FUTURARC

The Voice of Green Architecture in Asia-Pacific

4Q 2021 | volume 75

YEAR-END ISSUE

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MCI (P) 002/01/2022 PPS 1786/04/2013(022947)

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LOW-CARBON BUILDING INNOVATIONS ARE CHANGING FUTURE ARCHITECTURE: A CASE STUDY FROM CHINA

by **Professor Stephen Lau**

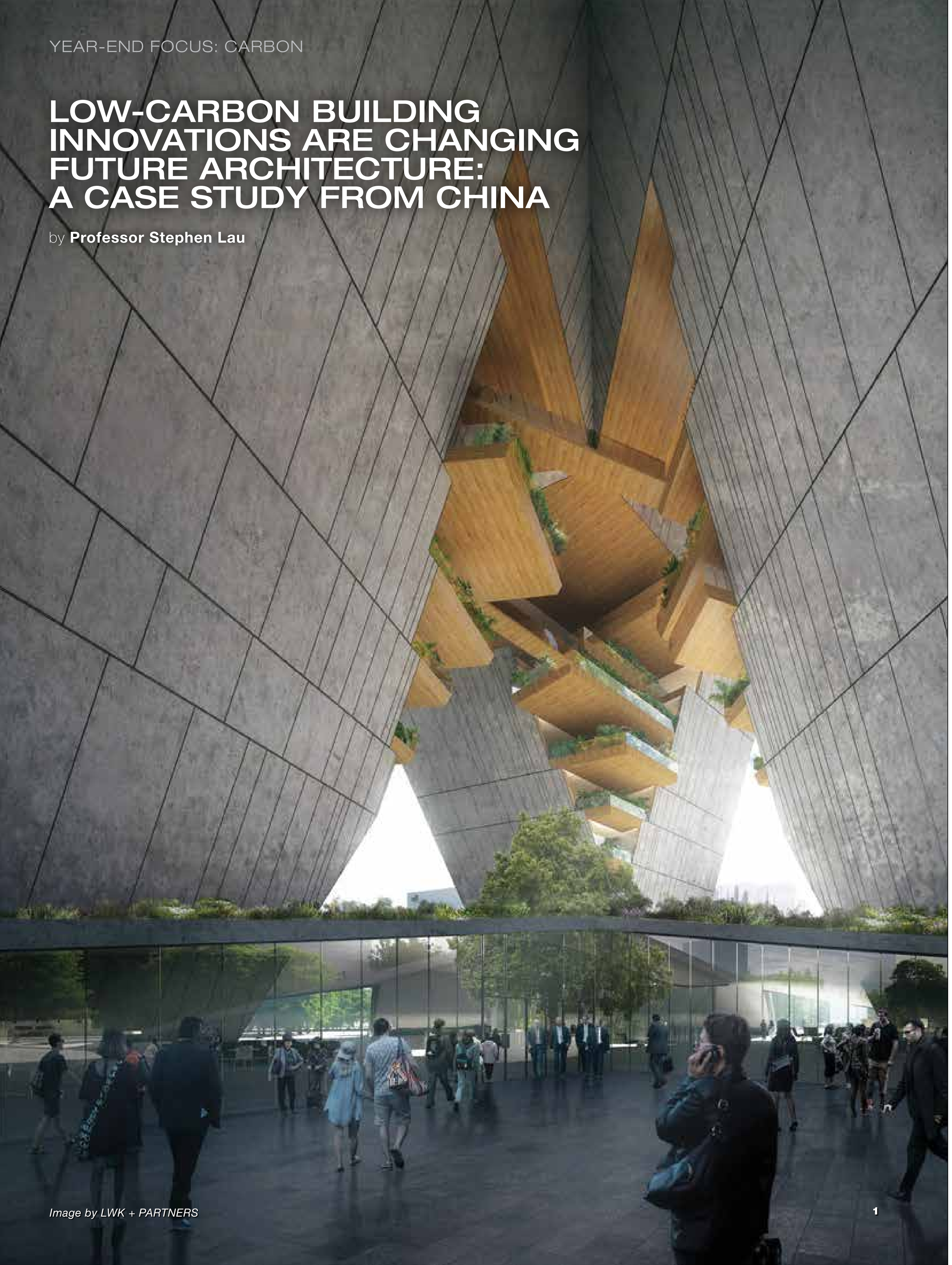

Image by LWK + PARTNERS

1 Building form as passive design tool: a central negative space promotes a microclimate in this office building competition proposal, allowing natural light and wind through its core

Climate-resilient design as a key tool of passive design needs to reach a higher level to bring down energy demand.

NEW ARCHITECTURAL DESIGN REQUIREMENTS UNDER CARBON NEUTRALITY GOALS

With rapid urban and economic development, energy consumption is increasingly posing threats to the natural environment while the quantity and intensity of energy use in buildings are growing. As the Paris Agreement is leading a global shift towards a Greener economy and setting out the minimum actions required to protect our planet, it is having a huge impact on worldwide political and economic activities. With China's pledge to peak its carbon dioxide (CO_2) emissions by 2030 and achieve carbon neutrality by 2060, carbon has now officially become the world's environmental index. According to the *China Building Energy Consumption Report* published by the China Association of Building Energy Efficiency in 2020, the building sector will be contributing 51.3 per cent of the carbon emissions from industry, building and transportation—the three main sectors in need of Green reform. Therefore, the design, operation, management and use of buildings will directly affect the effectiveness of carbon neutrality efforts in cities. An emphasis on architectural design that can save energy, cut emissions and create carbon sinks is also becoming a preferred strategy for tackling climate change and meeting carbon targets.

This article investigates the aspects of designing zero energy buildings with a case study in China. As Deputy Director of the China Green Building (Hong Kong) Council and Design Research Director leading the Design Research Unit at LWK + PARTNERS, my team and I believe that zero energy buildings are a key means of achieving China's carbon goals and therefore a future market trend. They require a technical approach that prioritises principles in the following sequence: apply passive strategies first before active enhancement; maximise renewable energy use; and a human-oriented post-occupancy evaluation. It aims to ensure healthy building interiors; achieve functionality and efficiency; formulate useful design features; create new low-energy building typologies; improve energy efficiency and smart integration; promote passive design and renewable energy use; and foster better energy-saving performance in buildings.

APPLICATIONS OF LOW-CARBON BUILDING INNOVATIONS

The Carbon-Neutral Building Design project in Guangdong, China is close to transport infrastructure and consists of five large buildings, taking up a site of 80,000 square metres with a maximum building density of 48,000 square metres. During the early design stage, a strength and weakness analysis was conducted on existing solutions, resulting in the decision to integrate the project with low-carbon design. We work closely with the client to evaluate traditional methods and develop better design frameworks. In response to carbon neutrality objectives, it involves a close review of the site, building envelope and roof to inform a low impact development, and low-energy integrated design based on 'passive first' and 'maximising renewable energy' principles. Below details the low-carbon technologies applied by the team.

Building envelope design

The Carbon-Neutral Building Design project is classified under the 'hot summer and warm winter zone B' in the thermal zoning of Chinese buildings, which emphasises natural ventilation, heat insulation and solar shading. According to China's General Principles of Green Factory Assessment and Assessment Standard for Green Buildings, factories are recommended to save materials, energy, water and land; minimise harm; and use renewable energy through the choice of materials, structures and lightings. The thermal insulation performance of the roofs and external walls should also meet requirements stated in the national standard of GB 50176 Thermal Design Code for Civil Buildings. These are why, in addition to maintaining a standard level of insulation of the structures such as focusing on insulating the western side of the building, using materials with lower heat transfer coefficients and applying light-coloured finishes and insulative paints, we propose five key strategies for designing the building envelope:

- Strategy 1: Orient the building to receive more solar radiation
- Strategy 2: Adopt uneven façades to reduce heat transfer
- Strategy 3: Use ventilated façades to improve energy efficiency
- Strategy 4: Adopt intelligent design to optimise energy use and assist with energy management
- Strategy 5: Apply passive design features to save energy

In line with Strategy 2, the Carbon-Neutral Building Design project is slightly slanted and

> **Post-occupancy evaluation closes the loop by taking into account the experience of real users to inform future design.**


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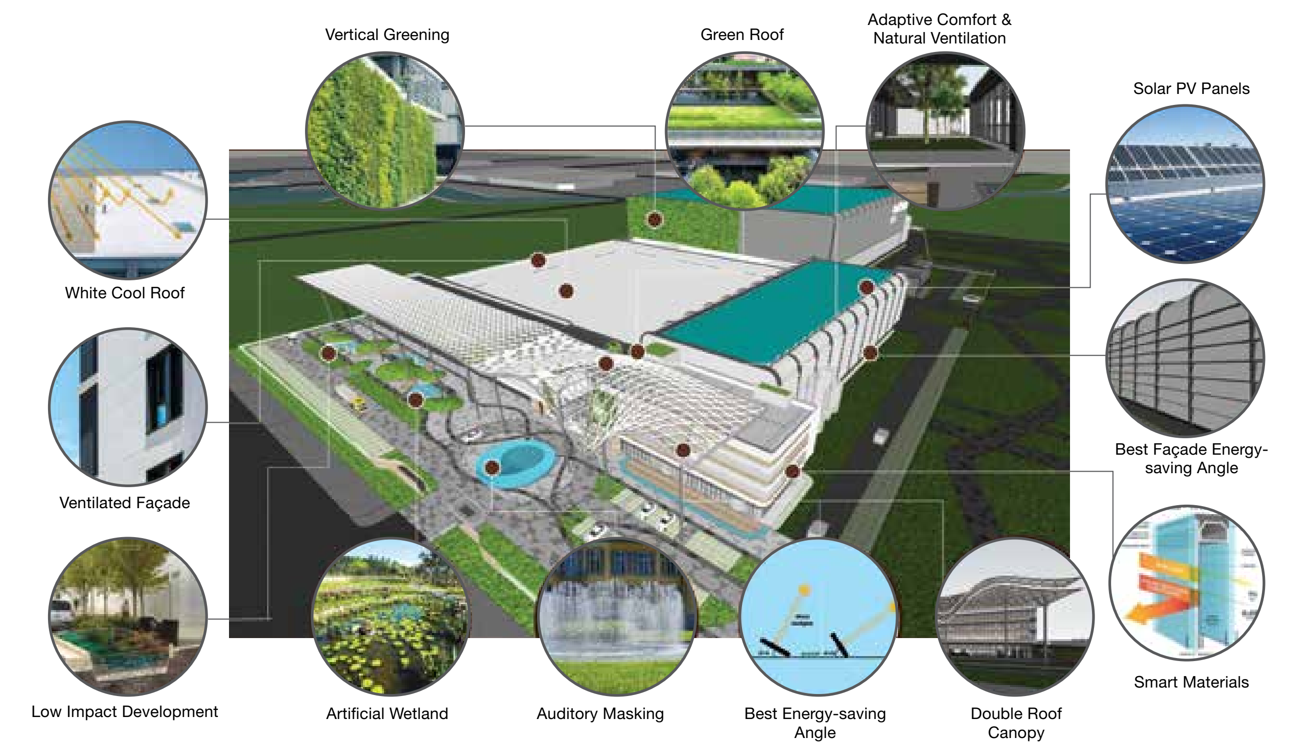

Images by LWK + PARTNERS

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adopts uneven façades to raise energy efficiency and cut CO_2 emission. For example, on the summer solstice, for the best results in cooling and smoke extraction, horizontal devices along the façade can be adjusted at 28° 27', which is exactly the same as the respective angle of the sun. This setting is recommended to last until 5pm on the day. Under Strategy 3, ventilated façades are designed to form double-layered curtain walls through supporting structures, creating a chimney effect to activate convective air circulation and improve the acoustic and thermal insulation of the building, thus increasing energy efficiency.

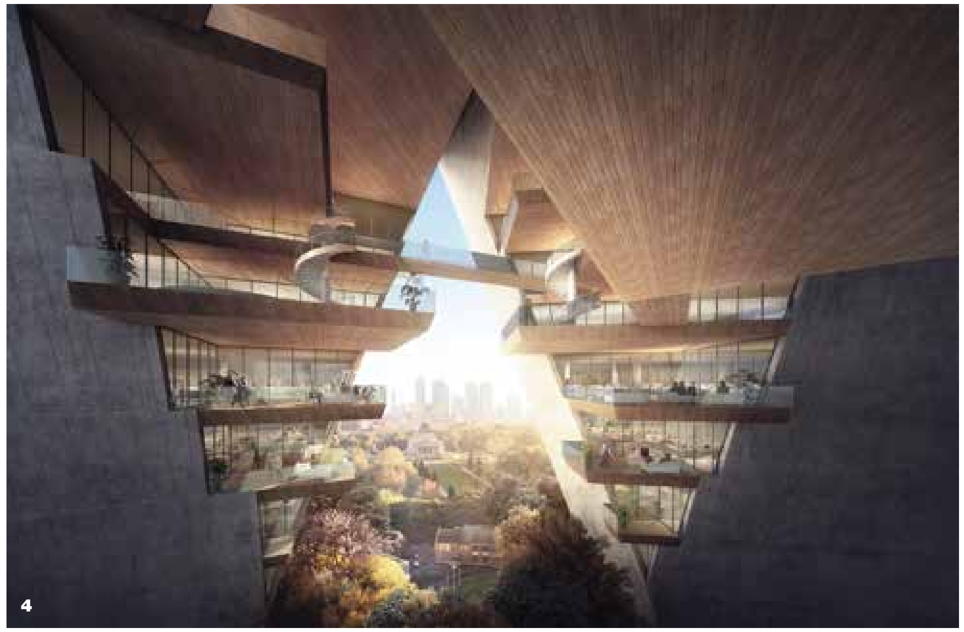
Canopy design

Climate-resilient design as a key tool of passive design needs to reach a higher level to bring down energy demand for heating and air-conditioning in buildings, while giving architects and designers greater opportunities to implement design objectives. Based on climate analysis, the most appropriate passive design strategies are shading, indoor heat gain, natural ventilation for cooling, dehumidification and optimisation of air-conditioning efficiency. These strategies are effective in improving energy efficiency and indoor comfort. The following example from the Carbon-Neutral Building Design project shows how canopy design can facilitate shading.

The project's canopies are designed in response to the angle of the sun's shadow. Considering the canopy's position in relation to the façade, two types of canopies have been adopted. Type 1 canopies are designed to shield building walls, which means they fend off direct exposure to the sun during spring, summer and autumn to minimise the heating or cooling load of the building surfaces. Type 2 refers to canopies over entrances and glass curtain walls. These are spots where people usually gather, so the main consideration is to bring sunlight inside the spaces during winter for lighting and warmth. Combined with calculations of the canopy dimensions and height of the building's southern façade, Type 1 features louvres for shielding radiation when the angle of the sun exceeds 13°. From site analysis of sun paths, we discovered that aluminium louvres can provide good shading from noon to around 5pm. For the canopies to be excluded from plot ratio calculations, they must be at least 80 per cent hollow while the slanting of aluminium louvres must be less than 11.5°. To optimise slanting for shading, the canopy itself must be slanted at 11.5°.

Moreover, we propose to add a second layer of canopy above the first, further shading the roof while squeezing out the heat between the first

2 Canopies at the Carbon-Neutral Building Design project in Guangdong, China improve energy efficiency and indoor comfort by optimising exposure to sunlight **3** Low-carbon features of the Carbon-Neutral Building Design **4 to 6** The same office building competition proposal (as per image 1) provides porous layers of experiential, landscaped spaces around the airy atrium; with shared facilities and communal areas centralised to take advantage of the natural lighting and ventilation; and shading provided over social spaces to enable an open-air experience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Images by LWK + PARTNERS

and second canopy layers and the roof, helping to reduce the cooling load on the building space. The double roof structure works with an air chamber to achieve separation, while the layer in between provides additional architectural lighting. If the layers have the same rate of hollowness, this kind of design also provides more shaded areas, creating a sheltered outdoor living space.

Aquatic design and landscape system for low impact development

In terms of climate, the Carbon-Neutral Building Design project sits on subtropical land susceptible to monsoons, humid weathers and generous rain. To reduce water consumption, which indirectly increases carbon emissions, the project contains features that collect rainwater from different sources including the roof, surface run-off and vegetation catchment. Water from initial disposal tends to be cleaner and can be reused for miscellaneous purposes after a simple treatment. It is estimated that reusing rainwater alone can supply 100 per cent of the miscellaneous water use for this project. The area's water supply will mainly serve office buildings, factories, plant watering and road sprinkling.

Referencing local low impact development (LID) requirements, the project also includes a range of other green features. These are often landscape features based on blue-green design principles that aim to promote carbon sinks, water recycling, sponge city concepts, artificial wetland landscapes and water savings. A LID strategy is mainly proposed for the southern side of the site. The first strategy addresses the large volume of rainwater run-off and potential overflow from the project site. This water can be used for a storm water wetland, retained through physical devices, aquatic plants and microorganisms. The wetland can be both an ecological landscape as well as a public space. The second strategy addresses the body of underground still water. Multiple layers of vegetation are used to build a revetment with permeable paving, rain gardens and other measures to create artificial wetlands. This way, rainwater undergoes infiltration, storage, regulation and purification, simulating the natural environment. The stepped arrangement of these semi-natural structures not only meets LID objectives, but also serves a variety of other functional needs.

Photovoltaic (PV) system

Maximising renewable energy entails offseting and balancing a building's energy consumption through the utilisation of renewable energy. In the Carbon-Neutral Building Design project, we make use of the building skin and nearby sources to generate renewable energy. Again, the local climate and angle of the sun were studied. PV simulation software was used to analyse rooftop radiation, optimal tilt angle of the PV panels and distance between the panels to derive the optimal amount of solar power to be generated annually, thereby estimating the reduction in the building's electricity consumption. This is then used to calculate how much electricity-related CO_2 emissions are saved after the use of PV panels.

Information on electricity emission factors was obtained from a report on the average CO_2 emission factors of China's regional and provincial power grids in 2010, published by the Department of Climate Change of the National Development and Reform Commission of China on 11 October 2013, on the China Climate Change Information website. The preset value of the electricity emission factor is 6,379 tonnes of CO_2 per million kWh, according to a carbon dioxide emission information reporting guide for Guangdong enterprises (revised in 2020). By multiplying the amount of PV-generated power and the electricity emission factor, we obtained the amount of carbon emissions saved. In the Carbon-Neutral Building Design project, PV panels are estimated to save approximately 89.3 tonnes of CO_2 emissions per year and will reduce 1,339.6 tonnes of CO_2 emissions over its entire life cycle, assumed to be 15 years.

CONCLUSION AND PROSPECTS

In general, all buildings take more or less the same technical approaches to save energy and reduce emissions. In 2019, China authorities launched the Technical Standard for Nearly Zero Energy Building. For the Carbon-Neutral Building Design project illustrated above, the design strategies mainly centred on 'passive first' and 'maximising renewable energy use' principles. To supplement the three approaches set out by this standard, we propose a fourth element, which is 'human-oriented post-occupancy evaluation'. This closes the loop by taking into account the experience of real users to inform future design and further enhance a building's performance in carbon reduction. We will apply this to the Carbon-Neutral Building Design project throughout the whole building's life cycle, from design to operation, management and use, tracking post-occupancy data through digital platforms. The practice believes that closely monitoring post-occupancy data has an informative effect on a project's carbon emission control, the improvement of user experience as well as construction cost control. In the long term, such data is also key to achieving carbon reduction goals.

Passive design is an effective tool to enhance building form and spatial design while upgrading the energy system. At the same time, low-carbon innovations are vital for integrating renewable energy use in architectural design and capturing human factors through user behaviour. As the threat of climate change looms large, architects and engineers have a leading role to play in China's carbon reduction goals and our future urban development as a whole.

Professor Stephen Lau leads the LWK + PARTNERS Design Research Unit as Design Research Director in its efforts to study the impact of buildings on its occupants and surroundings, focusing on eco-cities to help the practice bring about sustainable development. He is also Deputy Director of the China Green Building (Hong Kong) Council. Professor Lau is Honorary Professor of The University of Hong Kong, Adjunct Professor at Beijing University of Civil Engineering and Architecture, as well as Visiting Professor at Shenzhen University. He oversaw the building technology research and teaching division at the National University of Singapore's Department of Architecture, and served three times as Associate Dean at The University of Hong Kong's Faculty of Architecture.

Publication: FuturArc 4Q 2021 Volume 75
Publication Date: December 2021
Original Article: Low-carbon Building Innovations are Changing Future Architecture: A Case Study from China

迈向建筑未来 — 低碳新建筑技术应用：中国项目案例

撰文：刘少瑜教授

碳中和背景下建筑设计新要求

在城市和经济快速发展的背景下，能源和环境矛盾日益突出，建筑能耗总量和能耗强度上行压力不断加大。国际上应对气候变化《巴黎协定》代表了全球绿色低碳转型的大方向，是保护地球家园需要采取的最低限度行动，全球政治和经济活动都受到巨大影响。在“碳中和”目标下，中国承诺二氧化碳排放于2030年前达到峰值，争取2060年前实现碳中和，“碳”已是全球各国环保新姿态！基于产业、建筑、交通等三大减排领域中，建筑业所占碳排放比例未来达到51.3%左右（注：《中国建筑能耗研究报告》，中国建筑节能协会能耗统计委员会，2020）。因此，建筑的设计、运营、管理、使用将直接影响城市碳中和的成效，强化建筑设计手法的节能、减排及碳汇能力，成为面对气候变化和“碳中和”达标的优选策略之一。

本文以一个中国项目为案例，探讨实践零能耗建筑设计的各种面向。我除了担任中国绿色建筑与节能（香港）委员会副会长，也同时以LWK + PARTNERS设计研究总监的身份带领该事务所的设计研究组，我们团队认为零能耗建筑是达到“2030年碳达峰、2060年碳中和”承诺目标的重要建筑手段和未来市场趋势，而被动优先、主动优化、可再生能源最大化、建筑使用后评估以人为本是实现迈向零能耗建筑的的重要四大技术路径。其目标在于保证健康建筑室内环境、功能和效率，提炼碳中和低能耗的建筑设计语言，酝酿碳中和新建筑类型，提高能源利用效率和智能化交互，推动被动式设计和可再生能源建筑应用，引导建筑不断提升节能水平。

低碳新建筑技术应用

以中国广东碳中和建筑设计项目为例，建筑群主要由五大建筑物组成，邻近交通基建，占地面积为80,000平方米，建筑密度上限为48,000平方米。在前期设计阶段，基于已有的建筑方案优缺点比较后，就已经介入低碳建筑技术设计手法。LWK +

PARTNERS 与业主共同应对“碳中和”，担当绿色整合的角色，优化传统建筑设计方法，应用革新设计框架，在项目场地、建筑围护结构、屋面等提炼低影响开发、低能耗的“被动优先和可再生能源最大化”的整合设计。具体的低碳技术应用如下所述。

建筑围护结构分析策略

该碳中和建筑设计项目在中国建筑热工设计分区中属于“夏热冬暖 B 区”，强调自然通风，隔热和遮阳设计。根据《绿色工厂评价通则》及《绿色建筑评价标准》，建议工厂建筑从材料、结构、采光照明等方面进行节材、节能、节水、节地、无害化和可再生能源利用，且满足“5.1.7 屋顶和外墙隔热性能应满足现行国家标准《民用建筑热工设计规范》GB 50176 的要求”。因此在建筑立面低能耗设计方面，LWK + PARTNERS 提出围护结构隔热性能总体建议之余，即节能设计需考虑西外墙的隔热性能，采用导热系数更小的隔热材料，考虑采用浅色饰面或隔热涂料等等，也同时采用五大策略进行建筑围护结构节能设计。其中包括：

策略一：调校建筑立面的角度以迎接更多太阳辐射。
策略二：采用凹凸建筑立面，减少热量的传播。
策略三：利用通风外墙提高能源利用率。
策略四：智能材料降低建筑能源利用，提高能源管理。
策略五：被动式设计辅助节能。

以策略二为例，碳中和建筑设计项目的建筑立面以一定角度的倾斜和凹凸减少热量的传播，可以提高能源效率、减少二氧化碳的排放量；例如在当地夏至日，综合考虑建筑立面的散热、排烟等需求，立面横向的设置在夏至日建筑西立面的角度建议遮挡到下午 5 点，基于当地当日太阳高度角度是 28 度 27 分，故建议此立面横向角度为 28 度 27 分。又如策略三，通风外墙通过支撑结构形成内外双层幕墙，产生烟囱效应激活对流空气循环，改善建筑的隔声隔热性能，从而提高能源利用率。

雨棚遮阳设计策略

由此可见，气候适应性设计作为被动式设计的主要手段，需要提升至更高水平去降低建筑的供暖空调能量需求，也同时让建筑师等有关设计人员可在设计前期占有一定主导性。基于气候分析的总结，最合适的被动式设计策略分别为提供遮阳；室内热量增益；自然通风冷却；除湿及有效优化空调效能。此等策略能有效提高能源效率及室内环境的舒适性。在遮阳方面，以下以雨棚遮阳设计为例进行分析详述。

本项目的雨棚遮阳设计是在建筑日照倒影分析的基础上，综合考虑雨棚所在区域所对应的建筑立面，进行两种类别的区域划分。雨棚区域一对应建筑立面为实体墙面，其主要遮阳策略是春、夏、秋季遮挡更多阳光，尽量避免建筑立面收到阳光照射，减少建筑立面热冷负荷变化。区域二是雨棚对应区域为出入口、玻璃幕墙的，考虑到入口人流聚会活动外，冬天阳光能尽量多照射到建筑室内深处，有助采光及暖人节能，其主要遮阳策略则是冬季接收更多阳光。雨棚格栅遮阳角度的计算以区域一为例，是根据雨棚高度、长度，及建筑南立面高度，估算太阳高度角要大于13°时，雨棚发挥遮阳效果。再根据当地经纬度，从项目春夏秋季日照分析可知，在中午至下午5点左右期间，雨棚铝格栅能提供遮阳效果。同时又根据当地雨棚的不计算容积率方法，雨棚透空率需大于80%；铝格栅的倾斜角度估算必须小于11.5°，因此如果雨棚要提高遮阳效果，铝格栅应以尽量多的倾斜角度呈现，即得出雨棚格栅遮阳角度为11.5°。

此外，LWK + PARTNERS也建议雨棚上方再添加为双层雨棚，一方面可为屋顶遮阳，同时还可使积聚於雨棚一层、二层及屋面之间的热气逸出，有助于降低建筑空间的冷负荷需求。双层屋顶结合空气腔进行分隔，夹层可增加灯光的建筑照明效果。在透空率一致的情况下，也可扩大外墙遮阳范围，创造遮阳的户外生活空间。

水设计与绿化系统低影响开发

在气候方面，碳中和建筑设计项目属亚热带季风性湿润气候区，雨量充足。为减少水资源消耗间接增加碳排放。本项目收集各种雨水来源，包括建筑屋面雨水、道路广场雨水和绿地雨水。初期弃流后水质较好，收集后经简单处理可回用于杂用水。经估算，仅回用雨水就可以100%供应本项目杂用水，区域用水量主要为办公楼用水、工业厂房用水、区域内绿化浇灌用水、道路浇洒用水。

另外基于项目现有建筑方案与绿化概念，综合考虑项目所在地的当地相关低影响开放指标要求，以“蓝绿设计”的原则，同时增加碳汇，采用水资源再生利用、海绵城市、人工湿地景观、节水措施等理念，提出绿化系统低影响开发方面的低碳生态设计策略建议。总体建议在场地南侧绿化系统实施低影响开发（LID），策略一是考虑到项目基地径流雨水量较大，存在溢流，可用于营造雨水湿地景观，利用物理、水生植物及微生物等作用滞留雨水；以雨水湿地为主要自然水体景观，生态减排，打造人工湿地广场。策略二是以自然池底、静水水体为主，驳岸分层次搭配植被，组合利用透水铺装、雨水花园等技术措施，通过打造人工湿地，对雨水进行渗透、储存、调节、净化，模拟自然，阶梯布置低影响开发设施半人工半自然构筑，满足多功能需求。

太阳能光伏系统

可再生能源最大化是通过使用可再生能源系统对建筑能源消耗进行平衡和替代。LWK + PARTNERS 充分挖掘碳中和建筑设计项目中的建筑物本体表皮、周边区域的可再生能源应用潜力，对能耗进行平衡和替代。同样基于气候分析和日照倒影分析，另外运用光伏模拟软件进行屋顶太阳辐射分析、光伏板最佳倾角分析和光伏板距分析，得出光伏板的最佳年发电量，从而预估建筑的电力消耗减少量，再利用电力排放因数计算使用光伏后本项目的二氧化碳减排量。

电力排放因数资料来源于中国国家发展和改革委员会应对气候变化司於2013年10月11日在中国气候变化资讯网发布的《2010年中国区域及省级电网平均二氧化碳排放因数》中广东电网平均二氧化碳排放因数。再参照“广东省企业（单位）二氧化碳排放资讯报告指南（2020年修订）”，电力排放因数的预设值为6.379吨二氧化碳/万千瓦时。因此，在使用光伏发电系统的情况下，通过光伏发电系统的发电量和电力排放因数相乘来算出碳减少量。本项目采用光伏发电预估可以每年减少约89.3吨的二氧化碳排放量，并在整个生命周期内，以十五年计算，将减少1339.6吨二氧化碳排放量。

小结与展望

综合而言，建筑在迈向更优节能减排的方向上，基本技术路径是一致的。中国已在2019年颁布《近零能耗建筑技术标准》国家标准。碳中和建筑设计项目的上述设计策略主要体现在被动优先和可再生能源最大化的整合。不止于此，LWK + PARTNERS 为三大技术路径做出提升和补充，提出闭环的第四大技术路径：以使用者导向的建筑人因设计理念，结合人因与建筑设计，整合管理与使用，进一步优化建筑和空间设计，以达到减排最终目的。LWK + PARTNERS 将贯彻项目的设计、运营、管理、使用等全生命周期的重要意义，对该项目进行数字化的以人为本使用后评估追踪。LWK + PARTNERS 确信建筑使用后评估与建筑碳排放控制、用户使用感受和建筑建造运营成本密切相关，对实现建筑精准瞄准“减碳”和“零碳”的成效至关重要。

可见，通过被动设计手段优化建筑外形和空间设计、提升能源系统、利用可再生能源系统与建筑设计施工一体化、针对使用者行为的人因设计等方面，低碳新建筑技术的应用对节能减排具备重大意义。因此，建筑师及工程师等有关设计人员是可以在“碳峰值 + 碳中和”行动中通过各种有关技术和建筑设计起到带动作用的，以此展现建筑行业等城市建设行业在应对气候变化挑战的重要担当！