Computer simulation to achieve low carbon buildings

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计算机模拟技术在低碳建筑设计中的应用

本文介绍了整体式低碳建筑设计的方法，同时概述了计算机模拟技术和建筑物理工程师在实现建筑低碳节能设计中的重要作用。文章结合当前瑞士节能建筑实例，进一步阐述计算机模拟技术如何帮助建筑师优化设计方案以实现低碳节能，同时创造出舒适健康的人居环境。计算机模拟技术可以准确预测建筑设计方案的性能或量化不同设计方案的性能以提供最合理方案，其主要功能包括预测室内空气温度，表面积辐射温度，计算室内得热量，制冷采暖负荷，机械通风和自然通风情况，以及室内外气流分布状况。

1 Introduction

In response to the concerns of climate change and depletion of fossil fuels, 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 industry's approach to achieve 'near-zero' carbon buildings. A 'near-zero carbon building should first have its energy demand reduced through 'passive design' combined with efficient HVAC systems, and second to meet the remaining energy demand through renewable energy supply systems. The emphasis should be on 'fabric first', which includes the form, orientation, construction elements of building design, which will in general remain unchanged throughout its life. Of course the HVAC system should then be an integral part of the design, together with any building integrated renewable energy supply. This should all result in providing an optimised solution for comfortable and healthy environment for the occupants with significantly reduced energy demand and carbon dioxide emissions.

Once a low energy design has been achieved there are new options for heating, cooling and ventilation. More efficient and comfortable surface heating and cooling systems (for example heated floor, chilled ceiling, chilled beam etc.) become available. The heating and cooling becomes mainly decoupled from the ventilation, with fresh air supplied by mechanical ventilation just satisfying occupancy ventilation rates, significantly lower than 'all air' cooling systems. With the introduction of 'smart' facades, incorporating insulated glazing systems with controlled shading layers, larger areas of glazing are possible without incurring an energy or comfort penalty. However, the key is to apply these components as an interactive system rather than to treat them as a group of bolted on elements.

1.1 Steps to a Low Carbon Design

The essence of low carbon design is to transfer the external climate condition to comfortable internal environment, including temperature, relative humidity, fresh air supply, air movement and lighting conditions. In order to do so, an integrated approach is required (Figure 1), to help the designer to clarify design objectives and recognize applicable passive strategies.

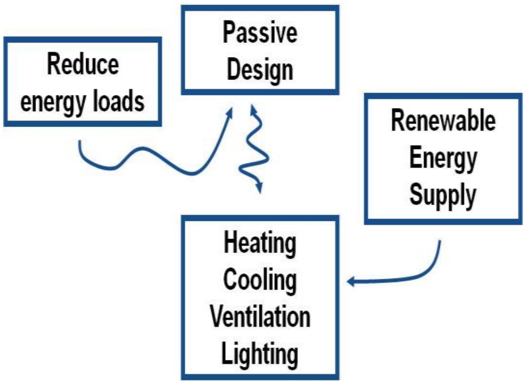


Figure 1: Integrated approach to low carbon design

Step 1: The first step is to reduce the heat loads on the space by building design. This saves the direct electrical energy used for lighting, small power and also leads to more efficient and effective environmental services for cooling, heating and ventilation. Solar heat gains should be controlled as well, to balance good daylight and lower cooling demand through façade design, especially layered facades.

Step 2: The second step is to apply passive design strategies to improve the internal built environment, such as provide shading, encourage desired air movement, increase thermal mass or introduce cool surface.

Step 3: The third step is to integrate efficient environmental services to achieve the required internal condition. The effective method is to decouple ventilation from cooling and heating so that ventilation is primarily for occupants and the major part of cooling and heating is delivered through separate 'surface' type systems. Surface cooling and heating offers a comfortable energy efficient system.

Step 4: Finally, renewable energy systems can be integrated to generate the energy demand for the environmental system and more for the grid if possible.

Of course all four stages must be carried out within the context of the climate and location of the building and the comfort needs associated with its use.

1.2 Design Tools

There are traditionally several types of tools can help architects' decision making during this new holistic approach in order to improve a buildings' performance as well as to reduce energy demand, including design guide lines or rules of thumb, traditional physical calculation methods, correlation based methods and building simulation. Due to the complex dynamic thermal interactions between external environment, building fabrics, internal heat gains and the building service systems determining the building energy consumption and the indoor built environment, building simulation provides the most direct help to the designers. The commonly applied function of simulation include prediction of the internal air, radiant temperature, calculation of the internal gains and the heating and cooling loads, mechanical and natural ventilation, and air movement patterns inside space. These days advanced dynamic simulation tools such as HTB2, developed at the Welsh School of Architecture, Cardiff University, can simulate the integrated combination of 'smart' facades with surface cooling and heating, together with the ventilation system operation.

1.3 The Building Physicist

The role of the building physicist has emerged as someone who can understand the building science associated with achieving a low carbon design. Their expertise covers both the physics of building performance together with the comfort criteria needed by occupants, and they can also use the more advanced building simulation tools. Their role covers not only the thermal and energy related aspects of design, but also, the daylighting and acoustics, thus ensuring that environmental performance as a whole is dealt with in an integrated way. In Switzerland, they are an important member of the design team and are involved with a project from the early stages. Building physics, like low carbon design, is not a bolt on activity.

This paper reviews a number of buildings in Switzerland designed around the above principles. These projects use building simulation to help designers optimize their design decisions to achieve a comfortable environment within a low carbon approach.

2 Case studies

2.1 Shading design

Building simulation can accurately calculate the amount of solar radiation entering the space, taking into account the actual position of the sun, shading effect from the terrain, surrounding structures and shading devices. By comparing the solar gains from different design options, the designer can optimized the design of shading device for any façade.

Figure 2: Image of IC hotel

The pioneering architecture of **InterContinental Davos Resort & Spa** is designed by Matteo Thun (Figure 2). The main building envelope includes an oval shaped outer shell and triple glazed windows inside. Besides the aesthetic aspect of design, the outer shell can behave as a shading device to reduce the solar penetration.

With the highly insulated and air tight building envelope, very little heat transfer between the external environment and the internal space. During summer time, the HVAC system is effective in providing the required environments for the occupants. The outer shell significantly reduces solar gain and contributes to the cooling efficiency. However, excessive solar radiation enters the rooms at afternoon time in winter time, at this time unshaded by the outer shell due to the low altitude of the sun. Figure 3 shows the difference between winter and summer, the situation visualised in Figure 4. The large amount of solar gain (about $40W/m^2$) causes the space to overheat during daytime, even when average external air temperature is -10°C. So, cooling is required during the heating season, and not heating. External shading was advised to be installed on those exposed windows, designed to address the specific problem.

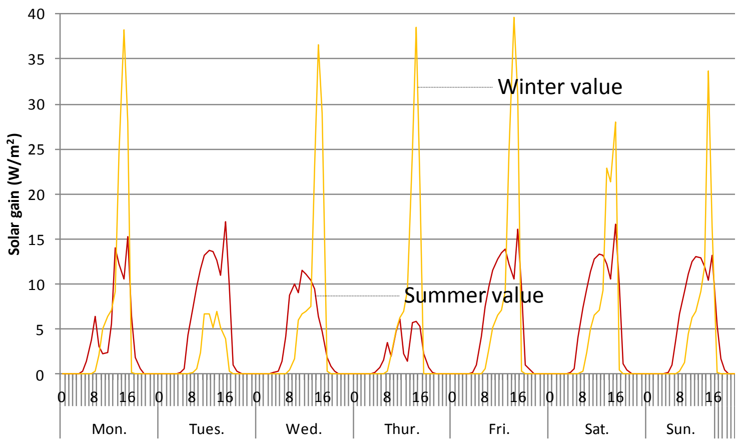


Figure 3: Solar gain comparison

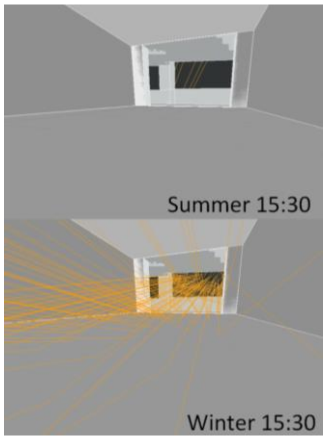


Figure 4: Solar radiation enters the room

2.2 Façade design

Building simulation can calculate the heat transfer through building envelops, and predict the internal surface temperature of any chosen element, with consideration of the thermal parameters of the construction, for example for glazing, including its thermal conductance, and radiant absorption, reflection and transmittance. The range of simulation results of the internal temperatures and energy consumption from various design options can directly inform the designers with the best performance options. It is important that the internal glazing temperature in summer does not exceed 5°C above internal air temperature, to maintain a satisfactory comfort level. By comparing the internal glazing surface temperature and the internal air temperature across options, the designers can avoid potential discomfort from excessive radiant effects from hot or cold surfaces and any associated downdraught.

Vichow 14 is 'transparent' laboratory building designed by Koolhaas in Basel, Switzerland (Figure 5). In order to achieve the transparency design concept without jeopardizing the building's performance and energy efficiency, the architects applied different glazing systems to the façades of different orientations, namely, a double skin facade on the south/ east, a double skin façade with blind on the west and triple glazing with no blinds on the north covering the main service spaces (Figure 6). The double skin façade on south, east and west can be naturally ventilated. Dynamic simulation was carried out to investigate the performance of the façade systems, including an assessment of the solar gain through each façade and the consequent influence on the internal thermal environment. The investigation included studying the air movement through the naturally ventilated double skin gaps, and checking the internal surface temperatures of the glazing and relating to thermal comfort. The simulation result (Figure 7) indicated that the east, west and north façade can successfully reduce the excessive solar radiation and provide the required indoor air temperature, as well as the glazing internal surface temperature criteria (about 4.0°C higher than the internal air temperature in summer, which is below the 5°C maximum).

Figure 3: Image of Virchow 14 laboratory

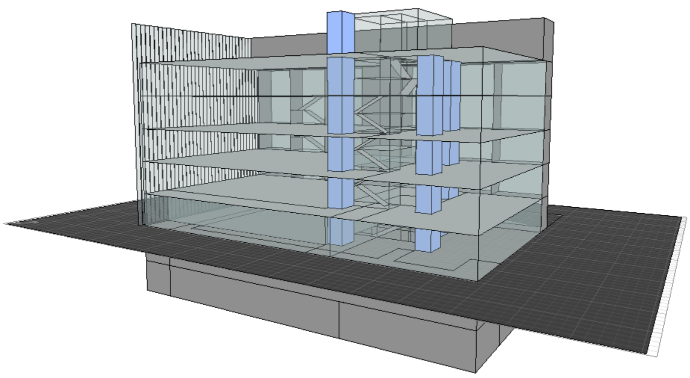


Figure 4: Illustration of different facade

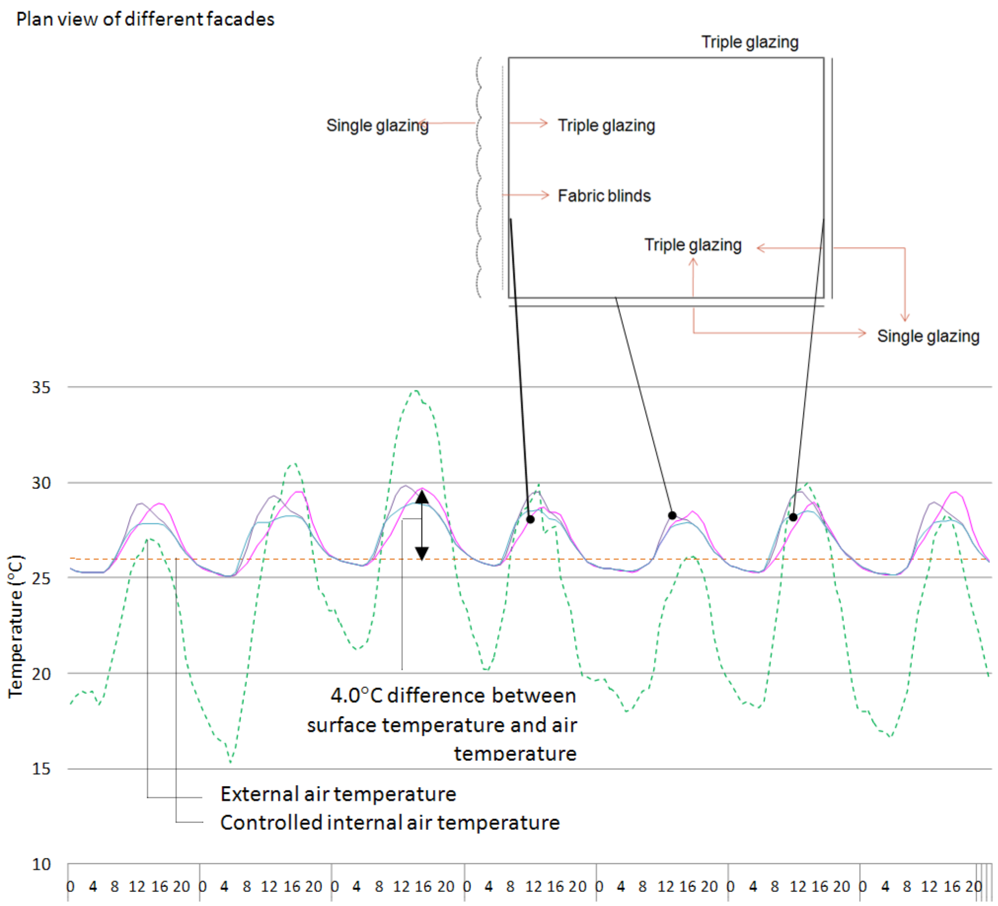


Figure 5: Simulation result

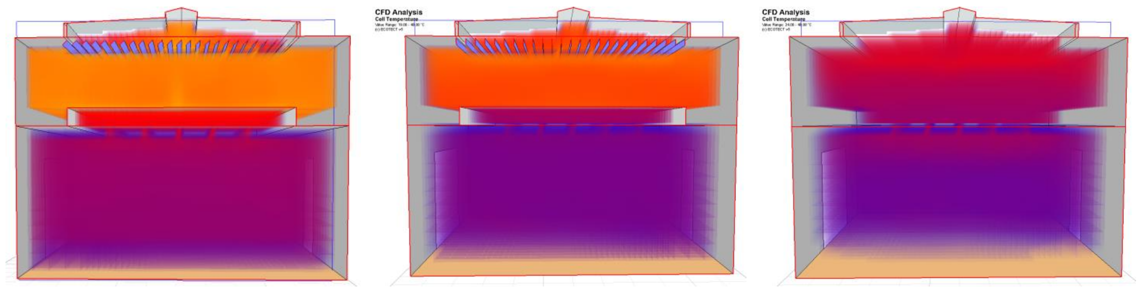
2.3 Layered roof design

Some buildings require specific daylighting performance, whilst avoiding solar heat gains and glare discomfort.

Kunsthaus is a leading fine art museum in the centre of Zurich (Figure 8). Natural dayighting was essential for the new extension to the Kunsthaus. A five layered roof system was proposed to introduce natural light into the space to create evenly lit internal environment without glare during daytime. The five layers included external sunscreen, outer layer of the glazing, adjustable louver, inner layer of the glazing (double glazed), and light cover (single glazed). Artificial lights were placed in the double skinned roof, under the louver. The design aimed to reduce the heat gains in the main space as well as providing uniform dayighting for the exhibition. Natural ventilation was introduced between the louver and the outer layer glazing to take away the heat (from the solar gains and electric lighting) trapped in the roof space. In the exhibition space, mechanical ventilation was provided through the perimeter of the floor, with extract through the light cover on the ceiling. As there was no ceiling area to provide for chilled surface cooling, the chilled surface system was applied to the walls.

Figure 6: Image of Kunsthaus

In order to achieve the optimized performance with cost effect, glazed ceiling systems with different parameters were tested, including double glazing or triple glazing for the outer layer, and the combination of open external sunscreen and closed louver, closed sunscreen and open louver. Air flow modelling combined with dynamic simulation was used to compare the different options and provid visualized results to inform the design (Figure 9).



a) Sunscreen open, louver closed   b) Sunscreen closed, louver open   C) Sunscreen closed, no louver and no light cover

Figure 7: Visualized prediction result

2.4 Thermal mass design

Thermal mass is an essential part of the integrated design associated with the low energy and low carbon approach. It can be used in an active way, with the mass elements being directly cooled by water or air, and in a passive way, where the building is night cooled through natural ventilation. Thermal mass can also be used directly in the space through exposed high mass construction elements, such as the ceiling, or it can be used indirectly, for example, by drawing ventilation air through the ground and pre-cooling it before it enters the space.

EMPA, design by BOB GYSIN & PARTNER BGP (Figure 10), is a five floor office surrounding an atrium, which serves as a buffer zone providing daylight into the building and used as part of the natural ventilation night cooling system. The building is well insulated and has movable vertical diffuse glass panels, which are sunlight controlled; provide optimized shading throughout the day. Its ventilation system uses ground cooling and night time ventilation. The building has solar thermal and photovoltaic systems, uses recycled materials and has water reservation system and a green roof. It is neither heated nor actively cooled by conventional means.

Figure 8: Image of EMPA building

The exposed reinforced concrete ceiling construction works as a heat and cold storage unit, while the clay and gypsum walls regulate air humidity. During summer night, as soon as the external temperature drops below room temperature, the cooler outside air will be drawn into the building through the automatically controlled windows on the external façade and between the offices and the atrium. This exhausts the heat stored in the thermal mass during daytime out thought the atrium roof openings through natural buoyancy. During daytime, ventilation air in provided through the underground cooling/ heating network of pipes, using the thermal storage effects of the ground for pre-cooling. In winter the same system can be used for pre-heating the ventilation air. There is heat recovery from processing on the site which is also used for space heating when needed. There is therefore no cooling or heating system in the traditional sense. Figure 11 shows the atrium and underground cooling system.

Figure 9: Atrium and underground cooling pipes

2.5 Building service design

Building simulation can also help in choosing the efficient building systems for delivering heating, cooling and ventilation to optimize their operation.

Figure 10: Image of Wurth Verwaltungsgeb

Würth Verwaltungsgeb designed by Gigon Guyer Architekten is an office building in Rorschach (Figure 12), that has (a) a highly insulated building façade with low air infiltration rate (the main building fabric has a double skin façade with single glazing outside and triple glazing inside), (b) a shading system with adjustable blinds that are installed against the external surface of the internal glazing), (c) a surface heating and cooling system with pipes located 8cm from the surface inside the ceiling slab, and (d) a mechanical ventilation system with heat recovery providing fresh through a raised floor and extracts at ceiling level during operation time.

In order to exhaust the heat gain away from the space, the chilled ceiling system and mechanical ventilation were proposed. Dynamic simulation was carried out to optimize the efficiency of the system. The result suggested the chilled ceiling system should be switched on during non-operation time to use the thermal mass (ceiling slab) to precool the space for operation. During operation time, cool fresh air is supplied by mechanical ventilation system. Figure 13 is the prediction of how these two systems work together for cooling effect. The graph shows that the chilled ceiling can typically provide 25W/m^2 cooling load during operation time, while the ventilation can take away the other 10W/m^2. This arrangement enables both systems to share one chiller (Figure 14). The chilled ceiling system can maintain the internal air temperature above 19.0°C as required.

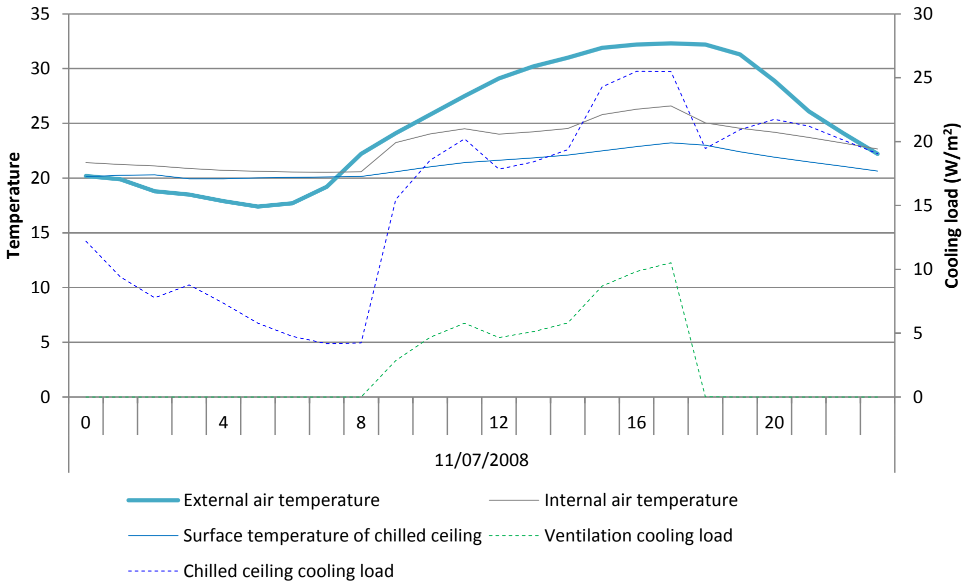


Figure 11: Cooling loads for chilled ceiling system and mechanical ventilation system

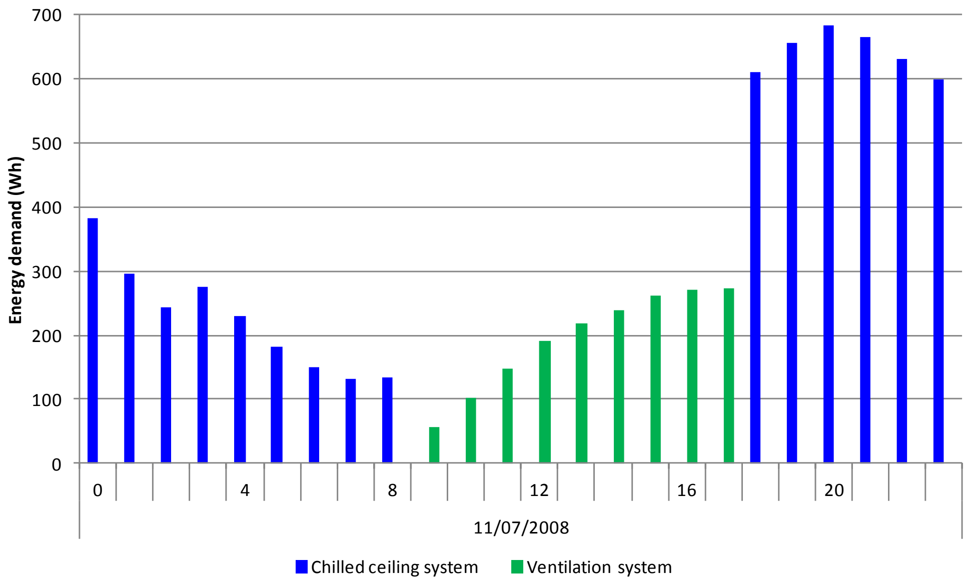


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Figure 12: Energy demand for chilled ceiling system and mechanical ventilation system

3 Conclusion

Low carbon buildings are attracting more attention in China now. It is important that they are also low energy in relation to reducing the energy demand through energy efficient building construction and HVAC system. This requires the application of more advanced building simulation to predict the integrated building performance. Such tools have been developed and are being increasingly used to inform low carbon building design. Also, the building physicist is an emerging role in the design team in using these tools to provide quantified information to support decision-making in design process. The combination of the building physicist and the application of the building simulation tools provides a necessary resource to ensure the achievement of low carbon design. This has become common practice in Switzerland and other parts of Europe and may point the way for low carbon energy efficient design in China.