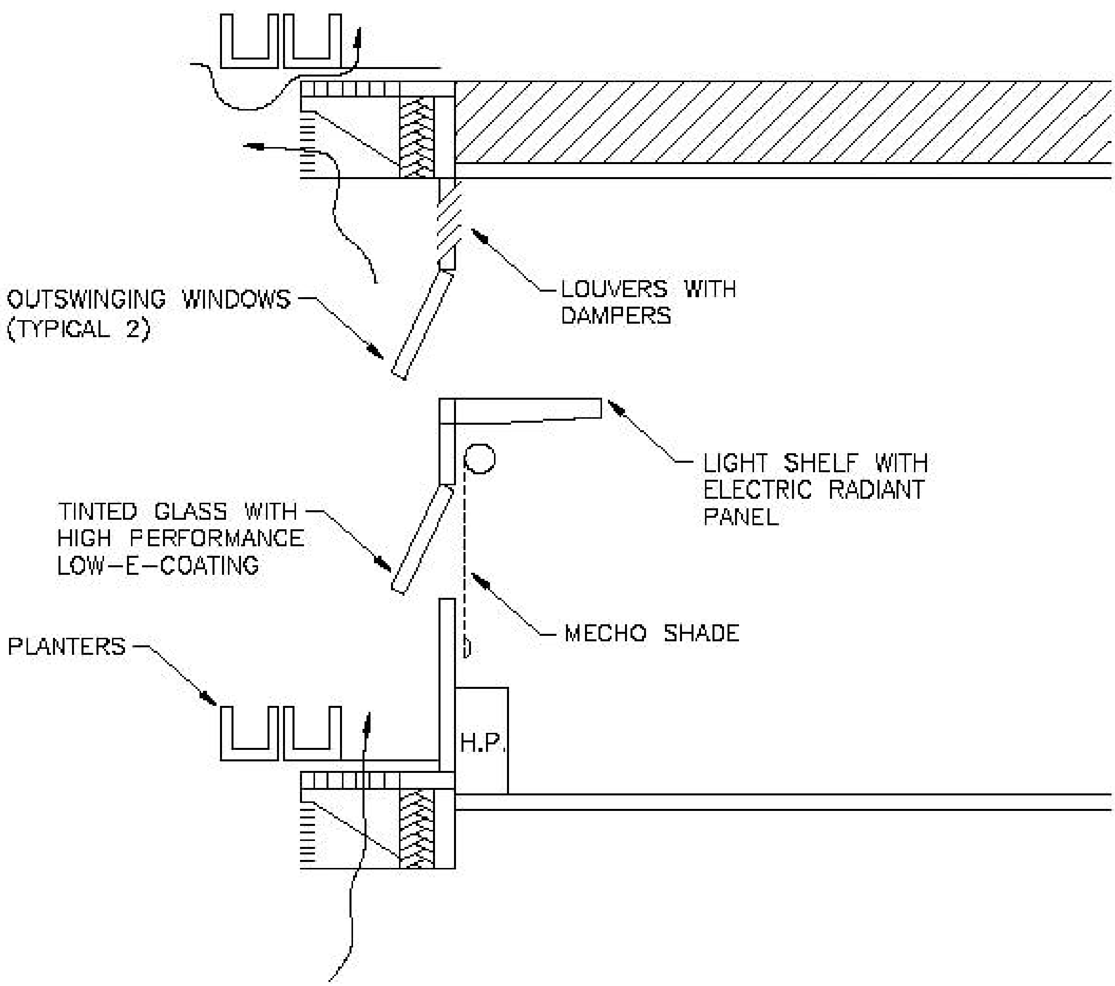


Figure 5. Design of Bioclimatic Wall and Light Shelf.

Light shelf

A light shelf attached to perimeter wall on the interior side provides shading in the summer time; in the winter months allows the sun light to enter the space, heating the walls and furniture and providing daylight deeper into perimeter spaces. Light shelf can be used for supplemental heating at the perimeter wall when provided with electrical heating panels.

Figure 5 provides the design sketch of the bioclimatic wall and light shelf.

Design of Windows and Wing Walls

The location, size, and placement of windows, and wing walls have been designed to enhance natural ventilation. For example, wing walls that extend beyond flat façade can act as scoops to help wind capture and generate different pressures on the same side of the building. The wing walls have been integrated into the building design (Figure 6). Furthermore, for the two-story multipurpose room, windows are placed on lower and higher level of the wall for better ventilation.

Ventilation wells

Ventilation wells connecting all floors help the efficiency of natural ventilation due to the thermal stack effect. When used in combination with mechanical ventilators, ventilation wells extend the time for the natural ventilation to warmer days; by increasing the velocity of the ventilation air, even warmer air can be used to offer pleasant perception for the occupants. A ventilation well has been placed next to the Multipurpose room on the first floor and Activity Room on the second floor.

SYSTEM DESIGN

Many green technologies and systems have been integrated into the design. For mechanical systems, closed loop design distributed geothermal system and natural and mechanical ventilation have been designed; For electrical systems, daylight dimming and motion sensors are used in order to reduce the amount of required continuous electrical consumption; For plumbing systems, gray water and rain water collection system, low flow fixtures such as waterless urinals and composting toilets, and solar water heating system for domestic water have been applied. This section is focusing on the mechanical system design.

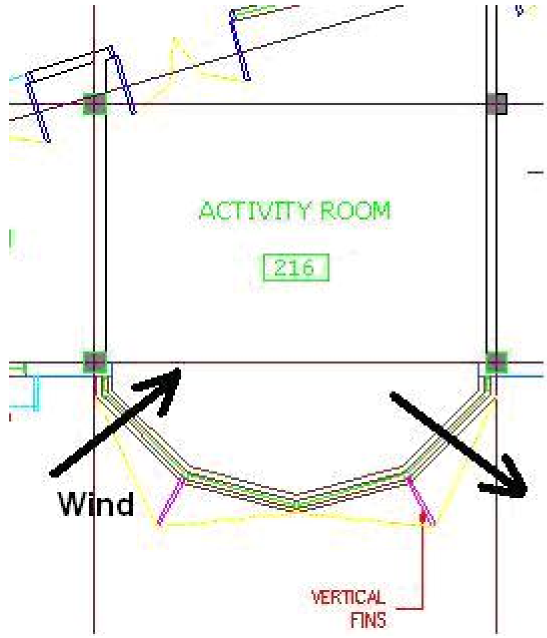


Figure 6. Integration of Wing Walls to the Design.

Building cooling and heating requires that the interior be maintained under a comfortable level of temperature and humidity. The proposed system for building cooling and heating is forced air and radiant heating: geothermal closed loop distributed system, which provides multiple zone control, assures cooling and dehumidification for the space during hot and humid days, and heating for cold days; electric radiant panels mounted on the light shelves that assist heat pumps to heat the space during the very cold days.

Geothermal System

Geothermal system provides heat in the winter and cooling in the summer at efficiencies that are far better than those for most heating and cooling conventional building systems. Like conventional heat pumps, they are air conditioners that can run in reverse to provide heat in the winter. The primary difference is that they rely on the nearly constant temperature of earth or pool water for heat transfer instead of the widely fluctuating temperature of the outside air.

The system proposed for this project is Closed Loop Design Geothermal system. A closed loop ground coupled system uses special plastic piping that is buried or submerged to provide a geothermal heat exchanger. This heat exchanger can reject or draw heat from the earth or pond by circulating water through the loop. The reason to use the closed loop design is because that the use of well water for an open loop application is prohibited by the local Water

Resource Bureau. This design applies vertical loop systems due to limited space available. In such a system, a water/antifreeze mixture is circulated through sealed pipe loops buried in vertical bore holes. Heat is transferred by the heat pump system from the ground during the winter and to the ground during the summer. The proposed design is a Distributed System, which has a central loop, water pump, earth as heating resource, and individual console type heat pumps to serve individual rooms and areas.

The benefits by applying such system are: high efficiency, No ground-level outdoor equipment to suffer from deterioration from weather and no outdoor noise; Easily fitted and zoned.

Building Ventilation

Both natural and mechanical ventilation are design for the building. When outdoor air is dry and cooler than desired indoor air, the fans located above the ventilation wells start running. The perimeter grilles located above window are modulated by the motorized dampers to draw the cool air from outside into the space. The ventilation air is then transferred through grilles above the doors between the rooms and corridors, and is expelled to the outside.

During hot and humid days, ventilation air is drawn into the space from the perimeter grilles by maintaining the motorized dampers opened at a predetermined minimum position. The console type heat pumps cool and dehumidify the ventilation air by re-circulating the air over the cooling coils.

Building Management System

The building management system (BMS) incorporates controls for geothermal system, window disconnects, outdoor wet bulb temperature sensors, and lighting automatic controls. The BMS System with the help of the computer software performs tasks such as: determine when it is safe to use ventilation air and turn-off heat pumps, turn off lights on schedule, etc.

CONCLUSIONS

A sustainable demonstration building has been designed in Shanghai, China. The local climate in terms of temperature, humidity, and wind has been analyzed to identify the effective strategies for heating, cooling, and ventilation. In consideration of the local customs, windows are designed to be motorized operable type, and indoor design conditions are extended compared to the thermal comfort zone developed by ASHRAE.

Advanced green design practice and technologies have been introduced into the design. In terms of design standards, the proposed design complies with the relevant standards and building regulations in China, in conjunction with the best design practices in the USA. An integrated design process has been followed through close collaborations between architects and engineering consultants. For example, to improve ventilation effects and avoid excessive solar heat gains, the architectural design has been modified by introducing ventilation well, upper-lower window placement, bioclimatic facades, light shelf, and wing walls. In addition, many green features have been incorporated into the design, such as geothermal heat pump, hybrid ventilation, daylighting dimmer, green roof, and composting toilets, etc.

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Attachment A. Building Envelop Prescriptive Requirements for Nonresidential Buildings: Comparison Between Shanghai and Washington, DC (ASHRAE 90.1-2004, Climate Zone 4A)

Opaque Elements		**Assembly Maximum K (w/m2 K)**	**Assembly Maximum U (Btu/h ft2 F)**	**Insulation Min. R-Value**	
Roofs					
Shanghai		0.70	0.12	8.11	
Washington DC	Insulation Entirely above Deck		U - 0.063	R - 15.0 ci	
	Metal Building		U - 0.065	R - 19.0	
	Attic and Other		U - 0.034	R - 30.0	
Walls Above Grade					
Shanghai		1	0.18	5.68	
Washington DC	Mass		U - 0.151	R - 5.7 ci	
	Steel framed		U - 0.124	R - 13.0	
	Wood framed and other		U - 0.089	R - 13.0	
Floors					
Shanghai		1	0.18	5.68	
Washington DC	Mass		U - 0.107	R - 6.3 ci	
	Steel Joist		U - 0.052	R - 19.0	
	Wood-Framed and Other		U - 0.051	R - 19.0	
Fenestration		**Assembly Max. K W/m2 K**	**Assembly Max. U (Fixed/Operable)**	**Assembly Max. SC (All Orientations /North-Oriented)**	**Assembly Max. SHGC (All Orientations /North-Oriented)**
Vertical Glazing, % of Wall					
Shanghai	0-20%	4.7	0.83		
	20.1-30%	3.5	0.62	0.55/--	0.48/--
	30.1-40%	3	0.53	0.50/0.60	0.44/0.52
	40.1-50%	2.8	0.49	0.45/0.55	0.39/0.48
	50.1-70%	2.5	0.44	0.40/0.50	0.35/0.44
Washington DC	0-10%		0.57/0.67		0.39/0.49
	10.1-20%		0.57/0.67		0.39/0.49
	20.1-30.0%		0.57/0.67		0.39/0.49
	30.1-40.0%		0.57/0.67		0.39/0.49
	40.1-50%		0.46/0.47		0.25/0.36
Skylight					
Shanghai		3	0.53	0.4	0.348
Washington DC					
Skylight with Curb, Glass, % of Roof	0-2.0%		U_{all} - 1.17		$SHGC_{north}$ - 0.49
	2.1-5.0%		U_{all} - 1.17		$SHGC_{north}$ - 0.39
Skylight with Curb, Plastic, % of Roof	0-2.0%		U_{all} - 1.30		$SHGC_{north}$ - 0.65
	2.1-5.0%		U_{all} - 1.30		$SHGC_{north}$ - 0.34
Skylight without Curb, all, % of Roof	0-2.0%		U_{all} - 0.69		$SHGC_{north}$ - 0.49
	2.1-5.0%		U_{all} - 0.69		$SHGC_{north}$ - 0.39

Note:
NR = No insulation requirements
ci = Continuous insulation
SHGC = Solar Heat Gain Coefficient
SC = Shading Coefficient, SC = SHGC/0.87