The Sino-Italy Environment & Energy Building (SIEEB): A model for a new generation of sustainable buildings

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ABSTRACT

The Sino-Italy Environment & Energy Building (SIEEB) is an intelligent, ecological and energy-efficient building and seen as a model for a new generation of sustainable buildings. This paper describes the integrated design procedure for the SIEEB building design and the methodologies adopted for sustainable architecture and energy saving measures by using advanced technological solutions and control strategies. The results on the building energy simulation, plant optimisation and first estimation of CO_2 emission reduction potential through SIEEB are also presented.

1. INTRODUCTION

China is experiencing an extraordinary growth in its building stock. From year 1991 - 2000, the residential buildings were built for nearly 5 billion square meters. In only four years (1996-1999), energy consumption of the building sector jumped from 24.59% to 27.81% of the total energy consumption. It is expected that the building stock, residential and commercial, will be doubled by year 2015 (Chen, 2004). The energy structure of China is coal-based, resulting in emission of large quantities of pollutants and greenhouse gases (GHGs). It is therefore, strategically important to introduce advanced environmental and energy technologies into this field and to promote the construction of green energy-saving buildings.

The Italian Ministry for the Environment and Territory, in cooperation with the Chinese Ministry of Science and Technology, are starting the construction of a new-generation of sustainable building, the Sino-Italy Environment & Energy Building (SIEEB) in the campus of the University of Tsinghua in Beijing. SIEEB is technologically advanced, efficient from the point of view of the environment and energy consumption, and intended to house offices, laboratories, classrooms, an exhibition area for Italian technology, and a conference hall with a total floor space of 20,000 m^2.

The SIEEB is also regarded as a platform to develop the bilateral long-term cooperation in the environment and energy fields, and a model case for showing the CO_2 emission reduction potential in the building sector in China.

The building design was carried out by the Department of Building and Environment Science and Technology (BEST) of the Politecnico di Milano, in cooperation with University of Tsinghua, MCA Mario Cucinella Architects and China Architecture Design & Research Group, in a collaborative experience among consultants, researchers and architects. The integrated design process of SIEEB is a most distinctive part of the project and a key issue for green buildings.

In the preliminary design process, a number of appropriate shapes were considered and a feasibility analysis was carried out to check how the building was able to cope with all the requirements in terms of available area, specific building volume and space distribution. The resulting shapes were then analysed in terms of their solar performance. Using the shape analysis, best shape was developed with the aim of maximizing solar gains in winter and minimizing them in summer. Further, the designing of SIEEB building is carried out on the basis of various advanced technological solutions and control strategies which include sun shading, radiant heating and cooling, displacement ventilation, efficient artificial and natural lighting etc.

This paper describes the integrated design procedure for the SIEEB building design and the methodologies adopted for sustainable architecture and energy saving measures by using advanced technological solutions and control strategies. The results on the building energy simulation, plant optimisation and first estimation of CO_2 emission reduction potential through SIEEB are also presented.

2. BUILDING DESIGN PROCESS

2.1 Building Shape

The SIEEB building shape, shown in Fig. 1, derives from the analysis of the site and of the specific climatic conditions of the Beijing. Located in a dense urban context, surrounded by some high-rise buildings, the building optimises the need for solar energy in winter and for solar protection in summer. The shape of the building evolves from a series of tests and simulations carried out earlier by present authors (Butera et al., 2003).

2.2 Advanced Technologies and Control Strategies

The envelope characteristics derive from a series of simulations of the thermal behaviour of the building, optimising between energy and architectural factors. Building energy analysis, carried out by means of detailed computer simulations, showed that, in order to minimise CO_2 emissions, the key issue was electricity consumption, mainly because of the highly polluting electricity production and distribution system in China. The envelope characteristics were defined on the basis of the advanced technologies for energy savings.

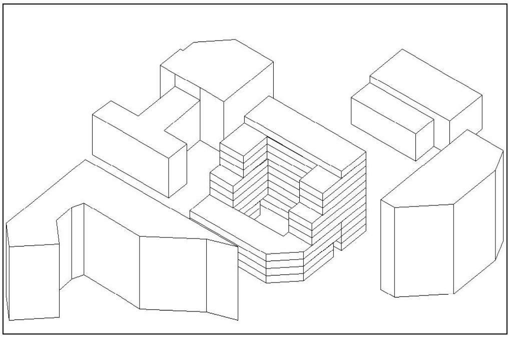

Figure 1: SIEEB building shape.

From such an evidence the following design strategies were considered:

- to maximise natural lighting, for minimising the need of artificial lighting,
- to minimise the electricity demand of the HVAC system,
- to cover as much as possible the electricity demand of the building by means of cleaner production systems.

2.2.1 Building Envelope

The building optimises energy performance thanks to a dynamic structure that modifies itself in response to weather and light conditions, both internal and external. Form and function are integrated in order to minimize environmental impact.

The building envelope is conceived as a protective shell towards the north, opening south towards the sun. The materials used e.g. special brickworks, glass and aluminium introduce an innovative look with a high aesthetic value.

The envelope characteristics were defined on the basis of the advanced technologies for energy savings. On the facade facing the sun a system of semi-reflecting glazed louvers move in relation to the sun's position, deflecting the rays onto the ceiling of the spaces behind so that light penetrates deep into the building. The louvers also reflect solar radiation in summer and let it pass through in winter. Artificial lighting is based on high efficiency lamps and fittings, controlled by a dimming system capable to adjust the lamps power to the actual local lighting needs, in combination with the natural light contribution. The geometrical positions of the lamps are optimised too. A presence control system switch off lights in empty rooms. The integration of the envelope components chosen and the controls systems will reduce by several times the electric energy consumption for lighting.

In the east and west facades an horizontal element, a light shelf, diffuses the light onto the ceiling, and internal reflecting blinds control direct sunlight.

A large surface of photovoltaic cells completes the shell. The electrical energy generated is also used for an experimental production of hydrogen supplying a fuel cell (Fig. 2).

2.2.2 HVAC and Combined Heat and Power (CHP) Systems

Thermal comfort conditions are provided by a primary air, distributed by means of a displacement ventilation system, and radiant ceiling system. This combination minimises electricity consumption in pumps and fans. Light weight radiant ceilings allow for lower air temperature in winter and higher in summer, thus reducing energy consumption; moreover, the presence sensors, coupled with CO_2 sensors, can modulate either the air flow and the ceiling temperature when few or no people are in the room, thus avoiding useless energy consumption. In summer night cooling takes place.

The CHP system is the core of the energy system of the building. It consists of gas motors coupled with electrical generators to produce most of the electricity required. The waste heat from engines is used for heating in winter and cooling in summer, by means of absorption chillers, and for hot water production throughout the year. Since in China presently is not allowed to sell electricity to the grid, the system is controlled in such a way that neither the electricity production exceeds the building’s demand nor the waste heat produced exceeds the heating or cooling demand. This means that sometimes, when thermal loads are low, electricity production is not sufficient and some power has to be taken from the grid. Some other times the cooling loads – that are higher than the heating ones – are so high that too much electricity would be produced; in this case, the excess electricity is diverted to compression chillers, slightly reducing, at the same time, the power of the engines. A sophisticated, intelligent control system manages the plant. A scheme of HVAC and CHP systems in the SIEEB is shown in Fig. 3.


Figure 2: SIEEB building envelope.

Because of the cleaner electricity produced, the amount of CO_2 emissions per square meter of the SIEEB will be far lower than in present Chinese commercial building stock.

3. BUILDING ENERGY SIMULATIONS

The energy simulations of SIEEB were carried out using DOE 2.1 building energy simulation programme, developed by the Lawrence Berkley Laboratory (1980). Based on preliminary design of SIEEB, the characteristics of building are defined in Table 1.

The simulation model of preliminary design of the SIEEB is shown in Fig. 4.

For energy simulation, the whole building is divided into 28 thermal zones according to location and function of each zone. In each zone, different categories of spaces were considered in respect of their use in the building, e.g. office, laboratory/meeting room, atrium, corridor and underground space (box). Among these, the offices, laboratories and atrium are conditioned spaces and, the corridors and underground space (box) are non-conditioned spaces. The HVAC systems, four-pipe induction unit (FPIU), were simulated for providing thermal comfort conditions inside each zone by primary air distribu-

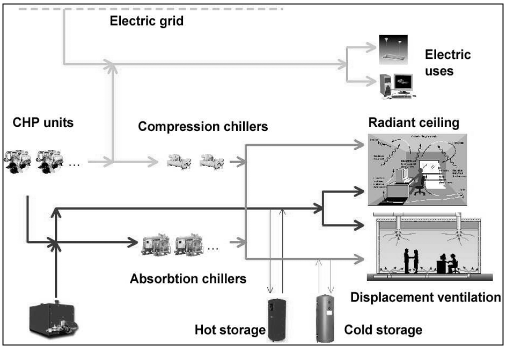

Figure 3: SIEEB HVAC and CHP Systems.

Table 1: SIEEB characteristics –Preliminary design.

Location	Tsinghua University, Beijing Latitude: 39° 48' N, Longitude: 116° 28' E
Building type	Office building, 10 storeys above ground + 2 storyes underground
Floor area	Total floor area - 15,107 m^2 Air-conditioned area - 12,226 m^2
Building	Envelope
Exterior wall	Plaster + 18cm hollow brick + 6cm insulation + 8cm hollow brick + plaster U value = 0.40 W/m^2 K
Window	*South, East & West* low-e 5mm glass + 22mm air-gap with Venetian blinds + low-e 6 mm glass U-value = 1.3 W/m^2 K, Shading coefficient = 0.63 *North & Interior Court* 5mm glass (low-e) + 15mm gap filled with argon gas + 6 mm glass (low-e) U-value = 1.1 W/m^2 K, Shading coefficient = 0.63
Roof	1cm ceramic +2 cm concrete + 6cm insulation + 25cm hollow brick + plaster U-value = 0.42 W/m^2 K
Ratio Glazing to total area	South = 42%, East and West = 34% and North = 14%

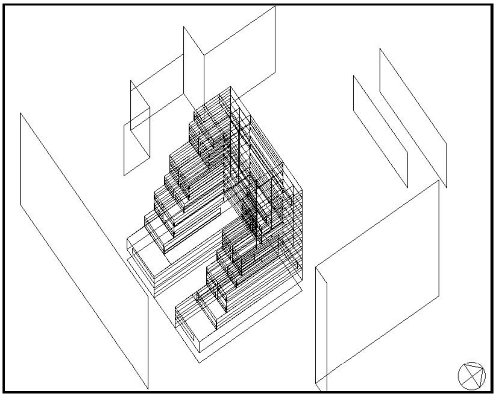

Figure 4: SIEEB simulation model.

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3.1 Reference case

The reference case of SIEEB corresponds to the preliminary design of the building with optimised envelope. The characteristics of building envelope include the low e-values of windows, walls and roof. The plant configuration corresponds to a traditional chiller, gas boiler and the required electricity is supplied by Central Power station (Electricity grid).

3.2 Optimised case

The optimised case of the SIEEB resulted from the advanced technological solutions and control strategies such as sun shading, radiant ceilings, displacement ventilation and maximizing natural and minimizing artificial lighting. The plant configuration corresponds to the absorption and compression chillers, hot and cold storages, back-up boiler and CHP units for electricity generation.

3.3 Building Load Estimation

The results of building load estimation corresponding to reference and optimized case were presented by us earlier (Adhikari et al., 2004). The study shows that the energy demand for air-conditioning has a very high contribution in total energy loads of SIEEB. Cooling demand dominates the building energy loads (40%) and the heating demand is relatively lower (18%). The estimated annual energy loads for reference and optimized case are estimated as 2415 MWh and 1883 MWh, respectively. The peak loads for cooling, heating and lighting & equip. in SIEEB are 963, 357 and 230 kW respectively. Further it was concluded that for the optimised case, the annual energy load reductions for cooling, heating and lighting and equipments can be achieved up to 30%, 23% and 20% respectively.

3.4 Plant Configuration, Optimisation and Performance Results

Both the design and the optimisation of plant configuration for SIEEB were performed by means of detailed simulations of the thermal and electrical requirements for the HVAC system. Based on the simulations carried out for different plant configurations and control strategies, an optimised case is obtained which corresponds to minimum primary energy consumption.

CHP systems are considered for the production of electricity required in the SIEEB. The waste heat of CHP is used for heating in winter, for cooling by means of absorption chillers in summer and for hot water production throughout the year. Detailed simulation studies were made on the different control strategies of the

CHP operation, e.g. thermal, electric, maximum and minimum, and between the thermal and electric driven. Further, the options on the suitability of desiccant cooling system (both solid and liquid) and compression chillers were also investigated. The studied were also made on the use of one-stage and two-stage absorption chillers and the total/partial heat recovery from the two-stage absorption chillers.

The final optimised plant configuration corresponds to electrical driven CHP system, absorption and compression chillers, hot and cold storage, back-up gas boiler. Some typical results of plant simulations are discussed below:

Figs. 5-8 show the hourly electricity and heat consumptions for optimised case during winter and summer months. The results are plotted for a week of January and July.

Since, the CHP system is electrical driven, all electricity requirement of SIEEB is fulfilled by non-polluted electricity produced from CHP system during summer, however, a small amount of electricity is supplied by grid during winter because of load mismatch. In the same manner, for both summer and winter periods, most of the heat requirements is covered by the waste heat of CHP system.

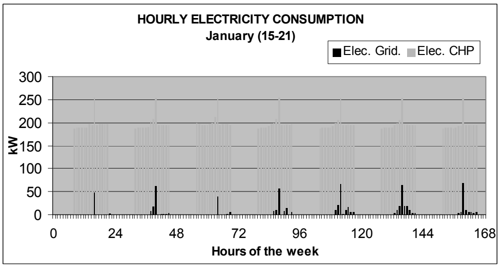

Figure 5: SIEEB (Optimised case) - Hourly electricity consumption during winter.

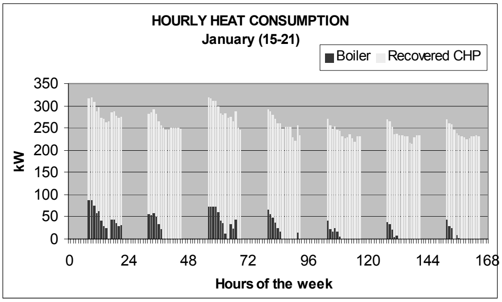

Figure 6: SIEEB (Optimised case) - Hourly heat consumption during winter.

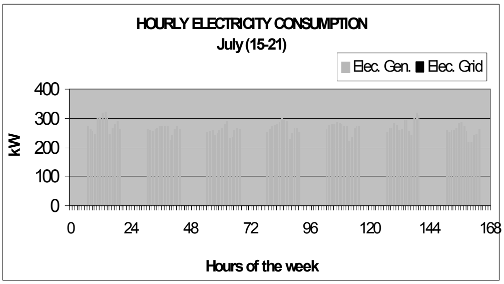

Figure 7: SIEEB (Optimised case) - Hourly electricity consumption during summer.

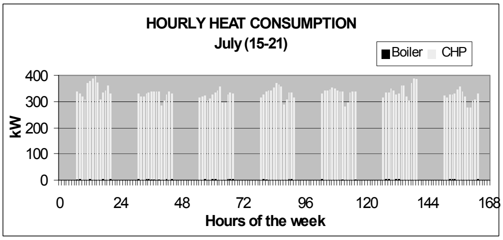

Figure 8: SIEEB (Optimised case) - Hourly heat consumption during summer.

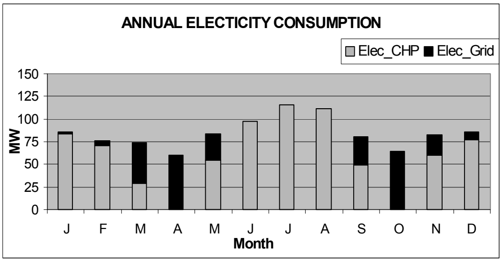

Figure 9: SIEEB (Optimised case) – Annual electricity consumption.

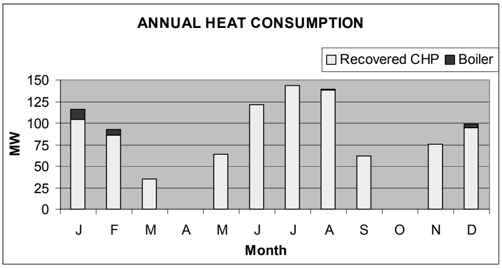

Figure 10: SIEEB (Optimised case) – Annual heat consumption.

The monthly electrical and heat consumptions corresponding to optimised case are shown in Figs. 9 and 10.

It is evident from the figures that most of the time during the year, the electricity requirement

Table 2: SIEEB Plant Performance.

	Optimised case	Reference case
Electricity in (MWh)	271	1820
Electricity out (MWh)	0	0
Waste heat (MWh)	0	0
CO_2 emission (t eq.)	688	1776

is almost satisfied by the CHP system except those months when HVAC system is not in operation during mid-seasons (16 March–14 May and 16 September–31 October) of the year. However, the heat requirements of SIEEB is almost covered from waste heat of CHP systems.

For simulations, the operational period of the HVAC system is defined as per the real functional hours of the building, and the actual plant functioning in Beijing during the whole year (Adhikari et al., 2004).

Some important estimated data related to the plant performance for the reference and optimised cases are shown in Table 2. The CO_2 emission calculations are based on the data suggested by IPCC (2000).

4. CONCLUSIONS

A general overview and detailed methodology is described for energy efficient design of the Sino-Italy Environment & Energy Building (SIEEB). The results on the building energy simulation, plant optimisation and first estimation of CO_2 emission reduction potential through SIEEB are presented. It should be noted that these results are in comparison with a reference case in which the building envelope is already optimised, therefore, compared to a baseline building, constructed as per the current practices in China, the SIEEB is expected to contribute much higher amount of energy savings. In the SIEEB function and form, current practice and innovation are integrated in order to achieve very low CO_2 emissions and ecological design combined with high functional and comfort standards.

In the final construction design, however, significant changes were made in the envelope appearance – and therefore performance –, motivated by formal reasons.

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