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Transparency in Urban Environment

城市环境的透明度

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Leung's work includes Burj Khalifa, the world's current tallest man-made structure; multiple times recipient of the "Excellence in Engineering" award from the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE); awards from National Institute of Building Sciences, among others. Selected projects also include the General Motors Global Headquarters, Embassy of Ottawa in China, Embassy in Beijing, Rolex Tower in Dubai, and Pertamina Tower – the tallest and largest net zero building in the world etc.

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Abstract | 摘要

A generation of tall buildings has been dominated by International Style with full height glazing that is often vision glass. Large glass was intended to bring the outside in, to allow a connection to the natural environment, and to promote daylighting. Yet the glass box model of architecture is now under criticism due to expense to build, thermal and visual comfort issues for occupants, large carbon footprints, danger for birds, and aesthetic concerns with lack of transparency. This paper will take a fresh look at glass, transparency, energy consumption, and human health before offering alternative paths forward.

Keywords: Comfort, Energy, Façade, Healthy, Sustainable

高层建筑的时代被采用通高玻璃（通常是透视玻璃）的国际风格主导。采用大面积的玻璃是为了将室外的元素，如自然环境带入到室内，提高日光的利用。然而，建筑设计中的玻璃盒模式由于它的建造成本、对使用者的热舒适度和视觉舒适度的影响、大量的碳排放、对鸟类产生的危险，以及透明度低影响美观等方面的因素受到批评。本节在提供其它向前发展的途径之前对玻璃、透明度、能耗和人类健康方面重新进行审视。

关键词：舒适度、能源、幕墙、健康、可持续性的

Reconsidering Full Height Glass

Glass buildings with current technology are undergoing reconsiderations. From the "Death Ray" in Las Vegas that heated up guests, the concaved "Walkie Talkie" that melted Jaguar car parts, the stringent glazing reflectance codes from Shanghai to Dallas, and energy consuming "nightmares," to the blinding glare on Sheikh Zayed Road, there are room for improvements. Selected cities, for example Toronto, regulate glass reflectance to avoid killing of birds near ground; others, like Chicago, have "lights out" programs for migratory birds. While full height glass is perceived as a connection between inside with outside, this connection often stops at visuals in tall buildings. When it comes to energy consumption, almost without exceptions, full height glass buildings perform worse than more opaque ones. The best performers in New York City, accordingly to the city's benchmarking, are the pre-1930 buildings. This suggests that we might have moved the building energy needle in the wrong direction in the last 100 years. Recent research suggests a healthier environment is not only an environment that connects visually to the outside, but also one that connects all senses. Are current all-glass tall buildings, often hermetically sealed, the best way forward? This essay will evaluate glass in light of performance and health to determine ways forward.

对于全高玻璃的重新思考

采用当前技术的玻璃幕墙建筑正在接受重新审视。从灼伤客人的拉斯维加斯"死光（Death Ray）"，伦敦"对讲机"摩天大楼凹形立面玻璃幕墙的反光将捷豹车零件热熔，从上海到达拉斯严格的玻璃反光规范，能耗的"梦魇"，到迪拜谢赫扎耶德路（Sheikh Zayed Road）上建筑的耀眼眩光，都说明还有完善设计的空间。如多伦多等城市，规定玻璃的反射率应避免杀死靠近地面的鸟；芝加哥等其它城市，则为候鸟制定了"熄灯"计划。虽然全高玻璃能够有助于建立室内与室外之间的联系，这种视觉连接却经常在高层建筑群中被打断。从能源消耗方面讲，几乎没有例外，通高玻璃幕墙建筑的节能效果要低于采用更多不透明幕墙的建筑。除了受到建筑肌理的影响以外，根据城市衡量标准，纽约市能耗性能最佳的建筑是1930年之前建成的建筑。这表明在过去的100年里，我们可能将建筑节能标准指错了方向。最近的研究表明，一个更健康的环境，不仅是在视觉上与外界连接，而是一个与所有方面都有联系的环境。目前全玻璃幕墙的高层建筑常常是完全封闭的，这是未来发展的最好方式吗？本文将从玻璃的性能、健康及所选择的未来发展方式等方面对玻璃进行评估。

What is Glass For?

Glass can provide daylighting, solar energy (performance), and visuals to outside (health). Windows can provide fresh air, free cooling, sound transfer, and better resiliency. Do the basic functions of glazing (daylighting, solar energy, and visual connection), require full-height glazing?

Performance

Energy: For most buildings, full height glass does not save energy. It is consistent in all climate zones. See Figure 1 for a study of a typical office building at 50 M (164.0') x 50 M (164.0') with 8M (26.2') perimeter zone (Figure 1). As hermetically sealed boxes, glass curtain walls have higher infiltration rates than opaque wall construction (7.3 M3/Hr; 0.4 CFM/sf for infiltration in glass vs. 2.2 M3/Hr; 0.12 CFM/sf for opaque wall per DOE-K Gowri, 2009) and worse thermal resistance. Conventional glass has a significantly lower (more than 5 times) thermal performance compared to insulated walls (prescriptive requirement of fenestration maximum: U-0.35 Btu/Hr.ft2.ºF, U-1.99 W/M2.ºC, nonmetal framing; wall maximum: U-0.064 Btu/Hr.ft2.ºF; U-0.365 W/M2.ºC, Steel Building, Climate Zone 4, per ASHRAE 90.1, 2013). As a result, the ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) prescriptive standard limits glazing to 40% (ASHRAE 90.1, 2013). See Figure 2 on performance when percentage of glazing is different than the 40% baseline within the same office building (Figure 2). In its 2013 issue, the prescriptive requirements also limited east and west façades to have less than 25% window wall ratio (WWR, low angles create glare). IECC 2012 specifies the window wall ratio at 30%, though the way it calculates walls is slightly different. In cooling-dominated environments, heat gain through windows from solar radiation and conductance are much more than opaque walls. In heating climates, since direct solar heat gain is dynamic and moves from east to west throughout the day, while conductance heat lost is continuous throughout 24 hours, the net effect is usually an increase in glazing percentage worsens energy performance.

Daylighting: From our study regarding a conventional office building, full height glass buildings provide more daylight to a space. The Advanced Building Daylighting Pattern Guide suggests that a space with a 9' ceiling, a 100% interior wall glazed façade can get 95% of the space day lit with 300 Lux at 7.92 m (26') lease span. However, this daylighting

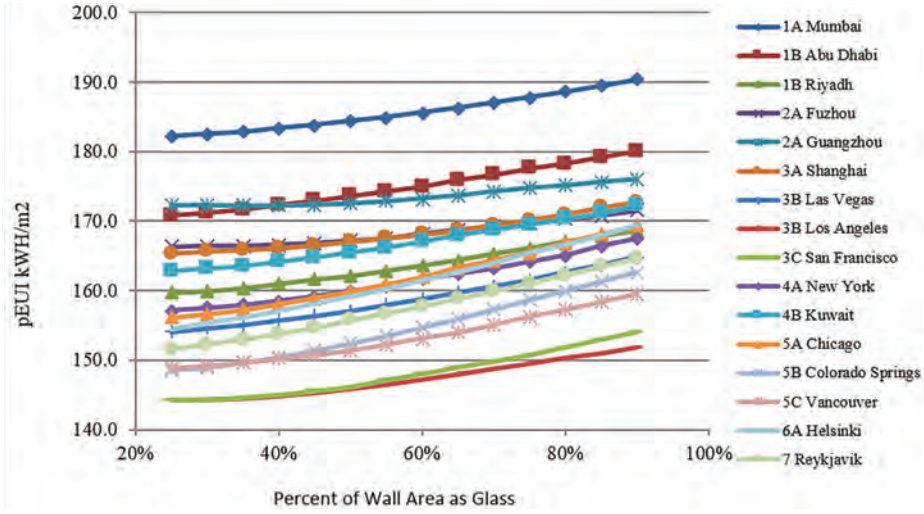

Figure 1. Predicted energy use intensity of an office building in all climate zones (Source: SOM)
图1. 座办公建筑在所有气候区预测能源使用强度（来源：SOM）

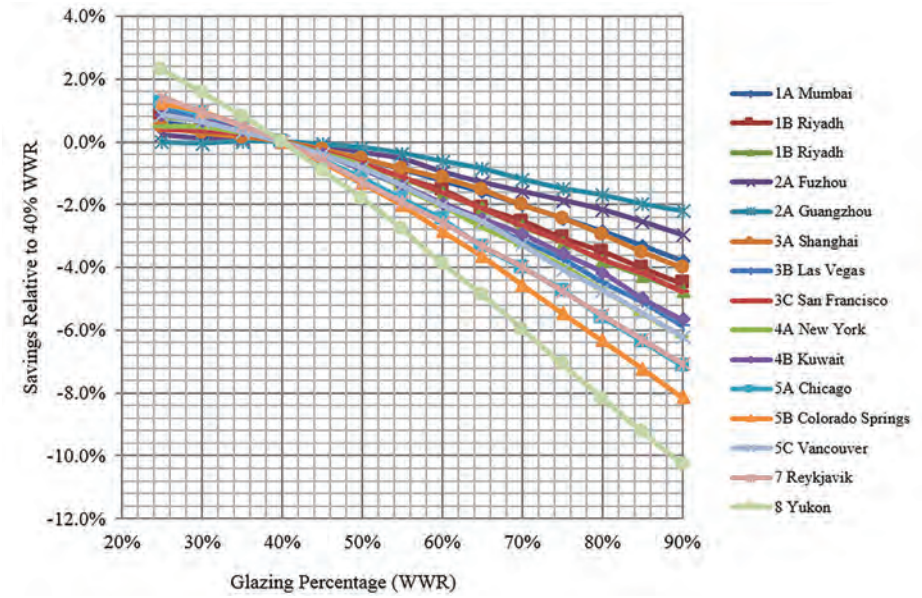

Figure 2. Energy use difference in percentage of an office building in all climate zones (Source: SOM)
图2. 座办公建筑在所有气候区能耗差异的百分比（来源：SOM）

玻璃的用途

玻璃可以提供采光、太阳热能（节能）及与室外景观的视线联系（健康）。窗户通常由玻璃组成，可以提供新鲜空气、自然冷却、声音传递及更好的适应性。玻璃的基本功能（采光、太阳能和视觉联系）要求全高落地玻璃吗？

性能

能源：对于大部分建筑，全玻璃幕墙并不节能。在所有气候区均如此。如图1所示，为一项针对50 米（164.0'）x 50 米（164.0'）、8米（26.2'）外围进深区域的标准办公建筑的研究（图1）。为了保持一致性，在所有的气候区均采用相同的玻璃，尽管在实践中有些气候响应特性有所不同，特别是极端差异的气候。作为一个封闭箱，玻璃幕墙比不透明墙具有更高的渗透率（根据美国能源部2009年数据，玻璃幕墙7.3立方米/小时；0.4 立方英尺/分钟/平方英尺，而不透明幕墙2.2立方米/小时；0.12立方英尺/分钟/平方英尺），且热阻性能更差。尽管较高的渗透率能够为室内引入更多的室外新风，但这是无法控制的、难以量化的，且往往会产生能源损耗。相对于保温墙体，传统玻璃的热工性能更低（相差5倍以上），（规范规定要求可视区域最大值：U-0.35 BTU / Hr.ft2.ºF，U-1.99 W /M2.ºC，非金属框架；墙体最大值：U-0.064 BTU /Hr.ft2.ºF；U-0.365 W /M2.ºC，钢结构，气候4区，根据2013年美国供暖、制冷和空调工程师学会ASHRAE 90.1标准）。其结果是，ASHRAE规定玻璃使用的标准限值至40%（ASHRAE 90.1，2013年）（图2）。关于同一办公楼玻璃比例不同于40%基准时的性能表现。在其2013年发布的标准中，规范性要求也限制了东西外墙的窗墙比应低于25%（WWR，低角度形成眩光）。国际节能规范（IECC）2012规定窗墙比为30%，其对墙体的计算方式略有不同。在供冷为主导的环境中，通过窗口从太阳辐射和传导所获得的得热比不透明外墙多得多。在供暖环境中，由于直

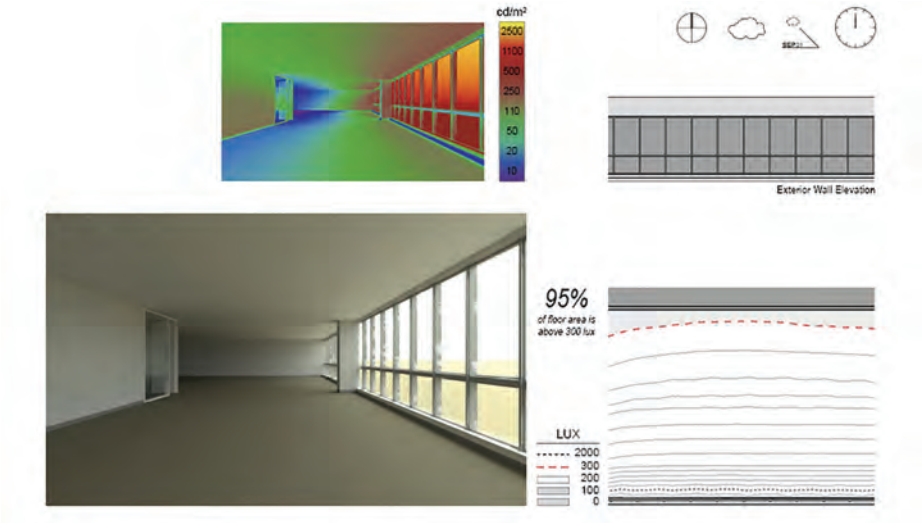

Figure 3. Daylighting with 100% interior windows at 2750mm (9') ceiling (Source: ADVANCED BUILDINGS INSTITUTE)
图3. 带有100%室内窗户的2750mm（9英尺）吊顶空间的采光（来源：ADVANCED BUILDINGS INSTITUTE）

comes at the expense of higher total energy consumption (Figure 3). In Figure 4, using the same office building in Shanghai as an example, while increasing window wall ratio has benefits in daylighting and reduction in the "interior lights" category, the "heating" and "cooling" energy change is much more significant, and as result, overall energy consumption is increased. The change in slope with window to wall ratio in Figure 4 illustrates the same point (Figure 4).

Besides daylighting, another benefit of full height glass can be improving the day time circadian rhythm. People in urban areas often spend much of the time indoor and suffer from "light deficiency" during the day. Increased window wall ratios can bring more daylight indoors to improve the situation, especially for people that are unable to go outside, e.g., sick patients in intensive care. At night, the situation is reversed. Without closing the window curtains, bright light from surrounding buildings through glass can potentially disturb the circadian rhythm with too much light available while the body is trying to rest. This is especially true with blue lights from neon signs or from exterior lighting of other buildings. A rational solution can be walking outside during noon time, especially sunny days, roughly getting 80% of the anchoring (First 30-60 minutes) effect required in the daytime circadian rhythm, followed by dimmed lights in the evening.

Thermal Comfort: Achieving thermal comfort with full height conventional glazing is more difficult than a building with a lower window to wall ratio. Thermal comfort, in terms of operative temperature, is an average of air temperature and mean radian temperature. Since glass has lower thermal resistance compared to a solid wall, a full height glazed space will be hotter in the summer and colder in the winter in mean radian temperature. It is more difficult in extreme climates (hot or cold) to achieve comfort close to the exterior wall area. As a result, some occupants in the exterior zones of the office buildings may have to dial up the air heat in the winter or dial down the cool air in the summer to "offset" the mean radiant temperature. This can be part of the reason why we are seeing overheating and overcooling of the air temperature in many offices which have a glass exterior.

Glare: Full height glazing will create more glare. Part of the issue is the nature of the sun's path from east to west creates many hours of low angled sunshine that is hard to shade. This can partially explain Urban Green's "Seduced by the View" report that 59% window area was covered by blinds and shade at all time. Over 75% of buildings had more than half their windows covered by blinds. Dynamic glazing that can change opacity can help, though people with very sensitive eyes still can have glare issues.

接太阳得热在一天内从东到西呈现动态变化，而通过传导损失的热量在24小时中是连续的，玻璃比例的净效应通常是增加玻璃比例将降低节能性能。

采光：从我们对传统办公建筑的研究中得出，通高玻璃幕墙能够为室内空间提供更多的日照。先进的建筑采光模式指南中建议，对于9英尺吊顶的空间，100%落地玻璃立面使得室内95%的空间能够获得日照，7.92米（26英尺）的出租跨度内为300Lux。但这样的采光是以更高的总能耗为代价的（图3）。在图4中，以上海同样的办公建筑为例，尽管增加窗墙比有利于建筑室内空间获得更多的日照，减少"室内照明"用量，但供暖和制冷能源方面的变化更为显著，因此总能耗是增加的。图4中窗墙比的变化率证明了这一观点（图4）。

除了采光，通高玻璃幕墙的另外一个优点是能够提高日间的生理节律。生活在城市区域的人们停留在室内的时间较多导致受"日照不足"的影响。增加窗墙比能够使更多的日光照射到室内，从而改善这种情况，特别有利于那些无法到室外的人们，例如在重症监护室的病患。在夜间，情况正好相反。如果不拉窗帘，在人们的身体需要得到休息的时候，周边建筑透过玻璃的明亮的光线会扰乱生理节律，特别是来自霓虹灯的蓝色光线或其它建筑的外部照明。一种比较合理的解决方案是正午时在室外行走，特别是在天气晴朗的日子，约可获得日间生理节律所需的锚定效应（起初的30–60分钟）的80%，其余的则通过在夜间变暗的灯光获得。

热舒适度：采用通高传统玻璃来实现热舒适度比窗墙比较低的建筑更难。从有效温度方面而言，热舒适度是指空气温度以及平均辐射温度的平均值。由于与实心墙相比，玻璃的热阻较低，在平均辐射温度方面，夏季带有通高玻璃的空间将会更热，冬季则会更冷。在极端气候条件下（热或

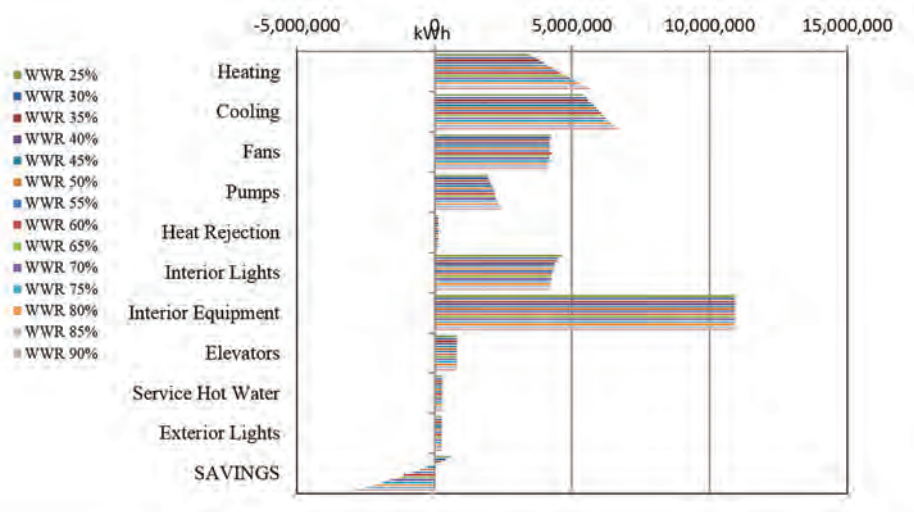

Figure 4. Window Wall Ratio impact on energy consumption for an office building in Shanghai (Source: SOM)
图4. 一幢上海办公建筑中窗墙比对能耗产生的影响（来源：SOM）

Resiliency: Sealed, full height glazing reduces the resiliency of buildings, particularly tall buildings. In the event of a power outage or failure of a mechanical system, building occupants need a certain level of indoor comfort maintained. In cooling-dominated buildings – most offices – sealed full height glazing increases solar gains and indoor temperatures. Lower window-to-wall ratios help reduce solar gains to maintain more comfortable indoor conditions. Operable windows can further improve the resilience of a building by providing ventilation and cooling even when mechanical systems or power may have failed. The United States Green Building Council (USGBC) offers a LEED pilot credit for Resilient Design, and particularly for Thermal Resilience, which describes how well a building can passively maintain livable indoor conditions in the event of an emergency. Tall buildings can exacerbate this resiliency concern for all glass buildings because they are less often mutually shaded by surrounding buildings, which exposes them to even more solar radiation.

In summary regarding performance, while full height glazing can bring about better daylighting and daytime lighting for circadian cycle, it is not as beneficial to energy, thermal, comfort, glare, resilience, and potential night time circadian rhythm performance.

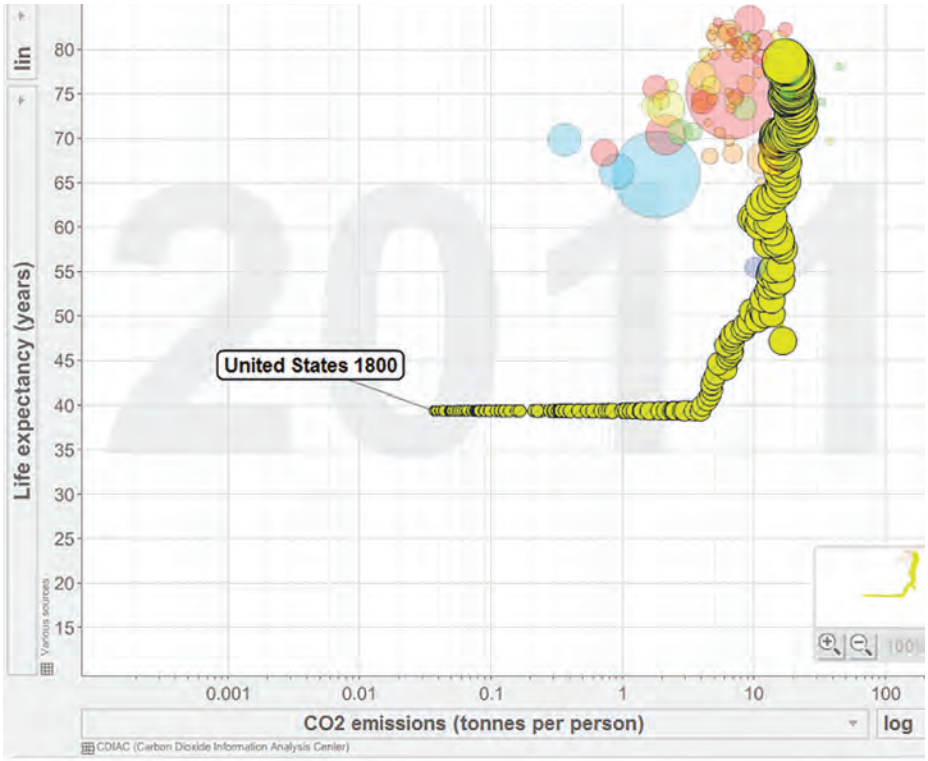

Figure 5. Life expectancy and carbon emission growth in the US, from 1800 (Source: GAPMINDER)
图5. 美国自1800年以来预期寿命和碳排放增长（来源：GAPMINDER）

Health

The urban environment, especially in hermetically sealed tall buildings, has decoupled humans with nature. Humans and animals have important roles in the ecology of life, both in contributing and receiving the benefits from the ecology system. Isolation of a species can have unintended consequences. Urban populations spend 90% of their time indoor in relatively sterile environment. Life expectancy in the US during much of the 1800s was about 40 years, though infant and childhood mortality were important factors to consider. Starting around 1890, life expectancy in US started to climb (yellow bubbles in Figure 5 (Figure 5), coinciding with a switch to a more fossil fuel basd economoy and also with acceleration of urbanization (see Figure 5). In 2015, US estimated life expectancy was 79.68.

We almost doubled our life expectany in the last century. The US is not alone, as many countries have also increased their life expectancy with urbanization. Life exptancy is expected to climb further in the near future in most countries. As we live longer, several trends suggest the human race is becoming

冷），靠近外墙的区域更难实现其舒适度。因此，办公建筑外区的部分使用人员可能在冬季需要调高供热或在夏季调低供冷以“抵消”平均辐射温度的影响。这就是我们在很多采用玻璃外墙的办公建筑中发现室内温度过热和过冷的部分原因。

眩光：尽管有多种因素会影响眩光，但通高玻璃很容易就会带来过多地光线。此问题的部分原因是由于从东向西的日照路径会产生多个小时的低角度日照，很难遮挡。这也部分解释了城市绿化委员会“Seduced by the View”报告中所提到的59%的窗户区域一直被百叶和遮阳装置遮挡的情况。超过75%的建筑中有多于一半的窗户被百叶遮挡。能够调节通透度的动态玻璃会有所帮助，但对于眼睛敏感的人来说，仍存在眩光的问题。

适应性：封闭的、通高玻璃减少了建筑的适应性，特别是高层建筑的适应性。在断电或机电系统发生故障的情况下，大楼内的使用人员需要室内保持一定的舒适度。大多办公建筑为供冷为主的建筑，封闭的通高玻璃增加了太阳得热，提高了室内的温度。较低的窗墙比有助于减少太阳得热，保持更为舒适的室内环境。可开启窗通过提供通风和冷却，即便在机电系统或电力发生故障的情况下，也能进一步改善建筑的适应性。特别是对于经常发生断电区域内的建筑，设置可开启窗十分有利，应提供规格适宜的可开启窗并布置在合理的位置，提供最低限度的通风量。美国绿色建筑委员会（USGBC）提供了一个适应性设计，特别是热适应性设计的LEED试行得分项，描述了在紧急情况下，建筑如何很好地被动保持舒适的室内环境。在所有的玻璃幕墙建筑中，高层建筑在适应性性方面的顾虑更大，因为它们通常不会与周边的建筑形成相互遮阳，使得这些建筑暴露在更多的太阳辐射下。

综上所述，从性能方面而言，尽管采用通高玻璃能够带来更好的日照以及更好的日间生理节奏，但对于能源、热工、舒适度、眩光、适应性以及夜间生理节奏表现而言益处相对较少。

健康

城市生态环境，尤其在封闭的高层建筑中，人与大自然分隔开来。无论是对生态系统做出的贡献，还是从生态系统获得所带来的益处，人类和动物都扮演着非常重要的角色。城市居民90%的时间都处在相对无菌的室内环境中。远在19世纪，美国的预期寿命在40岁左右，（尽管婴儿和儿童的死亡率是需要考虑的重要因素）。大约从1890年开始，伴随着矿物燃料为基础的经济更替及城市化进程的加快，美国的预期寿命开始攀升（请参见图5中的黄色气泡部分）（图5）。在2015年，美国估计的预期寿命为79.68岁。

在过去的一个世纪中，我们的预期寿命几乎翻了一倍 。 不仅仅在美国，其他许多国家的预期寿命也随着城市化进程而有所提高。在大多数国家，预期寿命在不久的

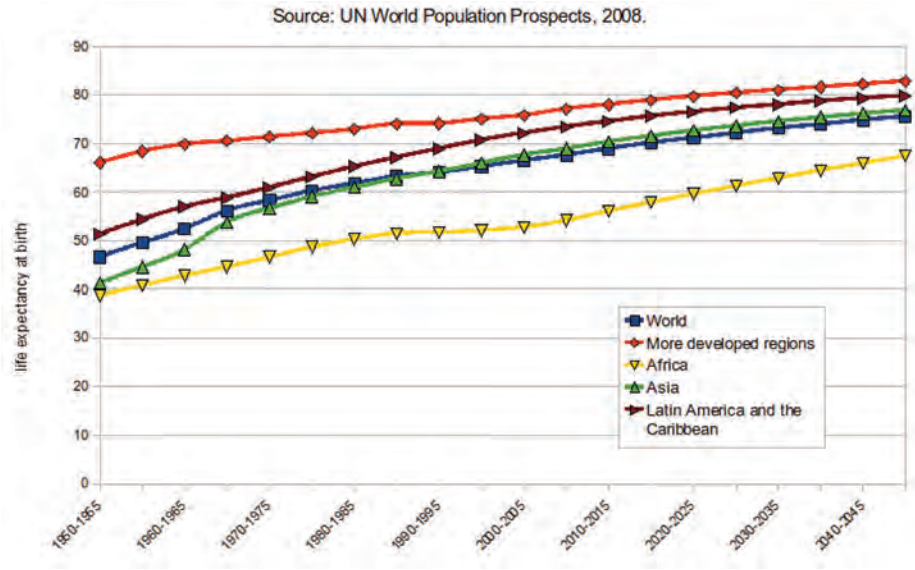

Figure 6. Life expectancy and birth by region, 1950–2050 (Source: UNITED NATIONS)
图6. 1950年至2050年，预期寿命及出生率（按地区划分）（来源：UNITED NATIONS）

more fragile, and decoupling with nature is at least part of the reason (Figure 6).

Humans become more obese: Obesity in the US accelerated around the early-mid 20th century, around the time when air conditioning was introduced and popularized. Today, obesity has become an epidemic in selected developed countries. Obesity is projected to become an even larger problem in the future by the Organization for Economic, Cooperation and Development (Figure 7). While diet, exercise, and genetics are often blamed as causes, living in conditioned, indoor environments can be a cause of obesity. Recent studies also indicate obesity can be caused by our hermetically sealed buildings that isolate the microbial biome from the outdoors and interrupt the natural circadian cycle.

Chronic Diseases: Asthma has been identified as a developed world disease. Allergies are on the rise with increasing urbanization. While the causes of asthma and allergies can be varied, they are also linked to the disturbances of the microbial biome through hermetically sealed buildings. Interruption of the circadian cycle, potentially from bright and blue light from surrounding the urban environment through all glass buildings, was related to causing different types of cancer. Further scientific research is still required to confirm these findings.

Mental Health Disorder: According to Richard Louv, US author and journalist, our generation suffers from "Nature Deficit." Without proper interaction with nature, our children suffer from a wide range of disorders, which are not documented in the medical manual as a disorder, e.g., ICD-10, DSM-5. A study from Stanford University also indicated that the urban environment is associated with more mental disease, and a 90 minute walk in nature can reduce activities in the area of the brain where it is known to cause depression, which is vital in the urban environment. The same study concluded city dwellers have a 20% higher risk of anxiety disorder and 40% higher risk of mood disorder.

Moving Forward

Energy: Due to higher infiltration and lower thermal resistance, all glass buildings consume more energy. To mitigate the impact, either glass percentage has to be lowered, full height glazing impact must be minimized by integrated building elements, or advance façade designs must be developed. Current SOM projects have a

将来也有望持续攀升。当我们的寿命变长，我们也会变得更加脆弱吗？一些趋势表明人类正变得越来越脆弱，与大自然的脱离至少是其中部分原因（图6）。

人类变得更加肥胖：大约在二十世纪初至二十世纪中，当空调在美国引入及推广的时候，美国的肥胖率开始加速增长。尽管导致肥胖的其它因素在那段时间也同样发生了变化，但不可否认空调的推广使得更多的人们愿意花更长的时间在封闭的建筑内，成为了导致肥胖的一大因素。如今，肥胖已成为一些发达国家的流行病。经济合作与发展组织预计肥胖在未来会成为更大的问题（图7）。尽管饮食，运动，和基因经常被指为肥胖的成因，但长期生活在室内空调环境中也会造成肥胖。最近的研究还表明，封闭的建筑隔离了室外的微生物种群并打断了自然的昼夜周期，这也会造成肥胖。上述示例科学地解释了将人类与自然隔离后所产生的影响。

慢性疾病：哮喘已被认定为一种在世界上广泛流行的疾病 。随着城市化进程的加剧，过敏反应的发病率也在上升。虽然哮喘和过敏的发病原因可以是多种多样的，但封闭的建筑对微生物种群的干扰与哮喘和过敏的病发有着联系。干扰昼夜周期,城市周边环境透过全玻璃幕墙进室内的强光特别是蓝光，会对生物钟造成干扰，也是造成不同类型癌症的原因。这些研究发现仍需要进一步的科学研究证明。

精神健康障碍：美国作家兼记者理查德·洛依表示，我们这一代人遭受着“自然缺失”所带来的影响。如果不能与大自然进行适当的互动，我们的孩子会患有多种疾病，这些疾病并没有记录在医疗手册中，例如ICD-10，DSM-5。斯坦福大学的一项研究也表明，有更多的精神疾病与城市环境相关，在大自然中散步90分钟可以降低

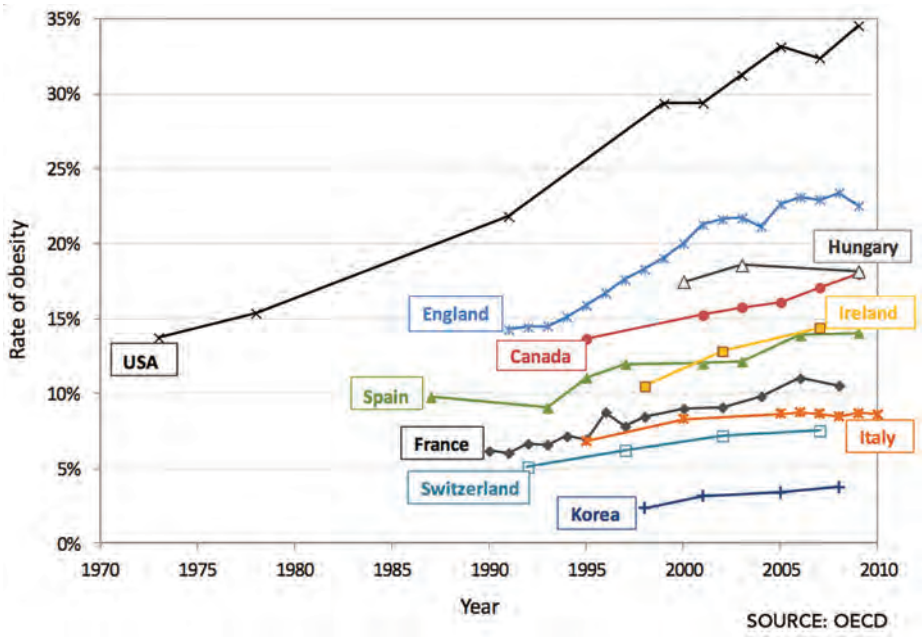

Figure 7. Obesity rate in developed countries from OCED data (Source: OCED)
图7. 发达国家的肥胖率（来自经济合作与发展组织的数据）（来源：OCED）

Figure 8. China State Construction Engineering Corporation Headquarters, Beijing: less than 40% window wall ratio (Source: SOM)
图8. 北京CSCEC总部大楼，低于40%窗墙比（来源：SOM）

Figure 9. Guiyang Tower, Guiyang, China, integrated façade shading to minimize WWR and glazing impacts (Source: SOM)
图9. 贵阳大厦，贵阳，中国，整合的外立面遮阳，尽可能减少窗墙比以及对玻璃产生的影响（来源：SOM）

wide range of window wall ratio, including buildings with 34% (Figure 8). While the building does not exceed 40% window wall ratio overall, full height glass was strategically place in area of highest potential for view and transparency. There are websites that have exemplary buildings that are below 40% glazing, e.g., "40 under 40" – forty exemplary buildings under 40% window wall ratio. Other buildings have integrated shading devices that use non-reflective material to minimize glare and shade the window (Figure 9). The use of ceramic elements to reduce WWR and help shade the glazing is another option.

Regarding advance façades, a fan assisted double wall can be integrated with an atrium to provide inside-out ventilation for the Bank of Beijing. Rather than bring outside air in for natural ventilation, this building will use the atrium to bring the outside air into the base of the building, then use stack effect of the ventilated double wall windows, with fan assist, to pull the atrium air to work spaces (Figure 10).

大脑中已知的会导致抑郁区域的活跃度，这在城市环境至关重要。同一研究还得出一项结论，即城市居民患上焦虑症的风险要高20%，患上情绪障碍疾病的风险要高40%。

未来的发展

能源：由于较高的渗透和较低的热阻，全玻璃建筑能耗更大。为了减轻这种影响，可以减少玻璃的百分比，必须通过整合的建筑元素将通高玻璃产生的影响降到最低，或必须采用先进的外立面设计。SOM目前的项目中所设计的窗墙比范围较广，包括34%窗墙比的建筑（图8）。在建筑整体上不超过40%窗墙比的前提下，全层高玻璃被精心安排在视线和通透度最佳的位置。有些网站中列出了玻璃比例低于40%的建筑范例，例如"40 under 40"–列出了窗墙比低于40%的40个范例建筑。其它建筑则结合了遮阳装置，采用非反射材料，以尽可能地减少眩光并为窗户提供遮阳（图9）。利用陶瓷构件降低窗墙比，为玻璃提供遮阳。

有关先进的外立面系统，北京银行项目中采用了带有风机辅助的双层幕墙系统，结合中庭，为建筑提供了由内而外的通风。该建筑并没有在办公空间直接引入室外新风进行自然通风，而是利用中庭将室外自然新风引入建筑的底部，再利用通风双层幕墙上窗户的烟囱效应，借助风机，将中庭的空气引入工作空间（图10）。

需要进行更多的研究，使得窗户能够像不透明墙体一样节能。未来的开发项目需要采用能够与太阳进行动态呼应的玻璃系统，可采用电致变色玻璃来实现，与不透明墙体具有相似的热工性能（热阻值和渗透率）。应注意到很多的窗户技术，包括R–20窗户，已经问世，需要大批量生产以降低制造成本。

健康：封闭的全玻璃幕墙高层建筑仅提供了视觉上的联系，整体性感官，包括视觉、嗅觉以及触觉等多方面可为人们提供一种更健康、更积极的体验。最近的研究表明，居住在最绿色地区中的女性（同样适用于男性)和生活在其它区域的人相比，患肾脏疾病的死亡率要低41%，患呼吸系统疾病的死亡率要低34%，患癌症的死亡

Figure 10. Bank of Beijing ventilated double wall (Source: SOM)
图10. 北京银行项目通风双幕墙（来源：SOM）

Much research needs to be done to make windows as energy efficient as opaque walls. Future developments need glazing that can dynamically react to solar, which can be done with electrochromatic glazing, and has similar thermal performance (R value and infiltration) compared to an opaque wall. It should be noted that many window technologies, including R-20 window, are available already, although they need to be mass produced to lower cost production cost.

Health: Rather than just visual connection in our hermetically sealed all glass tall buildings, a holistic spectrum of senses, visual, olfactory, and tactile can create a healthier and more positive experience. Recent studies indicated women (also applicable to men) that live among the greenest areas have 41% lower death rate for kidney disease, 34% lower death rate for respiratory disease, and 13% lower death rate for cancer. Another study on trees lost due to the Emerald Ash Borer concluded human mortality related to cardiovascular and lower-respiratory-tract illness increased as a result. Though the study cautioned that they explored correlation and not causation, these findings add to a growing knowledge that nature provides major public health benefits.

Visual: Full height glass views can have positive health benefits if the view is perceived as an open view of nature. The aesthetic of a full height glazing view to the outside can be fantastic, but the perceived openness and what occupants see through the window also matter. Recent research suggests the positive visual effect of having windows may be more about the perceived openness, which tall buildings can offer. Also, seeing green landscape has the most benefit regarding visual impacts. Seeing water is also better than seeing the urban built environment. Visuals of nature can improve cognitive abilities and help us to relax. Research in Toronto by Professor Marc Berman from The University of Chicago suggested having 10 trees on a city block can make a person feels $10,000 richer and 7 years younger. Also, disconnected nature, similar to potted plants inside a building, are less likely to thrive than plants integrated with nature outdoors. Taller buildings in urban environments can provide greater access to open views of nature given the increased view range from higher elevations. While a low-rise building may not provide views of the nearby ocean or park, a high-rise building is more likely to provide such a view.

Olfactory and beyond: Connection to air from nature does not require full height glass, and can bring about both physical and mental benefits through microbials, Phytoncides, and negative ions. A University of Oregon study indicated indoor air with mechanical ventilation has less diversity of microbials and more pathogens, while outdoor air tends to have a larger diversity of micro bacteria and less pathogens. A building with operable windows has more diversity of micro bacteria than a sealed building. This suggests a building should be opened to outside where possible given the outdoor ambient reflects a higher diversity of microbials. The immune system of humans can be enhanced by breathing in Phytoncides from the forest according to the New York State Department of Environmental Conservation. Phytoncides are an antifungal and antibacterial chemical that is produced by trees. When breathed into human bodies, they increase the white blood cell count to boost our immune system. In urban areas, the Phytoncides level is lowered than in a forest with trees. Additionally, the effect of having a hermetically sealed building with only visuals to the outside can be compared to humans feeling lethargic during cloudy days. This is because of the impact of indoor positive ions (carbon dioxide with a positive charge) can make us feel lethargic and tired. On the contrary, negative ions (oxygen molecule with a negative charge) are a mood enhancer. The ocean shore, mountains, trees, and waterfalls are all great sources of negative ions. Compared to country air, an average of 2000–4000 of negative ions per cubic centimeter, indoor "acceptable" environments only have 200–400 negative ions per cubic centimeter. The net effect is humans can feel more tired indoors in hermetically sealed buildings with minimal ventilation.

Tactile: Touching nature can be beneficial. Researchers from New York University, after studying the microbial biome in different indoor surfaces in the City of Manaus in Brazil and the Village of Checherta in Peru, concluded, "The remarkable changes in home microbial content across differing levels of urbanization raise the possibility that the reduced microbial exposure to environmental bacteria seen in modern homes contributes to immune and metabolic disorders, from asthma to obesity, which have become the new disease paradigm in the industrialized world" (J. F. Ruiz-Calderon, 2016). Researchers also found that the touching of other microbes outdoors can have positive impacts. For example, Mycobacterium Vaccae, a bacteria often found in soil that people will touch through gardening, may stimulate serotonin production, which mirrors the effect on neurons similar to drugs like Prozac.

率要低13%。另一个针对绿灰虫导致树木受到严重破坏的研究表明人类因此而患心血管疾病和下呼吸道疾病而导致的死亡率也有所增加。尽管该研究中谨慎提醒他们探究了相关性，而不是因果性，但从这些发现中可以看出大自然为人们提供了主要的公共健康福利：

视觉：对于通高玻璃视线，如果人们认为获得了自然开敞的视线，则它能够为人们的健康带来积极的影响。透过通高玻璃向外望去，能为人们带来美好的体验，但同时人们所感受到的开阔性以及人们透过窗户所看到的是怎样的景致也十分重要。最近的研究显示窗户所产生的积极的视觉效果更多的是关于人们所感受到的开阔性，而高层建筑能够为人们提供这样的感受。同时，从视觉影响角度而言，欣赏到绿化景观是最有益的，欣赏到水景比欣赏到城市建筑环境更佳。自然的视觉效果有助于提升人们的感知能力，使人感到放松。芝加哥大学Mac Berman教授针对多伦多市进行的研究显示在一个城市街区内种植10棵树会让人感觉到多拥有$10,000的财富，并年轻了7岁。同时，隔离的自然系统，例如大楼内的盆栽，则不如生长在室外大自然中的植物成长的茁壮。在城市环境中，较高的建筑能够提供更加开阔的视野，因为随着标高的增加，视线范围也随之扩大。而低层建筑也许无法提供周边海洋或公园的景致，而高层建筑更有可能让人们欣赏到这样优美的景色。

嗅觉：与自然空气相连，并不需要采用通高玻璃，可通过微生物、芬多精以及负离子为人们同时带来身体和精神上的益处。俄勒冈大学的一项研究表明利用机械通风的室内空气中微生物的种类较少，病原体种类较多，而室外新风中往往有更加多样性的微细菌以及较少的病原体。相比封闭的建筑，带有可开启窗的建筑有更加多样性的微细菌。这表明建筑应尽量在适当的位置与室外相通，因为室外环境中存在更多样性的微生物。根据纽约州环境保护部门，人们通过吸入森林中的芬多精能够增强人类的免疫系统。芬多精是树木所排放的一种抗真菌和抗菌化学物。当吸入人体后，它们能够增加人体内白细胞的数量，增强人体的免疫系统。在城市区域，芬多精的含量与森林相比较低。此外，在与室外仅有视觉联系的封闭的建筑中，其产生的效果与阴天时人们感到昏昏欲睡、无精打采的效果类似。这是因为室内的正离子（带有正电荷的二氧化碳）会令人感到昏沉和疲倦。与此相反，负离子（带有负电荷的氧分子）则有利于提升人们的情绪。海岸、山脉、树木和瀑布都富含有负离子。乡间空气中每立方厘米平均含有2000–4000的负离子，而可以"接受的"室内环境中每立方厘米平均仅含有200–400的负离子。最终的结果是在带有极少通风的封闭的建筑中人们在室内会感到更加疲惫。

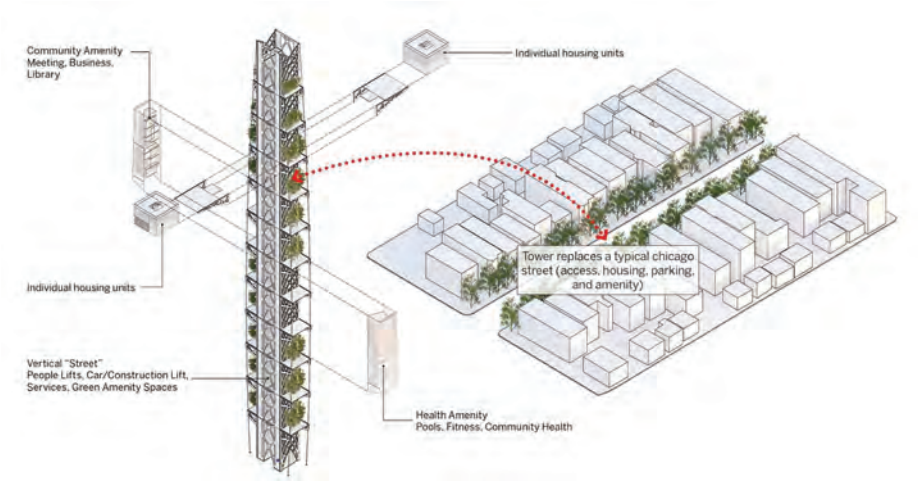

Figure 11. Experimental Home of the Future (Source: SOM)
图11. 未来住宅实验项目（来源：SOM）

More research suggests a healthier environment is one that humans can holistically integrate with nature through all our senses rather than hermetically sealed buildings that decouple humans from the natural environment. However, this points to a larger issue of how much nature we are getting in our cities. Given the environment in many cities, even when the buildings are opened to the outside, we may be getting more of the byproducts from urban environment in terms of noise, air quality, visual, and tactile than nature. Some suggest bringing nature into our buildings, but this has to be a very thoughtful process, since not all plants are necessarily healthy indoor. Selected plants, e.g., Caladium, are poisonous to humans, others plants like the Peace Lily, and associated micro bacteria in the soil, can generate potential harmful volatile organic compounds. The other solution is to design outdoor spaces that have more nature and can be used through extended periods of time through half climate conditioning (shading, spot heating, spot cooling etc.), so people can spend more time outdoors. SOM has developed an experimental housing scheme that stacks suburban homes to form a tall building with potential gardens for each home (Figure 11). The idea allows each dwelling to have its own access to nature. There are still many issues we do not understand when decoupling people with nature in our tall buildings. More research will need to be done.

触觉：接触大自然有益人们的身心健康。纽约大学的研究人员在对巴西马瑙斯市以及秘鲁Checherta村落室内不同表面的微生物种群进行研究之后做出以下总结：“在城市化各个层面中室内微生物含量发生了显著的变化，减少了现代家庭中微生物暴露于环境细菌中的机会，从而增加了人类免疫系统和新陈代谢系统紊乱的可能性，例如哮喘和肥胖，这些疾病已成为工业化国家中新增的疾病种类（J. F. Ruiz–Calderon, 2016）。”研究人员还发现接触户外空间其它的微生物也会带来正面的影响。例如：牝牛分枝杆菌，这种细菌通常存在于土壤中，人们在进行园艺作业的时候会接触到，这种细菌可能会促进血清素的产生，其对神经元的效用，与抗抑郁药物Prozac的效果相似。

更多的研究表明一个更加健康的环境应该是人们可以通过所有的感官与大自然进行互动，而不是在封闭的建筑中将人与自然环境分隔开。但这将引出一个更大的问题，即我们所居住的城市中有多少自然环境？在很多城市的环境中，即便建筑与室外有某种程度的接触，但与自然环境相比，人们还是会受到诸如噪音、空气质量、视觉以及触觉等诸多城市环境副产品所带来的负面影响。有些人建议将自然带到我们的建筑中，但这必须经过深思熟虑，因为并非所有植物都适宜种植在室内，例如花叶芋对人类是有毒的，其它植物例如和平百合及其土壤中的微细菌，也会产生有害的挥发性有机化合物。另外一种解决方案是在室外空间中设计更多的自然景观，并采用半气候调节措施（例如遮阳装置、局部供暖、局部制冷）来延长该空间的使用时间，以便人们在室外逗留更长的时间。SOM已经研发了一种实验性住宅，将郊区的独栋住宅竖向叠加，形成一栋高层建筑，每一个家庭都拥有自己的花园（图11）。该设想使得每一个家庭都拥有与自然环境接触的机会。在高层建筑中人与自然脱钩所产生的其它影响还有待进一步研究。

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