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Ultra-Low Energy Consumption in Upper Floors of Skyscrapers
摩天大楼高区超低建筑能耗的实现

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Abstract

Based on the simulation of the outdoor Climate Vertical Distribution in Dalian, this paper analyzes the regularities of gradient distribution from ground to 1000 meter in terms of temperature, humidity, and wind speed. In summer, the climate of upper floors can effectively reduce the building's energy consumption.

Through the building energy consumption calculation, this paper can analyze the features of high floor air conditioning(A/C) load. The efficient measures can be used in the fields of building envelopes, sunshade, fresh air. Through renewable energy sources and high efficiency air conditioning systems, it is possible to achieve ultra-low energy consumption, low carbon in upper floors of skyscrapers.

Keywords: Skyscraper, upper floors, ultra-low energy consumption, low carbon

摘要

通过模拟大连地区室外气候垂直分布，分析出地面至千米高空大气的温度、湿度、风速存在一定的梯度分布规律，特别在夏季高区可以出现较为适宜的节能型气候区。

通过建筑能耗计算，可以分析高区建筑的负荷特点，提出围护结构、遮阳、新风的有效优化方案，并采用高效的能源系统，从而实现摩天大楼高区建筑的超低能耗和低碳目标。

关键词: 摩天大楼，高区，超低能耗，低碳

Introduction

With the fast development of the economy and technology, the number of high-rise buildings and super high-rise buildings (over 600 meters high) grows rapidly. The height record of the tallest building in the world is also changing often. The Burj Khalifa, built in 2010, reached 828 meters high, while Kingdom Tower in Jeddah and Qingdao Sky II are all designed to be over 1000 meters.

Compared to traditional buildings, super high-rise buildings have massive volume and large vertical heights. In this age of promoting green buildings and energy savings, the problem of energy consumption in high-rise buildings causes wide public concern. People began to doubt the energy consumption and the comfort at the top floor of super high-rise buildings, especially higher than 600 meters.

Through analysis of the outside air vertical distribution and air-conditioning load distribution of a kilometer level super high-rise building in Dalian, this paper presents the technology of reducing energy consumption in upper floor areas of high-rise buildings.

引言

随着经济和科学技术的高速发展，超高层建筑、甚至超过600米的巨高层建筑数量增长迅速，世界第一高楼的高度也不断被刷新，2010年建成的哈里法塔高度已达828米，正在策划的吉达王国大厦和青岛天空二号的设计高度已超过1000米 。

与普通建筑相比，超高层建筑体量大，竖向高度大。在倡导绿色节能的今天，对于超高层建筑的建筑能耗情况越来越引起大家的关注，并对600米以上高区部分的建筑耗能和舒适性提出质疑。

本文通过研究大连千米级摩天大楼室外气候垂直分布规律和建筑负荷分布规律，探寻了摩天大楼高区建筑的低能耗技术实现。

千米级摩天大楼室外气候垂直分布

摩天大楼室外气候主要参数为室外空气的温度、湿度和风速。对于近地面的气象参数，比较容易从气象部门获得相应数据，研究机构也作了大量的气象统计，并为一些城市编制了典型全年气象资料。对于高度方向的室外垂直气候分布，在气象学中属于小范围领域，而且受地势地貌等影响很大，实际监测也比较困难，因此还没有通用的数据可以利用。

The Vertical Distribution of the Outside Air for Kilometer High Skyscraper

The major parameters of the outside air for a skyscraper are outside air temperature, humidity, and wind speed. The ground level outside air parameters can be acquired easily from the meteorological department. Meteorological Research institutions have conducted many statistical studies and compiled typical meteorological data for a number of cities. The vertical distribution of the outdoor climate in height direction belongs to a small field of meteorology. It can be greatly affected by local terrain, topography, etc. It is also relatively difficult to measure these parameters, so usable data is generally not available.

In Dalian, for example, mesoscale meteorological model WRF was used to calculate the climate parameter distribution along vertical direction under different seasons. The temperature and humidity distribution in January and August are shown in Figure 1 ~ Figure 4.

As shown in Figure 1 and Figure 2, the air temperature in Dalian reduces linearly with the height from the ground level. The relative humidity of the air increases with the height, but peaks at about 1000 meters. Over the peak point, the relative humidity of the air gradually reduces with the height increasing. At 1000 meters above the ground, the outdoor air temperature is about 6 ˚C lower than the ground, while the relative humidity is about 20% higher than the ground. Due to the effects of ground radiation and sea breeze, air temperature and humidity near the ground is largely affected by the terrain and different types of ground radiation (Liu Yu-che, 2007). The air temperature changes significantly at different hours during a day. Further away from the ground, the ground effect gradually decreases, and the influence of sea breezes plays the leading role. The temperature varies slightly with different hours. At heights of over 1000 meters, relative humidity of the air decreases gradually.

According to the calculation results, the pattern of the air relative humidity, temperature and wind velocity along the vertical direction are summarized and analyzed. The simplified formulas(1), (2), (3) and (4), applicable to the range of height up to 1000 meters, can describe how the temperature, relative humidity vary with height in both summer and winter. They are:

$$T_{x,1} = T_b - 0.0056x - 0.3149 \quad (R^2=0.96)$$

$$T_{x,8} = T_b - 0.0058x - 0.3837 \quad (R^2=0.96)$$

$$\varphi_{x,1} = 0.0239x + 5.6145 + \varphi_b \quad (R^2=0.94)$$

$$\varphi_{x,8} = 0.0127x + 3.6514 + \varphi_b \quad (R^2=0.92)$$

Where T_b is the air temperature (°C) in the distance 10 meters from the ground.

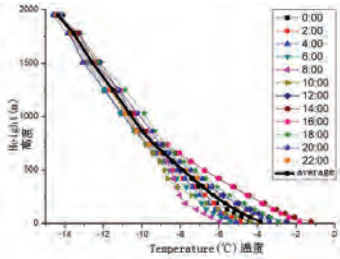
T_x is the air temperature (°C) in the distance x meters from the ground.

φ_b is the relative humidity(%) in the distance 10 meters from the ground.

φ_x is the relative humidity(%) in the distance x meters from the ground.

Subscript 1, 8 is the generation month.

x is the height(m).



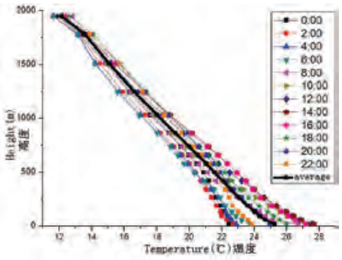
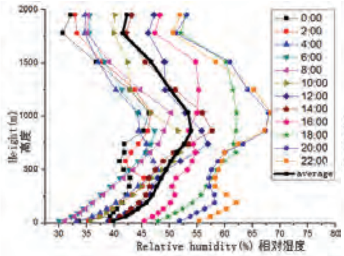


Fig 1. (Left) The hourly average temperature change with height in January in Dalian (Source: Man Xiao-xin)
图1. (左) 大连一月逐时平均温度随高度变化 (出自: 满孝新)
Fig 2. (Right) The hourly average temperature change with height in August in Dalian (Source: Man Xiao-xin)
图2. (右) 大连八月逐时平均温度随高度变化 (出自: 满孝新)



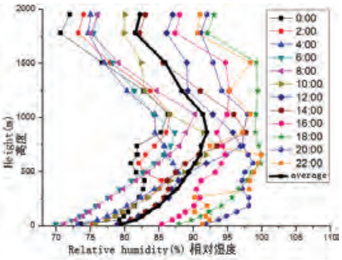


Fig 3. (Left) The hourly average relative humidity change with height in January in Dalian (Source: Man Xiao-xin)
图3. (左) 大连一月逐时平均相对湿度随高度变化 (出自: 满孝新)
Fig 4. (Right) The hourly average relative humidity change with height in August in Dalian (Source: Man Xiao-xin)
图4. (右) 大连八月逐时平均相对湿度随高度变化 (出自: 满孝新)

以大连地区为例，利用中尺度气象模式WRF，计算了该地区不同季节垂直高度的气候参数分布，其中一月和八月的气温湿度分布请见图1~图4。

从图1与图2中可以看出，大连地区的大气温度随着距离地面高度的升高呈现线性降低的规律; 空气相对湿度随着高度升高逐渐变大，在高度1000米附近相对湿度出现峰值，但随着高度的升高，空气的相对湿度又逐渐降低。该地区千米高度的室外空气温度比地面降低约6℃，相对湿度比地面高20%左右。由于受地面辐射和海陆风的双重作用，温湿度接近地面处由于地形、种类等不同，地面辐射影响相对较大 (刘玉彻，2007)，不同时间段温度值变动较大; 越远离地面，地面影响逐渐减弱，海陆风的影响起主导作用，不同时刻间温度值差异变小，超过千米高度空气的相对湿度出现了逐渐降低的变化。

根据计算结果整理分析了该地区空气相对湿度、温度和风速在垂直方向上的变化规律，并拟合出了1000米高度范围内夏季和冬季温度、相对湿度随高度变化的简化关系式 (1) (2) (3) (4)，即:

$$T_{x,1} = T_b - 0.0056x - 0.3149 \quad (R^2=0.96)$$

$$T_{x,8} = T_b - 0.0058x - 0.3837 \quad (R^2=0.96)$$

$$\varphi_{x,1} = 0.0239x + 5.6145 + \varphi_b \quad (R^2=0.94)$$

$$\varphi_{x,8} = 0.0127x + 3.6514 + \varphi_b \quad (R^2=0.92)$$

式中 T_b 为距离地面10米处的空气温度，℃; T_x 为夏季距离地面x米处的空气温度，℃， φ_b 为距离地面10米处的空气相对湿度，%; φ_x 为距离地面x米处的空气相对湿度，%，下标1, 8分别代对应月份; x为距离地面高度，m。

根据冬季典型月一月和夏季典型月八月空气温湿度沿垂直方向的变化规律，对《民用建筑供暖通风与空气调节设计规范》(GB 50736-2012) 中大连地区冬季和夏季的空气计算干球温度和相对湿

According to "Design code for heating ventilation and air conditioning of civil buildings" (GB 50736-2012), based on the vertical variation of air temperature and humidity in a typical winter month of January and a typical summer month of August, the winter and summer air dry-bulb temperature and relative humidity in Dalian area are corrected to account for height. The corrected value of the dry-bulb temperature and relative humidity are shown in Table 1.

The outdoor air temperature, humidity, and enthalpy changes significantly with the increase of the height. The ground level meteorological data and the psychometric chart are no longer applicable for load calculations for high-floor HVAC systems. Hence the parameters need to be corrected to account for height factor.

As shown in Table 1 and Table 2, when the ground level is in hot summer condition, at 500 meters or higher, it is as cool as in spring and autumn. That means, in summer, the upper floors of skyscrapers are in favorable condition, which consumes less energy, where outdoor air enthalpy is 14kJ/kg lower than on the ground.

The vertical distribution of outdoor wind speed generally increases along thewith height within complex patterns. According to the calculated results, in August in Dalian, while the hourly average wind speed is 5 m/s at ground level, it is about 11 m/s at 500 meters height, and about 10 m/s at 1000 meters height.

The main effect of wind speed on building energy consumption is reflected in the convective heat transfer coefficient of the outer surface. However, due to the relatively small thermal resistance formed by the convective heat transfer coefficient of the outer surface, the impact of the wind speed on the thermal resistance or heat transfer coefficient of the building envelope is relatively small, about 2-3%. The effect of wind speed on the building cooling load sometime can even be negligible.

The Building Air Conditioning Load

For a typical super high-rise building, the upper floors are mostly residential apartments and hotels. This paper takes an apartment as an example to study the air conditioning load characteristics in the upper floors of buildings.

The calculation parameters are: the heat transfer coefficient of exterior walls is 0.6W/ (m^2•K), the heat transfer coefficient of glass curtain wall is 2.8 W/ (m^2•K), the shading coefficient is 0.5, the window/wall ratio is 0.7. The indoor design temperature in summer is 26 °C, the Relative humidity is 60%. The indoor design temperature in winter is 20 °C, the relative humidity is 40%.The outdoor air rate is 50m^3/h per person.

According to the meteorological parameters, the air conditioning load of different heights are calculated, as shown in figure 5.

As shown in the figures, the changes of outside air condition due to height changes can significantly affect the cooling load of skyscraper. The summer peak load hours vary with the room orientations. The hourly cooling load gradually reduces as the height increases, and the lowest is at 1000 meters height. The hourly cooling load reduces by about 0.8W/m^2 when the building height increases every 100 meters.

The ground level room cooling load index is 73.4W/m^2 (East), 57.6W/m^2 (South),74.7W/m^2 (West), and 45.8W/m^2 (North); the room cooling load index at 1000 meters above ground is 65.7W/m^2 (East), 49.8W/m^2

	Height 高度	Height of ground 距地面高度	300m	500m	800m	1000m
summer 夏季	Dry bulb temperature(°C) 干球温度	29	27	26	24	23
	Wet bulb temperature(°C) 湿球温度	24.7	23.8	23.15	21.8	21.1
	Relative humidity (%) 相对湿度	71	77	79	83	85
	Moisture content(g/kg) 含湿量	18.32	17.67	17.07	15.89	15.31
	The value of enthalpy(kJ/kg) 焓值	76.08	72.32	69.76	64.67	62.15
	Dew point temperature(°C) 露点温度	23.09	22.5	21.95	20.8	20.2
winter 冬季	Dry bulb temperature(°C) 干球温度	-9.8	-11.8	-13	-14.6	-15.7
	Wet bulb temperature(°C) 湿球温度	-11.1	-12.65	-13.65	-15	-16
	Relative humidity (%) 相对湿度	56	68	73	80	85
	Moisture content(g/kg) 含湿量	0.91	0.92	0.89	0.84	0.81

Table 1. The corrected value of meteorological parameters at different heights in summer and in winter (Source: Man Xiao-xin)
表1. 夏季不同高度室外气象参数修正值 (出自: 满孝新)

Height 高度	Height of ground 距地面高度	300m	500m	800m	1000m
Dry bulb temperature(°C) 干球温度	-9.8	-11.8	-13	-14.6	-15.7
Wet bulb temperature(°C) 湿球温度	-11.1	-12.65	-13.65	-15	-16
Relative humidity (%) 相对湿度	56	68	73	80	85
Moisture content(g/kg) 含湿量	0.91	0.92	0.89	0.84	0.81

Table 2. The correctional value of different meteorological parameters with height in winter
表2. 冬季不同高度室外气象参数修正值 (出自: 满孝新)

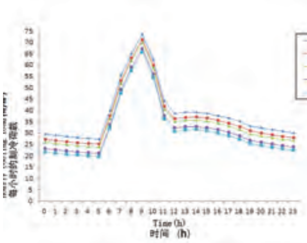
度进行高度修正，得到不同高度空气计算干球温度和相对湿度修正值 (请见表1) 。

随着建筑高度的增加，室外空气的温度、湿度和焓值已发生较大变化，在进行空调负荷计算时，地面的气象资料和焓湿图不再适用，需要采用高度修正的计算参数。

从表1与表2可以看出，在地面为炎热的夏季时节，位于500米高度以上的室外气候已经变为宜人的春秋季节，也就是说，摩天大楼的高区部分在夏季处在了较为适宜的节能型气候区，室外空气的焓相差14kJ/kg。

室外风速的垂直分布基本是随着高度的增加而加大，规律较为复杂。根据计算，大连八月逐时平均风速地面附近为5m/s时，500米高度约为11m/s，1000米高度约为10m/s。

风速对建筑能耗的影响主要是其对外表面对流换热系数的影响，但由于外表面对流换热系数形成的热阻比较小，所以对围护结构的热阻或传热系数影响较小，大约在2%左右，所以可以忽略风速对建筑冷负荷的影响。



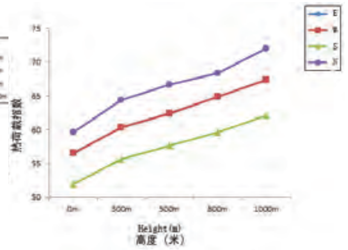


Fig 5. (Left) The hourly cooling load per unit area of the east room at the different heights in summer (Source: Man Xiao-xin)

图5. (左) 夏季不同高度东向房间逐时单位面积冷负荷 (出自: 满孝新)

Fig 6. (Right) The heating load of the room at different heights in winter (Source: Man Xiao-xin)

图6. (右) 冬季不同高度房间供热指标 (出自: 满孝新)

(South), 67W/m^2 (West), and 38W/m^2 (North), which are about 10.5% (East),13.5% (South), 10.3% (West), and 17% (North) less compared to the rooms on the ground.

Figure 6 shows the room heating load indexes at various heights. The heating loads in the rooms facing east and west are equal. The heating load increases when the height increases. The maximum heating load occurs at the height of 1000 meters above the ground. The heating load increases about 1 W/m^2 when the height increases every 100 meters.

As shown in Figure 10, the ground level room heating load indexes are 56.5W/m^2 (East, West), 52.0W/m^2 (South), and 59.6W/m^2 (North); at 1000 meters above the ground, the room heating load indexes are 67.4 W/m^2 (East, West), 62.1 W/m^2 (South), and 72 W/m^2 (North), which are about 19.3% (East, West), 19.4% (South), and 20.8% (North) more compared to the rooms at ground level.

As shown in Figure 7 and 8, the building envelope load forms the biggest component in the room load. Along with the increase of height, the percentage of the building envelope load is also increasing. Optimizing the building envelope is the key to reducing the total load and building energy consumption.

Optimization of the Building Envelope

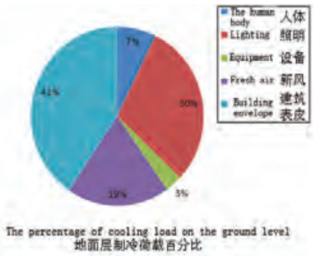
Assuming that the building envelop is improved in the following ways:

- Heat transfer coefficient of the external wall is 0.3W/(M^2•K)
- Double glazing breathing curtain wall is adopted, and the heat transfer coefficient of glass is 0.8 W/(M^2 •K)
- By using operable sun shade, the shading coefficient in the summer is 0.2,and 1 in winter.

The load calculation results are shown as Figure 9 and 10.

The room cooling load index at 1000 meters are 33.3W/m^2 (East), 28.6W/m^2 (South), 33.6W/m^2 (West), and 25.2W/m^2 (North). The cooling load index decreases by49.3 % (East), 42.6% (South), 50% (West), and 33.7% (North) after the insulation improved.

As shown, the room heating load index at the height of 1000 meters are 22.8W/m^2 (East, West), 21.6W/m^2 (South), 24.8W/m^2 (North). The room heating load index decreases 66.2% (East, West), 65.2% (South), and 65.6% (North) after the insulation improved. Energy savings is more apparent in heating load than in cooling load.



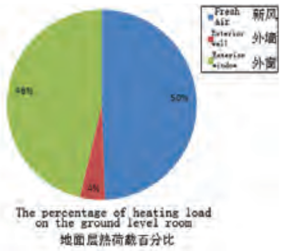


Fig 7. (Left) The percentage of cooling load on at ground level (Source: Man Xiao-xin)

图7. (左) 地面高度房间各项冷负荷所占比例分布 (出自: 满孝新)

Fig 8. (Right) The percentage of heating load on the ground level room (Source: Man Xiao-xin)

图8. (右) 地面高度房间各项热负荷所占比例分布 (出自: 满孝新)

建筑空调负荷

从目前的巨高层建筑来看，高区部分的功能大部分为公寓或住宅、酒店。本文以公寓为算例探讨高区建筑空调负荷的特点。

计算参数如下: 外墙传热系数0.6W/(m^2•K)， 玻璃幕墙传热系数2.8 W/(m^2•K)，遮挡系数0.5，窗墙比0.7; 夏季室内温度26℃、相对湿度60%，冬季室内温度20℃、相对湿度40%，每人新风量50m^3/h。

按照不同高度的室外气象参数，分别计算了不同高度的空调负荷 (请见图5) 。

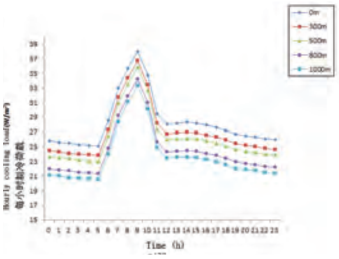
可以看出，室外垂直气象参数的变化对摩天大楼的负荷影响很大，不同朝向夏季最大逐时冷负荷出现的时刻不同，逐时冷负荷随着房间高度的升高而逐渐减小，1000米处房间冷负荷最小。建筑高度每升高100米，其逐时冷负荷降低约0.8W/m^2。

可以看出，在地面处房间的冷负荷指标为73.4W/m^2 (东) 、57.6W/m^2 (南) 、74.7W/m^2 (西) 、45.8W/m^2 (北) ; 在1000米处房间的冷负荷指标为65.7W/m^2 (东) 、49.8W/m^2 (南) 、67W/m^2 (西) 、38W/m^2 (北) ，与地面房间相比减少了10.5% (东) 、13.5% (南) 、10.3% (西) 17% (北) 。

图6给出了不同高度房间冬季热负荷指标 (请见图6) ，东西方向热负荷相等，随着高度的升高，热负荷逐渐增加，在1000米处房间热负荷最大，建筑高度每升高100米，热负荷约增加1W/m^2。

从图10可以看出，在地面处房间的热负荷指标为56.5W/m^2 (东、西) 、52.0W/m^2 (南) 、59.6W/m^2 (北) ; 在1000米处房间的热负荷指标为67.4W/m^2 (东、西) 、62.1W/m^2 (南) 、72W/m^2 (北) ，与地面房间相比增加了19.3% (东、西) 、19.4% (南) 、20.8% (北) 。

从各项负荷的比例分布 (请见图7,8) ，可以看出，围护结构形成的负荷在房间负荷中的比例最大，随着高度的增加，围护结构形成负荷的比例也会增加。因此围护结构的优化对减小负荷、降低建



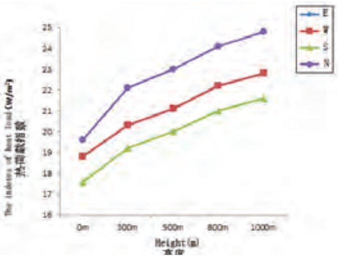


Fig 9. (Left) The hourly cooling load per unit area of the east room at different heights in summer (After optimization) (Source: Man Xiao-xin)

图9. (左) 夏季不同高度东向房间逐时单位面积冷负荷(优化后) (出自: 满孝新)

Fig 10. (Right) The hourly cooling load per unit area at different heights in winter (Source: Man Xiao-xin)

图10. (右) 冬季不同高度房间单位面积热负荷 (出自: 满孝新)

Energy Saving Optimization of Outside Air Intakes

The outside air temperature in the Dalian area decreases when the height from the ground increases. Similarly, the outside air enthalpy in summer decreases with height. At the height of 1000 meters, the enthalpy of outdoor air is about 14KJ/Kg less than that at the ground level. The outside air intake cooling load is only 17.6% of that at ground level, reduced by 82.4%. Therefore the energy consumption of the air conditioning system is significantly reduced. Except for extraordinary conditions, the outside air enthalpy at 1000 meter above ground is lower than the indoor air enthalpy. The outside air can be directly introduced to cool the rooms without using the chilling system, hence reduce energy consumption.

In winters, however, the decrease of outside air temperature due to the increase of the height will increase the room heating load. If necessary, the heat recovery device can be used to reclaim the heat from the exhaust air. The heat recovery device can be sensible heat exchanger or total heat exchanger between outside air and exhaust air. The allocation of room heating load is shown as Figure 11, which is based on the heat recovery efficiency of 70%.

As shown in Figure 11, when the heat recovery efficiency is 70%, the room heating load indexes at the height of 1000 meters are 12W/m^2 (East, West), 10.8W/m^2 (South), 12.7W/m^2 (North). And the heating energy consumption is reduced by 35.5% (East, West), 37.5% (South), 32.6% (North) after installing heat recovery devices, with significant energy savings.

Analysis of Ultra-Low Energy Consumption

By improving the insulation of the building envelope, utilizing operable shading system, and installing heat recovery system, the room cooling and heating energy consumption are significantly reduced. This is especially true in the upper floors where the average summer cooling load index is about 30 W/m^2, and the average heating load index is about 11.9 W/m^2, which can be categorized as typical low energy consumption.

In summer, the outdoor air temperature at 500 meters is equal to the indoor design temperature. That means, there is no cooling load caused by temperature differential heat transfer through the building envelope. The outdoor temperature at 1000 meters is lower than indoor design temperature by about 3˚C, which helps remove the indoor heat and reduce the cooling load. In suitable seasons, increasing outside air intake can reduce cooling energy consumption. In the upper floors of a high-rise building, high efficiency evaporative cooling technology can be used as the cooling source to greatly reduce the electricity consumption in the air conditioning system.

In the winter, thermal storage floor technology can be used. The solar energy accumulated during the day time can be released to maintain the indoor temperature during the night, which can further reduce the building energy consumption.

It is highly possible to achieve ultra-low energy demand in skyscrapers by combing the above energy efficiency measures with even more advanced technologies such as photo-voltaic curtain wall, wind power and other renewable energy sources.

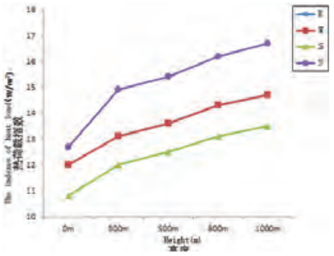


Fig 11. The heating load of the room at the different heights in winter (wWith 70% of the heat recovery rate) (Source: Man Xiao-xin)
图11.冬季不同高度房间单位面积热负荷 (热回收效率70%) (出自: 满孝新)

筑能耗是至关重要的环节。

围护结构优化节能

对围护结构进行优化，按照

增加外墙保温措施，传热系数0.3W/(m^2•K);

采用双层呼吸式玻璃幕墙，传热系数0.8 W/(m^2•K);

采用可变遮阳，夏季遮阳系数为0.2，冬季为1。

负荷计算结果 (请见图9,10) 。

可以看出，在1000米处房间的冷负荷指标为33.3W/m^2 (东) 、28.6W/m^2 (南) 、33.6W/m^2 (西) 、25.2W/m^2 (北) ，与加强保温前相比冷负荷指标减少了49.3% (东) 、42.6% (南) 、50% (西) 、33.7% (北) 。

可以看出，在1000米处房间的热负荷指标为22.8W/m^2 (东、西) 、21.6W/m^2 (南) 、24.8W/m^2 (北) ，与加强保温前相比热负荷指标减少了66.2% (东、西) 、65.2% (南) 、65.6% (北) ，热负荷的节能率比冷负荷效果更明显。

新风系统优化节能

大连地区的大气温度随着距离地面高度的升高逐步减小，夏季室外空气的焓值也随着减小，室外空气计算状态点焓值在1000米处比地面高度的焓值减小了约14KJ/Kg，新风冷负荷仅为地面新风的17.6%，减少了82.4%，使空调系统能耗大幅减少。因此，非极端条件下，千米高度室外新风的焓值应该低于室内空气的焓值，可以直接利用室外新风，消除室内余热，减少空调系统的开启。

但在冬季，大气温度随着高度的升高降低，必然引起房间热负荷增加、能耗加大。根据需要，新风系统可设置排风热回收器，让新风与排风在热回收器中进行显热或全热交换，把排风中的热量提取出来加热新风。按照热回收器的热回收效率为70%进行计算，房间热负荷分布请见图11。

从图11可以看出，当热回收效率为70%时，在1000米处房间的热负荷指标为12W/m^2 (东、西) 、10.8W/m^2 (南) 、12.7W/m^2 (北) ，与采用热回收前相比热负荷指标减少了35.5% (东、西) 、37.5% (南) 、32.6% (北) ，节能效果显著。

超低能耗分析

通过加强围护结构保温性能、采用可变遮阳系统、设置排风热回收系统，可以看到，房间的空调冷负荷指标和热负荷指标大大降

Conclusion

1. The vertical variation of the outside air conditions on sky scraper have significant impacts on the HVAC loads at different heights.
2. The cooling load of skyscraper reduces significantly along with the height increased. It is easier for skyscrapers in tropical and subtropical areas to achieve low energy consumption.
3. Based on the load characteristics of the upper floors of skyscrapers, improving the building envelope, utilizing operable shading system, optimizing the outside air intake, and installing high efficiency energy systems can achieve ultra-low energy consumption, low or even zero carbon emission.

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低。特别是在高区的夏季平均计算冷负荷指标约30W/m^2，冬季平均计算热负荷指标约11.9W/m^2，属于典型的低能耗建筑。

在夏季，在500米处室外气温已经与室内设计温度相等，也就是说，围护结构没有了温差传热冷负荷，1000米处室外气温比室内设计温度低3℃，开始帮助室内散热，减少空调冷负荷。在适宜的时节，直接采用室外新风即可消除室内余热。高区的气候环境，空调冷源可以采用高效的蒸发冷却空调技术，可大大减少空调系统的用电量。

冬季可采用蓄热地板等技术，积蓄白天进入室内的太阳能，晚上释放热量来维持室内温度，使得建筑能耗降到最小。

由于高区建筑的低能耗，配合高区建筑的太阳能幕墙发电、风能发电等可再生能源，完全有可能实现摩天大楼高区建筑的超低能耗。

结论

1. 摩天大楼的室外气候垂直分布直接影响不同高度的建筑空调负荷。
2. 摩天大楼的建筑冷负荷随着高度明显减小，建在热带、亚热带地区的摩天大楼更有利于节能。
3. 根据摩天大楼高区建筑的负荷特点，提出对围护结构、遮阳、新风采取有效的节能措施，配合高效的能源系统，完全可以实现摩天大楼高区建筑的超低能耗、低碳甚至零碳。

中建股份科技资助项目

(中国建筑千米级摩天大楼机电研究，CSCEC-2010-Z-01)

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