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Climate-Responsive Exterior Enclosure Design

响应气候的外墙设计

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As Technical Partner in SOM's San Francisco office, Keith Boswell orchestrates and oversees detailed design and construction documentation for some of the company's most technically challenging projects. He also provides overall development and coordination of design concepts, system design, and technical requirements, and is the standard bearer of technical excellence. Boswell's experience includes high-rise office buildings, residential and mixed-use complexes, government facilities, and international and domestic airport passenger terminals. He has developed expertise in coordinating overseas projects and is a specialist in the design and execution of technically complex exterior building enclosures, addressed in his book Exterior Building Enclosures.

作为SOM旧金山办公室的技术合伙人，Boswell策划并监督SOM技术难度最高项目的详细设计和施工文件。他负责概念设计、系统设计、技术要求的总体开发与协调，建立并坚持技术上的优秀品质标准。他的专业经验包括高层办公楼、住宅和混合功能综合体、政府设施以及国际/国内机场的旅客航站楼。Boswell擅长协调海外项目，在设计和建造技术复杂的建筑外墙方面是位专家，并就此著书《建筑外墙》。

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Michael Duncan is a Design Director in SOM's San Francisco office. Duncan has played lead roles in several of the firm's signature projects, and has extensive national and international experience in designing projects that include major commercial, residential, and civic complexes and buildings. His ambition is to leverage the powerful design engine of SOM to produce projects that push design to the highest tier in terms of program, structure, and building skin. This is especially significant in regards to buildings that pioneer refined, cutting-edge solutions addressing environmental responsibility and sustainability.

Michael Duncan是SOM旧金山办公室的设计总监。Duncan在SOM的数项代表性项目中担任领导角色，并在国内和国际重要的商业、住宅、市政综合体与单体建筑方面具有丰富的设计经验。\Duncan的抱负是利用SOM强大的设计动力打造出在功能布局、结构和建筑表皮这三方面都登峰造极的建筑项目。这对于率先采用精深尖端解决方案来兼顾环保和可持续性的建筑来说尤为重要。

Abstract | 摘要

In this paper, three different solutions in three different regions of China illustrate best practices for the design and execution of optimized building enclosure systems. Poly International Plaza in Beijing features a dual-wall enclosure that is directly related to its superstructure; Ningbo Guohua Financial Tower's perimeter structural diagrid engages directly with its exterior curtain wall, comprised of a combination of custom insulated glass and aluminum panels; and Agile Corporation Headquarters in Guangzhou features an array of transparent and opaque fenestration, including horizontal sun-screen fins that correspond to the solar load. Iconic tall buildings and their enclosures have become a catalyst for rapid urbanization in developing countries, particularly in China. Creating and implementing these enclosures requires balancing visual and performance aspects equally. Enclosures must be aesthetically pleasing, perform, and stand the test of time. The design of high-performance building enclosures must consider structural function, response to climate, energy efficiency, and user comfort.

Keywords: Building Enclosure Systems, China, and Tall Buildings

本文介绍了中国三个不同地区的三个不同设计方案来说明设计与建造最优建筑外墙系统的最佳方法。北京保利国际广场的双层外墙与建筑的上部结构直接相关；宁波国华金融大厦以定制中空玻璃和铝板组合构成外幕墙，与建筑的周边斜肋框架结构直接相接；广州雅居乐集团总部的外墙展现了一系列透明和不透明的窗墙面板，安装的横向遮阳板与日照负荷相对应。 标志性高层建筑及其外墙已成为发展中国家快速城市化的催化剂，在中国尤甚。这些外墙的设计与建造要求在外观和性能之间达到平衡。外墙必须美观，性能良好，经久耐用。高性能建筑外墙的设计必须考虑结构功能、气候响应、节能效率以及用户舒适度。

关键词：建筑外墙、中国、高层建筑

Introduction

Dense urbanization and the resulting cities created have often been described in negative terms, such as overcrowding, congestion, and diminished physical and social quality of life; but the benefits of urbanization far outweigh the challenges. Convenience to goods and services, reduced transportation, social integration, and many more positive factors can contribute to a healthy and livable city. Accordingly, dense urbanization necessitates building tall. Nowhere – and at no time in human civilization – is rapid urbanization more evident than in established and newly emerging cities in China.

Tall buildings require large investments in capital, resources, and time from owners, architects, engineers, and builders who all, together, have a responsibility to deliver high-quality work. With the proper investment, the resulting structure will thrive for many lifetimes. A long-term built reality must be predicated on the idea that anything worth doing is worth doing right, and then implementing this

引言

高密度城市化及其所造成的城市常常被贬落为太拥挤、交通堵塞、降低环境和社会生活品质等等。但是城市化的优点远远大于上述缺点。取得产品和服务的便利性、交通量的降低、社会融合以及许多其它正面因素都有助于建设健康宜居的城市。要高密度城市化，则必须建造高楼。没有任何地方——在人类文明史上也没有任何时代——像中国的成熟城市和新兴城市那样显现出迅速的城市化。

高楼建造需要业主、建筑师、工程师、工程队投入大量的资金、资源和时间，他们共同承担着保证建筑工程品质的责任。在适当的投资下，建成的建筑将经久不衰。从长远来看，建设时必须牢记并贯彻这个信念——任何值得建造的东西都值得费功夫好好建造。高效和永恒的高层建筑会达到更高的性能标准，并更和谐地融入周围城市环境。有视觉冲击力但浪费能源的产品，起初可能会刺激感官，但在历经好几代以后还会有意义吗？

我们相信建筑必须在一开始就设计得当。

Figure 1. Ningbo Guohua Financial Tower in the emerging New Town District (Source: Skidmore, Owings & Merrill LLP | Smilodon CG, 2016)
图1. 新兴新城区内的宁波国华金融大厦（来源：Skidmore, Owings & Merrill LLP | Smilodon CG, 2016）

concept thoroughly. Timeless and efficient, tall buildings will perform at a higher standard with a more harmonious integration within their urban context. While an energy hog that is visually unsettling may initially excite the senses, will it be relevant over the course of many lifetimes?

We believe that buildings must be designed right the first time around.

Many systems contribute to – or impede – a tall building's performance over a long period of time. The most visible building system is the exterior building enclosure. Design solutions for the exterior enclosure must balance visual composition (how it looks) and performance (how it works). Holistic exterior enclosure design for tall buildings must:

1. Be responsive to the climate;
2. Be responsive to the use;
3. Be carefully crafted in design, detail, and execution to perform on day one and be durable for many lifetimes thereafter;
4. Contribute to the urban environment and enhance the human experience – at street level and within.

Three buildings in three different Chinese cities are reviewed below for their exterior enclosure design response, with a focus on the topics identified above. Every climate, micro-climate, and use is unique; therefore, each exterior building enclosure design opportunity must acknowledge and specifically respond to its climate conditions.

One size does not fit all.

Ningbo Guohua Financial Tower – Ningbo China

Climate

Ningbo is one of China's oldest cities dating back to 4,000BC, with a humid, sub-tropical climate. Ningbo experiences typhoons and nearly 60 inches (1520mm) of annual rainfall. Temperatures average 40°F (4°C) in the winter months, to the mid 80's°F (28°C) in the summer. Ningbo is located in east China's Zhejiang province along the eastern coast of China and Hangzhou Bay at 29.8683°N latitude. Cities with similar latitudes are Houston, Texas, and Cairo (to provide some world climate context).

Use

Currently under construction, Ningbo Guohua Financial Tower (NGFT) is a 45-story, 206-meter-tall (676'-0") office tower with an attached four-story, mixed-use podium (Figure 1). The design brief required a floor plan to accommodate full-floor tenants, as well as multi-tenant-per-floor office configurations. The response is a rectangular floor plate measuring 62.5 meters x 36.4 meters (205'-0" x 120'-0") resulting in 2275

许多系统利于——或不利于——高楼的长期性能。最显眼的建筑系统即是建筑外墙。外墙的设计方案必须平衡视觉构造（外观）和性能（功能）。统筹考虑的高层建筑外墙设计必须达到以下几点：

1. 适应气候
2. 适应用途
3. 精到的设计、细节和实施一天起就性能完善，且经久耐用
4. 在街道层和建筑内都利于城市环境，改善人的体验

下文选择中国三座城市三幢建筑的外墙设计，着重讨论上文提出的问题。每种气候、微气候、用途都是独特的。因此，每个建筑外墙设计都必须针对所处气候条件提出相应措施。

非所有项目都可套用统一设计。

中国宁波——宁波国华金融大厦

气候

宁波是中国最古老的城市之一，原建于公元前4000年，属潮湿亚热带气候。宁波受台风影响，年降雨量近1520毫米（60英寸）。冬季平均温度4°C（40°F），夏季平均温度28°C（82°F）。宁波位于中国浙江省沿海杭州湾，北纬29.8683度。

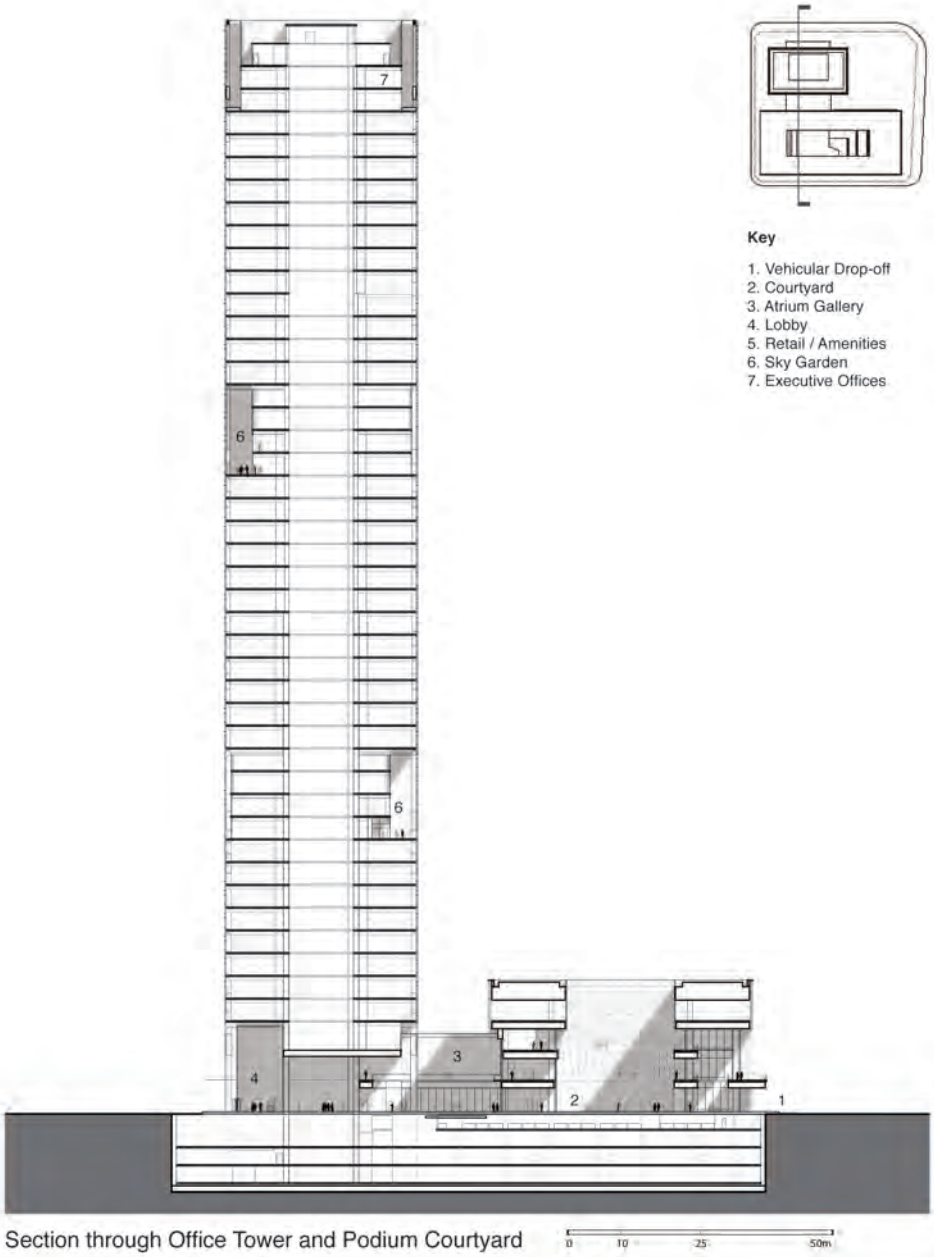

Figure 2. Ningbo Guohua Financial Tower section with sky gardens at 1/3 point (Source: Skidmore, Owings & Merrill LLP, 2016)

图2. 宁波国华金融大厦剖面，1/3高度处有空中花园（来源：Skidmore, Owings & Merrill LLP, 2016）

gross square meters (24,488 ft^2) per floor. The lease span, from building services core to the exterior enclosure, is a consistent 11 meters (36'-0"). Offices occupy floors 4 thorough 44. Floor-to-floor heights are a consistent 4.3 meter (14'-1 ¼"). China's tall building life safety requirements stipulate egress refuge floors at maximum vertical distances between groups of floors to allow safety refuge at designated floors in emergency egress events. These floors are often utilized for a combination of safety refuge and building services (mechanical, electrical, plumbing, and fire protection) equipment. The refuge floors of NGFT accommodate these uses in addition to a 4-floor-high community sky garden. The sky gardens are located at 1/3 points in the tower height providing spaces for casual meeting and recreation for the office tenants (Figure 2).

The building form is derived from the program use and utilizes a composite steel and concrete perimeter diagonal structure to respond to typhoon high pressure lateral wind loads. The plan organization and consistent floor–to-floor heights establish an organized and repetitive structural geometry for the entire tower. This geometry is visually expressed on the skyline directly in the composition of the exterior enclosure as 8-story diamonds with node intersections at 9-meter plan spacing every four floors of height. The diamond geometry "turns the building corner" by folding the diamond about its center, resulting in a building massing that is volumetric.

Enclosure Design & Detail

The exterior building enclosure – opaque diagonals and vision glass – is designed utilizing a custom unitized curtain wall. Opaque panels consist of male/female unitized aluminum frames with 5mm-thick (3/16") aluminum panels. The edges of the aluminum panels incorporate extruded aluminum in a channel profile to define and provide

世界上与之纬度相近的其它城市有美国德克萨斯州休士顿和埃及开罗，可用于气候比较。

用途

宁波国华金融大厦（NGFT）是高45层、206米（676英尺整）的办公塔楼，坐落在四层高的综合功能裙房上，目前正在施工（图1）。设计任务书要求提供单租户和多租户办公平面图。设计提供了长方形楼板，长62.5米（205英尺整），宽36.4米（120英尺整），每层总建筑面积为2275平方米（24,488平方英尺）。从楼宇服务核心筒到外墙的租赁空间跨度统一为11米（36英尺）。办公层从第4到44层。层高统一为4.3米（14英尺1 ¼英寸）。中国高层建筑生命安全要求规定每隔一定楼层须提供疏散避难层，在紧急状况下让人可到指定楼层避难。这些楼层通常兼作避难区和楼宇服务设施空间（机电、给排水、消防）。NGFT的避难层能起到这些作用，而且还提供了四层高的社区空中花园。塔楼每隔1/3高度设置空中花园，为办公租户提供休闲聚会娱乐的场所（图2）。

建筑形体取决于内部功能布局，用钢与混凝土组合周边斜交结构来抵御台风引起的侧向高压风载。平面空间组织和统一的层高为整幢塔楼结构建立了重复有序的几何造型。该造型在天际线上清晰可见，外墙呈现出8层高的菱形组合图案，节点位于每隔4层的9米平面间隔。菱形在楼体转角对半折，表现出建筑体量。

外墙设计与细节

建筑外墙为定制单元式幕墙，由不透明斜框和可视玻璃构成。不透明面板是在公/母单元式铝框内安装5毫米（3/16英寸）厚的铝板。铝板边缘结合铝槽型材，做出斜交上部结构的样式以及视觉深度。长方形和梯形的幕墙围护单元宽1.5米（5英尺整）到2.25米（7英尺4 ½英寸），高4.3米（14英尺1 ¼英寸），或位于斜交铝板之间，或与其整合一体，是在公/母铝框内镶中空夹胶低辐射透明玻璃（图3）。楼层结构的铝板和玻璃区域由中空可视玻璃和3毫米厚的带保温铝板阴影盒构成，阴影盒嵌入透明玻璃后面以达到视觉深度效果（图4）。所有单元式框架都使用聚酰胺型材断热，减少外墙框架构件位置从室外到室内的传热。高中物理课上就曾教过：热量从较热的地方传到较冷的地方。宁波属亚热带气候，主要温度梯度流（从热到冷）是从室外流到室内。断热通过铝框构件使热流“高速公路”出现“短路”。可视玻璃在各边用结构硅胶固定在框架内。硅胶固定方法也造成从玻璃通过边框的导热短路。经分析，相对于非隔热细节做法，隔热细节做法被证实是有效的。视觉设计上，外墙用铝型材固定玻璃，达到了表现外墙横框的目标。外墙上的这些横向元素也在内外铝框之间使用断热。厚5毫米的斜交铝板经定制设计为钩形形状有不锈钢销外套高抗

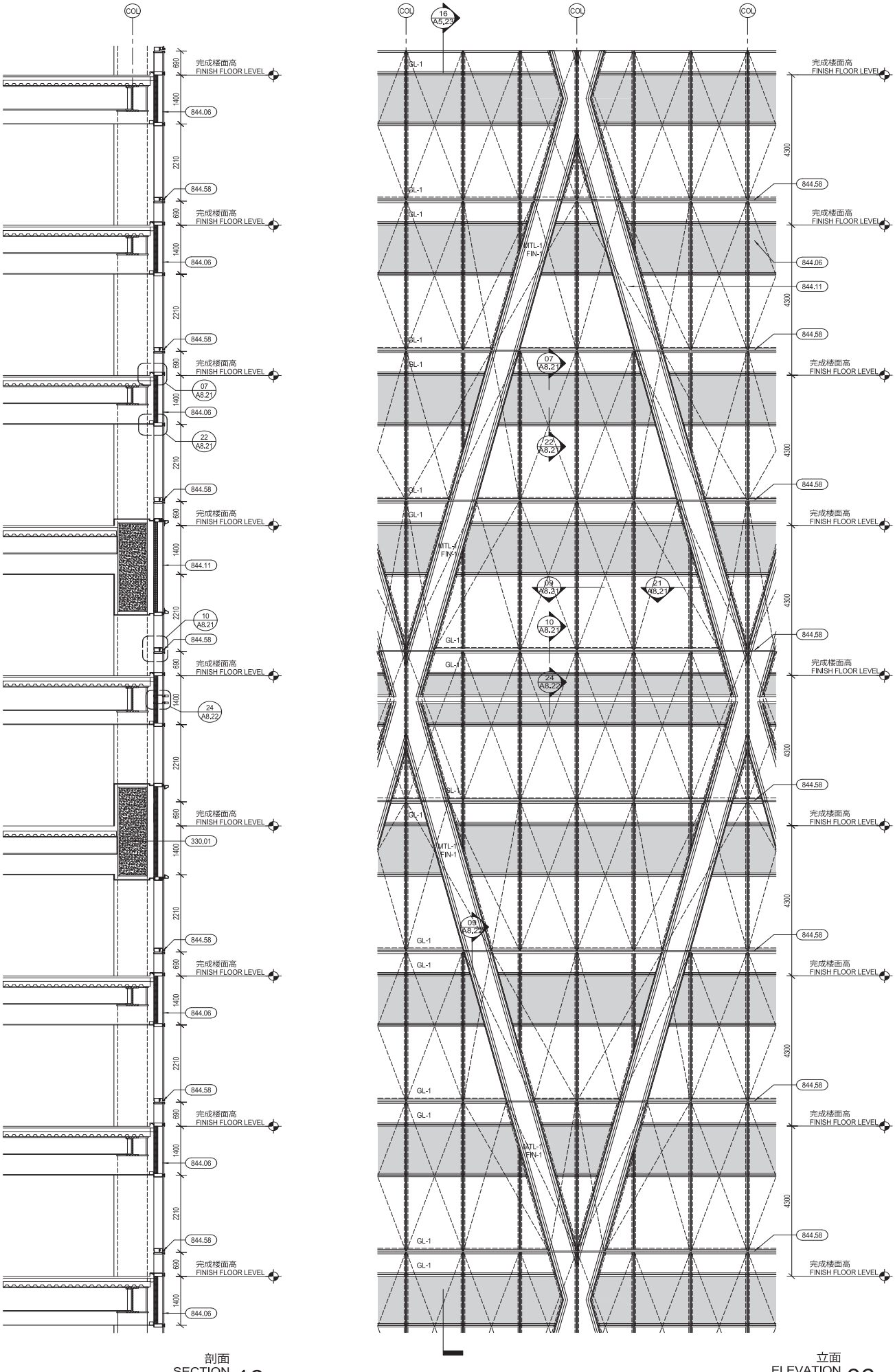

Figure 3. Ningbo Guohua Financial Tower enclosure with curtain wall unit panelization (Source: Skidmore, Owings & Merrill LLP, 2016)
图3. 宁波国华金融大厦的幕墙单元面板设计（来源：Skidmore, Owings & Merrill LLP, 2016）

Figure 4. Ningbo Guohua Financial Tower tri-dimensional enclosure design (Source: Skidmore, Owings & Merrill LLP, 2016)
图4. 宁波国华金融大厦三维外墙设计 （来源：Skidmore, Owings & Merrill LLP, 2016）

visual depth in the diagonal superstructure. Rectangular and trapezoidal curtain wall enclosure units of 1.5m (5'0") to 2.25m (7'-4 ½") width x 4.3m (14'-1 ¼") height occur either between or are integral with the diagonal aluminum panels with male/female aluminum frames and insulated/laminated low-E vision glass infill (Figure 3). The aluminum and glass areas at the floor structure are composed with insulated vision glass and a 3mm-thick insulated aluminum shadow box recessed behind the vision glass for visual depth (Figure 4). All unitized frames utilize thermal breaks of extruded polyamide to mitigate thermal transmission from outside to inside at the enclosure framing members. As a reminder to all from high school physics class – heat flows from hot to less hot. The Ningbo climate is subtropical, so the predominant temperature gradient flow (hot to less hot) is from the exterior to the interior; thermal breaks "short circuit" the thermal highway through the aluminum framing members. The vision glass infill is secured to the frames with structural silicone on all sides of the glazing. This silicone attachment method also short circuits thermal conductivity from glass through framing.
An analysis was performed to validate the thermal isolation detail in comparison to a non-thermally isolated detail. A visual design objective to express the horizontal enclosure framing is achieved via extruded aluminum exterior glazing retainers. These exterior horizontals also utilize thermal breaks from exterior to interior aluminum framing. The 5mm-thick aluminum diagonal panels are a custom-designed aluminum hook profile over stainless steel pins with high-impact plastic sleeves. The sleeves serve as thermal breaks to separate exterior to interior thermal conductivity.

A primary – and least understood – performance metric in exterior enclosure design is minimizing or eliminating air infiltration. Air moves when there is a pressure difference. Air also flows from hot to less hot – and air carries water; so, the design and detail goal is to control the air infiltration. If the exterior enclosure has a high infiltration rate from exterior to interior, exterior heat (summer) infiltrates the interior occupied spaces, requiring HVAC systems to work harder, which is bad for energy consumption. Actual air infiltration is measured in testing, however, the details must provide an effective method to execute air infiltration reduction. If the interior spaces are uncomfortable, this is also bad; so, the question in enclosure design is: "How is the primary air seal designed and constructed?" This should always be defined by the architect in a manner that is easily understood and can be effectively fabricated and installed to provide air separation between the exterior environment and interior conditioned spaces. The unitized curtain wall for NGFT is designed utilizing the pressure equalized rain screen principle. This means a primary air seal. The primary air seal doubles as the primary water protection seal. This seal must be continuous in 3 dimensions. The curtain wall design also incorporates a secondary "bulk" water diverter screen. The space between the primary air/water seal and the secondary bulk water diverter screen is the pressure equalization chamber. The enclosure design details locate the primary air/water seal towards the interior side of the curtain wall system with continuous gaskets in the vertical framing members that overlap in contact with continuous horizontal gaskets in the horizontal framing members. The gasket material is extruded silicone. Details live or die at intersections. Great care was exercised in the design development phase to illustrate the continuity of the air seal at the critical unit to unit intersection which occurs at every unitized curtain wall, panel to panel. Secondary water management is achieved towards the exterior side via female/female silicone bulb gaskets in the vertical members and an extruded silicone flap gasket in the horizontal unit to unit intersection. Openings in the exterior horizontal gasket (secondary water protection line) allow for water drainage to the exterior from the pressure equalized chamber, and promote drying of the chamber. This design and detail approach is applied to glass and aluminum unitized panels. During the tender document phase, this pressure equalized design/detail approach was initially not followed by the local Chinese engineer. During a work session, the detail logic was

冲塑料套管。套管作为断热，隔断从室外到室内的导热。

外墙设计中一项首要的——但最不被人理解的——性能指标是空气渗透的最小化或杜绝。有气压差即有气流。空气也从热处流向冷处。而且空气带有水分。因此设计与细节的目标是控制空气渗透。如果从室外到室内的外墙渗透率高，（夏季）室外热量就会渗透到室内待人空间，则需增加空调用量。这不利于节能。实际空气渗透率经实验测量，但细节必须提供有效的降低空气渗透率的方法。不然，室内环境不舒服，也同样不利。那么外墙设计的问题就是：如何设计并施工主要空气密封层？这应该都由建筑师以易懂的方式设计，并应能有效地制作和安装，隔开室外环境和室内空调间的空气。NGFT的单元式幕墙设计遵循了压力平衡雨幕原理。这意味着有主要隔气层。主要隔气层兼作主要防水层。该密封层必须在三维方向都是连续的。幕墙设计还采用了次要“大量”水流的导流幕。主要防水隔气层和次要大量水流导流幕之间的空间是压力平衡腔。外墙设计细节将主要防水隔气层布置在贴近幕墙系统的室内侧，在竖框构件内用连续胶条， 在横框构件内用连续的横向胶条，两种胶条重叠相接。胶条材料为硅胶型材。细节的成败在于相交节点。设计师于初步设计阶段，在单元式幕墙每两个面板之间出现的关键的单元之间相交点，精心表达了气密封的连续性。幕墙的室外侧则通过在单元体竖向构件内安装母/母硅胶球形胶条并在单元之间的横向接缝内安装硅胶型材片状胶条，达到让水流向室外的次级防水处理。室外横向胶条（次级防水层）的开口让水从压力平衡腔排到室外，加速压力平衡腔内干燥。玻璃和铝板单元式面板都采用了该设计和细节做法。在投标文件阶段，中国当地工程师最初并未采取压力平衡设计/细节做法，但之后经SOM再次解释设计的逻辑道理，当地工程师才恍然大悟并修改了细节，在外墙系统设计文件中采纳了这一原理。

对城市环境的贡献/改善人类环境

塔楼位于东部新城重要的东西大道上。项目场地的公共空间吸引来自各地的租户与访客。塔楼广场和裙房点缀以公共艺术，裙房有层台式露天庭院，内设瀑布与倒影池。塔楼的斜交结构以包铝V形结构连接首层，使塔楼占地面积最小化。公共空间从塔楼的V形结构缩入，围以17米（55英尺9英寸）高的超透明玻璃外墙。这处超透明首层空间为用户和访客提供了开放友好的场所（图5）。

中国广州——雅居乐集团总部大厦

气候

广州人口1400万，是珠江三角洲高密度城市，几百年来作为西方条约口岸蓬

Figure 5. Ningbo Guohua Financial Tower pedestrian-level amenities and experience (Source:Skidmore, Owings & Merrill LLP | APLUS CG)
图5. 宁波国华金融大厦行人层配套设施与体验（来源：Skidmore, Owings & Merrill LLP | APLUS CG）

explained, again, by SOM to the local engineer. The local engineer experienced an "Ah-hah" moment of understanding and revised the details to incorporate the principle in the enclosure system documentation.

Contribution to the Urban Environment / Enhance the Human Environment

The Tower is situated along a prominent east-west boulevard in East New Town. The site's public spaces draw tenants and visitors from all directions. The tower plaza and podium feature public art, and the podium features a terraced open air courtyard with waterfalls and a reflecting pool. The tower's diagonal structure engages the ground level with aluminum clad "V"s to minimize the tower footprint on the site. Recessed from the Tower "V" are public spaces enclosed with an ultra-clear glass enclosure 17 meters tall (55'9"). This ultra-clear ground plane promotes an open and inviting conditioned space for occupants and visitors (Figure 5).

Agile Corporation Headquarters Tower – Guangzhou, China

Climate: Guangzhou is a densely populated city of approximately 14 million people in the Pearl River Delta (PRD) that flourished for centuries as Canton – a western treaty port. China's third largest city has a warm and humid climate all year round, without a clear division between four seasons. Daytime temperatures average 21 to 29°C (70-84°F) with high levels of solar radiation. Average rainfall is 68 inches (1736mm) with the highest rainfall totals in the months of April and September. Guangzhou is located in the Guangdong province at 29.1291°N latitude. Cities with similar latitudes are New Orleans, Louisiana, and Kuwait City (to provide some world climate context).

Use

Agile Headquarters Tower is a 39-story, 190–meter-tall (623'-4") office tower. The tower is located in the Zhujiang New Town District, which was agricultural land only 20 years ago. The new town occupies an area of 6.5 square kilometers and is bounded by Huangpu Avenue to the North, Pearl River to the south, Guangzhou Avenue to the west, and the South China Expressway to the east. The new town is home to multiple high-rise commercial and residential towers and has two stops along the Guangzhou Metro subway. Fronting a major traffic circle to the west and the 70-story Pearl River Tower to the east, the Agile Headquarters Tower stands as a significant gateway to the emerging New Town Center (Figure 6).

勃发展。中国第三大城市广州全年气候温暖潮湿，四季不分明。日间平均温度21–29° C（70–84° F），日辐射高。平均降雨1736毫米（68英寸），降雨最多月份为四月和九月。广州位于广东省，北纬29.1291度。世界上与之纬度相近的其它城市有美国路易斯安那州新奥尔良和科威特的科威特市。

用途

雅居乐集团总部大厦是高190米（623英尺4英寸）的39层办公塔楼。塔楼位于珠江新城，仅20年前还是一片农地。新城占地6.5平方公里，北达黄埔大道，南临珠江，西起广州大道，东至华南快速干线。新城内有数幢高层商住塔楼和两个广州地铁线车站。雅居乐集团总部大厦西对主要交通环路，东朝70层高的珠江城大厦，矗立于新兴的新城中心重要的门户位置（图6）。

塔楼平面呈椭圆形，代表了与繁忙交通环路的连续衔接。建筑在场地上的朝向是，椭圆形长边的立面朝东西方向。办公层从第3到39层，标准建筑面积每层2200平方米。办公层标准层高为4.35米（14英尺3英寸）。

外墙设计与细节

建筑外墙用平板逐段做出契合平面椭圆形的曲线，通高平板宽2.2米（7英尺2 ½英寸）或1.1米（3英尺7 3/8英寸），高度通高。考虑到建筑的位置、形体、体量和相邻建筑，设计师用电脑模型分析了外墙表面从5月1日到10月31日的夏季得热，依据所得的日辐射图再设计出一系列横向遮阳板和多种玻璃和不透明镶板材料（图7）。

Figure 6. Agile Corporation Headquarters against the urban skyline (Source: Skidmore, Owings & Merrill LLP, 2016)
图6. 城市天际线上的雅居乐集团总部（来源：Skidmore, Owings & Merrill LLP, 2016）

The tower is an elliptical plan geometry which presents a continuous frontage to the busy traffic circle. The elliptical plan is oriented on the site with the long elevations facing east and west. Office floor plates from levels 3 to 39 are typically 2,200 square meters of gross per floor. Office floor-to-floor heights are typically 4.35m (14'-3").

Enclosure Design & Detail

The exterior building enclosure is organized into flat panels 2.2m (7'-2 ½") in width or 1.1m (3'-7 3/8") x full-floor height in a segmented curve to follow the elliptical plan. Factoring the building's location, shape, volume, and adjacent buildings, computer modeling was utilized to analyze heat gain on the enclosure surface during the summer months from May 1st thru October 31st. The resulting solar radiation map was translated into an array of horizontal sunscreens and multiple glass and opaque infill materials (Figure 7). As the density of sunscreens and enclosure cladding corresponds to the solar load, the pattern formed mirrors how the intense Guangzhou sun pattern moves across the building. This response balances the solar gain of the building in the round, stabilizing the cooling needs and reducing energy consumption when compared to a composition of repetitive glass and opaque materials evenly distributed across the enclosure.

Vision glass consists of insulated low-E glass. The insulating glass is a robust assembly of 12mm (1/2") tempered outboard lite, 12mm (1/2") air space, and 10mm (3/8") tempered in board lite to withstand the very high typhoon wind loads. The glass is secured to the unitized frame with structural silicone bordered by a 7mm-wide aluminum trim, connected to the interior aluminum framing with a thermally improved connection. The floor/beam spandrel zone is a shadow box assembly with insulated low-E vision glass and a corrugated aluminum panel. The corrugated panel is finished with a high-performance silver coating to reflect natural light, providing more visual depth in the glass enclosure. The corrugated panels are insulated toward the building interior with 50mm-thick (2"), semi-rigid thermal insulation. The sunscreens are detailed with 7mm (5/16") pattern-cut aluminum plates with a teardrop extruded aluminum profile that cantilevers 450mm (1'-6") from the glass surface. The sunshades are located strategically within the panels of vision glass to allow daylight and shield direct solar heat gain. Sunshade connections are thermally improved

遮阳板和外墙包覆的布置密度与日照负荷相对应，所形成的排列规律反映了建筑在广州一天内受到的日照变化。相比起在外墙上重复均匀地分布玻璃和不透明材料，该措施平衡了建筑外围一圈的日照增热，稳定了致冷需要，而且降低了能耗。

可视玻璃部分为中空低辐射玻璃。中空玻璃的构成部分为12毫米（1/2英寸）的钢化外片、12毫米（1/2英寸）的空气层、10毫米（3/8英寸）的钢化内片，很坚实，可抵御非常高的台风荷载。玻璃用结构硅胶固定在单元式框架内， 边缘做7毫米宽的铝边并采取了加强隔热措施连接到内部铝框。在楼板/梁的层间墙区域，用中空低辐射可视玻璃和波浪形铝板做阴影盒组件。铝板用高性能银涂层做饰面，反映自然光线，在玻璃外墙上加深视觉深度。铝板朝室内的一面设50毫米（2英寸）厚的半刚性保温层。遮阳屏的细节做法是，用切割出图案的7毫米（5/16英寸）的铝板，配以水滴形截面的铝型材，从玻璃表面悬挑伸出450毫米（1英尺6英寸）。遮阳板置于可视玻璃板内的有效位置，既容许自然采光，又挡住直接日照增热。遮阳板采用加强隔热措施以多个螺栓连接，可抵御强风荷载（图8）。

外墙系统采用压力平衡雨幕防风雨原理。主要气密/水密层位于最靠内侧位置，使压力平衡腔空间最大化。此处气密/水密位置经过仔细分析选择，使外墙能承受高风载和高雨量两者合并的工况。压力平衡原理

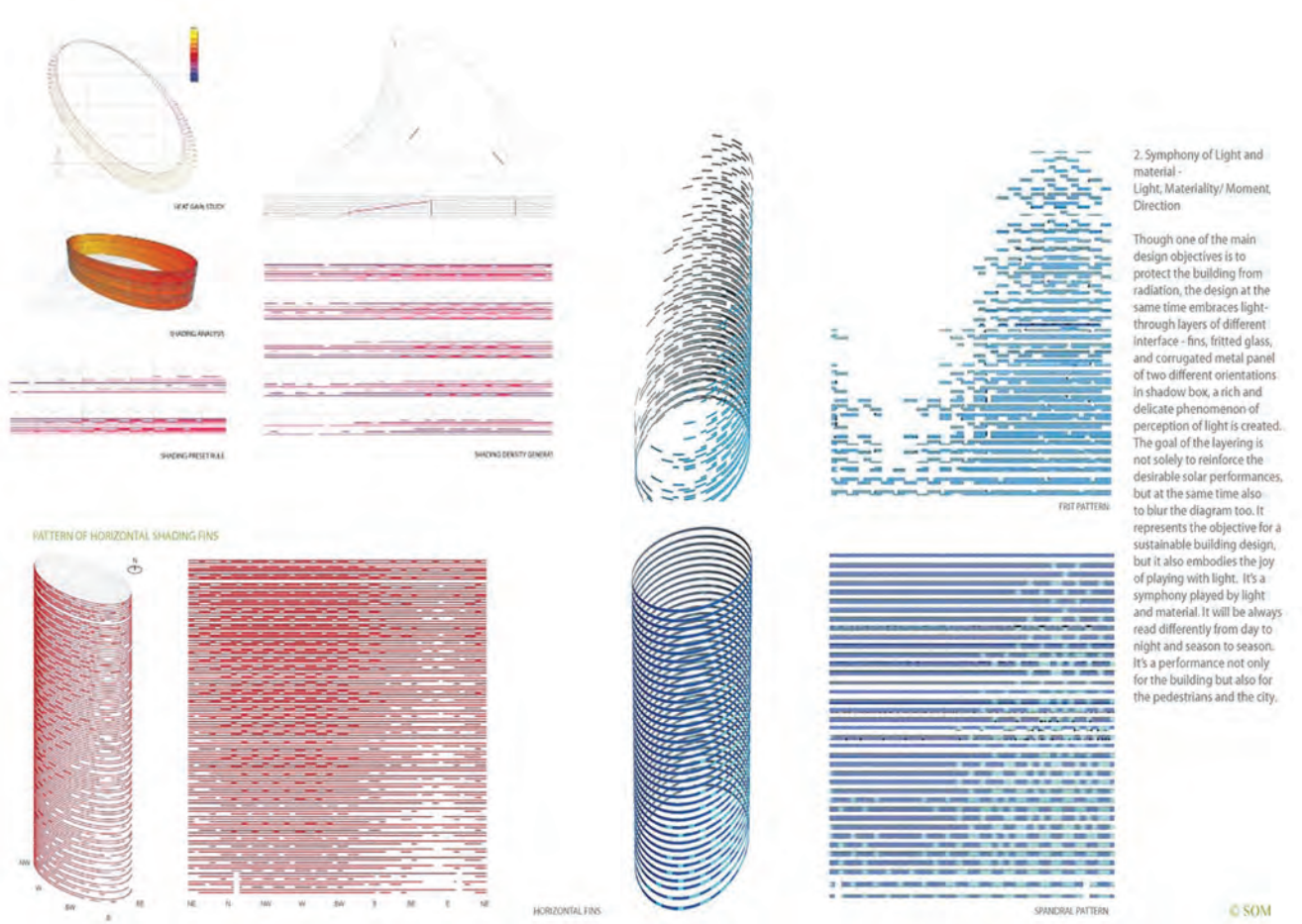

Figure 7. Agile Corporation Headquarters solar design and curtain wall response study (Source: Skidmore, Owings & Merrill LLP, 2016)
图7. 雅居乐集团总部的日照设计与幕墙响应研究（来源：Skidmore, Owings & Merrill LLP, 2016）

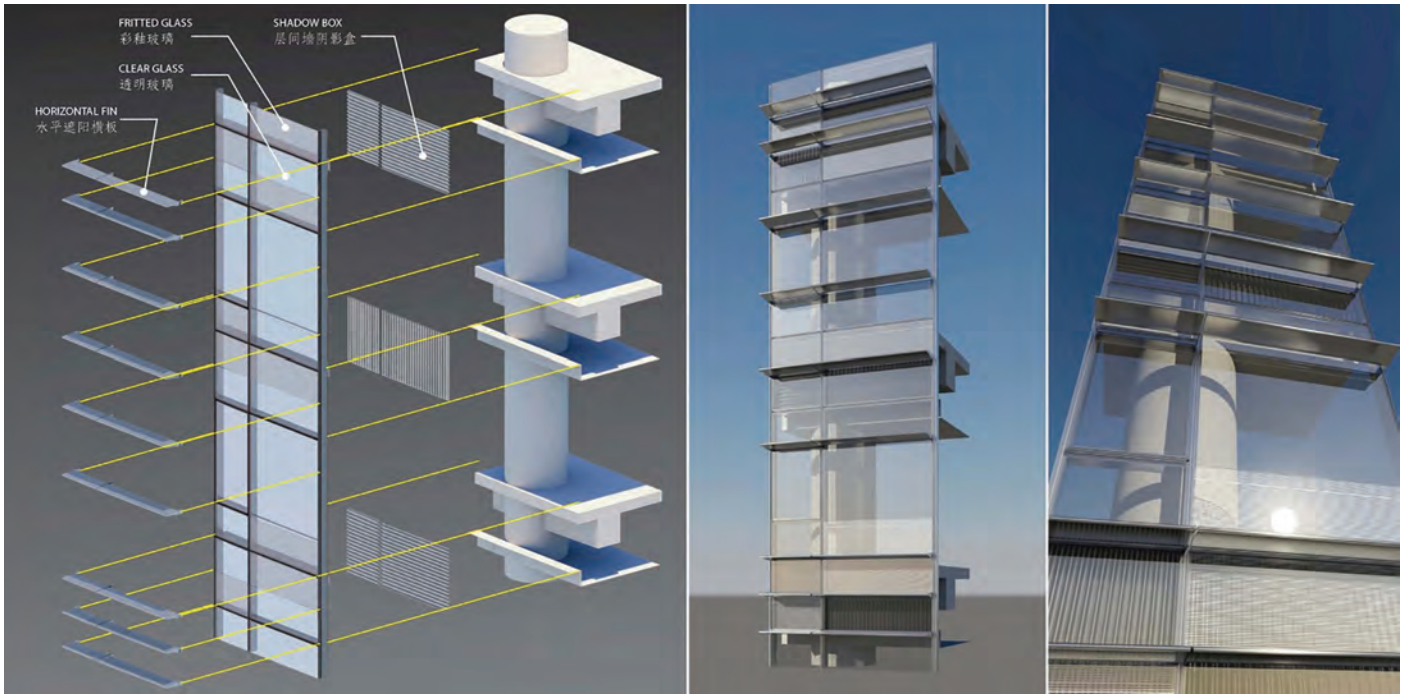

Figure 8. Agile Corporation Headquarters curtain wall assembly (Source: Skidmore, Owings & Merrill LLP, 2016)
图8. 雅居乐集团总部幕墙组成 （来源：Skidmore, Owings & Merrill LLP, 2016）

with multiple fastener connections to accommodate the high wind loads (Figure 8).

The enclosure system employs the pressure equalized rain screen weather protection principle. The primary air/water seal is located to the far inside location to maximize the pressure equalization cavity. This air/water seal location was carefully analyzed and selected to accommodate the combined high wind loads and high water (rain) volumes. The pressure equalization principle is not mysterious. It is simple. For water infiltration, three items must occur. These are:

1. Water
2. Force
3. Opening

If any of the three are removed, there is no water infiltration. Water is present during rain. The force is reduced significantly from outside to inside by a series of gaskets and overlapping gasketed aluminum profiles. The primary air/water line separating interior from exterior is continuous with no openings. Therefore:

1. Water – yes, during rain
2. Force – reduced through the pressure equalized chamber
3. Opening – no

One of the 3 items above is missing – mystery solved!

Contribution to the Urban Environment/ Enhance the Human Environment:
The ground and secured floor of the Agile Headquarters Tower is connected to adjacent buildings and services via an enclosed air conditioned elevated walkway at level 2. Elevated walkways are a New Town District pedestrian strategy to connect adjacent buildings and separate pedestrians from the busy automobile arteries.

Poly Dawangjing Tower 1 – Beijing, China

Climate
Beijing, China's capital city, has a long history dating back 3 millennia. While known for its ancient sites of the Imperial Palace and the Forbidden City, it is home to many iconic modern works of architecture. Beijing is one of the most populous cities in the world with a total of 21 million people as of 2013; it is the second most populous city in China after Shanghai. The average population density is 11,500 people per square kilometer. Beijing has a temperature and continental monsoon climate with four distinct seasons with big temperature differences between day and night. Summers are hot and humid, while the winters are cold and dry. Rainfall in Beijing is typically very light to non-existent, except between June and September. This low rainfall period, coupled with its location near the mountains and desert to the northwest, create long periods of poor and unhealthy air quality. Beijing is located at 39.9 north latitude in the northeastern area of China. Cities with similar latitudes are Valencia and New York City (to provide some world climate context).

并不神秘。它很简单。水的渗入必须有三个条件：

1.水
2.压力
3.开口

如果任一条件缺失，就不会有水渗入。下雨时就会有水。但是，从外到内用一系列胶条和使用胶条的交叠铝型材可以使压力大为减小。而且分隔室内外的主要气密/水密层连续而无孔隙。因此：

1. 水——下雨时有
2. 力——用压力平衡室减小
3. 孔隙——无

以上3个条件中缺少一个——疑难就解决了！

对城市环境的贡献/改善人类环境
雅居乐集团总部大厦的首层和带安保的楼层通过第2层的封闭式全空调天桥与相邻建筑及服务相接。天桥作为珠江新城的人行交通策略目的是连接相邻建筑并将人流与主干道上繁忙车流分开。

中国北京——保利大望京1号楼

气候
中国首都北京有三千年的悠久历史，既以故宫紫禁城而知名，又建造了众多的标志性现代建筑。北京是世界上人口最多的城市之一，2013年人口总计2115万，在中

Use

Located approximately halfway between the Forbidden City and Beijing Capital Airport, the Poly Dawangjing Plaza occupies a prominent position immediately adjacent to the Capital Airport Expressway near the intersection of the Fifth Ring Road (Figure 9). Poly Dawangjing Tower 1 is one of 3 towers that occupy 115,000 m2 of building area adjacent to multiple newly constructed and under construction office towers. An emerging district of 100-meter-tall residential buildings is rising approximately half a kilometer to the west, with an open reserve to the east. Major public open space adjacent to retail is planned to the south and industrial sprawl to the north. The Dawangjing area is a former village rapidly engulfed by Beijing's relentless and rapid outward expansion. Suburban/rural becomes the new urban. Tower 1 is a 31-story, 161-meter-tall (528'-3") office tower. The initial design brief stipulated a speculative office building design for multiple tenants per floor with the top 3 floors to be occupied by the client as a signature headquarters space.

The site location, while visually prominent and convenient to auto access, had no identifiable icon to establish the district as a "location." This is the 3rd major commission with Poly which demands unique, iconic, and timeless design solutions; Tower 1, although a speculative venture, is no different. The design response is a 3-D form that reflects natural light no matter the air quality, coupled with an exterior enclosure to address the climate and air quality issues particular to Beijing, resulting in a faceted, expressed diagrid with a dual exterior enclosure. The faceted exoskeleton enclosure system is part of the primary building structure forming an outer envelope sheathing an independent inner wall enclosing a pair of arc-shaped office spaces and atria at the building ends. The response is an elliptical floor plan with atria at each "short" end and two arc shape office lease areas with 10-meter lease spans. Floor-to-floor heights are a consistent 4.2 meters (13'-9").

Enclosure Design & Detail

The typical exterior enclosure along the two l ong sides of the faceted elliptical elevations is a dual-wall construction consisting of an inner, custom unitized curtain wall organized as a segmented curve in plan, interstitial space, and a faceted outer curtain wall with handset aluminum panels to clad the structural diagrid frame. This dual wall is organized in 2 story heights beginning at level 2 and terminating at the roof enclosure above level 31. The "short" ends of the elliptical elevations at the atria are enclosed by the faceted outer curtain wall with handset aluminum panels. Each enclosure layer of the dual wall, independently and compositely, have performance responsibilities (Figure 10).

Figure 9. Poly International Plaza, Tower 1, within its urban context (Source: Skidmore, Owings & Merrill LLP, 2016)
图9. 保利国际广场1号楼的城市环境（来源：Skidmore, Owings & Merrill LLP, 2016）

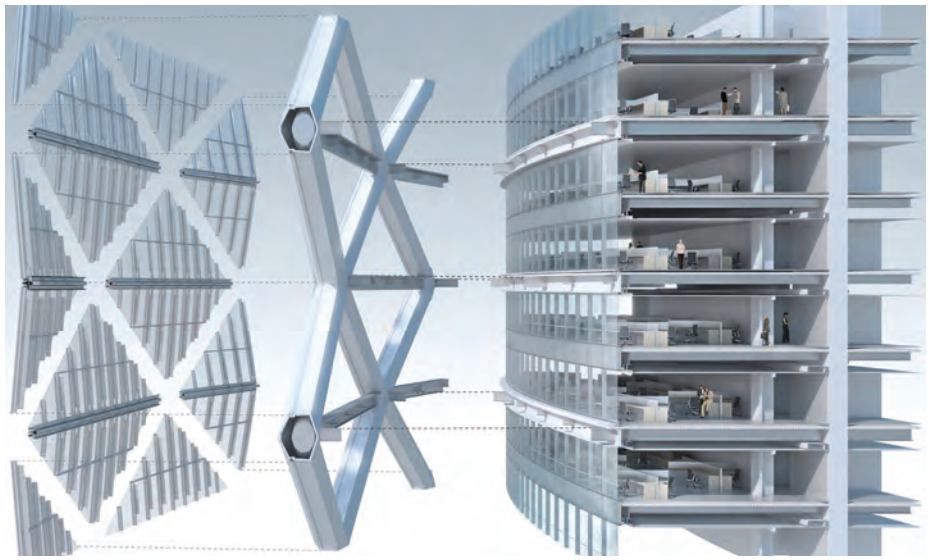

Figure 10. Poly International Plaza, Tower 1, with its dual-wall enclosure assemblies (Source: Skidmore, Owings & Merrill LLP, 2016)
图10. 保利国际广场1号楼双层幕墙组合（来源：Skidmore, Owings & Merrill LLP, 2016）

国仅次于上海。平均人口密度为每平方公里11,500人。北京属大陆性气候，受季风影响，四季分明，日夜温差大。夏季炎热潮湿，冬季极为寒冷干燥。北京降雨量一般在6月到9月间极为罕见。旱季加上靠近西北山脉和沙漠的地理位置，造成长期空气质量差。北京位于中国华北，北纬39.9度。世界上与之纬度相近的其它城市有西班牙瓦伦西亚（39度）和纽约（40度）。

用途

保利大望京广场位于从紫禁城到北京首都机场约一半距离的显要位置，紧邻首都机场高速公路和五环相交处（图9）。保利大望京毗邻多幢新建和在建办公楼，建筑面积115,000平方米，1号楼是项目的三幢塔楼之一。往西约500米，一个百米高层建筑住宅区正在拔地而起；东边保留开放空地；南面临近商业规划主要公共开放空间；北面工业建设正在拓展。大望京区原为村落，被北京迅猛的扩张迅速吞噬了。郊区变成了新市区。1号楼是高161米（528英尺3英寸）的31层办公塔楼。最初的设计任务书规定设计一幢建后招租的办公楼，每层租给多家租户，最高三层作为业主的标志性总部空间留为自用。

项目场地位置明显易见，交通便利，但没有鲜明标志来打造该区特色。这是保利委托的第三个重要项目，业主要求设计具独特性、标志性、永久性。1号楼虽然属建后招租性质其要求并无二致。设计成果是无论空气质量如何都会反射自然光线的三维形体，以表现斜交结构的多面体双层外墙来解决北京特有的气候与空气质量问题。多面体外骨架外墙系统是建筑主要结构的一部分，形成外墙外层，保护独立的内墙，其内部为一对弧形办公空间位于建筑尽端的中庭。楼层平面呈椭圆形，大楼每个“短”端为中庭，两个弧形办公空间的

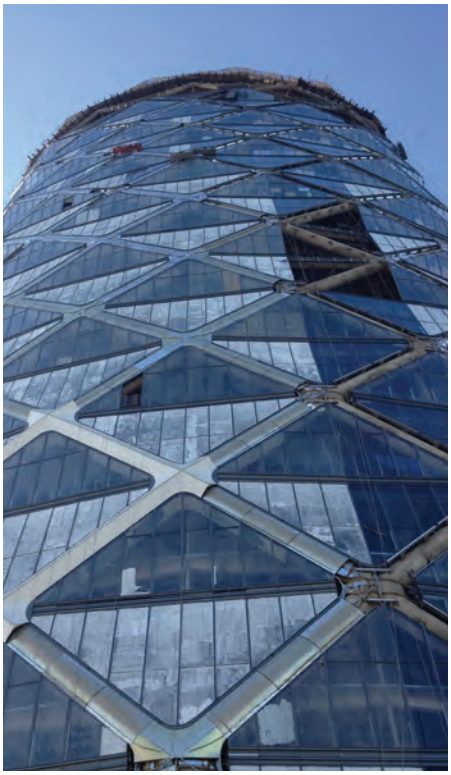

Figure 11. Poly International Plaza, Tower 1 enclosure under construction (Source: Skidmore, Owings & Merrill LLP, 2016)
图11. 保利国际广场1号楼外墙建造
（来源：Skidmore, Owings & Merrill LLP, 2016）

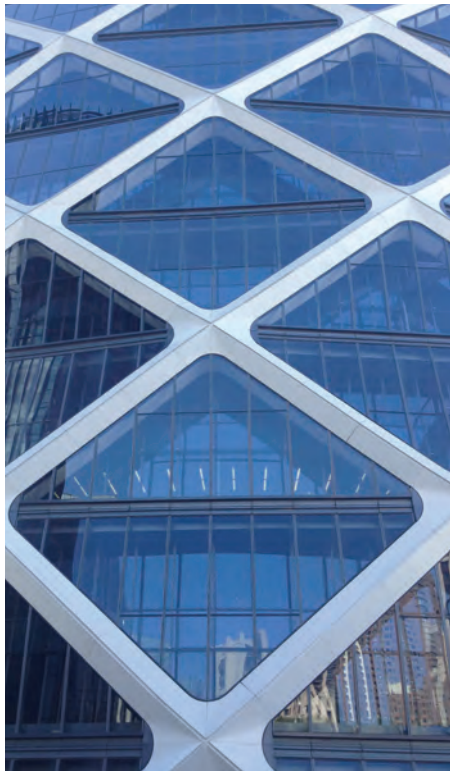

Figure 12. Poly International Plaza, Tower 1, enclosure complete (Source: Skidmore, Owings & Merrill LLP, 2016)
图12. 保利国际广场1号楼外墙竣工
（来源：Skidmore, Owings & Merrill LLP, 2016）

The inner wall encloses 2 floors vertically with unitized curtain wall panels 1.52m wide (5′-0″) by 4.2m tall (13′-9″). This enclosure provides air separation and thermal resistance between the occupied interior spaces and the interstitial space. Glass is secured to the frame with structural silicone at the sill and head and "captured" in a thermally broken extruded aluminum glazing adapter at the jambs. The floor/beam areas are insulated spandrel glass with 100mm-thick (4″) semi rigid insulation. A 1.5mm (1/16″) galvanized steel vapor barrier is applied to the spandrel and fully sealed at the perimeter. A horizontal laminated fire resistant glass panel is cantilevered from the spandrel in the 2-story space to mitigate flame transfer between floors in the interstitial space.

The outer wall tips inward or outward to complete the diagonal facets. Shop fabricated unitized curtain wall panels 1.52m-wide (5′-0″) by heights that vary from 0 to 7.4m (24′-3″) with laminated clear glass. 2-story-high triangles, with the apex up or down, are organized along an electronically powered ventilation slot that opens or closes to temperature presets. The outer wall is designed as the primary water protection line. The interstitial space is designed to be dry and a temperature buffer between interior and exterior. The outer wall is a singular membrane enclosure at the atria without the motorized vent so this enclosure is designed for air and water separator functions (Figure 11).

The structural diagrid enclosure consists of V-shaped galvanized steel sub frames, 1.5mm (1/16″) aluminum flashing with all seams fully sealed, insulation, and 4mm-thick handset multi-dimensional formed aluminum panels. The aluminum diagrid cladding is designed utilizing the rain screen principle, where the flashing is the primary air/water protection line and the exterior aluminum panels are the secondary water protection line. The aluminum panel joinery consists of recessed aluminum extrusions with gaskets to provide a definitive "dry joinery" appearance with no sealant. The cavity between panel and flashing is weeped and drained to the exterior every 2 floors. The diagrid node panel assemblies required extensive research in methods to form aluminum in multiple curved shapes to accommodate the building geometry. Aircraft manufacturers were consulted to specify suggested methods of fabrication. Fully developed 3-D computer files were provided to the fabricator along with "boat curve" contour draws at 3mm increments for each of the 6-node geometry families (Figure 12).

Contribution to the Urban Environment/ Enhance the Human Environment

Tower 1 is placed in a park-like setting with ultra-clear cable supported glass enclosures at ground level. The office lobby public spaces front the park with multiple entry points to visually and physical connect interior to exterior green spaces.

租赁跨度为10米。层高统一为4.2米（13英尺9英寸）。

外墙设计与细节

多面体椭圆形立面两条长边的典型外墙是双层幕墙，由内墙、中间空隙和外墙构成，内层定制单元式幕墙在平面上分段弯曲，外层幕墙呈多面体，用手工安装的铝板包覆结构斜交框架。双层幕墙从第2层起，以两层高度为单元，往上到第31层上的屋顶外墙为止。中庭位置是椭圆形立面的“短”端，外幕墙为手工安装铝板的多面体。外墙体双层表皮的每一层都有独立的和相关连的性能表现责任（图10）。

内墙为单元式幕墙，在竖向上围护2层楼层，单元面板宽1.52米（5英尺整），高4.2米（13英尺9英寸）。内墙为室内使用空间和双幕墙腔体提供空气和温度分隔。玻璃用结构硅胶固定在顶框和底框上，竖框用断热铝型材玻璃扣件“扣住”。楼板/梁区域为层间墙中空玻璃，有厚100毫米（4英寸）的半刚性保温层。层间墙使用了1.5毫米（1/16英寸）厚镀锌钢板隔汽层，四边完全密封。横向夹胶防火玻璃从两层高空间的层间墙悬挑伸出，延缓火焰在内外幕墙之间空腔内在楼层间蔓延。

外墙内倾或外倾来形成多面菱形。工厂加工的单元式幕墙面板为夹胶透明无色玻璃，宽1.52米（5英尺整），高度从0到7.4米（24英尺3英寸）不等。三角形高2层，尖端在上方或下方，沿电动马达驱动的、按预设温度开关的条形通风口布置。外墙设计成主要防水层。内外墙中间空腔设计成干燥的温度缓冲区。外墙在中庭部位是单层表皮结构，没有电动通风，因此这层围护结构设计成具有隔气和隔水功能（图11）。

结构斜交外墙的构成部分为V形镀锌钢支撑框架，交缝完全密封的1.5毫米（1/16英寸）铝披水板、保温层、4毫米厚手工安装多维成形铝板。斜交铝包覆的设计遵循雨幕原理，披水板为主要隔气防水层，外部铝板为次要防水层。铝板接缝用内嵌铝型材和胶条，不用密封胶而是提供明确的“干燥接缝”外观。铝板和披水板之间的空腔每隔2层楼设有排水孔将水排到室外。斜交节点面板组件的设计要求深入研究将铝材做成多种弯曲形状来适应建筑几何造型的方法。期间征询了飞机制造商的意见从而提出具体制作方法的建议。我们还为承包商提供了完备的3维电脑文件，并为每个6点节点几何形体以每3毫米为单位绘制了“船弧形”轮廓（图12）。

对城市环境的贡献/改善人类环境

1号楼位于公园般的环境中，首层用超透明玻璃索网幕墙。办公大堂公共空间面朝公园，有数个入口在视觉上和实体上连接室内空间和室外绿地。