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# Advanced Supertall Building Design in Hot-Summer and Cold-Winter Climates

# 夏热冬冷地区超高层建筑气候适应性的先进设计

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## Abstract

Climate adaptive design is a prerequisite for designing sustainable tall buildings. With rapid globalization and urbanization, different kinds of techniques and technologies developed abroad are introduced and applied to tall buildings in a region featuring a hot-summer and a cold-winter climate. Is it appropriate and responsive in the region with this climate? This paper aims to investigate the advanced design techniques and technologies by studying the latest tall buildings in the hot-summer and cold-winter climate regions. It discusses the criteria for the advanced techniques and technologies based on the climate, and thenexplores the strategies and criteria used in supertall building design. Finally, prospective techniques and technologies are examined. The result can help the developers and designers to utilize the suitable techniques and technology for supertall buildings in this region at an early design stage.

**Keywords: Climate adaptive design, Hot-summer and cold-winter climate**

## 摘要

超高层建筑气候适应性设计是可持续建筑设计的首要问题。随着全球化与城市化进程的扩大，一些带有不同气候区域特征的设计理念与技术被应用于夏热冬冷地区的超高层建筑。而它们是否能适用于自身气候条件却是值得思考的。本文先通过对夏热冬冷气候和超高层建筑的微气候特征分析，形成设计策略；然后对这一地区数座最新设计的超高层建筑的气候适应性设计展开调研，总结适用于超高层建筑的理念和技术；最后对有前景的技术应用进行展望。本文将帮助发展商和设计师在夏热冬冷地区超高层建筑项目设计前期选择合适的理念与技术。

**关键词：气候适应性设计、夏热冬冷地区气候、超高层建筑、先进设计技艺**

## Introduction

Climate adaptive design is the essential approach for designing sustainable buildings. It promotes passive design strategies and makes the best use of local climate conditions, which in turn improves the built environment quality and reduces energy consumption. This kind of building design method has been used for a long time, and it has been improved by combining with modern technologies. Climate adaptive design has been successfully applied in architectural design, such as Yeang's bioclimatic skyscrapers, Piano's Tjibaou Cultural Center, Foster's Swiss Re and other notable examples.

Supertall buildings, defined as buildings higher than 300m by the CTBUH, are developing in the hot-summer and cold-winter climate region in China. The number of super tall buildings to be constructed in the next five years will be more than three fold of that in the last five years (see Figure 1). As this region is about 180 million $km^2$, is densely populated and economically active in China, it implies that the number of super tall buildings will rapidly increase in this region in the near future. However, the super tall building is still

## 介绍

可持续建筑是当代建筑发展的方向，而气候适应性设计是实现可持续建筑的基本方法。它倡导被动式设计策略和最大程度地利用当地气候条件，改善环境质量和减少能耗。这种设计方法有着悠久的历史记录，同时在当代建筑设计中与技术的结合不断完善。气候适应性已成为激发建筑创造性和展示建筑新地域性特征的一个源泉。这样的成功建筑案例枚不胜举，如杨经文的生态摩天大厦，皮亚诺的吉宝欧文化中心，福斯特的伦敦Swiss Re保险大厦等等。

超高层建筑 （CTBUH定义为高度超过300m的建筑）在中国夏热冬冷地区进入蓬勃发展阶段。 据CTBUH统计，这个地区在今后五年内落成的超高层建筑的数量将会是前五年数量的三倍多（见图1）。这个地区是中国范围大（约180平方公里）、人口稠密和经济活跃的区域，预示着超高层建筑在这个地区有迅速发展的潜力。而超高层建筑在这个区域仍是个全新的建筑类型，相应的经验积累少，无资料可查。如何做到超高层建筑适应当地气候是目前面临的问题。因为这个区域的气候特别：夏天酷热，冬天严寒，并且天气潮湿，年降雨量大；同时超高层建筑随着建筑高度的

a new type of building in this region. How to make a supertall building adaptive to the climate still needs examination. Supertall buildings have their own micro-climate as the building increases in height. As a consequence, it is necessary to do an in-depth study on the complicated climate condition around the supertall building and the climate adaptive design within this region.

This paper aims to develop some design and technique guidelines for the climate adaptive design of supertall buildings in the hot-summer and cold-winter climate region. It firstly analyzes the characteristics of the regional climate and microclimate of supertall buildings, and then proposes the climate adaptive design strategies. Consequently, the investigation of the local supertall buildings is carried out. Finally, the current and prospective design strategies and techniques are discussed.

## The hot-summer and cold-winter climate and related design strategies

Building design usually assumes the regional climate as the design conditions, but the supertall buildings have to consider both the regional climate and the microclimate around the buildings. The building design strategies need to be responsive to these characteristics.

### The Regional Climate

The characteristics of the regional climate are hot summer and cold winter with damp weather. This region has long, hot summers for 4 months a year. The only three so-called 'stove cities' in China are all in this region because they have more than 70 days in which the daily temperature is higher than 30°C with 80% relative humidity. It has a rainy season with high temperatures and humidity between late spring and early summer. In addition, the cold winter lasts for 4 months, in which the average daily temperature, among 5 consecutive days, is lower than 10°C. It has the lowest temperature in winter than any other region at the same latitude in the world.  Furthermore, the annual rainfall in this region is greater than 1000mm, approximately 60% of rainfall happening in the summer. Annual solar radiation is about 110–160W/m$^2$, and solar duration is 1000–2400h. The prevailing wind is north in winter and south in summer.

People in this region have summarized design strategies from their past experiences (MCPRC, 2005). For example, the building geometry is compact in order to reduce the shape coefficient; the ratio of window to wall cannot be larger than 0.7; external walls  and windows should have lower U values and windows should also consider the shading coefficient; natural ventilation is popularly used to decrease energy consumption and improve indoor environmental quality. The potential for natural ventilation in this region accounts for more than 150 days per year, including spring, autumn and the cool period in summer. The yard and green roof are used to make the building adaptive to climate. These design strategies have been widely used in local buildings, particularly in the low-rise buildings. However, these design strategies are not always suitable for supertall buildings in the same region.

### The Microclimate

The microclimate around supertall buildings is generated by the increasing height. As atmosphere is inhomogeneous, air temperature, wind speed, humidity and solar radiation are all in variation with increased altitude. The effects of altitude on these parameters are tiny and can be ignored in the low-rise buildings, but they cannot be neglected in the supertall buildings. These effects are mainly in air temperature, air pressure, wind velocity, rainfall, solar radiation, etc.

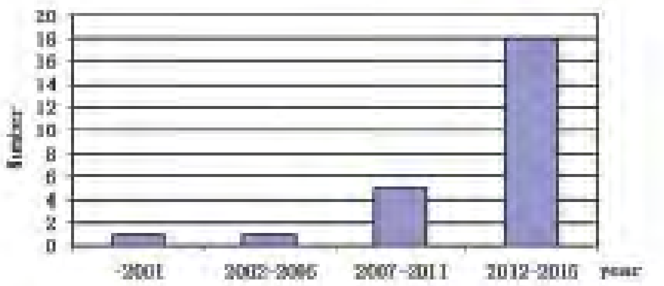


Figure 1. The number of supertall buildings in the hot-summer and cold-winter climate region (Source: CTBUH)
图1. 夏热冬冷地区超高层建筑的数量统计 （资料来源：CTBUH）

增加形成自身微气候特征。因此，有必要对这一地区超高层建筑形成的复杂的气候条件进行深入研究，对气候适应性设计进行综合分析。

本文目的是发展适用于夏热冬冷地区超高建筑气候适应性设计和技术方面的导则。 首先对这个区域的气候特征和超高层建筑的微气候进行分析，提出气候适应性设计策略； 然后针对当地的超高层建筑进行调研； 最后对当前的和未来的设计策略和技术展开探讨。

## 夏热冬冷气候及其设计策略

建筑设计通常以区域气候为设计依据，但是超高层建筑的设计必须综合考虑区域气候和建筑周围的微气候两个方面。建筑设计策略要反映区域气候和微气候对建筑的影响。

### 区域气候

这个地区气候特征是夏天酷热，冬天严寒，湿度大。夏季气温高，持续4个月以上。三大‘火炉’城市都集中在这一地区，这些城市一年中有70多天的日气温高于30℃，相对湿度大于80%。在春末夏初为长江中下游的梅雨季节，潮湿闷热。另外，寒冷冬天内连续5天的平均日气温低于10℃的时间持续约4个月。它的冬天的温度是世界上同一纬度地区最低的。这个地区年降雨量 大于1000mm，其中夏季占60%。 年太阳辐射照度为110～160W/m$^2$，年日照时数为1000～2400h，冬季盛行偏北风，夏季盛行偏南风。

人们从实践经验中总结出多种气候设计策略（MCPRC，2005）。建筑形体规整从而控制体型系数，窗地比应小于0.7，外墙和窗应当采用低传热系数的材料，窗户考虑遮阳系数要求；自然通风是常用的技术用来减少能耗和改善室内空气质量，因为 这个区域适合自然通风的过渡期（春天、秋天和夏季较凉爽的时期）一年中有150天。内庭院和屋顶绿化常用于应对气候并改善环境。这些以被动式设计为主的设计策略普遍应用于当前的建筑中，特别是低层建筑。而这些策略对于超高层建筑可能不再适用。

### 微气候

超高层建筑周围的微气候随高度增加而形成。由于大气为非匀质空间，气温、风速、湿度和太阳辐射都会随着高度的升高而变化。在低层建筑中高度的变化对这些参数的影响微乎其微，但在超高层建筑中这些因素不能忽视。 这些影响主要表现在对气温、气压、风速、降雨量和太阳辐射等方面。

**气温和高度.** 大气温度在竖向上由暖变冷呈梯度变化（见图2）。气温递减率取决于地面条件，热流传递和不受地面影响的空气混合程度（Geiger， 1973）。标准的大气模型测试表明气温递减率为约每升高150m，气温降低1℃ （Clair，2010）。

夏热冬冷地区超高层建筑室外气温的变化要求在对设计策略上有所反映。室外气温随高度升高而降低，在超高层建筑的顶部温度将会比地面降低2℃，湿度的减少，这对超高层建筑的上部处于不

**Air temperature and altitude.** The air temperature has a vertical gradient from warmer at the ground to cooler in the atmosphere (see Figure 2). Its lapse rate is dependent upon surface conditions, the transport of heat upwards and the extent of air mixing, regardless of the effect of the surrounding area (Geiger, 1973). The standard atmospheric model indicates a lapse rate of approximately 1°C with each 150m of additional height (Clair, 2010).

The air temperature lapse with increasing height indicates that the top of a supertall building will be 2°C lower than its ground level. It can produce an upper level of a supertall building at different climate zone. This temperature difference is helpful in reducing the cooling load but does increase the heating load caused by infiltration. It requires improving the insulation and air tightness of the upper level of buildings.

**Air pressure and altitute.** Air pressure on building envelopes is generated by the different densities in warm and cold air, which increases with the height between the openings. The pressure gradient of the cold air declines more than that of the warm air with the increase in height, as the density of the former is greater than the latter (see Figure 3). The warm air inside flows out at the top of the building and the cold air enters the building from the outside, at a position that is near the building's base. The neutral plan level (NPL) is the height at which the internal pressure is equal to the external pressure. The position of NPL is related to the size of the openings. When the opening areas at the upper level and the lower level are equal, the NPL is positioned in the middle, between the openings.

The air pressure in a large space generated by stack effect can be employed for natural ventilation in the supertall building if the openings can avoid the crosswind. It can solve the problem of wind driven ventilation in the supertall building. Care should be taken regarding a high space that can cause uncomfortable air draughts within the space.

**Wind velocity and altitude.** Wind velocity is affected by the surface roughness and typically increases along the vertical. Wind speeds with increasing height follow the power law or log law. The gradient wind in an urban area is reached at about 500m. According to the typical urban condition (power law exponent = 0.28), the wind speed at the top of the supertall building can be more than 2.6 times the speed near ground at 10m in height.

The average wind speed in the hot-summer and cold-winter climate region is 3m/s. The average wind speed at the top of a supertall building could be 7.8m/s, which can cause the serious problems of opening windows and straining the external shading system. It requires innovation in building envelope and shading systems, which are different from the low-rise or high-rise buildings. On the other hand, the high wind speeds at the top of supertall buildings could harness wind energy for electricity. Assuming a wind turbine is mounted above the roof, the available power per square meter (P) can be calculated from where ρ is the air density (about 1.2kg/m$^3$), V is the wind velocity, which is about 1.24 times of average wind velocity, T is numbers of hours per year (8760h), and η is the efficiency of the wind turbine (about 0.4). The electricity generated by a turbine on the super tall building in this region could produce 1902kWh/a.m$^2$.

The wind turbine has two modes for supertall buildings; horizontal and vertical. A horizontal axis wind turbine can collect the maximum amount of wind energy by a variable blade pitch. Its disadvantages are that it causes noise around the area, especially at night, and is sometimes visually annoying in appearance in the landscape. A building with horizontal axis turbines is the Strata in London (see

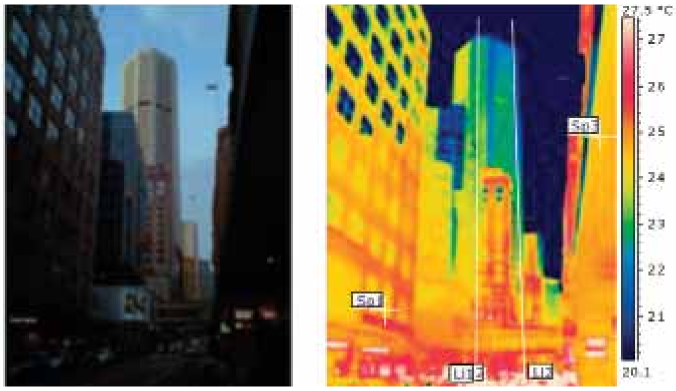

Figure 2. The thermal image of a super tall building (Source: Claire)
图2. 超高层建筑的热影像 （资料来源：Clair）

同的气候区。这有利于降低建筑的冷负荷，而热负荷由于空间渗透量的增加带来较大的热损失（Song & Kim，2011）。这就要求超高层建筑的外围护结构的气密性和保温性能方面提高标准，按新的气候区设计超高层建筑的上部。

**气压与高度.** 超高层建筑外开口表面的气压除受风压影响外，由竖向上空气密度不同引起， 随着开口竖向距离的增加而增大（见图3）。由于冷空气密度大， 冷空气的压力梯度减少比热空气大。 室内热空气在建筑的上部开口流出，冷空气从下部流入。中性面 （NPL）定义为内部压力与外部压力相等时的高度。中性面的位置与开口面积相关，当上下两个开口面积相等，中性面的位置在中间。

气压在大空间形成的烟囱效应可以在超高层建筑中用于自然通风。如果建筑开口的位置避开风压影响，可以解决超高层建筑自然通风问题。超高层建筑中设置中庭、空中花园等高大空间为这一策略的应用提供可能。但需要注意的是， 过于高大的建筑空间可能会造成空间内不舒适的气流。

**风速和高度.** 风速靠近地面受地面粗糙程度影响，在竖向上随高度而增加。风速竖向上增加可以用幂律或对数律表达，在城市区域梯度风高度可以达到500m。根据典型的城区条件(幂指数取0.28)，超高层建筑顶部的风速为地面10m高度处风速的2.6倍以上。

夏热冬冷地区的平均风速为3m/s，在超高层建筑的顶部风速可达7.8m/s。这一风速不利于超高层建筑开窗，且考虑到安全因素不能设置活动外遮阳设施。因此超高层建筑外围护设计需区别于低层或高层建筑，创造新的自然通风和遮阳方式。而另一方面，超高层建筑顶部较大的风速可以用于风能发电。假定风涡轮固定在超高层建筑屋顶上，每平方米产生的有效电能（P）可以通过公式 估算， 其中：ρ是空气密度（大约1.2kg/m$^3$）； V 是风速，大约是平均风速的1.24倍；T 是年时数 (8760h)； η是风涡轮系

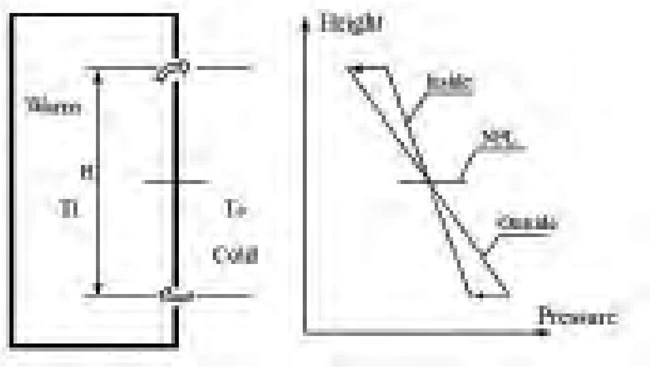

Figure 3. The diagram of air pressure inside and outside of a building vertical space (Source: Jianqiang Li)
图3. 建筑竖向空间内外气压示意图 （资料来源： 李建强）

(a) (b)

Figure 4. The combination of wind turbine and super tall building (Source: a: Waite, 2009, b: SOM)
图4. 风涡轮与建筑的结合方式 （资料来源：a:Waite, b: SOM）

Figure 4, a). The other mode is a vertical axis wind turbine, which has a low noise signature and lower startup speeds of about 2.8m/s. Its disadvantages are that its efficiency is only half of the horizontal one and it is difficult to change after completion (van Bussell & Mertens, 2005). A building with vertical axis turbines is Pearl River Tower in Guangzhou (see Figure 4, b).

A supertall building can have significant negative effects on the pedestrian wind comfort environment. When the wind impacts the building block, the considerable air flowing down produces a vortex at ground level, which will accelerate wind speed at the pedestrian level greater than the comfort criteria of 5m/s. A canopy or podium above the ground level is required to block this descending flow.

**Rainfall and altitude.** The amount of harvested rainwater is dependent upon the quantity and trajectory along the height. The driving rain intensity in light wind is on the roof while the upper level of the windward facade receives the largest rain intensity in a strong wind. The windward face can receive more than double the rain intensity than the roof in very high winds (Page, 1976). The wind-driven rain on the vertical facade is approximate equal to $0.222 \cdot V \cdot Rh \cdot \cos\theta$, where V is wind velocity, Rh is unobstructed horizontal rainfall intensity and θ is the angle between the wind direction and the line normal to the wall (Blocken & Carmeliet, 2004).

The hot-summer and cold-winter climate region has large amounts of annual rain but is still considered a water-deficient area. The roof area compared to the supertall building facade area is a small percentage. This creates the necessity of harvesting rainwater from supertall building facades. The design strategies for rainwater harvesting need to consider the building orientation, geometry and the prevailing winds in order to determine the amount of rain to be harvested.

**Solar radiation and altitude.** Solar radiation is affected by the ground surface forms and lower atmosphere and increases 4-5% with each additional 300m of building height under clear sky conditions (Leung & Weismantle, 2008). In urban areas, the level of solar radiation is reduced as the exposure to solar radiation is influence by building clustering, density and height leading to shade and reflection from adjacent buildings. The area of a tall building above the urban canopy layer can receive greater solar radiation than below the urban canopy.

Supertall buildings have large sections above the urban canopy layer, so solar radiation on the building facade is likely to be exposed for a greater period of time than the typical high-rise building. This provides

统的发电效率 （约是0.4）。 这样超高层建筑风涡轮每平方米的全年发电量为1902kWh/a · $m^2$。

风涡轮与超高层建筑的结合有两种方式：一种是水平轴风涡轮，它能够通过风页角度的变化获得最大化的风能。但缺点是产生噪声，特别是在晚上会影响周围居民生活；还有就是对景观产生影响，人们在心里上不能接受。典型案例有伦敦的Strata 大厦（见图4，a）。另一种是竖直轴风涡轮， 这种方式的优点是噪声低，同时对发电的风速要求低2.8m/s；缺点是效率只有水平轴风涡轮的一半，并且完工后不易更换 (van Bussell & Mertens, 2005)。典型的案例有广州的珠江大厦 (见图4，b)。

超高层建筑对行人风舒适环境有负面影响。当风吹向建筑，相当大的气流下行在地面处产生漩涡， 将会在行人高度放大风速，放大系数大于1，风速大于行人舒适风速5m/s。超高层在建筑设计中通过地面以上设置罩蓬或裙房可以阻止下行风，减少对行人风环境舒适性的影响 。

降雨和高度. 超高层建筑所能收集的雨量与降雨强度和降雨轨迹相关。降雨强度在轻风条件下集中在屋面上，而建筑迎风面上部在强风条件下雨量集中， 迎风面接受的降雨强度是屋面上的两倍以上（Page，1976）。风驱雨在竖直面上的强度大约是 0.222 • V • Rh • cos θ， 其中：V 是风速， Rh 是无干扰情况下水平面上的降雨强度， θ 是风向与墙面法线的夹角 (Blocken & Carmeliet, 2004)。

夏热冬冷地区年降雨量大，但仍未看作是缺水地区。超高层建筑的屋面相对于建筑立面的面积比例小，收集墙面的雨水显得尤为必要。为了收集最多的雨水，建筑设计策略需要考虑建筑朝向与盛行风的夹角，增大迎风面的面积或调整平面布局和建筑型体等来实现。

**太阳辐射和高度.** 太阳辐射受地面上形体和低空大气影响，在晴朗天空条件下高度每升高300m，单位面积的太阳辐射量增加4～5% （Leung & Weismantle, 2008）。在城市地区，超高层近地面城区冠层以下受建筑的集中程度，密度和高度影响，导致建筑接受太阳辐射量少，而高于城市冠层的建筑可以接受到较大的太阳辐射。

由于超高层建筑大部分体积高于城市冠层，其建筑外表面暴露于太阳辐射的时间和周期明显长于普通高层建筑。这就为超高层建筑提供了更多利用太阳辐射的机会。通过建筑朝向、造型、外表皮和遮阳系统的参数化设计来优化建筑接受太阳辐射量或增强光伏发电效果 。

通过对以上气候参数和高度引起超高建筑设计策略的分析， 建筑设计与微气候和气候适应性设计的关系可以用表1作为指引。表1中第一排是气候参数，左列为受气候影响的建筑构成因素。表中的圆点表明气候参数对建筑构成因素有影响，需要在设计中形成策略。空缺项表明气候参数对建筑构成因素的影响较小，可以不考虑。

## 案例分析

案例分析以夏热冬冷地区两个新建的超高层建筑为研究对象。一个是紫峰大厦， 2010年建于南京。另一个是上海中心，仍在建造中，预计2014年完工。 这两个建筑代表了各自的城市文化，采用了较先进的适宜于气候的设计策略和技术。

### 紫峰大厦

紫峰大厦建筑高度450m，89层，为世界上的第七高建筑。它是一个混合功能的超高层建筑，自下到上包括商场，办公和酒店等用房。建筑造型为层叠升高的塔楼，标准层平面为变形三角形 （见图5）。

这个建筑在气候适应性设计方面主要采用被动式设计方式。建筑

Figure 5. Zifeng Tower in Nanjing (Source: Jianqiang Li)
图5. 南京紫峰大厦 （资料来源： 李建强）

more potential opportunities to harness the solar radiation for solar heating or photovoltaic by optimizing the parameters of building orientation, geometry, building envelope design and shading systems et al.

After the above study on climate parameters and design strategies, the relationship between the microclimate and building climate adaptive design can be shown in Table 1. The first row indicates the climate parameters and the left column indicates the building elements, which are affected by the climate parameters. The points in the table indicate that the climate parameters may change the building design strategies. A blank in the grid indicates the climate parameter has little effect on building components.

## Case Studies

The case studies investigate the two new supertall buildings in the summer-hot and cold-winter climate region. One is Zifeng Tower, completed in 2010 in Nanjing, and the other is Shanghai Tower, which is still under construction and will be completed in 2014. Both of these represent their own city culture and adapt climate by the advanced techniques and technologies.

### Zifeng Tower

Zifeng Tower, 450m in height and 89 stories, is the 7th tallest building in the world. It is a mixed-use supertall building, including shopping mall on the lower levels, offices on the middle floors and a hotel at the top. The building rises up with diverse tiers. Its standard floorplan is triangular in shape (see Figure 5).

This building applies some passive design strategies responding to microclimate. Its building envelope is designed as a triangular curtain wall. This shape is helpful to reduce the solar radiation and has the function of self-shading. As the supertall building cannot mount an external shading system due to safety concerns, the self-shading, Low- E glass with an interior shading system are a hybrid strategy for shading in the hot-summer and cold-winter climate zone. The vertical façade consists of a porous steel panel and operable windows (see Figure 6 ). It is much more effective to separate the daylight, natural ventilation and shading system in the supertall building by the different building components.

### Shanghai Tower

Shanghai Tower, known as the tallest green building, will be completed in 2014. It has 121 stories with 632m in height. It is located in the

Figure 6. The details of operable walls in Zifeng Tower (Source: Jianqiang li)
图6. 紫峰大厦中可开启的外墙细部 （资料来源：李建强）

外围护结构采用三角形幕墙。这种形状有自遮阳功能，有助于减少太阳辐射。而超高层建筑考虑到安全因素不能安装外部遮阳设施。自遮阳、Low-E玻璃和室内遮阳系统形成了应对夏热地区遮阳的设计策略。对于自然通风，本建筑采用外部为固定的透空钢网，室内为可开启的外墙（见图6）。在超高层建筑中遮阳、通风和采光的分别处理，对于建筑能够更容易控制每个部分的功能 。

### 上海中心

将于2014年竣工的上海中心建筑高度有632m，共有121层，以最高的绿色建筑而扬名世界。它位于上海金融贸易中心，与邻近的上海金融中心和金茂大厦形成了超高层建筑群 (见图7)。

这个建筑采用了多种气候适应性设计策略。它的旋转几何形体由三个关键要素控制：水平向轮廓线，竖直向轮廓线和旋转的比率（Zeljic，2011）。旋转120°的建筑几何形体通过风洞试验和CFD测试优化，相比方塔减少32%的风荷载。建筑由9个区域组成。区1到区8 每层由3个中庭，作为热舒适的缓冲空间。 建筑外围护采用幕墙系统，由两层玻璃幕墙组成，形成上小下大的中庭（见图8）。这个空间可以减少冷热负荷。外层玻璃幕墙形成维护中庭微环境的屏障，材料为夹层玻璃。内层幕墙是真正建筑的外围护结构，采用断热玻璃幕墙。建筑遮阳采用不同比例玻璃釉，满足不同朝向的遮阳要求（Fan et al，2011）。建筑通过旋转的幕墙收集雨水用于浇灌植物。

| | Daylight 采光 | Sun Radiation 太阳辐射 | Wind Speed 风速 | Natural Ventilation 自然通风 | Air Temperature 气温 | Rainfall 降雨 |
|---|---|---|---|---|---|---|
| Orientation 朝向 | ● | ● | ● | ● | ● | ● |
| Geometry 形体 | ● | ● | ● | ● | ● | ● |
| Plan 平面 | ● | ● | ● | ● | ● | ● |
| Atrium 中庭 | ● | | ● | ● | ● | |
| Building Envelope 建筑围护 | ● | ● | ● | ● | ● | ● |
| Shading 遮阳 | ● | ● | | | ● | |

Table 1. Climate adaptive design assessment.
表1. 建筑与气候适应性设计

financial and trade area of Shanghai that constitutes a supertall building cluster with the other two supertall buildings: Shanghai Financial Center and Jin Mao Tower (see Figure 7).

This building applies various climate adaptive design strategies. Its twisted 120° geometry is controlled by the three key components: horizontal profile, vertical profile and rate of twist (Zeljic, A., 2011). The building's geometry, deduced by wind tunnel experiment and CFD test, reduces 32% of the wind load compared to a rectangular tower. The building consists of 9 vertical zones. Zones 1 through 8 have three atria per floor, which play the role of buffer space for thermal comfort. The building envelope adapts the curtain wall system, which consists of two glazed walls, with a tapering atrium in between (see Figure 8). This space can reduce cooling and heating load. The exterior curtain wall plays the role as a weather enclosure for the atrium space, so the curtain wall uses a laminated glass assembly. The interior curtain wall is the true building envelope, and its material includes an insulated glass assembly. The building shading system is accomplished by the different patterns of glass glazed for the differing building curtain walls (Fan et al, 2011). The tower collects the rainwater from a spiraling parapet and the roof, for watering plants.

Figure 7. Shanghai Tower (Source: Gensler)
图7. 上海中心 （资料来源：Gensler）

Figure 8. The buffer space in Shanghai tower (Source: http://openingbuilding.com)
图8. 上海中心缓冲空间 （资料来源：http://openingbuilding.com）

## Discussion

Compared to the low-rise and high-rise buildings, the supertall building has its own characteristics in climate adaptive design. The air temperature gradient and wind speed increasing with the height provide the supertall building with a unique microclimate. Full utilization of these features can shape the supertall building. Even with the drawback of the wind pressure on the building envelope, it is possible to resolve it by using stack effect ventilation if carefully designed, such as at Commerzbank Building in Frankfurt (Etheridge & Ford, 2008).

Supertall buildings have more opportunities to generate and utilize renewable energy. One resource is from solar energy. Both PV and solar heat are possible to employ in the super tall building. In addition, the atrium, double skin facade can be taken as a buffer space for passive solar. Wind energy is another source for renewable energy in supertall buildings. Installing wind turbines at the top of a supertall building has the potential for renewable energy ( Irwin et al., 2008).

In the near future, supertall buildings can use more advanced technologies to adapt the climate, which promote the passive design strategies and new technology. For example, the intelligent daylighting control system with double skin facades can conserve energy and optimize task illumination levels. This technology is becoming more common. Electrochromic windows can change from clear to opaque for reducing glare without losing vision. Their features include controlled visibility, partial dimming and privacy. They are often preferable to mechanical louvers. Supertall buildings applying electrochromic windows will not need shading systems.

## Conclusion

Climate adaptive design of supertall buildings in the hot-summer and cold-winter climate region needs to consider not only the region climate but also consider the effect of micro climate. The following can provide the developer and designer guidelines at the early design stage:

## 探讨

低层和高层建筑相比较，超高层建筑在气候适应性方面具有自身的特点。 空气温度梯度变化和风速随建筑高度而增加，形成了超高层建筑的微气候。全面利用这些特征能够重塑超高层建筑。即使建筑表面的风压对建筑有缺点，通过建筑设计 仍可以通过烟囱效应解决，例如 法兰克福商业银行等（Etheridge & Ford, 2008）。

超高层建筑有更多的机会产生和使用可再生能源。中庭、双层玻璃幕墙可以作为缓冲空间获得被动式使用太阳能。高空太阳辐射强度大，光伏可以结合超高层建筑外围护结构做光伏一体化设计，虽然目前薄膜式太阳能电池还没有大量应用于建筑。另外风是另一种超高层建筑可以利用的可再生能源。利用安装于超高层建筑顶部的风涡轮有潜力成为可再生能源（Irwin et al. 2008）。

- Supertall building, below the urban canopy, is most affected by the surroundings. The part above the urban canopy is mainly affected by microclimate.
- The ratio of window to wall can be variable to adapt to the solar radiation , insulation and building infiltration along the vertical.
- Shading systems can be applied by self shading and coating the glazing with interior shading systems, in order to avoid the hazard of external high wind speeds. In the near future, electrochromic windows may replace louvers.
- Stack effect for ventilation in the vertical space can be applied in a supertall building, provided the wind speed has less effect on internal ventilation.
- Supertall buildings have more potential to utilize the climate's resources, such as solar radiation and wind energy for renewable energy in the top levels.
- Passive design, along with intelligent systems, provides low energy consumption and flexible strategies for safe, healthy, environmentally friendly buildings and comfortable interior environments.

超高层建筑可以通过被动式设计策略和新技术的精心结合，形成更高级的适应气候策略。例如，智能化采光控制系统与双层玻璃幕墙的结合可以节能，优化建筑采光照明。这项技术在在超高层建筑中正在普及应用。电致调光玻璃可以从清晰变成半透明用于减少眩光，但不会失去可视度。这些特征包括视觉可控，部分变暗，私密性使得它的性能优于百叶窗。超高层建筑的使用将会减少对遮阳系统的依赖。

夏热冬冷地区超高层建筑的气候适应性设计需要考虑不仅是区域气候，而且需要考虑微气候。以下是为开发商和设计师在建筑设计前期提供的一些建议：

- 超高层建筑在城市冠层以下部分与周围环境有较多相互作用，以上部分多受微气候影响；
- 超高层建筑围护结构窗墙比应能够反映出太阳辐射量的增大，保温性能和气密性的提高；
- 超高层建筑遮阳系统可以使用自遮阳与涂层玻璃相结合，或室内遮阳系统，这样可以避免外部高速风对遮阳系统的危险，将来可以选用电致调光玻璃等先进技术。
- 超高层建筑自然通风系统可以在内部竖向空间采用，或采用局部内开式外窗。
- 超高层建筑有更多利用气象资源的潜力，比如结合建筑形体利用太阳能辐射，风能等可再生能源。
- 被动式设计与智能化系统的紧密结合可以创造出更多低能耗和易操作的方式，从而实现安全、健康、环保和舒适的室内环境。

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