

Influence of Building Shape Coefficient on Energy Consumption of Office Buildings in Hot-Summer-and-Cold-Winter Area of China

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ABSTRACT

Building shape coefficient is an important index in building energy efficiency design, it is considered that the smaller the indicator, the less heat loss via the building envelope and the less energy consumption. However, building energy consumption consists not only air-conditioning consumption, but also lighting consumption. This study is based on the concept of passive volume and assumed to fully use of passive energy, natural ventilation and daylighting, in the passive area of a building. Taking a group of office buildings in Shanghai as an example, with the help of the dynamic simulation software DeST-c, the relationship between the building shape coefficient and building energy consumption is studied.

KEYWORDS

Building shape coefficient, Passive volume, Energy consumption, Office building

INTRODUCTION

Buildings represent a large proportion of global energy demand. Approximately 40 percent of energy end-use in the developed world takes place in buildings, compared to a figure of 20 percent in the developing world – the latter still an increasingly significant amount (Pérez-Lombard et al 2008). Accordingly, the building sector is a main contributor to carbon emissions. In 2004, this resulted in global emissions of 8.6 GtCO₂e (Levine et al. 2007) or approximately 33 percent of all energy-related greenhouse gas emissions and 17.6 percent of all anthropogenic greenhouse gas emissions (Rogner et al. 2007). To realize energy conservation and emissions reduction, reducing building energy demand and improving energy efficiency are the key points.

Architecture design considerations at conceptual design stage have essential impact on building energy demand and consumption. In principle, three factors could play equally important roles in reducing energy demand: behavioural adjustments, technological advancement and design considerations. For the overall energy consumption in non-domestic buildings, Baker and Steemers (2000) suggest that these

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three factors together could account for variations in energy demand by a factor of 10 (2, 2, and 2.5, respectively). Recent years, to reduce building energy demand, passive building design has received attention again. Generally, passive building design makes use of nature energy, such as sunlight, wind, rather than conventional energy resources. Passive building design methods mainly include the following aspects: 1. Orientation; 2. Building shape; 3. Building insulation; 4. Ratio of window-to-wall; 5. Building shade; 6. Natural ventilation.

At conceptual design stage, building shape coefficient is an important consideration in energy saving. Moreover, according to Ratti et al.(2005), an important indicator, the ratio of passive-to-non-passive (passive volume ratio), also should be taken into account. This concept is made explicit with the definition of passive and non-passive zones/volume, which quantifies the potential of each part of a building to use daylight, sunlight and natural ventilation. By a simple rule of thumb, based on empirical observations, all perimeter parts of buildings lying within 6 m of the facade, or twice the ceiling height, are classified passive, while all the other zones are considered non-passive (Fig 1).

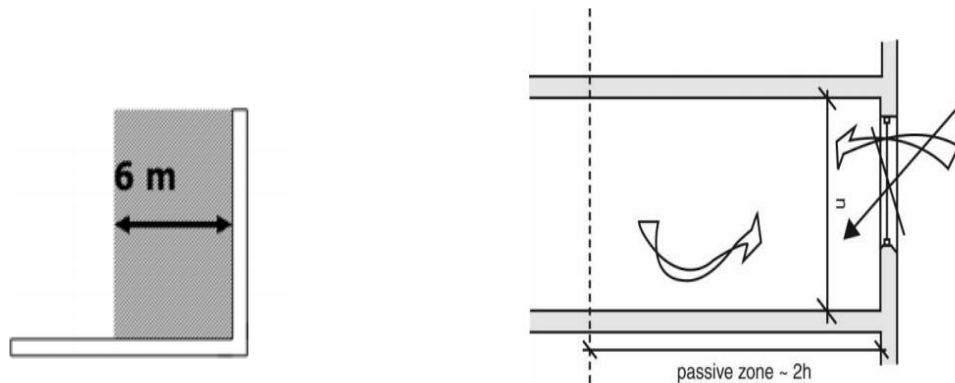


Fig 1. Parts of a building that can be naturally lit and ventilated are called 'passive zones'. Source: Ratti et al,(2005)

In addition, of all energy used in buildings, energy for space heating/cooling and lighting represents the greatest demand. However, most studies about building shape focus on the energy demand of space heating/cooling, and overlook the energy end-use of lighting (Salat S. et al. 2009).

This paper is based on the concept of passive volume ratio and assumed to fully use of passive energy, natural ventilation and daylighting, in the passive zone of a building. Taking a group of office buildings in Shanghai as an example, with the help of the dynamic simulation software DeST-c, the relationship between the building shape coefficient and building energy consumption is studied.

RESEARCH METHODS

The two common office building style is slab type and high-rise tower type shown in Fig 2 and Fig3 (Luo Guozhi. 2012).

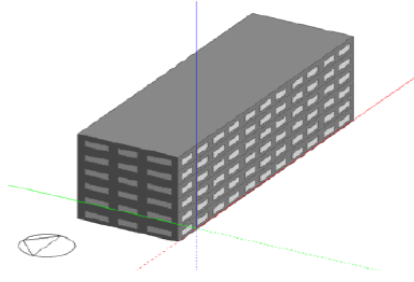


Fig 2. Slab-building

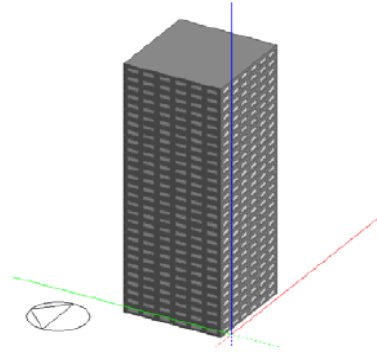


Fig 3. High-rise tower building

In this study, slab buildings and high-rise tower buildings are modeled by dynamic energy simulation software DeST-c, which is specialized for designing central air-conditioning system in commercial building. With the natural room temperature for the bridge, the software combines buildings and environmental control systems, inherits and expands the superiority of the DOE and the ESP-r on the architectural description and simulation analysis. And the results are reasonable and credible (Tinghua University DeST Development Team. 2005). It can calculate the building heating and cooling load. Air-conditioning consumption can be calculated considering the effect of natural ventilation. Lighting consumption considering daylighting can also be calculated. The software can calculate the reduction of lighting energy consumption via the accumulative hours which meet illumination standard using daylighting. The variables except shape coefficient such as orientation, window-wall ratio, insulation, climatic conditions, social preferences, schedule and HVAC form and efficiency are assumed constant. Different models corresponding with different shape coefficient and passive volume ratio are calculated. The formula (1) and (2) show the definition of building shape coefficient and passive volume ratio respectively. Due to the constant reference scenario, this performance data can be comparatively analyzed. Through the simulation results of heating/cooling load per building area, air-conditioning consumption per building area and lighting consumption per building area, the relationship between the building shape coefficient and building energy consumption is conducted.

$$\text{Building shape coefficient}(C) = \frac{\text{Building exterior area}}{\text{Built Volume}} \quad (1)$$

$$\text{Passive volume ratio} = \frac{\text{Passive Volume}}{\text{Built Volume}} \quad (2)$$

SIMULATION MODEL

Make eight slab office-building models and eight high-rise tower office building models. The slab type buildings are six floors, and high-rise tower buildings are twelve floors. The height of floor to floor is four meters. The area 6m from the

exterior wall is set as passive zone. The other building parameters are shown in the Table 1 and Table 2.

Table 1. Slab Building Model Parameters

Case	Building length (m)	Building width (m)	Building exterior area (m ²)	Building volume (m ³)	Building area (m ²)	Building shape coefficient (m ⁻¹)	Passive volume ratio
1	15	12	1476	4320	1080	0.342	1
2	30	12	2376	8640	2160	0.275	1
3	60	12	4176	17280	4320	0.242	1
4	90	12	5976	25920	6480	0.231	1
5	120	12	7776	34560	8640	0.225	1
6	60	40	7200	57600	14400	0.125	0.44
7	90	40	9840	86400	21600	0.114	0.39
8	120	40	12480	115200	28800	0.108	0.37

Table 2. High-rise Tower Building Model Parameters

Case	Building length (m)	Building width (m)	Building exterior area(m ²)	Building volume (m ³)	Building area (m ²)	Building shape coefficient (m ⁻¹)	Passive volume ratio
9	12	12	2448	6912	1728	0.354	1
10	24	12	3744	13824	3456	0.271	1
11	24	24	5184	27648	6912	0.188	0.75
12	36	24	6624	41472	10368	0.160	0.67
13	36	36	8208	62208	15552	0.132	0.56
14	48	36	9792	82944	20736	0.118	0.50
15	48	48	11520	110592	27648	0.104	0.44
16	60	60	15120	172800	43200	0.088	0.36

(1) Meteorological parameters

In this study, Shanghai is selected as typical zone in hot-summer-and-cold-winter area in China. Shanghai meteorological parameters are set in accordance with the database come with DeST-c.

(2) Building envelope

Building orientation is north. Take building envelope structure which comes with DeST compared with the actual construction condition and Design standard for energy efficiency in public buildings of Shanghai, then choose the closer parameters: the heat transfer coefficient of external wall is 0.7126W/(m² K), the heat transfer coefficient of proof is 0.437W/(m² K), the heat transfer coefficient of external window is 2.2W/(m² K), and the shading coefficient of external window is 0.3. The ratio of window to wall is 0.5.

(3) Internal loads

The thermal disturbance of people, lighting and equipment of office buildings are set in accordance with Design standard for energy efficiency in public buildings of Shanghai. The minimum illumination of room is set as 300Lx. Specific parameters are shown in the Table 3:

Table 3. Thermal disturbance parameter of various functions rooms

Occupant density (person/m ²)	Per fresh air capacity (m ³ /h)	Lighting load (w/m ²)	Equipment load (w/m ²)
0.2	30	11	20

(4) Air-conditioning system

The air condition temperature in summer is designed for 24~26°C, while in winter it is designed for 20~22°C. The relative humidity is designed for 50%~60%. For natural ventilation, the maximum temperature is 26°C, the minimum temperature is 18°C, and the maximum relative humidity is 60%. All rooms are used fan-coil plus fresh air system. Cold source is centrifugal chiller, and its COP is 5.0. Heat source is gas-fired hot water boiler, its efficiency is 95%. The schedule of people, lighting and equipment is shown in Fig 4.

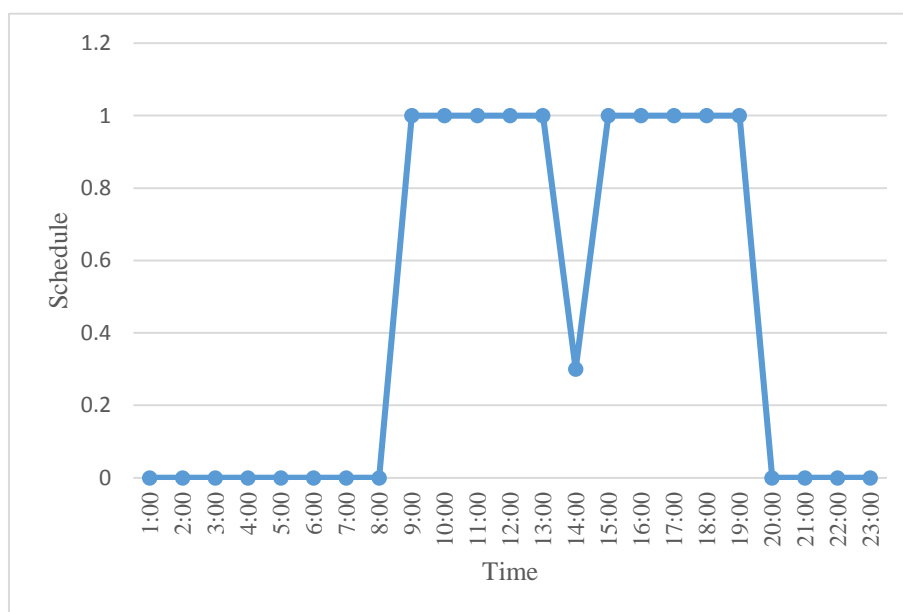


Fig 4. The schedule of people, lighting and equipment

RESULTS AND DISCUSSION

Heating load per building area and cooling load per building area of slab buildings are shown in Fig5. Air-conditioning consumption per building area, lighting consumption per building area and the sum of AC consumption and lighting consumption per building area of slab buildings are shown in Fig 6. Heating load per building area and cooling load per building area of high-rise tower buildings are shown in Fig7. Air-conditioning consumption per building area, lighting consumption per building area and the sum of AC consumption and lighting consumption per building area of

high-rise tower buildings are shown in Fig8.

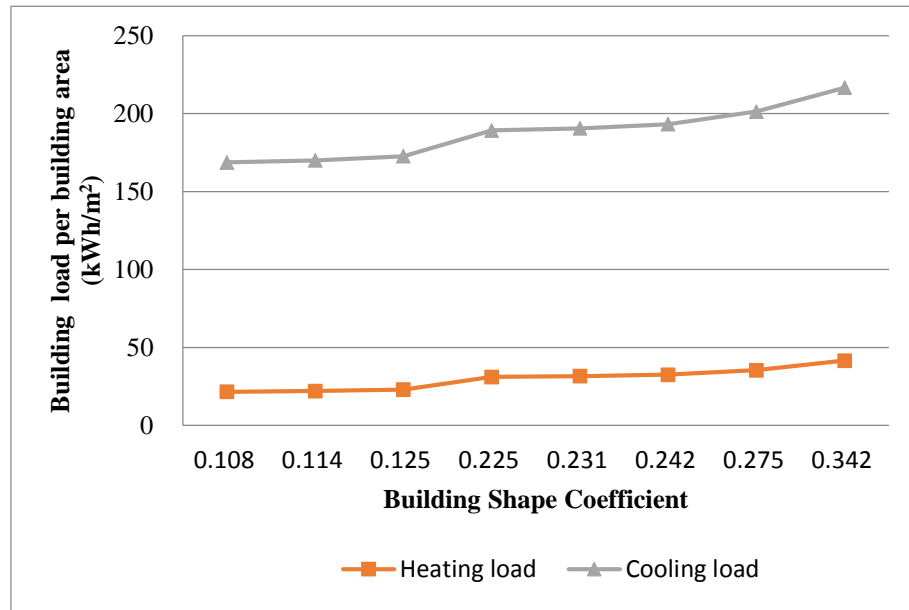


Fig 5. Building load per building area of slab buildings

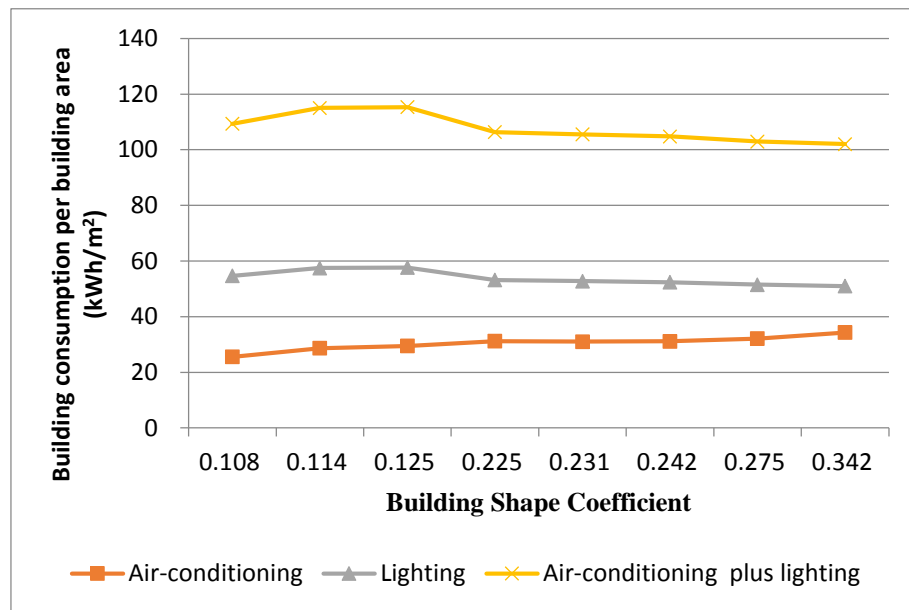


Fig6. Building consumption per building area of slab buildings

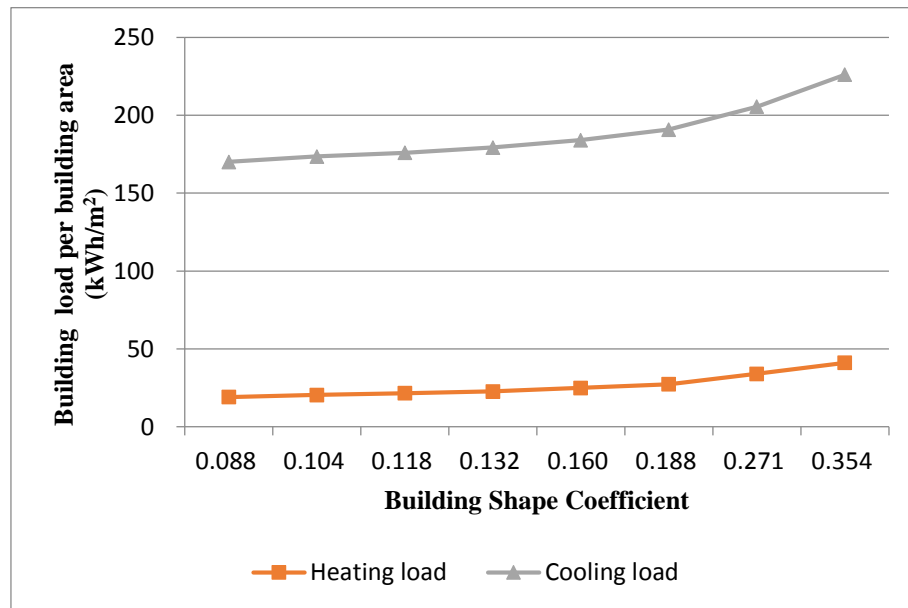


Fig7. Building load per building area of high-rise tower buildings

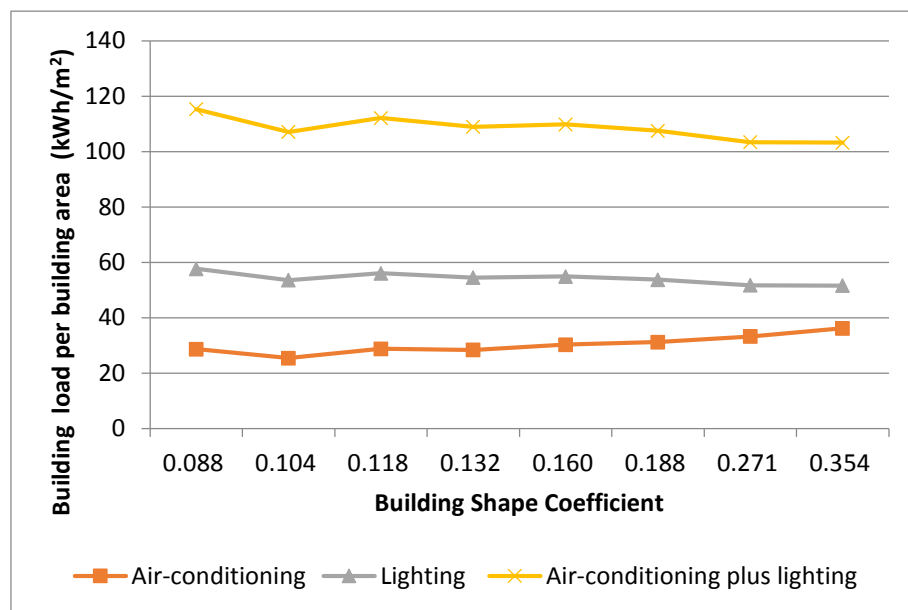


Fig 8. Building consumption per building area of high-rise tower buildings

Due to the constant reference scenario, these simulation data can be comparatively analyzed. Both slab office building and high-rise tower office building, the bigger the building shape coefficient, the bigger heating/cooling load. So air-conditioning consumption per building area is increasing with the building shape coefficient. However, with the increasing shape coefficient, lighting consumption per building area and the sum consumption of air-conditioning and lighting is decreasing. This is because, the bigger shape coefficient, the bigger passive volume ratio, the more potential to use passive energy, such as natural ventilation and daylighting, decreasing building total energy demand.

CONCLUSION

Building Shape coefficient has been a good indicator to building load. Minimizing heat losses requires minimization building shape coefficient; but this implies a reduction of the building envelope exposed to the outside environment, thus reducing the availability of daylight and sunlight and increasing energy consumption for artificial lighting, natural ventilation, etc. Building air-conditioning energy demand is only a part of building total energy demand. Considering the passive design technologies and the total energy consumption, the passive volume ratio is a good index at the architecture conceptual design period. When the passive volume ratio is less than 1, it is increasing with the building shape coefficient. So, to apply passive design technologies in hot-summer-and-cold-winter area in China, architectures can select the bigger shape coefficient for bigger passive volume ratio to reduce building energy demand.

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