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MFREE-S Closed Cavity Façade: Cost-Effective, Clean, Environmental

零维护——可持续封闭式腔体幕墙：经济、清洁、环保

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Abstract

Very few existing tall buildings comply with current energy and sustainability performance requirements. An innovative façade solution, "MFREE-S Closed Cavity Façade" (CCF), has recently been developed which merges the benefits of high-rise buildings (provision of daylight and external views) while meeting performance criteria such as low energy consumption, high user comfort, low long-term maintenance, as well as low initial and long-term costs. This paper compares the performances between the MFREE-S CCF and the traditional single and double skin façades by means of detailed simulation tools for energy, thermal and acoustic comfort assessments. The value of such assessments for tall building projects during early design phases is demonstrated and two example projects are given where the holistic design approach has led to improved sustainable and cost-effective solutions for highly transparent buildings.

Keywords: Closed Cavity Façade, Dynamic Façades, High-Performance Façades

摘要

目前，极少数的高层建筑能满足现时节能及可持续的性能要求。最近我们研发了一新型幕墙“零维护-可持续(MFREE-S)封闭式腔体幕墙(CCF)”。该系统融合了高层建筑的优点，例如：可充分利用日照， 拥有开阔视野；同时还具有低能耗，高人体舒适度，隔声效果优异，长期维护成本低的性能准则，以及较低初始投入及较低运营成本等特点。本文将概述与传统的单、双层幕墙的性能对比。采用深化的模拟软件工具于节能，隔热与隔声舒适度进行了评估。本文演示了在早期设计阶段进行此项评估对高层建筑项目的价值。同时通过两个工程案例来演示在高度透明建筑物中运用全面设计手法改进可持续性及成本效益的解决方案。

关键词：封闭式腔体幕墙(CCF)、动态幕墙、高性能幕墙

Introduction

For high-rise office buildings the façade is the largest surface area of the building perimeter where direct heat exchange between the outside and inside environment takes place and therefore can contribute significantly to achieving more sustainable buildings. Due to stringent energy and environmental targets set by governments and higher comfort requirements (thermal, daylight, acoustics, outside view) required by clients and tenants, traditional façades in high-rise office buildings face difficulties to comply.

Different façade technologies have developed in the past in order to comply with all the above requirements for high-rise buildings on which double skin façades (DSF) are mostly applied.

Although DSF technologies have been successfully integrated in numerous landmark buildings around the world, the following additional requirements to current DSF's are demanded by clients:

- elimination of interstitial condensation risks on glass surfaces between the two skins;

简介

对高层建筑而言，外墙是建筑周边的最大表面面积，室内外环境之间的直接热能转换也在幕墙进行。因此在对实现更加持续性的建筑物方面，幕墙设计可以作出重大贡献。由于各国政府相继制定更严格的节能环保政策，建筑业主及用户对室内舒适度的要求日益提高（人体热舒适度、自然采光、隔音、室外视野等等）。高层建筑的传统幕墙很难满足所有的要求。

为满足上述各项要求，业界开发了各种不同的幕墙技术，其中双层幕墙（DSF）最常用在高层建筑中。

虽然双层幕墙成功的应用到世界许多地标性高层建筑，业主对现時双层幕墙常会有以下额外的要求。

- 消除在内外幕墙腔体内玻璃表面上的填隙式结露现象；
- 在通风透气的腔体内减少对构件的清洁次数以降低维护成本；
- 减少清洁工出入建筑的次数，因部分办公用户（例如银行， 律师事务所等）视为妨碍，可能产生安保问题（如资料保密等）；
- 消除供通往透气通风腔体的内开门

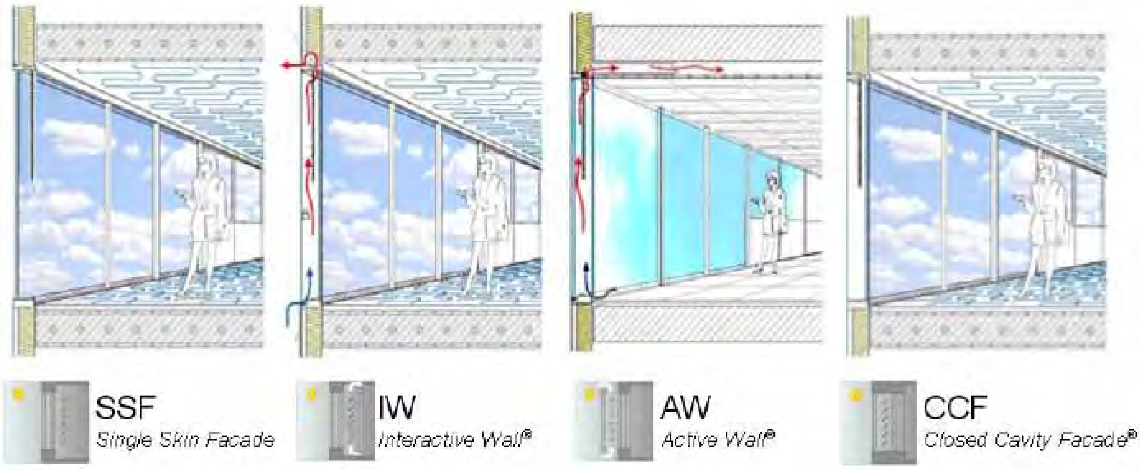

Figure 1. Different façade types (Source: Permasteelisa Group)
图1. 不同的幕墙类型（来源：帕马斯迪利沙集团）

- a reduced cleaning frequency of the components in the ventilated cavities in order to reduce maintenance costs;
- a reduced access frequency by cleaners in the building because some tenants of offices (banks, law firms,…) experience this as disturbing, it can generate issues on security (e.g. confidential information, etc);
- an increased 'effective net-lettable area' by eliminating the opening of internal windows for access to the ventilated cavity (requires regular moving of furniture or effective usable space loss).

Recently a new generation of DSF, the MFREE-S Closed Cavity Façade technology (CCF technology) has been developed by the R&D group of the Permasteelisa group and their research partners in order to provide solutions to the above mentioned requirements of clients regarding current DSF's.

A comparison between traditional façades and the novel CCF technology is needed to relate their performance requirements such as energy impact, thermal comfort, acoustic comfort, condensation formation, cleaning cost and access frequency, overall project cost, etc… Software analysis tools have been developed for detailed quantitative performance assessments such as energy consumption, thermal comfort, and acoustic performance. Qualitative evaluation is also provided for the other façade performances.

Different Façade Type Overview

In this paper the performance parameters of the following dynamic façades types are evaluated (see Figure 1):

Traditional façades

SSF:

- Interactive Wall® (IW): the IW is a DSF which consists of a single glazing toward the outside and a DGU toward the inside creating a ventilated air cavity where blinds can be integrated and air flowing from outdoor through the cavity returning back to the outdoor via stack and/or wind effects;
- Active Wall® (AW): the AW is a DSF with a single glazing toward the inside of the building and DGU toward the outside, with the indoor return air passing through the cavity of the DSF and then returning to the mechanical ventilation system.

以增加可出租面积的效率 （需定期挪动家俱或牺牲有效使用面积）。

近来帕玛斯集团研发部及其研发合作伙伴开发了一种新型双层幕墙，零维护-可持续(MFREE-S)封闭式腔体幕墙(CCF)技术，以解决业主对现时双层幕墙的上述要求。

在相关性能要求方面，传统幕墙与崭新的CCF技術是有必要比较的，诸如，能耗影响，热舒适度，隔音舒适度，结露形成，清洁成本及进出频率，整体项目成本等，有软件分析工具被开发作出详细的量化性能评估如能耗，热舒适度及隔音性能。同時也提供其他幕墙性能的量化评估。

不同幕墙类型综述

在本文中分析了下列动态幕墙类型的性能参数(见图1）：

传统幕墙

单层幕墙：

- 交互式墙体®（IW）：交互式墙体是为双层幕墙（DSF），包括外面为单层玻璃，内面为中空玻璃的组合，型成一个透气通风空腔，可合整遮阳在内。通过烟囱或风力效应空气流动从室外穿过空腔，再回流致室外，形成外循环气流。
- 主动式墙体®（AW）：主动式墙体层是为双层幕墙（DSF），包括外面为中空玻璃，内面为单层玻璃的组合， 並带室内回风穿过双层幕墙的空腔并回流致机械通风系统，形成内循环气流。

新幕墙技术

- 帕玛斯集团的零维护-可持续封闭式腔体幕墙（MFREE-S CCF）：封闭式腔体幕墙（CCF）带有全密封空腔并与交互式墙体（IW）一样的玻璃与遮阳构造。空腔体内不停的输入极小量干燥洁净气体以避免结露及尘埃在空腔内。一个详细的分析软件工具'DSCAT'被开发来设计送风系统以调节空腔内的空气状况（Laverge et al,2010）

详细动态整体建筑物模拟软件‘CAPSOL-EXCELLENT’

为了从办公楼带有通风透气腔体的双层幕墙获得可靠的节能性能预测，采用体积控制方法模块的整体建筑模拟软件工具是十分重要的（Saelens, 2006）。为此， 在与研发伙伴Physibel的基础上，作为帕玛斯迪利沙集团研发项目的一部分，开发了软

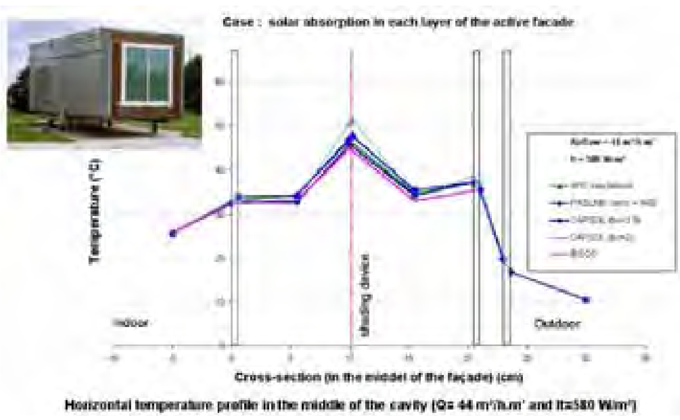

Figure 2. Temperature profile of AW in Passys test cell and simulation tools (Source: BBRI / Permasteelisa Group)
图2. 在Passys试验间和模拟软件工具的AW温度轮廓线（来源：帕马斯迪利沙集团）

New Façade technology

- Permasteelisa MFREE-S Closed Cavity Façade (CCF): the CCF has a fully sealed cavity and the same glazing and blind configuration as an IW. A very low volume of dry & clean air supply is used to prevent condensation and dust within the cavity at all times. A detailed analysis software tool 'DSCAT' is developed to design the air supply system in order to condition the cavity air (Laverge et al, 2010).

Detailed Dynamic Whole Building Simulation Tool 'Capsol-Excellent'

In order to obtain reliable predicted energy performance for office buildings with dynamic DSF systems with cavity ventilation, it is important to use whole building simulation tools with control volume method module (Saelens, 2006). Therefore a software program 'CAPSOL-Excellent' has been developed as part of a Permasteelisa Research Program based in collaboration with research partner Physibel (De Bleecker et al, 2007) and used in this study. The base engine of the software is 'CAPSOL' which was validated against numerous international standards (Physibel, 2002). In the research program 'Active Façade project' (BBRI, 2002) evidence was given that reliable assessments can be done when using such detailed dynamic whole building simulation methods. An example is given in Figure 2 indicating temperature profiles of an Active Wall® measured during a steady state period and results using different software tools. The temperature profile achieved with CAPSOL-Excellent was in very good agreement with the measured results from the Paslink test cell.

Impact Of Properties And Type Of Transparent Façade Systems On The Energy Performance Of A London Office

In this section, detailed energy analysis is provided for an office room of a high-rise building as described in Figure 3.

A comparative study of seven different high transparent façade configurations is performed in order to assess the impact of façade selection on the entire yearly energy consumption. The façades differ from each other by varying the thermal transmittance of the glass (by the number of glass layers: single, double and triple glazing); the solar transmittance of the glass coating (clear, low-e, high performance) and the type of glazing system (single skin façade, DSF with internal or external ventilation flow, novel MFREE-S CCF technology).

件‘CAPSOL-Excellent’（De Bleecker et al, 2007），并在本文的研究中采用。软件的基本引擎是‘CAPSOL’按一系列国际标准来进行验证（Physibel, 2002）。在一个研究项目“主动式幕墙项目”（BBRI, 2002）中已被证实采用详细的动态整体建筑模拟方法，可对其性能进行可靠的评估。图2显示稳态周期内使用不同软件模拟的Active Wall®（主动式墙体）的温度轮廓与测量结果的比较。使用CAPSOL-Excellent模拟的温度轮廓与在Paslink 试验间得的结果非常一致。

透明幕墙系统的属性及类型对一个伦敦办公室的节能性能的影响

本章描述了图3中高层建筑办公室的详细能耗分析。

为评估幕墙类型的选择对整体建筑年度能耗的影响，本文对七种不同的高透幕墙进行了对比。这些幕墙在以下方面有所不同：玻璃的传热系数（单玻，中空或双中空）；玻璃的镀膜的透射率（透明、低辐射或高性能镀膜），及玻璃系统的类型（单层幕墙、内或外循环DSF、崭新的MFREE-S CCF技术）。

图4给出了以下结果：

- 根据ISO15099（2003）给出了玻璃幕墙常规的稳态热工特性参数：U值、g值、LT值与内表面温度；
- 依据详细的动态整体建筑模拟（CAPSOL-Excellent）软件计算的办公室年度总基本能耗， 包括： 根据在建筑周边的办公层每平方的年度采暖，制冷及整体能耗。

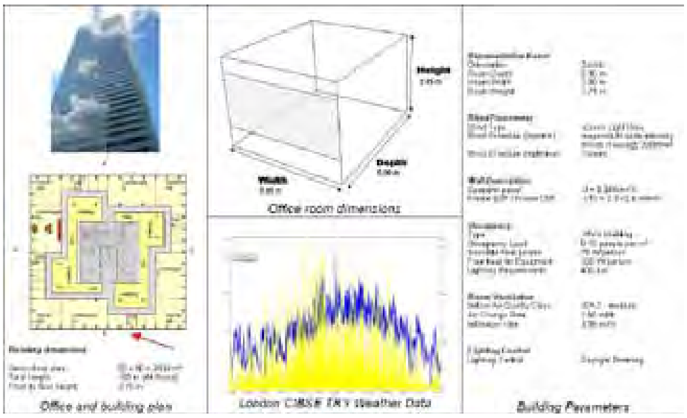

Figure 3. Representative office room in high-rise building with south facing façade and building parameters (Source: Permasteelisa Group)
图3. 在高层建筑南立面的典型办公室及其建筑设计参数（来源：帕玛斯斯迪利沙集团）

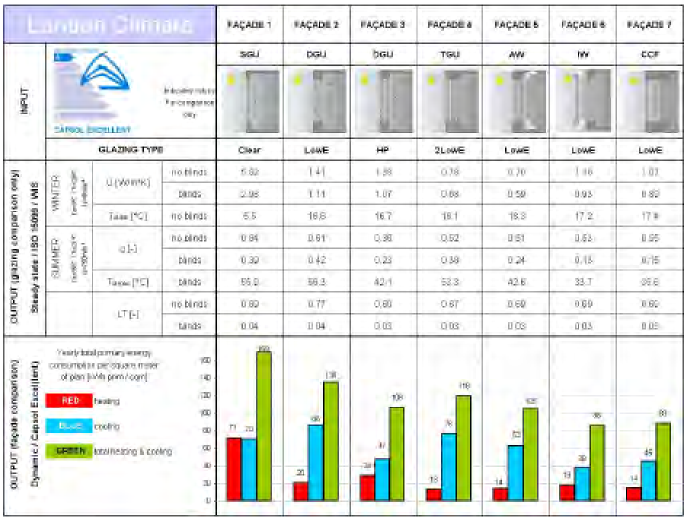

Figure 4. Impact of façade type on the energy consumption (Source: Permasteelisa Group)
图4. 幕墙类型对能耗的影响（来源：帕马斯迪利沙集团）

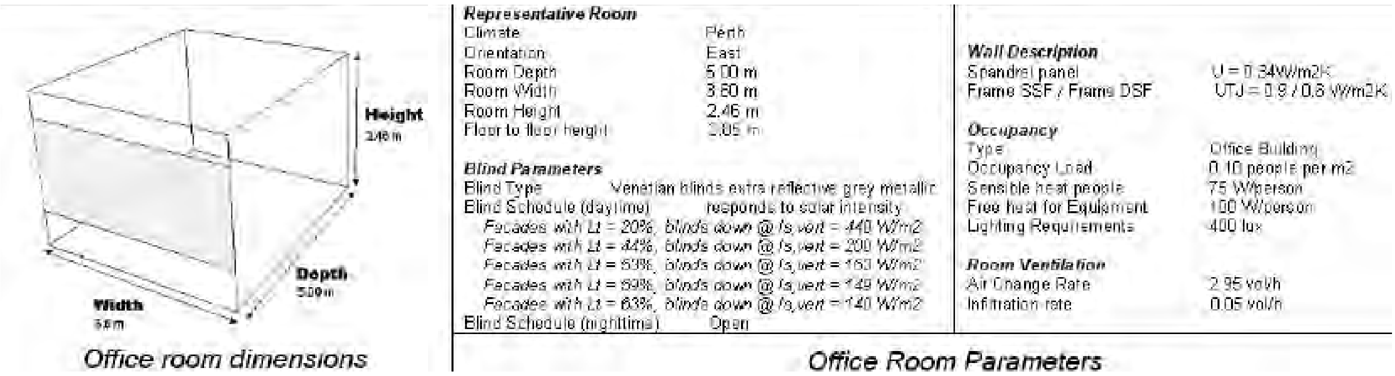

Figure 5. Representative office room with East facing façade and building parameters (Source: Permasteelisa Group)
图5. 在东立面的典型办公室及其建筑设计参数（来源：帕马斯迪利沙集团）

The following results are presented in Figure 4:

- The conventional steady state performance parameters of the glazed system in accordance with ISO15099 (2003): U-value, g-value, LT-value and internal surface temperatures;
- The yearly total primary energy consumption of the office spaces by means of detailed dynamic whole building simulation (CAPSOL-Excellent): heating, cooling and overall energy consumption on a yearly base per square meter office floor at the perimeter of the building.

Comparing the overall energy consumption on a yearly basis, it is clear that Façade3 with DGU and high performance coating has a lower energy consumption (mainly due to reduction in cooling energy) compared to Façade2 for which a clear low-e coating is used. In order to be able to use highly transparent façades, it will be a challenge to reduce the overall energy consumption concentrating particularly on the reduction of the cooling load (De Bleecker et al, 2004).

The dynamic whole building simulation analysis also shows that for the example office room, the triple glazed solution (Façade4) with a U-value of 0.78W/m2.K has a higher energy consumption than a CCF (Façade7) with a higher U-value (1.07 W/ m2.K). Although the g-value for the triple glazed system (g=0.52) is marginally lower than the CCF (g=0.55), the lower cooling energy for the CCF (Façade7) is due to the lower g-value when the blinds are down during the higher solar intensities (g=0.15 for Façade7 instead of g=0.36 for Façade4).

The results from the dynamic whole building simulations indicated that both DSF configurations (AW and IW) have a much lower cooling energy than the single skin façade systems (clear double, triple and single glazing). The strong variable differences in performance parameters for DSF's (U-value and g-value in function of the blind settings and ventilation flow) are at the basis of the lower yearly energy consumption for DSFs. Similar conclusions were found with other dynamic glazing systems such as electrochromic glazing (Carmody et al, 2004). Too many national regulations are based on strict steady state targets, e.g. U-values, whereas the detailed analysis show that dynamic transparent DSF and CCF systems have the potential to save more energy on a yearly basis.

Energy, Thermal And Acoustic Comfort Performance Comparison Of A Perth Office

Energy comparison

For this second study an office building in Perth (Australia) was investigated (see Figure 5) and energy results are presented in Figure 6.

对比年度整体能耗可见：与采用低辐射镀膜的幕墙2相比，有高效镀膜中空玻璃的幕墙3能耗较低（主要由于制冷能耗减少）。为使用高透幕墙，减少整体能耗将成为一种挑战，尤其是如何减少制冷能耗（De Bleecker et al，2004）。

以办公室为例，动态整体建筑模拟分析还表明：U值为0.78W/m²K的双中空玻璃方案（幕墙4），其能耗高于具有较高U值（1.07W/m².K）的CCF（幕墙7），尽管双中空玻璃系统的g值（g=0.52）仅稍低于CCF的g值（g=0.55），CCF（幕墙7）的制冷能耗较低是因为在太阳照度较高时，由于百叶降下，使其g值较低（幕墙7，g=0.15；幕墙4，g=0.36）。

动态建筑整体模拟结果表明：内或外循环双层幕墙的制冷能耗量都比单层幕墙（单玻，中空玻璃，双中空玻璃幕墙）系统低得多。双层幕墙比单层幕墙在年度总能耗巨大差别的原因是由于双层幕墙腔体内的通风对流及一体化电动百叶的升降翻转控制导致了系统U值及g值的差异。采用其他动态玻璃系统如电控调光玻璃（Carmody等人，2004）可得出相似的结论。很多的国家的建筑节能法规制定是基于稳态性能指标，如U值。然而详细的动态分析则表明，采用动态透明DSF与CCF系统每年都可能节约大量能源。

位于澳大利亚佩思市办公室的能耗、隔热与隔声舒适度性能对比

能耗对比

本文第二案例对澳大利亚佩思市的一幢办公大楼（见图5）进行了分析，其能耗结果如图6所示。

对佩思市的办公室采用两种幕墙系统（HP DGU与CCF）进行能耗计算， 由其结果可以得出以下结论：

- 采用透明的中空玻璃带内置遮阳导致非常高的制冷能耗（幕墙 I，II，III）
- 幕墙构造II与III（分别在中空玻璃中充空气及氩气）表明，在某种气候下较低的U值不一定能更节能。该结论清楚地说明了使用动态详细的整体建筑模拟-而非象很多国家建筑法规中简单地使用稳态特性次参数或（U值，g值…）采用固定稳态参数的简化动态分析 – 的必要性及优点（Saelens，2006）。
- 自动高反射内遮阳的使用对透明玻璃幕墙（I对II）及深色玻璃（IV对V）都有一些影响，但在CCF系统（VII对VI、VIII、IX）中的影响更为深刻。
- 所有带自动遮阳的CCF幕墙（VI，VIII，IX），其能耗都要比带自动内遮阳的传统透明幕墙（II，III）低很多。为使能耗与CCF相当，传统幕墙需采用带自动遮阳(VI,VII,IX)、非常深色/反射的玻璃，因而选用了可见光透射率低至LT= 0.2.（V）的玻璃。采用深色玻璃（LT=20%）的幕墙（VI）的能耗仍高于透明CCF（LT=63%）

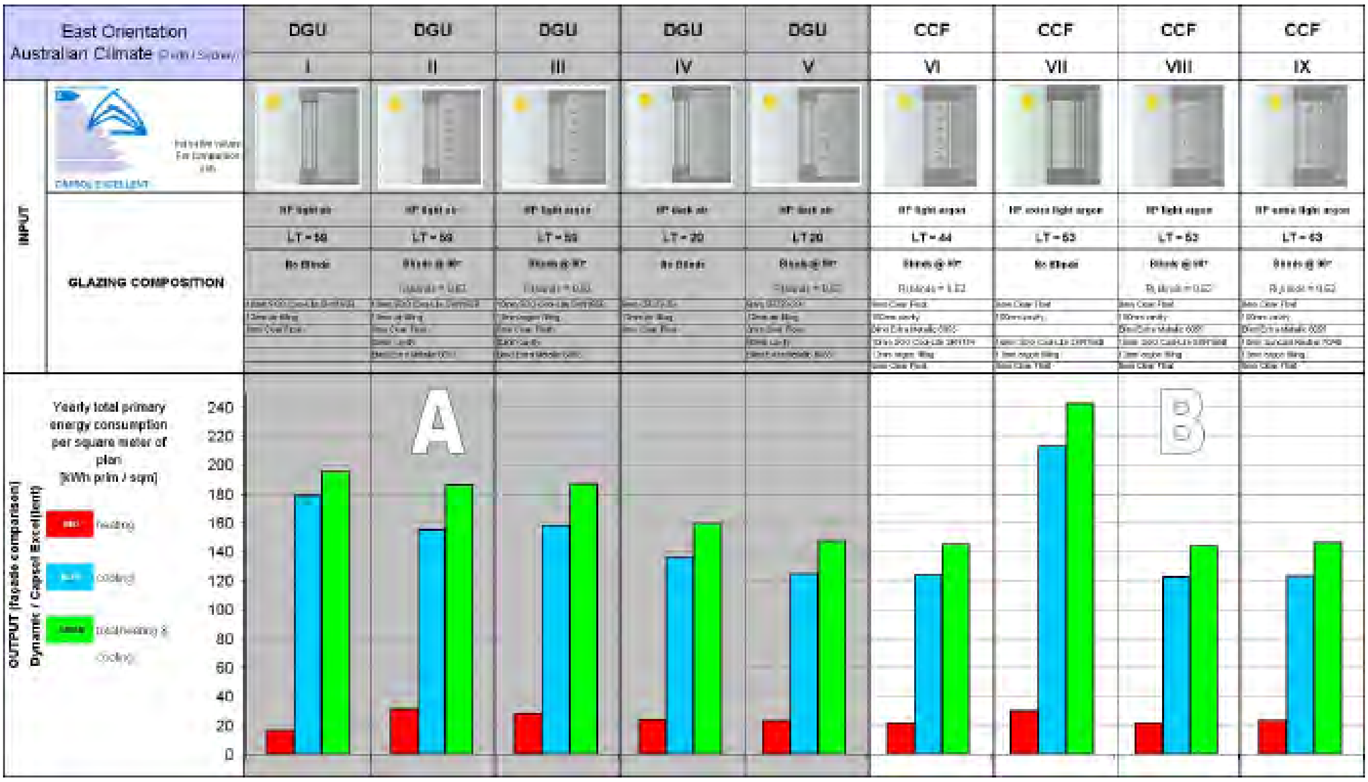

Figure 6. Energy simulation results for traditional CW and CCF (Source: Permasteelisa Group)
图6. 传统幕墙与CCF的能耗比较（来源：帕马斯斯迪利沙集团）

The energy consumption calculations of the office room in Perth with two different façade systems (HP DGU and CCF) lead to the following conclusions:

- DGU with clear glass and internal blinds results in very high cooling energy (façades I,II,III)
- Configurations II and III (use of DGU with air and argon respectively) show that in certain climates lower U-values do not necessarily lead to more energy saving. This clearly demonstrates the need and benefit of using dynamic detailed whole building simulation tools rather than fixed steady-state performance parameters targets from regulations or simplified dynamic simulation tools with fixed secondary parameters (U-values, g-values,…) (Saelens, 2006).
- The effect of using automated internal high-reflective blinds have some impact for both clear (I versus II) as dark glass (IV versus V) but the impact is most impressive for the CCF systems (VII versus VI, VIII, IX).
- All CCF façades with automated blinds (VI, VIII, IX) have a much lower energy consumption than the traditional transparent façades with automated internal blinds (II, III). In order to bring the energy consumption of the traditional façade with very dark/reflective glass with automated blinds to a similar energy performance as the CCF façades (VI, VIII, IX), a light transmittance of as low as LT=0.20 was chosen (façade V). The energy consumption of a curtain wall with very dark glass (VI) (LT=20%) is still higher than that for a transparent CCF (LT=63%) (although the electricity use for the lights are not yet added to the comparison). Note that for such dark glass (V) an increase of energy consumption for electric light can be expected (Simonella et al, 2003) to also impact the outside view out. Dark glass façades have been reported from occupants having depressed feelings by getting the impression that the weather

的能耗（虽然灯具所使用的电力都没有添加到比较）。需提请注意的是：由于采用深色玻璃（V），可预计能耗中电照明有所增加(Simonella et al, 2003)。 这也会影响室外的视野，有报告指出深色玻璃幕墙会使用户感觉天气长期不好而导致心情沮丧。而CCF幕墙可与电控变色玻璃一样既可节省人工照明用电，又可优化眩光控制（Carmody et al, 2004）。

- 内墙选用不同的中空玻璃，会导致CCF幕墙（VI, VIII, IX）具有不同的可见光透射率（LT）。但不同LT值导致的CCF（VI, VIII, IX）能耗相差甚小。这是因为太阳光强烈时，在所有CCF组合的遮阳都会下落，因此所有CCF幕墙会有很相似的可见光透射率及太阳热辐射系数（SHGC/g值）。

隔热舒适度对比

动态幕墙温度轮廓线也可从CAPSOL-Excellent评价软件工具中摘录 。图7显示了传统玻璃幕墙，系统A（幕墙II）及CCF, 系统B（幕墙 VIII）的相关资料。

通过对比CCF幕墙的内表面温度（Tsi,glass = 30.8° C）与传统幕墙带高反射内遮阳(Tsi = 49.5° C)-可以得出结论：尽管CCF腔体温度Tcav可以高至73.2° C, 传统幕墙的最高内表面温度还是会比CCF幕墙高约19° C。因此，CCF幕墙可提供较高的隔热舒适度，可提高办公人员的工作效率。

隔声舒适度对比

下列幕墙构造的噪音衰减指数（R）及噪音衰减指数的加权值（Rw）可由详细的声学软件工具进行评估（在帕马斯迪利沙集团研究项目ALABIK及一个博士研究论文内部开发（Blasco, 2011））：

- 一个带中空玻璃的幕墙（10-16-8）
- 一个带中空玻璃的幕墙，其中一块玻璃片有隔音内夹层（10-16-44.1A）
- 腔深为150mm的CCF（6-12-8/150/6）

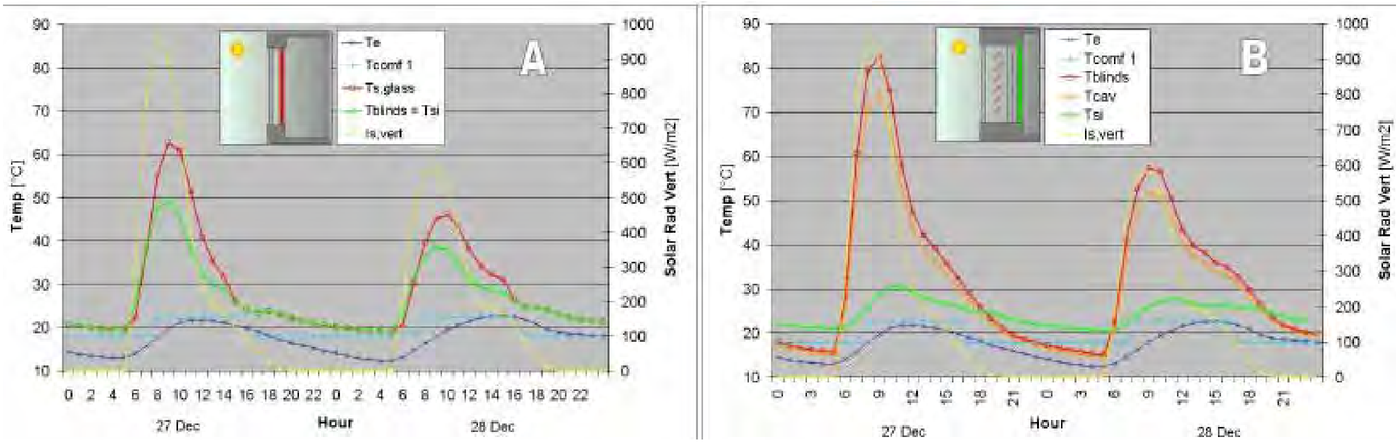

Figure 7. Dynamic façade temperature of CW and CCF (Source: Permasteelisa Group)
图7. CW与CCF的动态幕墙温度（来源：帕马斯迪利沙集团）

outside is always bad whereas the CCF has the potential to save electricity also for electric lighting similar to electrochromic glazing and optimizing for glare control (Carmody et al, 2004).

- The CCF façades (VI, VIII, IX) differ from light transmittance (LT) because of the choice of DGU of the inner wall. Only marginal differences in the energy consumption between the CCF façades with different LT-values are noted. This is because when the solar radiation is intense the blinds will be down in all CCF configurations and all CCF façades will end up with the same solar heat gain coefficient (SHGC/g-value).

Thermal Comfort Comparison

The dynamic façade temperature profile is also extracted from the CAPSOL-Excellent assessment tool and presented for a traditional glazed system A (Façade II) and a CCF system B (Façade VIII) in Figure 7.

Comparing the internal surface temperature of the CCF façade (Tsi,inner glass is 30.8°C) with the traditional curtain wall with high reflective blinds (Tsi=49.5°C), the conclusion is that the maximum surface temperature for a traditional façade is about 19°C higher than the CCF technology although the CCF cavity temperature Tcav can be as high as 73.2°C. Therefore it can be expected that the CCF technology is likely to result in higher thermal comfort which can lead to higher productivity of people in the office.

Acoustic Comfort Comparison

The sound reduction index (R) and weighted single value of the sound reduction index (Rw) of the following façade configurations have been assessed by means of a detailed acoustic software tool (developed within a Permasteelisa group research project ALABIK and a doctoral thesis (Blasco, 2011)):

- a curtain wall with DGU (10-16-8)
- a curtain wall with DGU of which one glass sheet has an acoustic interlayer (10-16-44.1A)
- a CCF with 150mm deep cavity (6-12-8/150/6)
- a DSF (non-ventilated) with 600mm deep cavity (6-12-8/600/6)

The following conclusions can be made (see Figure 8):

- The use of an acoustic interlayer in Façades (2) increases the R-value with 7 to 10 dB at the coincidence frequency compared to Façades (1) and Rw-value increases with 3 to 5 dB.
- For a CCF with a cavity bigger than 100 mm (Façade3) the R-value will further increase, especially in the lower frequencies and the Rw-value will typically be above 54 dB.

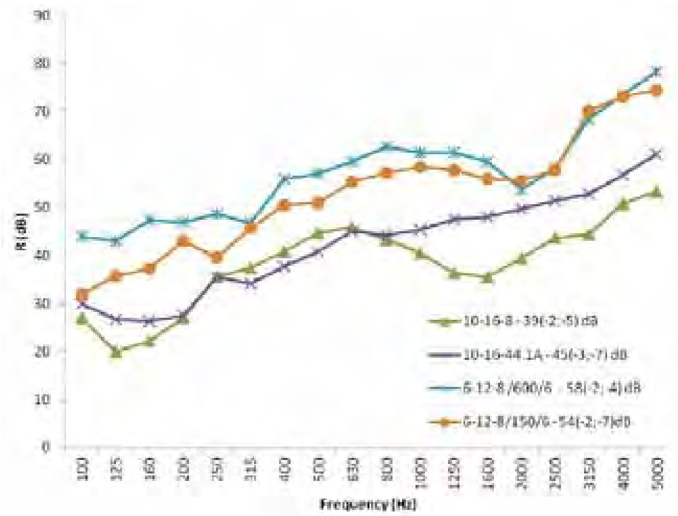

Figure 8. Sound reduction index R and Rw for different glazed systems (Source: Blasco)
图8. 不同玻璃系统的噪音衰减指数R与Rw（来源：Blasco）

- 腔深为600mm的DSF（无通风）（6-12-8/600/6）

综上所述，可得出以下结论（见图8）：

- 与幕墙（1）相比，幕墙（2）由于使用了隔音内夹层，其R值及Rw值在共振频率分别增加了7至10分贝及3至5分贝。
- 对于腔深超过100mm的CCF系统（幕墙3），R值将进一步增加，尤其是在较低频率，Rw值通常将高于54分贝。
- DSF（幕墙4）的腔深进一步增至600mm，会改善该幕墙的低频R性能，而幕墙4的Rw也会被改善（Rw=58 分贝）。注意：较大腔体的DSF通常使用自然通风，这将降低在中高频率的R值，然而相较交互式墙体（IW）与主动式墙体（AW）幕墙的少因通风切口是更为关键性的。通风相互作用幕墙的Rw值下降可致4至10分贝。

也就是说，简洁的CCF幕墙具有非常高的隔声噪音衰减指数，高于同样腔深的通风双层幕墙，至少在中高频具有与较大腔深的通风双层幕墙具有相同的隔音性能。此外，CCF是更为经济的，同时因所使用的材料相对较少自含能量也较低。

显然，如此详细的声学预测工具在项目的早期设计阶段非常有用，且已成功应用于高层建筑，如夏德伦敦桥与伦敦桥广场（见图9）。

- A further increase of the cavity depth to 600mm of the DSF (Façade4) will improve the low frequency R performance of the façade and therefore also the Rw of Façade 4 (Rw=58 dB). Note that large DSF's typically are naturally ventilated which will reduce the R-value at mid and high frequencies, although less than for IW and AW façades where the impact of the ventilation slit is more crucial. The decrease of the Rw of the ventilated (inter)active façade can be around 4 to 10 dB.

This means that the compact CCF has a very high acoustic sound reduction index which is higher than a ventilated DSF with the same cavity depth and at least as high as a ventilated DSF with larger cavity at mid and high frequencies. Additionally the CCF is much more cost effective and much lower embodied energy as much less material is used.

It is clear that such detailed acoustic prediction tool is very useful at the early stage design of the project and has been successfully applied on high-rise buildings such as the Shard London Bridge and London Bridge Place (see Figure 9).

Project Applications

Different façade types per orientation - Heron Tower
During early design stage of Heron Tower building (See Figure 10), the energy consumption was calculated for two types of façade (CW and IW) for each orientation of the Heron Tower building at early design stage.

As building control requested for Heron Tower to reduce CO2 emission by renewable energy use, panelized system using PV-cells were designed and placed on the South side of the building in order to generate renewable electricity by the solar energy.

For east and west sides of the building IW façades were chosen because of the significant positive impact on the energy performance and thermal comfort. For the north façade it is clear from the analysis that the energy saving impact by using a DSF is much less and therefore it is not cost-efficient to use DSF for the north side. A structural glazing solution is chosen in order to let a lot of diffuse daylight penetration deeper into the building having the potential of saving electricity by reducing the use of electric lights (view on atrium, see Figure 10). It should be noted that Heron Tower received the BREEAM Excellent rating certificate for offices.

Decision Matrix: Integrated Design Approach - UCLH
Façade configurations are rarely optimized for one sole parameter but many requirements have to be taken into account, e.g. energy performance, acoustic-visual-thermal comfort, initial costs and long-term maintenance and repair costs; architectural appearance; and many more. For every new project with its own specific critical requirements, a decision-making matrix can be made in order to facilitate the holistic optimization of the most suitable façade system early in the design process.

For UCLH hospital in London (see Figure 11) the single skin façades were eliminated from the list of suitable façade configurations: DGU with internal blinds which results in too high energy consumption whereas external blinds were not acceptable for long term maintenance costs and architectural appearance. The AW configuration was also found not to be suitable since there is an increased risk for interstitial condensation and potentially for bacteria growth. The IW configuration gave much better energy performance results but again the maintenance and cleaning of the interstitial

Figure 9. Shard London Bridge and London Bridge Place located at dense public transport area with high noise generation (Source: Renzo Piano Building Workshop)
图9. 位于密集且噪声很大的公共交通区域的夏德伦敦桥与伦敦桥广场（来源：伦佐皮亚诺建筑工作室）

项目应用

赫伦大厦 - 不同立面方向不同幕墙类型
在赫伦大厦（见图10）的早期设计阶段，对两种幕墙类型（CW and IW）在每个立面方向进行了建筑能耗计算。

因建筑控制要求赫伦大厦通过利用可再生能源来降低二氧化碳排放量，其南面设计选用了光伏电池板块系统，以利用日光热辐射生产可再生能源。

建筑的东西两侧选用IW幕墙是因为在节能性能与隔热舒适度均有显著的正面影响。关于北方立面，由分析可知利用DSF的节能效应非常低，因此如果在北立面选用DSF是不划算的。为使大量漫射日光更深的照入建筑物内部，选用了结构玻璃方案，以减少人工照明用电的可能（中庭视图，见图10）。同時也得注意赫伦大厦获得了BREEAM优秀办公室等级证书。

UCLH决策矩阵：综合一体化设计
幕墙构造很少只就一个单独的性能参数进行优化，而需考虑很多需求，如节能性能、隔音-视觉-隔热舒适度、建造成本与长期维护维修成本，建筑外观及其他许多因数。每个新项目都有其特殊要求，为此，可以制定决策矩阵使在设计过程早期选择最适合的幕墙系统来促进整体的优化。

伦敦UCLH医院（见图11）的合适幕墙构造列表中排除了单层幕墙。带内遮阳的DGU会导致过高的能耗，而带外遮阳的DGU则由于长期维护成本高及影响建筑外观也不被接受。AW主动式墙体构造也被发现不適用，因为有增加缝隙结露的风险及增加细菌生长的可能。IW交互式墙体虽然可提供更好的节能性能，却因在清洗过程中，累积在腔体内的灰尘可会被释放致室内，再次发现缝隙百叶的维护与清洁不適用。同时，因打开腔体内门进行腔体清洗/维护而移动医疗设备是不可接受的。从外部清洁腔体的方案由于外部玻璃面积较大被否认。

将CCF幕墙技术应用于UCLH建筑，能解决所有能耗与舒适度问题。除此之外， 还可以降低清洗成本，增加净租用面积，大大减少对正常医疗活动的干扰。同時也得注意，UCLH获得了BREEAM优秀医院建筑等级证书。

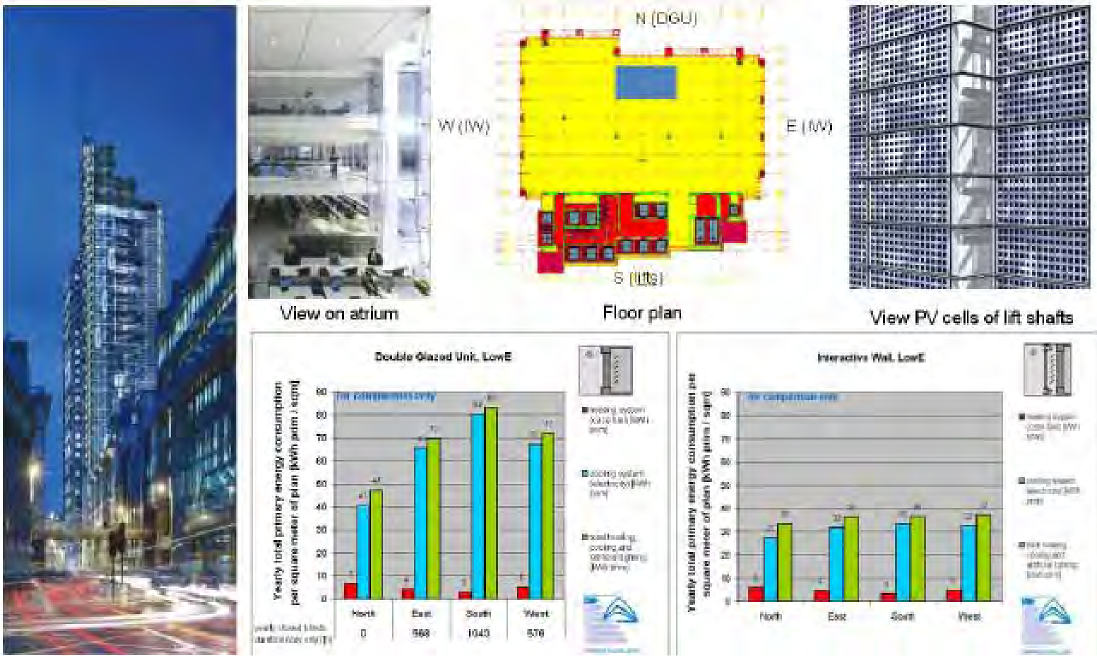

Figure 10. Energy calculations at early design stage of Heron Tower, London (Source: KPF Architects; Permasteelisa Group)
图10. 伦敦，赫伦大厦早期设计阶段的能耗计算（来源：KPF 建筑设计公司；帕马斯迪利沙集团）

blinds were found not to be suitable as dust build up in the cavity can be released to the inside during cleaning operations. Also remaining furniture in hospitals for opening internal doors for cavity cleaning/ maintenance was considered to be disturbing. Cleaning cavities from the outside was also not preferred (large external glass areas).

CCF technologies were applied in UCLH-building as it resolved all energy and comfort issues but equally gave benefits of reduced cleaning costs, increased 'effective' net-lettable area and high reduction of disturbances to hospital activities resulting in a very cost effective façade solution for the building owner. It should be noted that UCLH received BREEAM Excellent Hospital Building rating.

Conclusions

The following conclusions can be drawn from this study:

- Existing high transparent CW's face difficulties for tall buildings for compliance with more stringent energy regulations in some countries.
- EMFREE-S CCF has a much better performance than CW with internal blinds in terms of energy saving as also the potential for higher thermal and acoustic comfort and availability of daylight at the perimeter of tall buildings.
- The EMFREE-S CCF technology has been chosen on different building projects (including high-rise buildings) because its positive impact on energy saving, occupant comfort, lower maintenance & repair costs, higher 'effective net-lettable' area, high durability, optimized cost and material use results in lower carbon footprint;
- Advanced detailed dynamic whole building simulation tools can provide benefits for the early stage design decisions of low-energy and high comfort tall buildings;
- Cost-effective energy solutions at building level are likely to include different façade types at different sides of tall buildings.

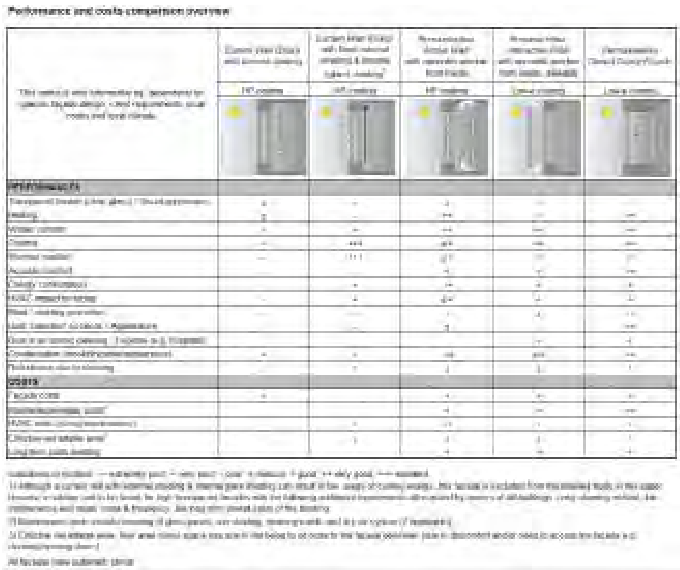

Figure 11. Decision matrix for early design UCLH (Source: Hopkins Architects; Permasteelisa Group)
图11. UCLH早期设计决策矩阵（来源：霍普金斯建筑事务所；帕马斯迪利沙集团）

结论

从研究中可得出以下结论：

- 现存的高透明幕墙于高层建筑方面在遵守一些国家更严格的节能法规上面临诸多困难；
- 在节能方面，零维护-可持续封闭式腔体幕墙（MFREE-S CCF）比幕墙带内遮阳有更好的性能表现，也同时在高层建筑的周边上有更高的隔热与隔音舒适度及有效自然采光；
- 因其在节能、人体舒适度、低维护维修成本、高有效净租用面积、高耐久性、成本与低碳材料的优化选用等方面的优越性，不同的建筑项目（含高层建筑）选用了零维护-可持续封闭式腔体幕墙 （MFREE-S CCF）；。
- 早期设计阶段采用先进的详细动态整体建筑模拟工具可以帮助实现低能耗与高舒适度的高层建筑设计。
- 在建筑水平的成本效益节能方案很可能包括不同外墙类型在高层建筑的不同面向。

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