可持续建筑
Sustainable Buildings

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前言

可持续建筑设计的定义非常宽泛，它既包括建造与使用期间能源、水资源、材料等的可持续性与可恢复性，例如，适应使用与气候的变化，同时也包括如何让设计更加“以人为本”，如何让建筑成为活跃的社会与经济社区的一部分等问题。可持续设计不仅是越来越成熟的可以计量的物理参数的贡献，而且涉及到设计的“软”方面，如空间创造、对地域美学与文化标签的反应等。表1总结了可持续设计的一些因素。建筑设计与建造并不是终点，可持续建筑鼓励居住者有可持续的生活方式和社区环境。

表1

将碳排放逐步减少至零
高效使用环境友好型材料
雨水回收，高效的利用水资源
提供优质的生活空间，冬暖夏凉，保持较好的室内空气质量
提供一个舒适、经济并适应居住者条件与气候变化的房子
增强当地建造环境
基地尽量选址在能利用可持续交通系统的地点，周边能够提供休闲绿色空间供休闲、餐饮并改善空气质量。
靠近社区公共服务设施

这些因素给出了可持续设计的整体方法，虽然被认为是非常好的事情，但却在实际建造中很难实现。也许，设计中那些可计量的数据被认为更加务实，特别是能源性能或目前被重点关注的减少化石燃料的碳排放等方面。

减少建造环境的二氧化碳排放已列入大多数国家的政府日程之上。新建筑的设计与建造和既有建筑的改造是政府完成节能减排目标的首要区域。启动低碳日程来推动可持续设计传达了一个清晰的政治信息：政府期待在相对短的时间内达到零碳建筑的目标。

1 零碳建筑

虽然从20世纪70年代开始人们就已经对低碳建筑表现出了浓厚的兴趣，但直到最近几年才正式提上日程。人们对于气候变化的关注使得各国政府将可持续建造环境摆在了优先发展的地位。这也导致建筑业在低碳日程上策略的阶跃式变化，零碳或碳中和建筑在针对气候变化时开始起到了主要作用。建筑业也发现，“零碳设计”相比全面、宽泛的“生态设计”似乎要简单一些。政府需要清晰地传递其对于零碳建筑的预期和目标，如何通过未来建筑法规逐步发展的高标准来确保达到这个目标。

那么，到底什么才是零碳建筑呢？低能耗建筑使用低能耗和被动设计的方法对运营能源的需求降低，例如，采用更加高效的取暖、照明、通风等。零碳建筑对降低能耗的要求更高，比如要达到德国被动房标准，我们通过使用可更新能源达到这些要求。这些可更新能源供给被整合到建筑设计之中或作为社区系统的一部分位于建筑周围环境中。一般的，系统是发展的一部分，而非来源于既有绿色能源。在降低运营能耗的同时，也应注意到潜在增长的建筑含能。对于零碳建筑来说，建筑

Introduction

The subject of sustainable building design is wide ranging. It includes how we design a building to be physically sustainable in relation to energy, water and material use and to be resilient, for example, to be able to adapt to change of use or climate change. It also includes issues of how we design to support ‘well being’ and a healthy lifestyle for people, and, how we design a building to be part of a socially and economically enlivening community. Sustainable design is not only about the more readily quantifiable physical attributes, but also about the ‘softer’ design aspects of creating place, and responding to a regional aesthetic and cultural identity. Table 1 summarises the aspects of sustainable design. The design and construction of the building itself is not the end point; a sustainable building must also encourage a sustainable lifestyle for its occupants and its surrounding community.

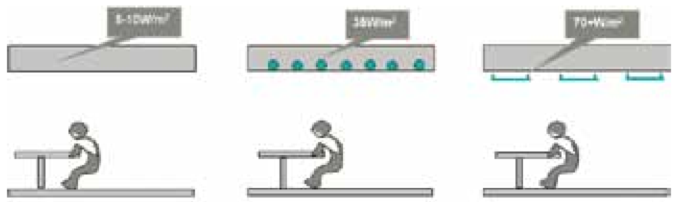
These factors point to a holistic approach to sustainable design, which is generally accepted as a ‘good thing’ but often difficult to achieve in practice. It may be more pragmatic to lead with the more quantifiable aspects of design, and in particular, its energy performance, or what is now considered important, the reduction of carbon dioxide emissions associated with fossil fuel energy sources.

Reducing carbon dioxide emissions in the built environment is high on the agenda for most governments as they attempt to deal with climate change, security of supply and the continual increase in demand for energy. The design and construction of new buildings and the refurbishment of the existing building stock is a main priority area for achieving government targets for carbon dioxide emission reductions. Using the low carbon agenda to drive sustainable design has provided a clear political message, with the aspiration to achieve ‘zero carbon’ new buildings within a relatively short time period.

Zero Carbon Buildings

Although there has been a growing interest low energy buildings since the 1970’s it is only in recent years that the pace has quickened. In response to the concerns over climate change, governments throughout the world have identified sustainability in the built environment as a high priority. This has resulted in a step change in the construction industries approach to the low carbon agenda, with zero carbon or carbon neutral buildings set to play a major role in mitigating against further climate change. Also, industry has probably found it easier to deal with the emphasis on the single issue of ‘zero carbon design’, than the more holistic and multi-parameter nature of ‘sustainable design’. There needs to be clear signals from government about its aspirations and targets for zero carbon buildings and how this will be achieved through a progressive ramping up of standards through future building regulations.

So what is a zero carbon building? A ‘low energy’ building has its operating energy demand reduced, for example, through more efficient heating, lighting and ventilation, using the ‘low energy’ and ‘passive design’ approaches discussed below. A zero carbon building will have further energy demand reductions, for example, achieving the German based ‘passive haus’ standard [ref], and then using renewable energy supply to meet this reduced demand. This renewable energy supply can either be integrated into the building design or be located ‘near-to’ as part of a community system. Generally speaking, the renewable energy system should be part of the development and not, for example, be assumed to come from existing green energy sources. It is also interesting to note the potential increasing significance of embodied energy as the operating energy is reduced. For a zero carbon building, the embodied energy may now be of a similar size to the operating energy



a 夜间通风（裸露板） b 冷水管 c 常规空调负荷

图1 冷水天花

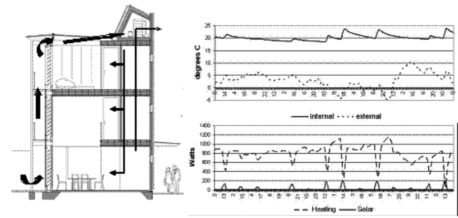


图2 Project house冬季通风模拟数据 室内外空气温度、采暖消耗和水平面太阳辐射总量

含能也许与运营能耗在建筑某个特殊的生命时期相等，这与建造方式息息相关。向零碳转变，建筑含能也许会随着材料与可再生能源系统的使用而增加。

达到零碳的步骤包括：1）减少内部照明和小电器得热；2）被动设计，优化建筑隔热、气密性、热质、天然光与太阳辐射控制；3）高效服务，提供舒适的环境；4）可更新能源供给与建筑一体化设计。

2 低碳建筑的舒适性与服务

低碳建筑与之前的非节能建筑相比具有不同的热特性：由于隔热墙体或玻璃幕墙较好的性能，得热与热损失均相对较低；遮阳和多层玻璃幕墙减少了太阳辐射得热；一般情况下采取自然通风或热恢复机械通风等；利用热质保持温度恒定与热量存储；最后，要最大限度地利用天然光，减少对电光源的依赖。总之，低碳建筑依靠建筑形式的被动式设计、建造与围护来减少暖通空调系统的负荷。被动式设计方法很容易理解，通过热工模型，考虑到建造、基地气候条件、居住环境得热等也能够预测其性能。唯一欠佳的是，在负荷相对较小的情况下，如何安排取暖、空调、通风才能最有效地提供舒适环境。

在很多低碳建筑中，系统设计的方法在某种程度上减少了自身体量。拿供暖系统来说，散热器越来越小而热分配与控制则无明显变化。有时，工程师惧怕系统体量过度带来的风险，随着体量减小而简单地增加对控制的依赖来达到缩减的需求。这并没有给节约成本带来好处，相反会因为在部分负荷的条件下，效率会大大降低。

因此，我们需要认真思考如何在低碳建筑中获得更加舒适的环境，特别是我们提供的系统既要满足降低建筑能耗的需求，又能满足舒适、健康和居住者福祉的要求。在许多低碳建筑中，我们也发现大面积制冷与取暖表皮系统的重新应用，这也带来了令人满意的热舒适与能效结果。图1显示了一系列的制冷表皮系统和其典型冷却能力。在这些建筑保持舒适度的情况下，气温的改变是能够被接受的。通过辐射制热、制冷提供房间舒适性是可行的，人体也在以辐射换热的形式与环境中与其他人进行热量传递。

低碳建筑旨在通过设计使得取暖、空调、通风与照明产生的二氧化碳排放达到最少，其中也包括一定比例的可再生能源所传递的能量，这些能源被固结在建筑设计、社区或网格基础中。零碳建筑要求所有的能源需求都来自可再生能源。大部分低碳与零碳设计都通过减少取暖与空调能耗来实现，因而系统也必须来适应这些减少的能耗需求并能通过高效的方式传递热量。特别的是，热量传递的方式和控制的方式不论是通过空气还是辐射系统都十分关键。照明也一样，要根据天然光情况适当控制电光源的提供量，这与那些被“智能”控制系统随机关闭的光源不同。

只有在系统能够适应这些降低能耗需求的基础上，低能耗性能才能实现。这并不一定意味着控制系统一定要很复杂。近年来，通过能源

over a typical lifetime, depending on the type of construction used. As a result of the transition to zero carbon, the embodied energy may even increase as a result of using more materials and renewable energy systems. The steps to zero carbon design include: 1)Reduce internal gains from lighting, small power, etc. 2)Passive design, to optimise for thermal insulation, air tightness, thermal mass, daylight and solar control. 3)Efficient services, for heating, cooling, humidity control, ventilation and electrical lighting, to provide appropriate levels of comfort. 4)Renewable energy supply integrated into the building or community, such as solar PV, solar thermal, wind, bio-energy, hydro, etc.

Comfort and Services for Low Carbon Buildings

Low carbon buildings have very different thermal characteristics to previous, less energy efficient, buildings. They have low levels of heat loss or gain, through better insulated walls and glazing systems. They have controlled solar gains, through shading and layered glazed facades. Often, they are naturally ventilated, or they use mechanically ventilation with heat recovery. They may use thermal mass to provide temperature stability and thermal storage. Finally, they should be designed to maximize the use of ‘natural’ daylight and minimise the reliance on electrical lighting. In all, they rely on passive design of the building form, construction and envelop to reduce energy demand for heating, cooling, ventilation and lighting, which then reduces the load on the HVAC systems. The passive design aspects of low carbon design are reasonably well understood and the performance can be predicted by thermal modelling, etc., which takes account of the building construction, the climate of the location, and the heat gains from occupancy. What is not so well developed is the most effective method of providing comfort, through heating, cooling and ventilating, for such buildings, where the loads are relatively small and intermittent.

In many low carbon buildings, the approach to system design has been in some way, to reduce the size of the system. For example, for a heating system, the heat emitters are smaller but the distribution and controls generally remain the same. Sometimes engineers are afraid to risk reducing system size too much, in case they undersize, and so they simply rely of controls to respond to the reduced demand. This does not then produce a benefit in terms of cost savings from being able to use a smaller system, and also there may be inefficiencies through operating at ‘part-load’ conditions.

We therefore need to look at how we might better achieve comfort in low carbon buildings, and in particular to provide a system that can both respond to the reduced energy demand of the building, together with the comfort and the health and well being needs of occupants. In some low carbon buildings, we see a return to large area chilled and heated surface systems, and these appear to produce good results, both in relation to thermal comfort and energy efficiency. Figure 1 shows a range of chilled surface system and their typical cooling capacity. In such buildings it is quite acceptable to allow the air temperature to vary whilst comfort is retained. Providing comfort through radiant heating and cooling can even improve comfort. This is perhaps not surprising when heat transfer of the human body is through radiant exchange with persons surroundings.

Figure 1: Chilled ceiling options, exposed slab (with night ventilation), chilled ceiling and chilled beam, with typical cooling loads.

Low carbon buildings are designed to minimise the carbon dioxide emissions that are associated with heating, cooling, ventilation and lighting. They may also have a proportion of their delivered energy from renewable sources, either integrated into the building design, or community, or grid based. A zero carbon building will have all its energy demand met by

图3 gateway大楼

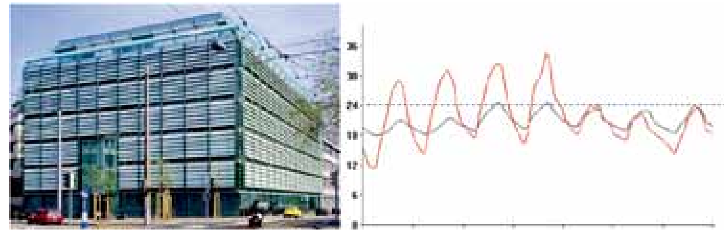


图4 TaMedia建筑物理分析

管理系统达到建筑的环境控制等变得非常复杂和昂贵，以至于实际上几乎不能有效操作，如很快就会校准失效，或不能随着使用形式的改变而变化。对大部分建筑来说，控制应该简单并让建筑使用者清晰明了。表2总结了与低碳建筑舒适度相关的问题。

表 2 与低碳建筑舒适性相关的方面

通过通风系统的去耦冷却/加热
考虑到表皮加热与冷却
取暖/空调供应低级可更新能源供应（热泵、太阳能光热等）
自然通风、热恢复机械通风
控制系统简单易操作

3 低碳建筑实例

对于零碳建筑的推动为我们带来了巨大的挑战，但到目前为止还鲜有真正意义上的零碳建筑。这里列举一些案例，也许能让我们更加接近零碳建筑。

在设计策略中采用整体方法的一个典型的应用就是威尔士建筑学院为Gwalia房屋协会设计的project house（图2）。它采用了可持续的材料和创新的预制施工方法，达到了零碳的性能标准。在英国，使用板或体积系统（或两者综合使用）的现代施工方法（MMC）也是可持续建筑研究的一部分。通过被动式设计，探寻建筑能源需求的降低与可再生能源的提供之间的平衡。数字表明，预测的随时间变化而改变的热负荷与室内温度结果刚刚超过1kW的设计热损失。通过机械通风的回热系统能够供给建筑取暖需求，冬季南向双层幕墙可以预热空气，将其提供给房间南侧的起居生活空间，并通过北侧的设备区排出。屋顶提供光伏与太阳能热水系统。对于只配备了玻璃幕墙和可再生能源系统的房子来说，因当时预算非常高没有建成。

Gateway大楼（图3）位于南威尔士巴格兰能源区，是一座工业建筑，于2001年竣工，并获得2002年RIBA地区设计大奖。这是一座低碳建筑，拥有太阳能光伏一体化幕墙系统，达到BREEAM优秀的标准，同时自然通风与天然采光良好。光伏安装在南向办公室之上，同时起到了遮阳作用，避免了对机械空调的额外需求。光伏与遮阳系统的大样见图2。

幕墙设计是低碳设计不可或缺的重要方面。大面积的玻璃幕墙为办公区提供了极佳的自然采光，但也应认真处理隔热与遮阳。图4，5所示的案例均位于苏黎世，散射玻璃百叶能根据太阳的位置而随时调整位置。如图4所示，无阳光时，水平百叶可以向上收起。图5的竖向百叶则随着太阳角度的变化而移动变化。两栋建筑都采用裸露的混凝土天花制冷。图4使用主动制冷天花，预埋在天花中的冷水管可提供35w/m^{2}的制冷峰值（参见图1b）。图5中建筑采用了被动式冷水天花，通过夜间通风净化制冷。白天，机械通风将空气从地板制冷系统引入室内（参见图5右），在夏季能提供高达10°C的降温。在这两种情况下，辐射温度均低于空气，提供了良好、舒适的条件。

renewable energy supply. Since a large part of low and zero carbon design is achieved by reducing heating and cooling demand, the resulting HVAC systems must respond to this reduced demand and be able to deliver heating and cooling in an effective and efficient way. In particular, the method of delivery, whether through air or radiant based systems, and their control, is critical in relation to energy efficiency and maintaining thermal comfort. The same applies to lighting in relation to controlling the level of electrical lighting in response to daylight, which is different from the sometimes apparent random switching off of lights through some so called ‘intelligent’ control.

A low energy performance can only be achieved if the systems can respond to the reduced demand. This does not necessarily mean that controls have to be complex. In recent years, environmental control of buildings through energy management systems, etc., has become so complex (and expensive) that they rarely work effectively in practice. They generally quickly go out of calibration or are too complicated to change in response to changes in use patterns. For most buildings, controls should therefore be simple and legible to the building users. Table 2 summarises comfort related issues for low carbon buildings.

Examples of Low Carbon Buildings

The drive towards zero carbon housing presents a big challenge, and although there are few truly zero carbon buildings to date, there are some good examples of how they might be achieved in future.

A typical application of applying a holistic approach to a zero carbon design strategy is the ‘project house’ designed by Welsh School of Architecture for Gwalia Housing Association (figure 1). It was designed to provide a zero carbon performance using sustainable materials with innovative off-site construction methods. In the UK modern methods of construction (MMC) have been explored as a means of delivering sustainable buildings, using either a panel or volumetric system (or a combination of the two). The balance of energy demand reduction and renewable energy supply was explored using passive design features. The figure shows the predicted time varying results for heat load and internal air temperature, indicating a design heat loss of just over 1kW. The building is heated using a mechanical ventilation heat recovery system which supplies air preheated in winter through the south facing double skin facade. The air is supplied to the living spaces on the south side of the house and air is extracted through the service zones on the north side. There is provision for photovoltaics and solar thermal water heating on the roof. The house was not built because of its estimated high cost at the time (2002) mainly associated with the glazed façade and renewable energy systems.

The Gateway building on the South Wales Baglan Energy Park was an industrial building and office completed in 2001 and winning an RIBA regional design award in 2002. It was designed with a low carbon performance, achieving BREEAM Excellent, and with a solar PV integrated energy façade. The building was naturally ventilated and had good daylight performance. The solar PV was located on the south facing offices to provide shading and avoid the need for mechanical cooling. Figure 2 shows the building and details of the PV shading system.

Façade design is an integral aspect of low carbon design. Highly glazed facades can provide good day lighting for offices, but they should also be well insulated and include solar shading. The examples in figures 4 and 5 are both located in Zurich and have facades where the diffuse glazed blinds move into position in response to the sun. In figure 4 the horizontal

图5 EMPA建筑物理分析

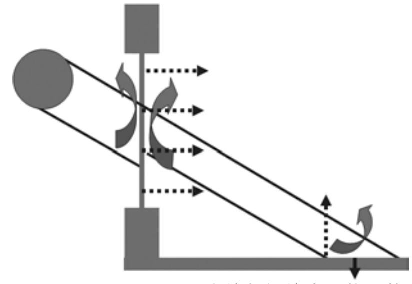


图6 直接与间接太阳能得热

图7 IFC光之塔

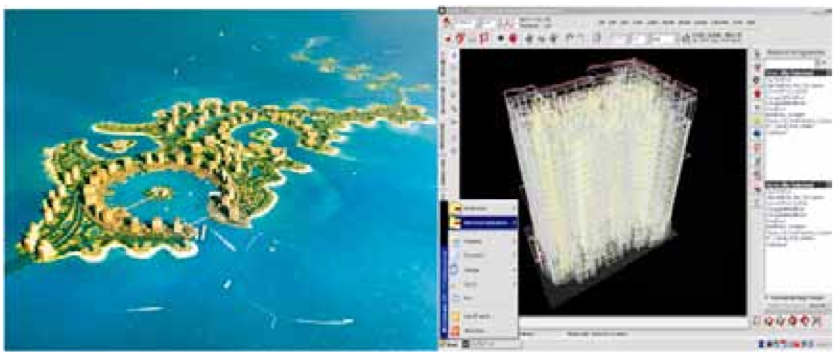


图8 珍珠

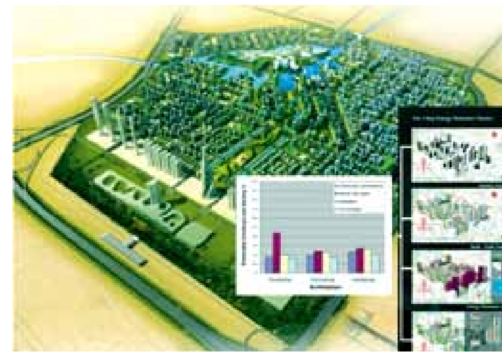


图9 RAK

幕墙设计需要对玻璃系统进行分析，特别是g值。g值用来衡量直接太阳得热、内部玻璃表面间接得热（图6）。对于一些玻璃系统来说，随着玻璃系统对太阳热辐射的吸收，这些热量要通过内表皮进入到室内，此时内表皮能达到相对较高的温度。内表皮温度最高不得超过室内温度5 °C，以避免过热。因此，太阳能得热应用在玻璃系统时，必须采取相应形式的通风处理，或对玻璃本身进行处理，如设置附加层等。

阿特金斯设计的位于迪拜的IFC“光之塔”（图7），节能目标为比当地同等的现有建筑减少65%的能源消耗。因此，设计者通过减少内部得热、控制太阳辐射与外墙得热的幕墙设计以及太阳能光伏与光热可再生能源一体化的设计等策略来达到此目标。能耗模拟由威尔士建筑学院和香港理工大学一起完成，建筑目前正在施工中。

对于某些发展规划，从城市角度考虑问题较单纯从建筑单体考虑更重要。卡塔尔珍珠岛发展规划（图8）旨在减少50%的能耗。我们进行了能耗分析，主要目标就是能减少开发片区所需能源供给的基础设施的面积。设计指导包括建筑材料标准、施工、朝向、环境服务、照明等。

Ras al Kaimha城市发展规划计划为250 000人口提供居住。早前的总规（图9）建立了降低能耗的指导原则。能耗模型考虑了降低内部得热、变化的施工细节（玻璃类型、u值等）、设置遮阳以减少太阳辐射得热及变化的朝向等，使得空调负荷显著降低。

4 未来的建筑

那么，未来如何延续过去的三四十年间从低能耗到零碳的发展趋势？什么样的新兴技术与建造程序会被应用到未来建筑中呢？

以零碳性能为目标将会是规划、设计、建造与运营的持续推动力。零碳的定义也会随着产业的发展壮大而发生变化。也许未来零碳将朝向“碳积极”的概念发展，建筑变成一个能源发生器，不仅满足目前“不规则”的电气耗能，还能将产生的能源运输。在目前关于零碳的定义中，重点已从更高效地利用能源转向为未来供给更多的可再生能源。

blinds retract upwards when there is no sun on the facade. In Figure 5 the vertical blinds move as the sun angle changes, optimising solar control. Both building have exposed concrete ceilings for cooling. Figure 4 uses an ‘active’ chilled ceiling which has chilled water pipes in ceiling to provide about $35W/m^2$ of peak cooling (see figure 1b). Figure 5 also has a ‘passive’ chilled ceiling which is cooled by night ventilation purging. In the day mechanical ventilation delivers air to the building through a ground air cooling system (right picture in figure 5), in summer providing up to 10°C of cooling. In both cases the radiant temperature is lower than air providing good comfort conditions.

Façade design requires an analysis of the glazing system and in particular its g-value. The g-value is a measure of the solar heat gains to the space both from direct gains and secondary gains from the internal glass surface (see figure 6). For some glazing systems the internal glazing surface can reach relatively high temperatures due to the solar heat gains being absorbed by the glazing system and transmitted into the space through the internal glazing surface (which could be glass or an internal blind). It is generally accepted that the internal surface should be less than 5°C above internal air temperature to avoid overheating problems. Therefore the solar heat gains to the glazing system must be dealt with by some form of ventilation, glass treatment, or additional layer (or a combination of).

The IFC Lighthouse tower proposed for Dubai and designed by Atkins (figure 7) had a target energy reduction of 65% compared to a standard tower for that region. This was to be achieved by a combination of reducing internal heat gains, façade design to control solar and external heat gains, and building integrated renewable, mainly solar PV and solar thermal. Energy modelling was carried out by the Welsh School of Architecture in collaboration with Hong Kong polytechnic University, demonstrating that the target savings could be achieved, however the building was not completed.

For some developments an urban scale approach, rather than a building approach is necessary. The Pearl development in Qatar (figure 8) aimed to achieve 50% reductions in energy demand compared to the standard for such developments in the region. Modelling was carried out to produce a set of guidelines for the main developer to issue to the plot developers. The main aim was to be able to reduce the size of the developments energy supply infra-structure. The design guidelines contained criteria relating to the building materials, construction, orientation, environmental services, lighting, etc, in order to achieve the 50% energy demand reduction.

The Ras al Kaimha gateway City development was planned for 250,000 residents. Early master-planning modelling (figure 9) was carried out to establish guidelines for reducing energy demand. The modelling considered reductions in internal heat gains, varying

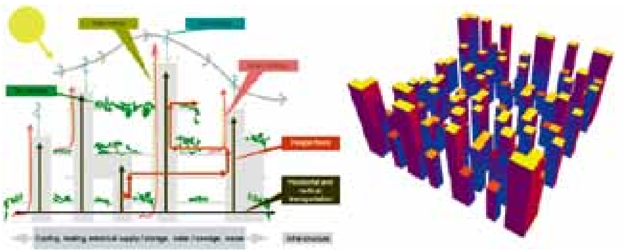


图10 高密度“超级组群”发展规划

未来的建筑应该是以“群”的形式出现，共同分享当地的能源。新的科技发展能为抵偿既有建筑能源的消耗做出更多贡献。比如，依靠新的以社区为基础的产能系统。因系统带来的需求更加多样化，热与电能源的能量存储技术也急需发展。英国和欧洲其他国家新的回购电价和可再生热动结构在此领域展示出了创新的潜力，为个人和公司提供了投资机会。

在建筑生命周期中，当建筑含能与运营能源相同时，也将成为需要发展的领域。我们已经有了材料含能的数据库，工厂也开始关注如何才能降低建筑产品的含碳量，未来我们在进行设计时将会在建筑的性能参数中注明产品含能值。当然，减少建筑含能最直接的方法就是减少建筑垃圾的产生。这些垃圾不仅数量庞大，还有可能是有毒的，在建造、改造、拆毁时很难处理。我们期待未来房屋建造能够应用更多新的环境友好型材料。

现代施工方法（MMC）是发展可持续建筑的一种手段，可以有效减少垃圾，为我们提供高质量的产品。这将有可能促进建筑一体化的发展，而不仅仅是设计的锦上添花，这也将有利于节约造价。

未来土地资源将会越来越紧张，近期与ACL–Hyder合作的一个越南河内高密度的“超级组群”规划（图10）分析就将在$1km^2$的土地上安置100万的人口。也许这个密度有些过大，但这些对未来的思考揭示了城市通风中的烟囱与通风廊、竖向交通与基础结构、可再生能源使用等问题。建筑的运营能源与含能的发展是合理的么？真正的健康与生活质量又是什么？未来无疑是可持续与碳中和的，但更加重要的，未来一定是宜居的。(译/李昭君)

construction details (glazing type, u-values, etc), over-shadowing of buildings to reduce the solar heat gains, and varying orientation. Significant reductions in cooling load were demonstrated, which can be used by the plot developers.

Building of the Future

So how will this trend over the past three to four decades, from low energy to zero carbon, extend into the future, and what are the emerging technologies and processes that will be applied to the building of the future?

The zero carbon performance target is likely to continue to be a driving force behind planning, design, construction and operation, and probably the definition of zero carbon will change over time as the industry becomes more confident in its ability to deliver. It is possible that in future the concept of zero carbon might develop into ‘carbon positive’, where the building becomes a net generator of energy, to cover not only the currently ‘non-regulated’ energy uses associated with electrical appliances, etc, but also to generate energy for transport. In the current definition of zero carbon, the emphasis is shifting from further energy efficiency measures (to reduce demand), to the application of renewable energy supply and in future there will be more activity on the supply side.

Buildings in future are more likely to be considered in groups or communities, where energy is shared locally and contributions are made from new developments to offset energy use in existing buildings, for example through new community based generation systems. Energy storage technologies will need to be developed both for thermal and electrical energy, as will systems that introduce greater diversity of demand. New electricity feed-in tariff and renewable heat incentive structures in the UK and elsewhere in Europe, have the potential to drive innovation in these areas, providing investment opportunities for both individuals and companies.

As embodied energy becomes equivalent to operating energy over a building lifetime, this will become an area of development. There are already databases emerging for embodied energy of materials and industries are already looking at how to decarbonise their products, Future designs may have an embodied energy value in kWh/m2 associated with the whole building performance. Of course the ‘low hanging fruit’ for reducing the embodied energy is the reduction of waste. Waste is becoming a major concern not only in the volume of waste produced during construction and refurbishment, but also the nature of the materials being used as part of energy efficient design, many of which might be considered poisonous and difficult to deal with in terms of construction, refurbishment and eventual demolition. We might therefore expect to see interesting developments of new and more ‘environmental friendly’ materials for house construction in future.

Modern methods of Construction (MMC) are now considered to be a means of delivering sustainable buildings, through reducing waste and providing a better quality product. This is likely to result in a more integrated, rather than add-on approach to design, which should contribute to cost reductions over time.

In future there is likely to be competition for land, with food production a major concern. A recent planning analysis in collaboration with ACL-Hyder for a high density ‘super-cluster’ development in Hanoi considered a density of 1million people in 1km2 (figure 10). Although perhaps excessively high, such future thinking identifies issues of urban chimneys and breezeways to ventilation the city, vertical transportation and other infra-structures, and access to renewable energy. Is the operating energy and embodied energy of such developments acceptable, and what are the health and quality of life implications.

The future must be sustainable and carbon neutral, but it must also be liveable. AT

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Phil Jones，卡迪夫大学威尔士建筑学院院长，教授。2010年代表卡迪夫大学与天津大学建筑学院共同成立了低碳建筑国际研究中心。他的研究范围包括能源使用、环境设计、建筑环境可持续设计等多个方面，参与了一系列环境设计咨询工作，包括在瑞士与kopitsis bauohysiq合作的立面设计、卡塔尔珍珠岛发展规划能源分析、迪拜第一个低碳高层商业建筑“lighthouse”的建筑物理分析等。