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Climate, Cladding, and Conditioning Systems (One Size Fits All?)

气候、围护以及空调系统一体多用?


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Russel Gilchrist, a native of Scotland, has worked in the USA and UK on projects worldwide, as a director at AS+GG and SOM (Chicago), senior associate at Richard Rogers Partnership and senior designer at Foster + Partners (London). Completed award-winning high-performance projects include Pearl River Tower in Guangzhou, Protos Winery in Penafiel. Spain, 88 Wood Street, London, Reichstag Parliament Building in Berlin, Maison du Japon, Paris and an opera house in Glyndebourne, Sussex. He has published and lectured internationally on sustainability and tall buildings and is active on the CTBUH.

Russell出生于苏格兰，他多年来一直在美国和英国从事全球各地项目的设计工作，担任AS+ GG和SOM（芝加哥）的主管、Richard Rogers Partnership的高级副主任和Foster + Partners事务所（伦敦）的高级设计师。他所完成并且屡获殊荣的高性能项目包括：广州的珠江大厦，西班牙Penafiel的PROTOS酒厂，伦敦 Wood Street大街88号，柏林的国会大厦，巴黎的Maison du Japon，（英国）苏塞克斯郡戈林德伯恩歌剧院。他一直致力于有关高层绿色建筑的专著和讲演，他还积极参与CTBUH的各项活动。

Abstract

The construction of tall buildings is no longer confined to their origins in North America. This phenomenon has been migrating eastward via the Middle-East to East Asia. China alone proposes to build 50,000 new high-rise buildings by 2025. This proliferation has been compressed over a short timeline, so much so that the expertise to design, build and construct such architectural wonders does not as yet reside locally. Furthermore the design and manufacture of major building components has tended to reside in the USA and Europe. This paper examines the impact of building massing, the window to wall ratio (WWR), and two essential components of high-rise design - building envelope performance and the energy performance of the HVAC system, determining respective energy use intensities (EUIs) and exploring the suitability of such systems in their climatic context.

Keywords: Climate,Window-To Wall Ratio, Ventilated Curtain Wall, Energy Use Intensity

摘要

高层建筑建设早已不仅仅局限于其发源地北美地区了。高层建筑的建设通过中东向东亚发展。预计2025年，仅中国就将新建50000栋高层建筑。由于这样的高速发展过于集中，造成了当地对设计建造如此建筑奇观所应具备专业技能的非常匮乏。而且，建筑的设计和主要建筑构件的生产多来自于美国和欧洲。

本文将探讨建筑体量、窗墙比（WWR）的影响和作为高层设计两个基本元素：建筑外围护结构性能与空调系统的节能性能四者之间的相互作用关系，确定各自的能耗使用强度（EUIs），并探索不同气候条件下各系统的适用性。

关键词：气候，窗墙比，通风幕墙，能源使用强度（EUI）

Introduction/Project Statement

This paper seeks to address the issues surrounding the design of commercial buildings and their interaction with building systems in high-rise design around the globe. The proliferation of high-rise buildings in China and Southeast Asia in recent years means that the generic export of western curtain walling systems and HVAC system and equipment technologies need to be adapted or reconfigured in order to become appropriate for the geographical shift in high-rise design.

The process of designing any building project is nothing more than making choices between variables. When designing with reducing energy consumption as a priority an integrated and iterative design process aims to enable these choices to be judged based on measureable variables or a scientific method, however, caution should be taken to limit against using such a method in a purely reductionist context, rather it should be used in addition to the architects intuitive design sensibility and the engineers empirical knowledge.

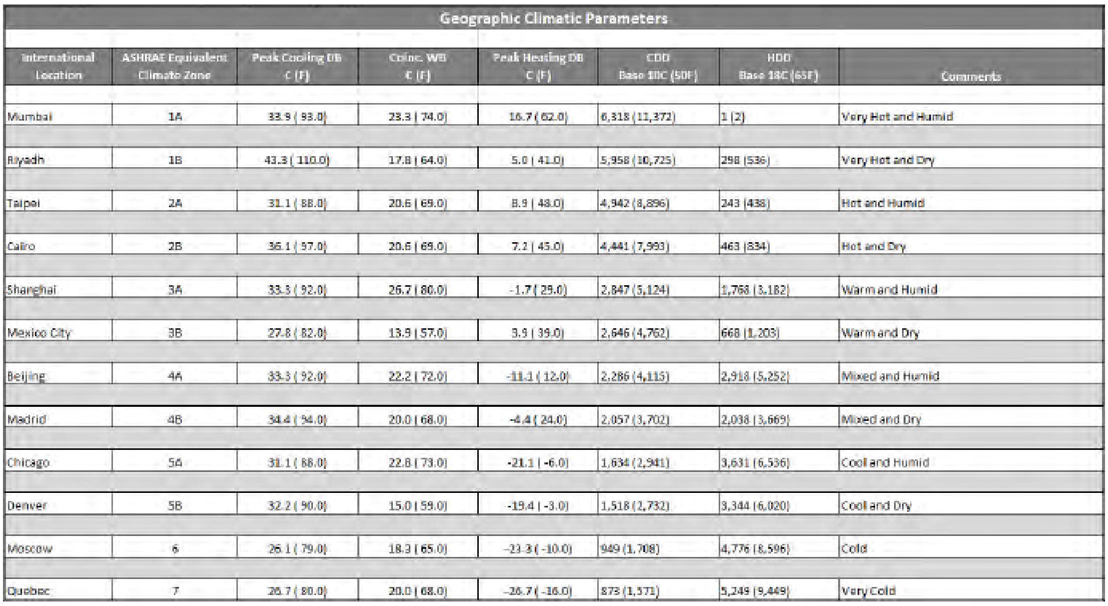
In order to assess the suitability of such systems one has to understand the various climate variations that exist worldwide from

引言/问题声明

本文旨在探究全球范围内商业建筑设计及与其相关的高层建筑各系统设计所面临的议题。近年来包括中国及东南亚地区在内的高层建筑建设高潮迫使各西方国家对其原有的幕墙系统、空调系统的输出以及相关设备技术进行有针对性的升级改造以适应不同地域高层建筑设计的需要。

所有建筑项目的设计过程无非就是一种多变量的选择过程。当以减少能耗作为首选项进行设计时，在整合和迭代的设计过程中，应能实现利用可测量的变量参数或相关的科学方法对（设计）所选参数技术指标进行评判。然而，对于一个纯粹的还原主义（设计）者来讲，应限制这种方法的使用，而应借助建筑师的设计灵感和工程师的经验知识（来予以实现）。

如果想要评估系统的适用性，首先就必须了解在全球范围内各种气候的变化，这个范围包括：从热带雨林地区到干旱或半干旱的温带和亚热带地区。除此以外，理解和掌握在高层建筑中所使用的众多外墙系统的适用性及优势，了解不同遮阳系统应用于高层建筑中的可行性也是十分重要的。再者，本文旨在揭示气候和外墙系统的选择与建筑空调系统存在着怎样一种相互作用的关系，从而进一步优化建筑的（能源使用）效率以减少对国家能源网络的依赖。本文还将揭示上述应用所总结出的



Geographic Climatic Parameters							
International Location	ASHRAE Equivalent Climate Zone	Peak Cooling DB C (F)	Coinc. WB C (F)	Peak Heating DB C (F)	CDD Base 10C (50F)	HDD Base 18C (65F)	Comments
Mumbai	1A	33.9 (93.0)	23.3 (74.0)	16.7 (62.0)	6,318 (11,372)	1 (2)	Very Hot and Humid
Riyadh	1B	43.3 (110.0)	17.8 (64.0)	5.0 (41.0)	5,958 (10,725)	298 (536)	Very Hot and Dry
Taipei	2A	31.1 (88.0)	20.6 (69.0)	8.9 (48.0)	4,942 (8,896)	243 (438)	Hot and Humid
Cairo	2B	36.1 (97.0)	20.6 (69.0)	7.2 (45.0)	4,441 (7,993)	463 (834)	Hot and Dry
Shanghai	3A	33.3 (92.0)	26.7 (80.0)	-1.7 (29.0)	2,847 (5,124)	1,768 (3,182)	Warm and Humid
Mexico City	3B	27.8 (82.0)	13.9 (57.0)	3.9 (39.0)	2,646 (4,762)	668 (1,203)	Warm and Dry
Beijing	4A	33.3 (92.0)	22.2 (72.0)	-11.1 (12.0)	2,286 (4,115)	2,918 (5,252)	Mixed and Humid
Madrid	4B	34.4 (94.0)	20.0 (68.0)	-4.4 (24.0)	2,057 (3,702)	2,038 (3,669)	Mixed and Dry
Chicago	5A	31.1 (88.0)	22.8 (73.0)	-21.1 (-6.0)	1,634 (2,941)	3,631 (6,536)	Cool and Humid
Denver	5B	32.2 (90.0)	15.0 (59.0)	-19.4 (-3.0)	1,518 (2,732)	3,344 (6,020)	Cool and Dry
Moscow	6	26.1 (79.0)	18.3 (65.0)	-23.3 (-10.0)	949 (1,708)	4,776 (8,596)	Cold
Quebec	7	26.7 (80.0)	20.0 (68.0)	-26.7 (-16.0)	873 (1,571)	5,249 (9,449)	Very Cold

Table 1. Geographic Climate Parameters for the relevant climate parameters for each of these representative geographies.
表1. 代表各地域的与气候参数相关的地理气候参数

the tropics to arid and semi arid as well as more moderate climatic regions. In addition, it is important to understand the availability and advantages of the multitude of exterior wall systems that can be utilized and the various shading systems that may or may not be viable in a high-rise context. Furthermore, the paper seeks to address how the climate and choice of exterior envelope system might interact with the building HVAC system to optimize building efficiency and reduce the reliance on national energy grids. The paper will seek to address both the broad variables outlined above using a standardized base building model to understand how it should be adapted across the globe in cities that experience different climatic conditions.

Geographic Climatic Profiles

Climates vary a great deal arrange the globe, from the equatorial tropics to the desolate polar regions. It is a virtual certainty that human migration from rural to urban areas for the foreseeable future, and in varying geographies and climates around the world. For this study, the authors have selected an appropriately diverse international representation of cities to evaluate the impact of climate, cladding and conditioning systems to determine if any particular correlations exist. These cities are also representative of the ASHRAE International Climate Zones:

- 1A (very hot and humid) – Mumbai
- 1B (very hot and dry) – Riyadh
- 2A (hot and humid) – Taipei
- 2B (hot and dry) – Cairo
- 3A (warm and humid) – Shanghai
- 3B (warm and dry) – Mexico City
- 4A (mixed and humid) – Beijing
- 4B (mixed and dry) – Madrid
- 5A (cool and humid) – Chicago
- 5B (cool and dry) – Denver
- 6 (cold) – Moscow
- 7 (very cold) – Quebec

多个广泛性变量参数，以及以一个标准化建筑能耗模型为例讲解如何适应全球不同气候条件。

地理气候概况

从赤道的热带地区到荒凉的极地地区，全球气候条件存在着巨大的变化差异。毋庸置疑的，在可预见的未来，无论身处全球任何一个气候带，人们都将（逐渐地）从农村迁徙至城市，（使得城市对能源的需求起来越大，而引发了建筑节能的议题）。在这项研究中，作者选择了一些具有全球多元化的城市来对气候、外墙及空调系统间的相互影响进行评估，以确定彼此之间是否存在特殊的相关性。所选城市同时也是了ASHRAE国际气候区域的代表（城市）：

- 1A（非常炎热且潮湿）—孟买
- 1B（非常炎热且干燥）—利雅得
- 2A（炎热且潮湿）—台北
- 2B 炎热且干燥）—开罗
- 3A（温暖且潮湿）—上海
- 3B（温暖且干燥）—墨西哥城
- 4A（混合且潮湿）—北京
- 4B（混合且干燥）—马德里
- 5A（阴凉且潮湿）—芝加哥
- 5B（阴凉且干燥）—丹佛
- 6（寒冷）—莫斯科
- 7（非常寒冷）—魁北克

能耗模型的模拟方法

建筑能耗模拟软件是一个非常实用的工具，用以在建筑使用甚至建造之前了解建筑物预期的耗能状况。这种能耗模型通常借助具体的对比分析掌握各个阶段的设计果效。为了建立能耗模型，用户需要通过（输入）楼层平面，楼层高度以及窗口布置等来创建一个建筑造型。建模还应包括中央机组，（分层）空调机组和建筑围护结构的具体说明以及其他相关运行参数，如照明功率强

Energy Modeling Methodology

A building energy simulation software program is a great tool to understand how a building is expected to perform, prior to occupying or building it. This energy model is generally used to inform the design at all stages through specific comparative analysis. To develop an energy model, the user creates a graphic representation of the building using floor plans, floor heights, and window configurations. Specifics of the central plant, air-handling units, and building envelope are included along with the operating parameters such as lighting power density, occupancy, building schedules, and airflow rates. The simulation uses 30-year typical hourly weather data to accurately estimate the energy consumption of the building for each hour of the year. For the purposes of this investigation, all energy modeling utilizes DOE 2.2, an industry standard simulation tool. DOE 2.2 allows for comprehensive and integrated studies of complex strategies and a clear understanding how each building component is performing.

To more fully understand the energy use of various glazing options in multiple climate zones, the investigation focuses on three primary efforts: (1) Window-to-Wall Ratio (WWR) Adjustment, (2) Massing Alternatives, and (3) Glazing/HVAC Alternatives. The process begins with an ASHRAE Standard 90.1 - 2007 minimally compliant building. The building has a 40% WWR and the glazing performance criteria match the Standard 90.1-2007 prescriptive compliance thresholds. Knowing the current trend for tall buildings with increased transparency and improved daylighting, the WWR Adjustment increases the glazing percentage to 65%. For each climate zone, the Solar Heat Gain Coefficient (SHGC) and Center of Glass (CoG) U-Values were adjusted so the building loads were identical to the 40% WWR minimally compliant model. Essentially, the WWR Adjustment improved the performance of the glass, often significantly, to eliminate the penalty of the increased glazing area.

Based on the WWR Adjustment outcome, the investigation then evaluated 3 distinct massing alternatives: square footprint, rectangular footprint with the long axis in the east-west orientation, and rectangular footprint with long axis in the north-south orientation (see Figure 1). This evaluation was performed using the improved, WWR Adjustment glazing performance and 65% WWR. The intention is to show how glazing orientation has a distinct impact on performance.

The investigation continues by addressing glazing performance, alternatives included: (4) double-paned insulated glazing units (IGU), (1) triple-paned IGU, (1) horizontal shading element, and (1) ventilated curtain wall (see Figure 2). These alternatives were each applied to the rectangular footprint with east-west orientation (maximizing south and north exposure). The alternatives have a broad range of both solar and conductance performance characteristics. By identifying the performance of all glass types for each climate zone, the benefit and/or the detriment is quantified.

Finally, the investigation addresses the potentially different comparative performance of the glazing selections given three alternative HVAC systems: 1) a baseline of conventional overhead variable air volume (VAV) with reheat system, 2) a VAV with reheat under floor air distribution (UFAD) system, and 3) ventilated chilled beams (CB).

This comparison is not intended to address all the permutations of UFAD and chilled beam as they compare to a base HVAC system, rather it is to determine if there are specific trends in the energy performance of three alternative HVAC systems for varying envelope configurations. Figure 3 graphically depicts the numerous combinations of massing, climate zone, envelope cladding alternatives, and system alternatives

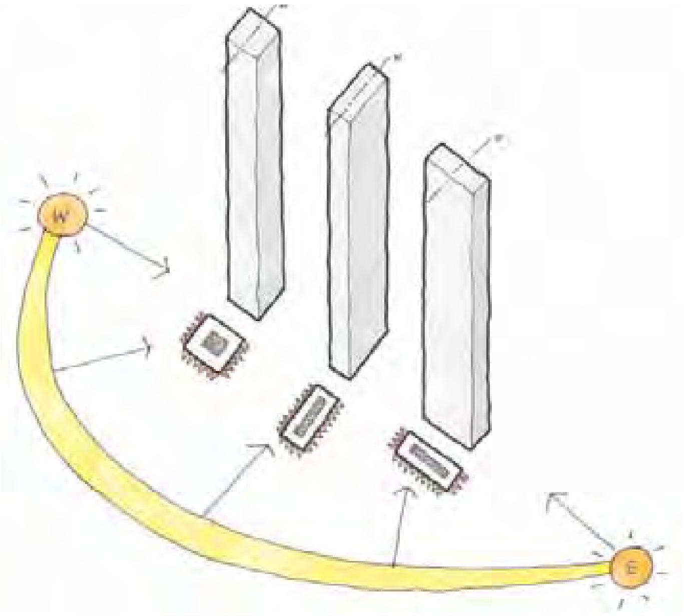


Figure 1. Massing Alternatives
图1. 体量替代

度，使用功能，建筑运行周期，气流速度等。模型所使用的气象数据为以小时计的30年间典型天气数据，准确估算一年之中每小时的建筑能耗。为了实现这一目的，所有的能量建模均使用称之为DOE2.2的一种工业标准模拟工具。DOE2.2能够全面、综合地研究复杂的策略并且清晰地理解每一个建筑部件的运行工况。

为了更加充分地理解各种玻璃窗选项在不同气候带的能耗情况，研究主要集中在以下三个主要方面：（1）窗墙比（WWR）的调整与变化，（2）建筑体量的变化，以及（3）不同玻璃窗体/空调系统的应用。这项（研究）从ASHRAE标准90.1 – 2007所规定的最低标准建筑物（能耗指标）着手开始。（最低标准为）建筑拥有40%的窗墙比，玻璃窗性能指标符合标准90.1-2007所限定阈值。众所周知，提高透明度和改善自然采光功能是目前高层建筑的发展趋势，因此（有必要）对窗墙比进行调整，增加玻璃窗的所占比例至65%。针对不同气候带地区，对阳光热能增益系数（SHGC）和玻璃中心（COG）位置传热系数值进行调整，使得建筑能耗负荷与40%窗墙比建筑的最低标准模型相同。从本质上讲，窗墙比的调整提高了玻璃的性能，（而提高了的玻璃性能）对消除由于增加玻璃面积所带来的负面影响具有十分显著果效。

基于调整窗墙比所得出的结果，此项研究随后对3种截然不同的建筑体量形式进行了评估：正方形建筑，东西朝向长方形建筑，以及南北朝向长方形建筑（见图1）。通过对性能改进的玻璃窗以及65%窗墙比的建筑能耗进行评估以揭示玻璃窗的朝向如何对建筑能耗产生明显的影响。

本文对玻璃窗的性能进行了研究，所选的窗体种类包括：（4个）双层隔热玻璃窗（IGU），（1个）三层隔热玻璃窗，（1个）带有水平遮阳组件的窗，及（1个）通风幕墙（见图2）。所有窗体都在东西走向的长方形建筑中使用（和测试）（使得窗体面向正南和正北方向）。这些窗体之间在阳光辐射和热传导特性方面存在着很大的差异。通过在不同气候带环境下对所有窗体的性能进行鉴别以便量化这些窗体形式的优劣性能。

最后，本项研究还探讨了在3种不同空调系统运行的情况下玻璃窗潜在的不同性能：1）满足最低能耗要求的常规变风量再热式上送风系统，2）变风量再热式地台送风系统(UFAD)，以及3）通风冷梁系统（CB）。

这项对比并非要探究三种空调系统运行情况下涉及玻璃窗性能的所有问题，而是针对不同的外墙结构确定在三种空调系统形式之间是否存在着一种特定的变化趋势。图3空调系统分析方法。这

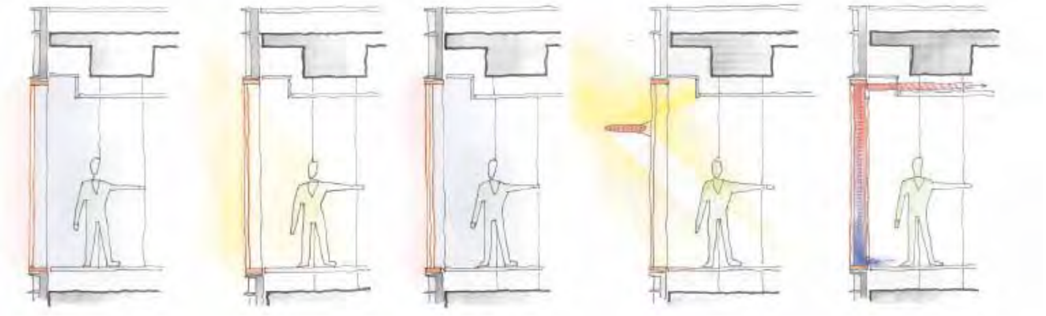


Figure 2. Envelope Cladding Alternatives
图2. 覆层式围护结构

that comprise the variables in the analysis. Out of the 750 possible combinations, this study evaluates 336 combinations.

Baseline Energy Modeling Assumptions

The baseline building configuration for this performance modeling study is generally assumed to be185,800 gsm 2 million gsf, 80-storey tall office tower with 2,325 gsm (25,000 gsf) per floor, with an assumed underground parking structure of 113,800 gsm (1.2M gsf). Occupant densities, internal lighting loads, internal miscellaneous plug loads, zoning of daylight penetration, and operational schedules are consistent with general typical operations for office buildings, and are generally consistent with the parameters defined by ASHRAE Standard 90.1-2007, Energy Standards for Buildings Except Low-Rise Residential Building. Exterior lighting and vertical transportation loads are not included in the models for this study (see Table 2).

The baseline building envelope configuration assumes a 65% window-to-wall ratio (WWR), which varies somewhat from an ASHRAE 90.1 prescriptively compliant building (40% WWR) but is more consistent with the international style of architecture that expresses a more "transparent" aesthetic. The relative thermal performance data for roofs and walls are also modeled in accordance with ASHRAE 90.1 prescriptive thermal requirements, and several alternative glazing systems and their associated solar and thermal performance form a specific focus of this study (see Table 3).

The baseline building HVAC systems configuration is consistent with an ASHRAE Standard 90.1 compliant HVAC system for a building of this size and occupancy type – namely VAV with reheat for comfort conditioning, climate-responsive air-side economizers for free cooling when appropriate, and a central heating and cooling plant consisting of boilers, chillers, cooling towers and associated pumps (see Tables 4 and 5).

Alternative Envelope Configurations

The energy modeling takes account of several variables as it relates to building envelope, including building floor-plan, orientation and the specifications of external envelope insulated glazed unit (IGU) accounting for light transmittance, shading co-efficient (SC) and the amount of solar heat gain (SHGC) that passes through the external wall assembly.

The energy modeling included a square floor plan 48.2 x 48.2m (2,325m^2) and a rectilinear plan 30.5 x 76.25m of equal floor area. The rectilinear plan (with an aspect ratio of 2.5:1) was modeled in both an N-S and an E-W orientation to understand the effects of potential

Figure 3. Climates, Claddings, Conditioning Systems Analysis Methodology
图3. 气候，外立面

General Building Model Input Parameters	
Occupancy Type	Office Building
Program Area	
Tower	185,800 sqm (2,000,000 sqft)
Underground Parking	113,800 sqm (1,225,000 sqft)
Number of Floors	80
Area per Floor	2,325 sqm (25,000 sqft)
Occupancy Schedule	
Weekday	12 hours/day
Weekend	6 hours Saturday Only
Occupant Density	18.6 sqm/person (200 sqft/person)
Lighting Power Density	11 W/sqm (1 W/sqft)
Plug Load Equipment Power Density	27 W/sqm (2.5 W/sqft)
Daylighting	
N-S Perimeter Zones	6m from perimeter (20 ft)
E-W Perimeter Zones	3m from perimeter (10 ft)
Exterior Lighting Load	Not Included
Vertical Transportation Load	Not Included

Table 2. General Building Model Input Parameters for general baseline modeling parameters for the building and the internal loadings
表2. 针对建筑及室内负荷，常规模型中的基本输入参数

种方法是以图形的方式描绘在分析中所使用的大量的综合数据集合。综合数据集合包括建筑体量、气候带、外墙覆层结构，以及由各种变量参数所组成的不同系统。此项研究从750个综合数据集合中筛选出336个做出分析研究使用。

基本能耗模型假设

对于这种（建筑）性能的模拟研究，基本的建模配置一般需要185,800GSM（2M GSF），一栋80层的高层办公楼，每层需要2,325 GSM（25,000 gsf），并且假定地下停车场结构需要113800gsm（1.2M gsf）。人员密度，室内照明负载，室内（电

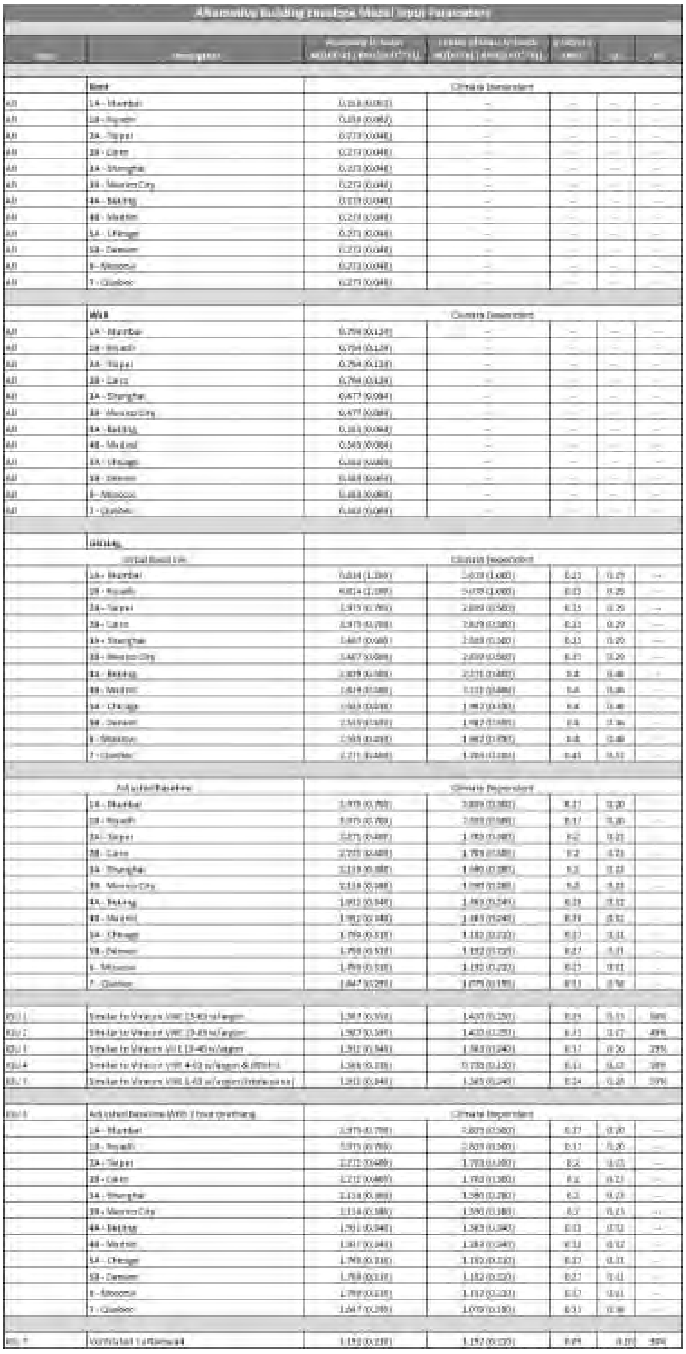


Table 3. Alternative Building Envelope Model Input Parameters
表3. 不同建筑围护结构模型输入参数

energy savings simply by understanding the implications of building orientation.

The study examined seven external envelope configurations using a proprietary argon filled 25mm insulated (double) glazed units (IGU) using a relatively clear glass to other assemblies each with varying low-E coatings accounting for varying degrees of visible transmittance, reflectance, shading and solar heat gain through the glazed units. One of the options modeled had a ceramic frit applied to the IGU to understand the implications of additional solar control to the envelope with regard to energy performance. In addition, the sixth option introduced an external horizontal louver (600mm wide) mounted 2,200mm above finished floor level, acting as both external shading device and as a light shelf to maximize daylight into the floor plate. The final external envelope variant introduced a "ventilated cavity" to the external wall. This the form of an additional hinged single glazed clear glass panel attached to the mullions of the IGU on the inside face of

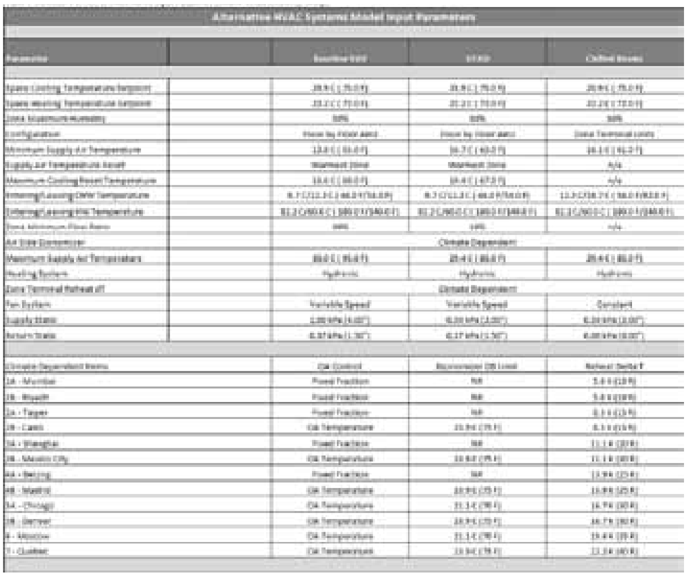
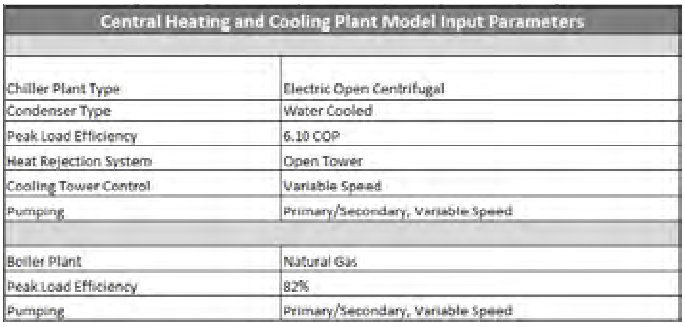


Table 4. Alternative HVAC Systems Model Input Parameters
表4. 不同空调系统的模型输入参数



Central Heating and Cooling Plant Model Input Parameters	
Chiller Plant Type	Electric Open Centrifugal
Condenser Type	Water Cooled
Peak Load Efficiency	6.10 COP
Heat Rejection System	Open Tower
Cooling Tower Control	Variable Speed
Pumping	Primary/Secondary, Variable Speed
Boiler Plant	Natural Gas
Peak Load Efficiency	82%
Pumping	Primary/Secondary, Variable Speed

Table 5. Central Heating and Cooling Plant Model Input Parameters
表5. 集中供热制冷系统的模型输入参数

源）插头负载，日照时区以及运营时间表应与典型的办公建筑的运营状态相一致，还应与ASHRAE标准90.1-2007（建筑能耗标准）中所定义的相关参数相一致，标准中针对多层住宅建筑的要求除外。在本项研究中室外照明和垂直交通负载可不计入内。（见表2）。

（模型中），基本的围护结构被设置为65%的窗墙比（WWR），这与ASHRAE 90.1中所规定的标准建筑（40%的窗墙比）稍有区别，但与国际建筑风格相吻合，体现出更为"透明"的美感。屋顶和墙壁的相应热物性参数依照ASHRAE 90.1标准的有关热物性要求以及本研究项目所关注的玻璃窗系统及其相关的阳光及热力学性能进行确定。（见表3）。

（模型中）基本的空调系统配置应与ASHRAE标准90.1中规定的相同规模和相同使用功能的建筑所使用空调系统相一致 —— 即在选择由锅炉、冷却器、冷凝塔及相关泵组成的集中供热制冷系统时，使用变风量再热式空调进行空气调节，在非制冷季节则使用气候适应型空气节能器。（参阅表4和表5）

不同的外墙结构

由于涉及到建筑外墙结构，因此在搭建能耗模型时需要包括建筑平面布置，建筑走向及隔热隔热玻璃窗的设计说明。设计说明应涉及透光率、遮阳系统以及穿过外墙组件的阳光热能增益系数等（SHGC）。

能耗模型包括尺寸为48.2 x48.2米（2325平方米）的正方形平面图和同等面积的直线图，其长宽尺寸为30.5 x 76.25米。以直线图（长宽比为2.5:1）为蓝本，在南北和东西方向，通过了解建

the building envelope to create a 200mm ventilated cavity between this additional layer and the standard IGU. This option included a fully mechanized operable perforated blind tracking the sun to minimize solar gain and provide some level of glare control for building occupants. Each of the seven envelope configurations were modeled with each of the three HVAC systems in each climatic zone (see Table 3).

It should be noted that all the options were modeled as standalone buildings as it was not practical to assume what urban context might exist and therefore any subsequent reliance on adjoining buildings and the shading that they may have afforded was not taken into consideration.

Alternative HVAC Systems Modeled

Three alternative HVAC comfort cooling systems have been evaluated for each of the respective geographies/climate zones to maintain occupant thermal comfort and appropriate indoor air quality to the occupied office areas. General descriptions of these systems are as follows (see Table 4):

Variable Air Volume (VAV) with Reheat: This system assumes conventional overhead VAV air distribution with hydronic reheat coils in the VAV boxes using floor-by-floor air handling units providing cooled and heated supply air to maintain space temperature set points. The reheat coils offset the envelope heat losses. The air handling systems incorporate climate-responsive air-side economizers.

Under Floor Air Distribution (UFAD) with perimeter hydronic heating: This system assumes under floor air distribution using a raised floor supply air plenum and floor diffusers, and a ceiling level return air path, also using floor-by-floor air handling units providing cooled and heated supply air to maintain space temperature set points. The perimeter hydronic heating system offsets the envelope heat losses. The air handling systems incorporate climate-responsive air-side economizers.

Ventilated Chilled Beams with perimeter hydronic heating: This system assumes ventilated chilled beams located at ceiling level of the occupied areas provide local cooling to maintain space temperature set points. Floor by floor air handling units provide tempered supply air to the chilled beams for ventilation as well as required to achieve the appropriate induction effect common to these system types. The perimeter hydronic heating system offsets the envelope heat losses. The air handling systems incorporates a fixed level of ventilation, so this system incorporates a water-side economizer as part of the central chilled water plant to account for free cooling opportunities.

Results

The results of this study are presented graphically in charts and tables that follow. Generally, the results presented for each climate and each HVAC system type have been sorted accordingly in the following charts to reflect specific trending studies:

Building Massing Study: The annual source energy intensity of alternative architectural massing, assuming a consistent baseline VAV with reheat HVAC system. This evaluation presents the modeled results for each climate zone/geography in each of the three alternative massing configurations – square, rectangular with an east-west orientation (long sides facing north and south, short sides facing east and west), and rectangular with a north-south primary orientation

筑物朝向对能耗的影响来简单地了解节能潜力。

这项研究共（模拟）测试了7个外围护结构配置（的能耗结果），（这7种外围护结构的共同之处在于都）都是设有25mm空腔填充专用氩气且双面涂层隔热窗，（不同在于）使用不同程度的低辐射涂层以获得不同的透光率，反射率，遮光率以及阳光热量吸收率等。其中一种配置将陶瓷玻璃替代普通玻璃以探究针对（建筑）能耗特性而强化阳光控制能力的果效。除此以外，第6个选项是从外部加装水平百叶窗（600mm宽），（百叶窗）安装在距地板水平面2200毫米处，既可作为外部遮阳设备，又可作为光栅使用，使得日光射入量最大化。最后一种外围护结构变换是将“通风腔”引入到外墙设置中。附加敷有涂层的单层透明玻璃板以悬挂方式在建筑外围护结构的内表面与隔热窗窗框的立柱相联结，从而在附加玻璃板与标准的隔热窗之间产生了200mm的通风空腔。在这种选项中包括了一种全自动的遮阳幕帘跟踪装置，加装这种装置可以使阳光热量摄入量最小化同时也可以在一定程度上地为居住者提供眩光控制。在每个气候带的3种不同空调系统形式下模拟这7种外围护结构设置的能耗情况。（见表3）。

应当指出，所有的选项都以独立的建筑物为蓝本，由于它并不涉及实际当中的市区内其他建筑物，因此对毗邻的建筑物和遮光性都将不予考虑。

所模拟的不同空调系统

分别对3种空调制冷系统在每一种地理/气候地区的运行工况进行模拟研究。（空调系统的运行）应能满足办公区域内热舒适度及良好室内空气质量的需求。空调系统的通用性描述如下（见表4）：

变风量再热系统（VAV空调）：该系统采用常规上送风再热式风机盘管，每层设置空调机组提供冷气和热风以维持（室内）空间温度的恒定。再热式风机盘管可以弥补外围护结构的热损失。空调机组中包含了气候适应型的空气末端节能装置。

周边循环加热式地台送风（UFAD）（系统）：该系统采用地板下送风方式，使用以活动地板下空间形成的送风静压箱和地板送风口（提供送风），使用天花板作为回风路径。同时使用每层设置空调机组提供冷气和热风以维护（室内）空间温度的恒定。周边循环加热系统可以弥补外围护结构的热损失。空调机组中包含了气候适应型的空气末端节能装置。

周边循环加热式通风冷梁（系统）：该系统的通风冷梁位于使用空间的天花板高度。冷梁为相关区域提供冷源以使该空间的温度达到恒定。每层的空调机组提供为冷梁提供冷气并为这类系统提供必要的（空气）诱导效应。周边循环加热系统为外围护结构的热损失提供补偿。空调机组结合定量式通风系统使得系统与水基节能装置一同作用以满足中央水冷机组在非制冷期的（温度控制）需要。

成果

以下的图表和表格生动地展现了本项研究的成果。总的说来，每一种气候条件和每一个空调系统类型都按照以下能够反映特定趋势的研究图表进行分类展示。

建筑体量研究:对设有基本配置空调系统即变风量再热系统的不同体量建筑（进行的）年度能耗强度（研究）。本项评估展示了针对每个气候带/地理区域，不同建筑体量配置的模拟结果 ——正方形，东西朝向建筑（南北方向长边，东西方向短边），南北朝向建筑（东西方向长边，南北方向短边）。可以很直观地推断出，无论哪一种气候带/地理区域，南北朝向（长立面为东西方向）的建筑能耗都是最最高的，而东西朝向（长海拔面对南北方向）能耗则是最低的，（参见图4，10A，10B，11）。

(long sides facing east and west, short sides facing north and south). As one might deduce intuitively, for each climate zone/geography the energy performance is consistent with the north-south orientation (long elevations facing east and west) being worst and the east-west orientation (long elevations facing north and south) being the best, with the square orientation being somewhere between the others (See Figures 4, 10 A, 10B, 11).

Alternative HVAC System Study on the East-West Massing with Adjusted Baseline Envelope Performance: The annual source energy intensity of alternative HVAC system configurations. This evaluation presents the modeled results for the three alternative HVAC systems – VAV with reheat, UFAD, and chilled beams in each climate zone/geography for the baseline building envelope performance (65% WWR, and climatically-dependent U-factor, and SHGC – see Table 3) for the east-west architectural massing. The trend indicates that VAV is generally highest in energy consumption, followed by chilled beams, with UFAD as typically being the lowest in energy consumption, with the largest magnitude of UFAD savings in the colder climates. The results indicate a few deviations from this trend, with the chilled beam system consuming the least energy in the Mumbai and Riyadh climates (where little to no heating is required, but the higher enthalpy climate requires the higher supply air temperature of the UFAD system to sub-cool and reheat for humidity control), and the chilled beam system consuming the most energy in the Quebec climate (where heating is very significantly dominant) (See Figures 5, 10A, 10B, 11).

Alternative HVAC System Study on East-West Massing with the Ventilated Curtain Wall Performance: The annual source energy intensity of alternative HVAC system configurations. This evaluation presents the modeled results for the three alternative HVAC systems – VAV with reheat, UFAD, and chilled beams in each climate zone/geography for the ventilated curtain wall envelope performance (see IGU 7 in Table 3) for the east-west architectural massing. Similar to the trend with the adjusted baseline envelope performance, the trend indicates that VAV is generally highest in energy consumption, followed by chilled beams, with UFAD as typically being the lowest in energy consumption. Also similarly, the results indicate a few deviations from this trend, with the chilled beam system consuming the least energy in the Mumbai and Riyadh climates (where little to no heating is required). The ventilated curtain wall appears to have the most significant energy reduction impact in generally mild climates, and appears to have limited energy savings potential in the warm climates (See Figures 6, 10 A, 10B, 11).

Alternative Envelope Performance Study on East-West Massing with Variable Air Volume with Reheat HVAC System: The annual source energy intensity assuming a consistent baseline VAV with reheat HVAC system for alternative envelope performances. This evaluation presents the modeled results for the VAV with reheat HVAC system for each of the six alternative insulated glazing unit (IGU) performances (see IGU 1-6 in Table 3) for the east-west architectural massing. Note that IGU-6 glazing performance is identical to the adjusted glazing baseline (climatically dependent), but assumes a two-foot overhang is incorporated. The results indicate that glazing performance sensitivity is more significant in warmer climates than it is in moderate or colder climates, with an opportunity for energy reduction more than double in warm climates than cold climates by selecting higher performing glazing (especially lower SHGC). The only glazing type of this series that offers savings over the baseline in the warmer climates is IGU 4, which is an ultra low SHGC glazing using tint, low-E coating and frit. Lastly, IGU-5, the triple pane configuration with a much lower U-factor than the double-pane IGUs, generally performs worse than the other

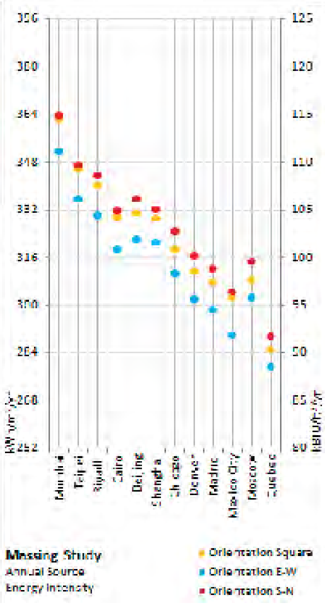


Figure 4. Annual Source Energy Intensity for Alternative Architectural Massing with Baseline VAV Reheat HVAC System (Source: Syska Hennessy Group)

图4．对设有基本配置空调系统即变风量再热系统的不同体量建筑的年度能耗强度研究 （出自： Syska Hennessy Group）

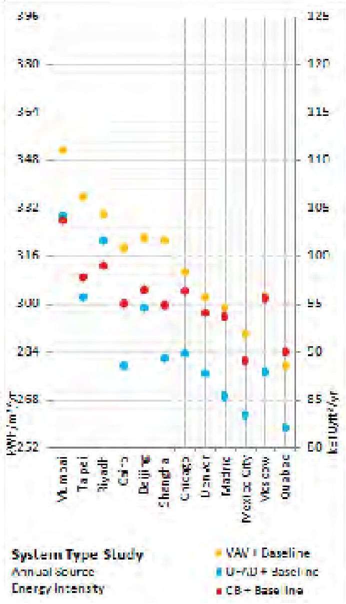


Figure 5. Annual Source Energy Intensity for Alternative HVAC Systems on Baseline E-W Architectural Massing (Source: Syska Hennessy Group)

图5．东西朝向建筑基本体量的不同空调系统能耗的研究（出自： Syska Hennessy Group）

东西朝向建筑基本的外围护结构优化后不同空调系统能耗的研究：（一项）对不同空调系统配置（建筑）的年度能耗强度研究。这项评估展示出不同气候/地理环境下三种空调系统在具有统一外围护结构特性（65%窗墙比，赖候传热因子以及太阳能热增益系数，一见表3）的东西朝向建筑的能耗模拟结果。三种空调系统包括：变风量再热系统，周边循环加热式地台送风系统UFAD，冷梁系统。趋势研究表明，常规情况下，变风量再热系统的能耗最高，其次是冷却梁，能耗最低的是地台送风系统UFAD。越是在寒冷的气候条件下，地台送风系统的节能优越性就更为明显。当然研究结果也存在着一定的差异，对于孟买和利雅得等无供暖需求但需要除湿的气候环境，冷梁系统的能耗最低。而在魁北克省，（这样以供暖为主要能耗的地区）冷梁系统的耗能则为最大（参见图5，10A，10B，11）。

东西朝向建筑采用通风幕墙结构不同空调系统能耗的研究：（一项）对不同空调系统配置（建筑）的年度能耗强度研究。这项评估展示出不同气候/地理环境下三种空调系统在通风幕墙结构下（见表3中的IGU7）的东西朝向建筑的能耗模拟结果。三种空调系统包括：变风量再热系统，周边循环加热式地台送风系统UFAD，冷梁系统。与前项优化后的基本外围护结构能耗趋势研究相似，趋势表明，通常情况下，变风量再热系统的能耗最高，其次是冷却梁，能耗最低的是地台送风系统。研究结果的差异性也十分相似，对于孟买和利雅得等无供暖需求但需要除湿的气候环境，冷梁系统的能耗最低。通风幕墙结构在气候温和地区有着非常显著的节能减排效应，但在气候温暖地区的节能潜力却显得有限（参见图6，10，10B，11）。

设有变风量再热空调系统的东西朝向建筑不同性能外围护结构的能耗研究：（一项）对设有变风量再热空调系统的建筑，不同性能外围护结构（建筑）的年度能耗强度研究。这项评估展示出6种不同性能的隔热玻璃窗（见表3的IGU1-6）结构且设有变风量再热空调系统的东西朝向建筑的能耗模拟结果。值得注意的是IGU-6玻璃窗性能与优化的普通玻璃性能相同，仅加装了两英尺的悬挂（遮阳装置）。研究结果表明，在选择高性能玻璃窗（特别是低阳光热增益性SHGC）过程中，气候温暖地区的玻璃性能敏感性比气候温和地区和气候寒冷地区的敏感性更为强烈。IGU4

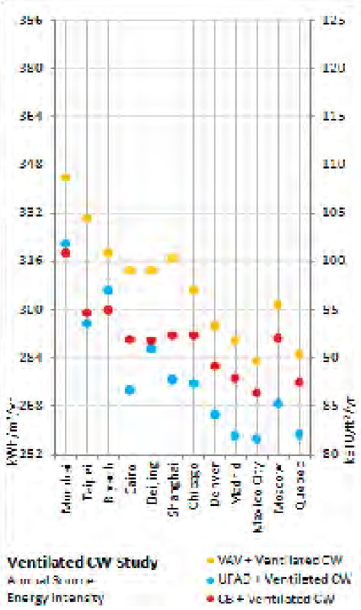


Figure 6. Annual Source Energy Intensity for Ventilated Curtainwall with Alternative HVAC Systems on Baseline E-W Architectural Massing (Source: Syska Hennessy Group)
图6. 东西朝向建筑采用通风幕墙结构的的不同空调系统能耗的研究（出自：Syska Hennessy Group）

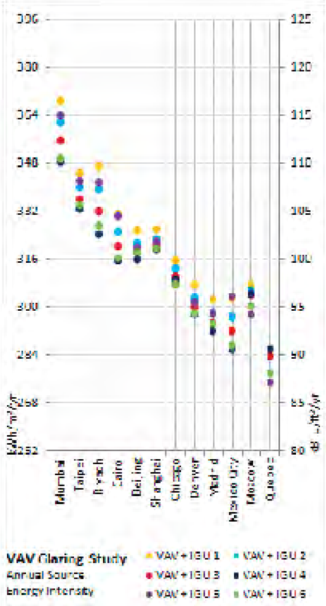


Figure 7. Annual Source Energy Intensity for Alternative Envelope Performance Configurations with VAV HVAC System on Baseline E-W Architectural Massing (Source: Syska Hennessy Group)
图7. 设有变风量再热空调系统的东西朝向建筑的基本体量的年度能耗的研究（出自：Syska Hennessy Group）

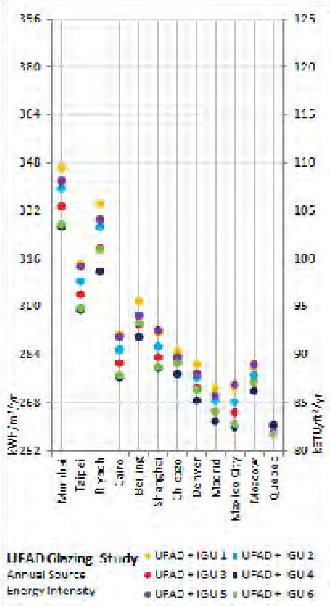


Figure 8. Annual Source Energy Intensity for Alternative Envelope Performance Configurations with UFAD HVAC System on Baseline E-W Architectural Massing (Source: Syska Hennessy Group)
图8. 设有地台送风空调系统的东西朝向建筑的基本体量的年度能耗的研究 （出自：Syska Hennessy Group）

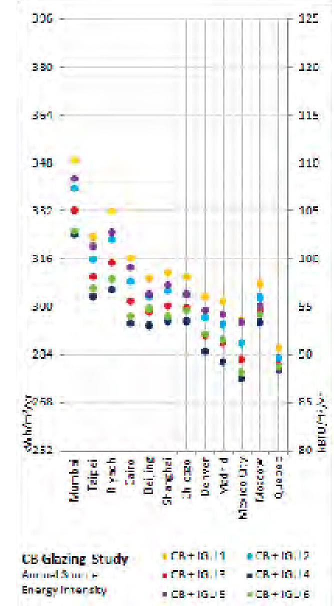


Figure 9. Annual Source Energy Intensity for Alternative Envelope Performance Configurations with Chilled Beam HVAC System on Baseline E-W Architectural Massing (Source: Syska Hennessy Group)
图9. 设有冷梁的空调系统的东西朝向建筑的基本体量的年度能耗的研究 （出自：Syska Hennessy Group）

glazing alternatives, except in the cold and very cold climates of Moscow and Quebec (See Figures 7, 10 A, 10B, 11).

Alternative Envelope Performance Study on East-West Massing with Under Floor Air Distribution HVAC System: The annual source energy intensity assuming a consistent UFAD HVAC system. This evaluation presents the modeled results for the UFAD VAV with reheat HVAC system for each of the six alternative insulated glazing unit (IGU) performances (see IGU 1-6 in Table 3) for the east-west architectural massing. The results for this portion of the study are similar to those described above for the conventional VAV with reheat HVAC system, except that the respective Energy Use Intensities (EUI) for the UFAD system are generally lower than for the VAV with reheat system (See Figures 8, 10 A, 10B, 11).

Alternative Envelope Performance Study on East-West Massing with Chilled Beam HVAC System: The annual source energy intensity assuming a consistent Chilled Beam (CB) HVAC system. This evaluation presents the modeled results for the CB HVAC system for each of the six alternative insulated glazing unit (IGU) performances (see IGU 1-6 in Table 3) for the east-west architectural massing. The results for this portion of the study are similar to those described above for the conventional VAV with reheat HVAC system, except that the respective Energy Use Intensities (EUI) for the CB system are generally lower than for the VAV with reheat system (See Figures 9, 10 A, 10B, 11).

Conclusions

- It is difficult to draw any hard and fast conclusions from this initial broad study attempting to evaluate any trends that might specifically tie HVAC system selection to alternative building envelope configurations. However, a few general consistencies, some intuitive and some not, that can be drawn from the results of this study are: In hot climates, the required SHGC for the adjusted baseline is significantly low, 0.17 (0.20 SC). With

，一种敷有超低SHGC值涂层的有色低反射陶瓷玻璃窗是唯一一种在温暖气候条件下节能效果超过基本节能要求的涂层类型。最后，IGU5，一种三层玻璃结构较两层玻璃窗体具有更低传热值的窗体除在寒冷和非常寒冷气候地区，如莫斯科、魁北克等地，相对于其它窗体的节能效果更为不好。（见图7，10A，10B，11）。

设有地台送风空调系统的东西朝向建筑不同性能外围护结构的能耗研究：（一项）对设有地台送风空调系统的建筑，不同性能外围护结构（建筑）的年度能耗强度研究。这项评估展示出6种不同性能的隔热玻璃窗（见表3的IGU1-6）结构且设有变风量再热式地台送风空调系统的东西朝向建筑的能耗模拟结果。这部分的研究成果与常规的变风量再热式空调系统的研究成果基本相似，有所不同的是地台送风空调系统的能耗使用强度通常都低于变风量再热式空调系统。（见图8，10A，10B，11）。

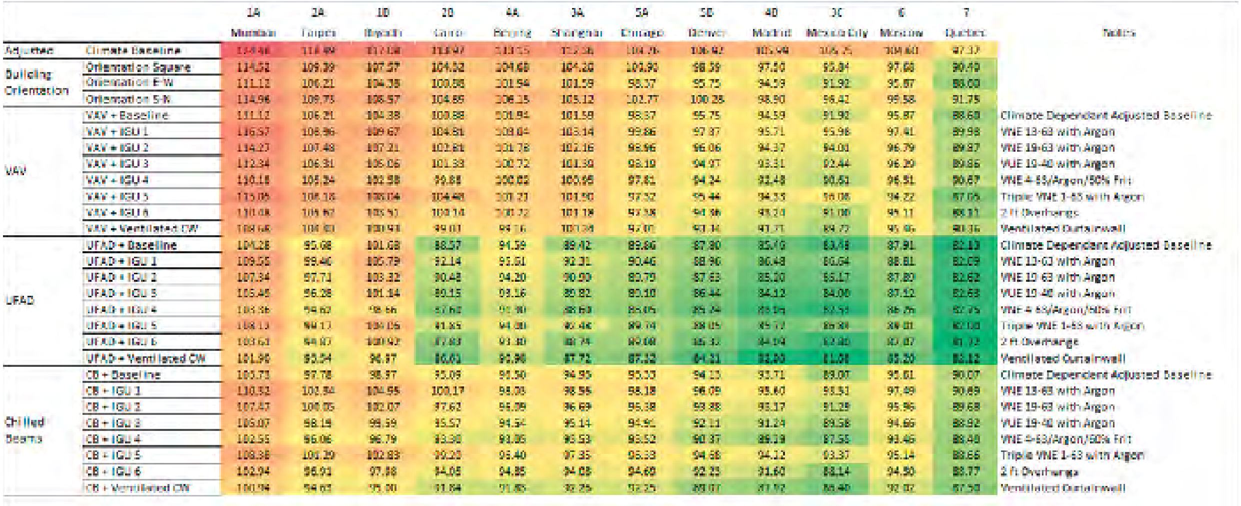
设有冷梁空调系统的东西朝向建筑不同性能外围护结构的能耗研究：（一项）对设有冷梁空调系统的建筑，不同性能外围护结构（建筑）的年度能耗强度研究。这项评估展示出6种不同性能的隔热玻璃窗（见表3的IGU1-6）结构且设有冷梁空调系统的东西朝向建筑的能耗模拟结果。这部分的研究成果与常规的变风量再热式空调系统的研究成果基本相似，有所不同的是冷梁空调系统的能耗使用强度通常都低于变风量再热式空调系统。（见图9，10A，10B，11）。

小结

- 由于本项研究仅就空调系统选择与不同建筑外围护结构间的关联趋势进行了初步评估与探讨，因此，很难就此得出任何硬性的结论。尽管如此，从这项研究的成果中仍然可以获得一些直观或非直观的研究成果，如：在炎热气候条件下，为了达到优化能耗的要求，阳光热增益值必须有明显的降低。即值应为 0.17（0.20SC）。相当于使用透光率为29%（35%的陶瓷含量）优质的工业镀膜涂层。如果仅依靠玻璃技术（而不使用镀膜涂层技术）实现基本的节能

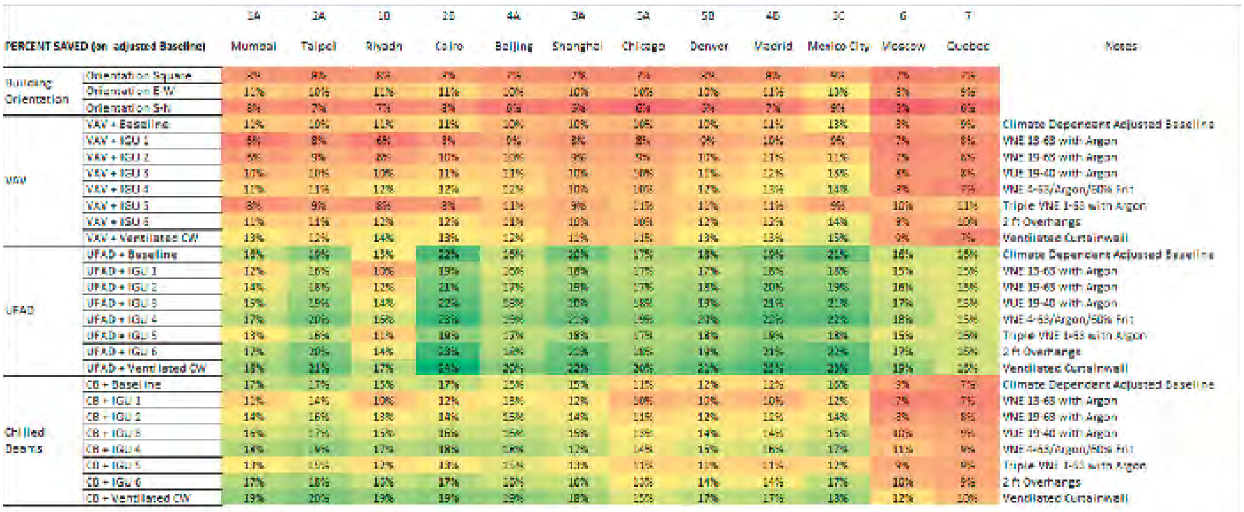
		1A Mumbai	2A Taipei	1B Riyadh	2B Cairo	4A Beijing	3A Shanghai	5A Chicago	5B Denver	4B Madrid	3C Mexico City	6 Moscow	7 Quebec	Notes
Adjusted	Climate Baseline	382.48	378.54	368.10	353.81	356.74	354.15	341.88	337.07	334.14	333.88	320.78	306.96	
Building Orientation	Orientation Square	362.25	344.88	358.12	328.80	330.08	328.51	318.10	310.82	307.38	301.16	307.06	285.00	
	Orientation E-W	350.32	334.84	329.07	318.05	321.38	320.20	310.11	301.86	298.12	288.78	301.25	270.93	
	Orientation S-N	362.48	345.05	342.27	330.68	334.66	331.41	324.01	316.13	311.80	303.97	313.93	280.27	
VAV	VAV + Baseline	350.32	334.84	329.07	318.05	321.38	320.20	310.11	301.86	298.12	288.78	301.25	270.93	Climate Dependant Adjusted Baseline
	VAV + IGU 1	367.50	343.50	345.77	330.43	324.86	325.17	314.81	306.58	301.73	301.58	307.11	288.68	VNE 13-63 with Argon
	VAV + IGU 2	360.25	338.85	337.38	324.14	320.89	321.07	311.88	302.83	297.52	296.37	305.16	288.84	VNE 19-63 with Argon
	VAV + IGU 3	354.17	335.14	331.20	319.47	317.55	318.64	306.54	299.42	294.18	291.42	306.57	288.81	VUE 19-40 with Argon
	VAV + IGU 4	347.35	330.78	328.40	314.88	315.33	318.26	308.36	297.11	291.55	285.66	308.63	285.84	VNE 4-63/Argon/60% Frit
	VAV + IGU 5	362.30	341.36	340.61	323.37	318.87	321.25	306.82	300.88	297.38	301.92	307.05	274.43	Triple VNE 1-63 with Argon
	VAV + IGU 6	348.32	332.38	326.34	315.60	317.55	318.58	307.01	297.47	298.86	286.88	296.86	277.79	2 ft Overhangs
	VAV + Ventilated CW	342.62	329.34	318.30	312.30	312.61	316.32	305.85	294.16	288.12	281.87	300.96	284.88	Ventilated Curtainwall
UFAD	UFAD + Baseline	328.77	301.63	320.56	279.24	298.30	281.90	288.31	276.80	260.42	269.22	277.16	258.92	Climate Dependant Adjusted Baseline
	UFAD + IGU 1	345.38	313.56	338.51	290.50	301.42	291.08	285.18	288.45	271.64	273.15	280.00	260.69	VNE 13-63 with Argon
	UFAD + IGU 2	338.42	308.04	325.74	285.25	296.80	286.56	288.07	276.15	268.60	258.52	277.08	260.47	VNE 19-63 with Argon
	UFAD + IGU 3	332.57	308.55	318.86	281.05	293.70	288.18	280.92	271.51	265.10	264.83	274.66	260.50	VUE 19-40 with Argon
	UFAD + IGU 4	325.87	298.31	311.04	276.16	288.72	279.34	277.58	268.74	261.57	260.18	271.05	250.88	VNE 4-63/Argon/60% Frit
	UFAD + IGU 5	340.86	312.64	328.07	288.58	296.35	291.57	281.92	277.58	270.40	273.79	280.62	258.51	Triple VNE 1-63 with Argon
	UFAD + IGU 6	326.55	299.80	318.17	276.31	294.15	279.76	288.84	273.13	266.12	261.03	274.51	257.93	2 ft Overhangs
	UFAD + Ventilated CW	321.25	294.80	305.71	273.85	286.82	276.54	275.38	265.40	258.52	257.50	268.61	255.90	Ventilated Curtainwall
Chilled Beams	CB + Baseline	327.02	308.38	312.01	299.77	304.28	298.87	308.68	296.75	295.44	280.80	301.48	288.05	Climate Dependant Adjusted Baseline
	CB + IGU 1	347.70	322.65	338.87	315.80	305.06	310.74	308.54	302.98	301.30	294.81	307.96	285.92	VNE 13-63 with Argon
	CB + IGU 2	338.80	315.42	321.70	307.77	301.95	304.82	308.85	295.97	298.74	287.80	300.52	281.72	VNE 19-63 with Argon
	CB + IGU 3	331.24	306.55	318.36	301.31	298.06	298.85	298.13	290.40	287.66	281.41	298.44	280.82	VUE 19-40 with Argon
	CB + IGU 4	323.31	302.86	305.14	294.16	293.35	294.85	294.85	284.81	281.40	276.01	294.65	278.68	VNE 4-63/Argon/60% Frit
	CB + IGU 5	341.68	319.82	324.18	312.76	308.81	306.81	308.70	298.51	297.06	294.97	299.95	273.58	Triple VNE 1-63 with Argon
	CB + IGU 6	324.55	305.58	308.50	296.52	299.02	296.50	298.52	290.78	288.80	277.80	297.20	270.85	2 ft Overhangs
	CB + Ventilated CW	318.23	298.34	298.50	288.54	288.50	296.87	296.84	288.82	277.18	271.40	290.80	275.85	Ventilated Curtainwall

Figure 10a.Annual Source Energy Intensity Results(kWh/SQW*YR)-Alternative Envelop Performance Configurations and HVAC Systems Types. (Source: Syska Hennessy Group)
图10a. 年度能耗强度结果(单位： kWh/SQW*YR)—— 不同性能外围护结构和不同空调系统 （出自：Syska Hennessy Group）



		1A Mumbai	2A Taipei	1B Riyadh	2B Cairo	4A Beijing	3A Shanghai	5A Chicago	5B Denver	4B Madrid	3C Mexico City	6 Moscow	7 Quebec	Notes
Adjusted	Climate Baseline	121.46	119.99	117.08	113.97	113.15	112.26	104.76	106.92	105.99	105.75	104.60	97.37	
Building Orientation	Orientation Square	114.52	109.39	107.57	104.32	104.68	104.20	101.90	98.39	97.50	95.84	97.68	90.49	
	Orientation E-W	111.12	106.21	104.38	100.88	101.94	101.59	98.37	95.75	94.59	91.92	95.87	88.60	
	Orientation S-N	114.96	109.73	108.57	104.85	106.15	105.12	102.77	100.28	98.90	96.42	99.58	91.75	
VAV	VAV + Baseline	111.12	106.21	104.38	100.88	101.94	101.59	98.37	95.75	94.59	91.92	95.87	88.60	Climate Dependent Adjusted Baseline
	VAV + IGU 1	116.57	108.96	109.67	104.81	103.04	103.14	99.86	97.37	95.71	95.98	97.41	89.98	VNE 13-63 with Argon
	VAV + IGU 2	114.27	107.48	107.21	102.81	101.78	102.16	98.96	96.06	94.37	94.00	96.79	89.87	VNE 19-63 with Argon
	VAV + IGU 3	112.34	106.31	106.06	101.33	100.72	101.30	98.19	94.97	93.31	92.44	96.29	89.86	VUE 19-40 with Argon
	VAV + IGU 4	110.18	105.24	102.58	99.88	100.02	100.95	97.81	94.24	92.48	90.61	96.51	90.67	VNE 4-63/Argon/50% Frit
	VAV + IGU 5	115.05	108.18	108.04	104.48	101.21	101.90	97.32	95.44	94.33	96.06	94.22	87.05	Triple VNE 1-63 with Argon
	VAV + IGU 6	110.48	105.67	103.51	100.14	100.72	101.18	97.38	94.36	93.24	91.00	95.11	88.11	2 ft Overhangs
	VAV + Ventilated CW	108.68	104.80	100.93	99.01	99.16	100.34	97.00	93.14	91.71	89.72	95.46	90.16	Ventilated Curtainwall
UFAD	UFAD + Baseline	104.28	95.08	101.68	88.57	94.59	89.42	89.86	87.80	85.46	83.48	87.91	82.13	Climate Dependent Adjusted Baseline
	UFAD + IGU 1	109.55	99.46	105.79	92.14	95.61	92.31	90.46	88.96	86.48	86.64	88.81	82.09	VNE 13-63 with Argon
	UFAD + IGU 2	107.34	97.71	103.32	90.48	94.20	90.90	89.79	87.63	85.20	85.17	87.80	82.62	VNE 19-63 with Argon
	UFAD + IGU 3	105.46	96.28	101.14	90.15	93.16	89.82	89.10	86.44	84.12	84.00	87.12	82.63	VUE 19-40 with Argon
	UFAD + IGU 4	103.36	94.62	98.66	87.62	91.90	88.60	88.05	85.24	83.16	82.55	86.26	82.75	VNE 4-63/Argon/50% Frit
	UFAD + IGU 5	108.13	99.13	104.06	91.85	94.00	90.46	89.74	88.05	85.77	86.88	89.01	82.00	Triple VNE 1-63 with Argon
	UFAD + IGU 6	103.61	94.87	100.92	87.83	93.30	88.74	89.08	86.32	84.04	82.80	87.07	81.72	2 ft Overhangs
	UFAD + Ventilated CW	101.96	93.54	96.97	86.81	90.98	87.72	87.12	84.21	83.20	81.08	85.20	82.12	Ventilated Curtainwall
Chilled Beams	CB + Baseline	103.73	97.78	98.97	95.09	93.50	94.95	95.33	94.13	93.71	89.07	95.61	90.07	Climate Dependent Adjusted Baseline
	CB + IGU 1	110.32	102.34	104.95	100.17	98.08	98.56	98.18	96.09	95.60	93.51	97.49	90.89	VNE 13-63 with Argon
	CB + IGU 2	107.47	100.05	102.07	97.62	96.09	96.69	96.38	93.88	93.17	91.29	95.96	89.68	VNE 19-63 with Argon
	CB + IGU 3	105.07	98.19	99.59	95.57	94.54	95.14	94.96	92.11	91.24	89.58	94.66	88.92	VUE 19-40 with Argon
	CB + IGU 4	102.55	96.06	96.79	93.30	93.05	93.53	93.52	90.37	89.19	87.55	93.46	88.40	VNE 4-63/Argon/50% Frit
	CB + IGU 5	108.38	101.29	102.83	99.20	96.40	97.35	96.38	94.68	94.12	93.37	95.14	88.66	Triple VNE 1-63 with Argon
	CB + IGU 6	102.94	96.91	97.88	94.05	94.85	94.08	94.60	92.23	91.60	88.14	94.50	88.77	2 ft Overhangs
	CB + Ventilated CW	100.94	94.63	95.00	91.84	91.85	92.25	92.25	89.07	87.92	86.40	92.02	87.50	Ventilated Curtainwall

Figure 10b. Annual Source Energy Intensity Results(KBTU/SF*YR)-Alternative Envelop Performance Configurations and HVAC Systems Types. (Source: Syska Hennessy Group)
图10b. 年度能耗强度结果(单位：KBTU/SF*YR)——不同性能外围护结构和不同空调系统（出自：Syska Hennessy Group）



PERCENT SAVED (on adjusted Baseline)		1A Mumbai	2A Taipei	1B Riyadh	2B Cairo	4A Beijing	3A Shanghai	5A Chicago	5B Denver	4B Madrid	3C Mexico City	6 Moscow	7 Quebec	Notes
Building Orientation	Orientation Square	5%	8%	8%	7%	7%	7%	7%	6%	8%	9%	7%	7%	
	Orientation E-W	12%	10%	11%	11%	10%	10%	10%	10%	11%	13%	8%	9%	
	Orientation S-N	8%	7%	7%	8%	6%	6%	6%	6%	7%	9%	3%	6%	
VAV	VAV + Baseline	12%	10%	11%	11%	10%	10%	10%	10%	11%	13%	8%	9%	Climate Dependent Adjusted Baseline
	VAV + IGU 1	5%	8%	6%	8%	9%	8%	8%	9%	10%	9%	7%	8%	VNE 13-63 with Argon
	VAV + IGU 2	6%	9%	8%	10%	10%	9%	9%	10%	11%	11%	7%	8%	VNE 19-63 with Argon
	VAV + IGU 3	10%	10%	10%	11%	11%	10%	10%	11%	12%	16%	8%	8%	VUE 19-40 with Argon
	VAV + IGU 4	11%	11%	12%	12%	12%	10%	10%	12%	13%	14%	8%	7%	VNE 4-63/Argon/50% Frit
	VAV + IGU 5	8%	9%	8%	8%	11%	9%	11%	11%	11%	9%	10%	11%	Triple VNE 1-63 with Argon
	VAV + IGU 6	11%	11%	12%	12%	11%	10%	10%	12%	12%	14%	9%	10%	2 ft Overhangs
	VAV + Ventilated CW	13%	12%	14%	13%	12%	11%	11%	13%	13%	15%	9%	7%	Ventilated Curtainwall
UFAD	UFAD + Baseline	14%	19%	13%	22%	18%	20%	17%	18%	19%	21%	16%	15%	Climate Dependent Adjusted Baseline
	UFAD + IGU 1	12%	16%	10%	19%	15%	18%	17%	17%	18%	18%	15%	15%	VNE 13-63 with Argon
	UFAD + IGU 2	14%	18%	12%	21%	17%	19%	17%	18%	20%	19%	16%	15%	VNE 19-63 with Argon
	UFAD + IGU 3	15%	19%	14%	22%	18%	20%	18%	19%	21%	21%	17%	15%	VUE 19-40 with Argon
	UFAD + IGU 4	17%	20%	16%	23%	19%	21%	19%	20%	22%	22%	18%	15%	VNE 4-63/Argon/50% Frit
	UFAD + IGU 5	13%	16%	11%	18%	17%	18%	17%	18%	19%	18%	15%	15%	Triple VNE 1-63 with Argon
	UFAD + IGU 6	17%	20%	14%	23%	18%	21%	18%	19%	21%	22%	17%	16%	2 ft Overhangs
	UFAD + Ventilated CW	18%	21%	17%	24%	20%	22%	20%	21%	23%	23%	19%	16%	Ventilated Curtainwall
Chilled Beams	CB + Baseline	17%	17%	15%	17%	15%	15%	11%	12%	12%	16%	9%	7%	Climate Dependent Adjusted Baseline
	CB + IGU 1	12%	14%	10%	12%	13%	12%	10%	10%	10%	12%	7%	7%	VNE 13-63 with Argon
	CB + IGU 2	14%	16%	13%	14%	15%	14%	11%	12%	12%	14%	8%	8%	VNE 19-63 with Argon
	CB + IGU 3	16%	17%	15%	16%	16%	15%	13%	14%	14%	15%	10%	9%	VUE 19-40 with Argon
	CB + IGU 4	18%	19%	17%	18%	18%	17%	14%	15%	16%	17%	11%	9%	VNE 4-63/Argon/50% Frit
	CB + IGU 5	13%	15%	12%	13%	15%	13%	11%	11%	11%	12%	9%	9%	Triple VNE 1-63 with Argon
	CB + IGU 6	17%	18%	16%	17%	16%	16%	13%	14%	14%	17%	10%	9%	2 ft Overhangs
	CB + Ventilated CW	19%	20%	19%	19%	19%	18%	15%	17%	17%	18%	12%	10%	Ventilated Curtainwall

Figure 11. Percentage of Annual Energy Savings on the Adjusted Baseline - Alternative Envelope Performance Configurations and HVAC System Types. (Source: Syska Hennessy Group)
图11. 调整基准的年度能量节省百分比—— 不同性能外围护结构和不同空调系统 （出自：Syska Hennessy Group）

industry leading glazing coatings, this equates to a 29% VLT (35% using a frit). To improve upon this baseline performance using glass technology alone, an envelope would need to utilize heavily tinted, fritted glass and accept a VLT (visible light transmittance) below 20%.

- Ventilated cavity walls generally perform the best from an energy perspective given their improved U-factor, SHGC and opportunity for incorporating active external shading systems to minimize direct solar gain from entering the occupied space.
- Triple glazing performs well in both hot and cold climates due to improved U-factor, but its improvement over baseline IGU performance is much more significant in cold climates such as Moscow than hot climates such as Riyadh. SHGC is more important in hot climates, and U-factor is more important in cold climates, although the U-factor still can have positive impact in hot climates as well.
- The use of external shading consistently improves the envelope energy performance in general, but in the context of tall building may not be practical to incorporate. It is worth noting here that an internal blind is not a solar shading device, but rather a glare control device – once the solar load is in the occupied space it is a load that needs to be overcome by the comfort cooling system.
- UFAD generally performs the best amongst the three-systems modeled, especially in mild and cooler climates with reasonable wet bulb temperatures, where air-side free cooling can be utilized for significantly more hours during the year.
- In the context of this study, the combination of ventilated cavity wall envelope with an under floor air distribution HVAC system consistently performed the best.
- The specific conditions of the climate and its daily and annual diurnal variability are important factors in the selection of the most appropriate and energy efficient HVAC systems in a tall building – likely more important than the building envelope configuration.

More precise and specific analyses for individual building proposals should always be undertaken to determine the appropriate complement of envelope to HVAC system appropriate for the needs of the building. There is no "one size fits all". Furthermore, the authors are mindful that the successful design of a building relies on the design and ingenuity of the architects and engineers; therefore, any metrics applied should be used as an aide rather than a determinant.

Acknowledgment

The Authors wish to specifically acknowledge the assistant of Kristopher Baker and Shreshth Nagpal of Syska Hennessy Group with energy modeling methodology and execution in this study.

性能，则需要使用深色陶瓷玻璃且玻璃的透光率应低于20%。

- 从节能角度看，在改进了外墙的热传导因子、阳光热增益系统以及与主动式外墙遮阳系统相结合的基础上，使用有通风腔的墙体结构能够最大限度地减少阳光热能对室内空间的影响。
- 由于对热传导因子的改进，三层玻璃窗在炎热和寒冷的气候条件下均表现出良好的性能，特别是在如莫斯科等寒冷地区，其节能特性相对于在如利雅得等炎热地区的使用更为显著。阳光热增益系统对于炎热地区更为重要，虽然传热因子在炎热地区应用也有其积极的作用，但其在寒冷地区的作用更为重要。
- 一般来说，使用外部遮阳系统可以持续改善外墙节能特性，然而对于高层建筑而言这样的做法并不实际。这里值得注意的是，建筑物内遮帘并不是一种遮阳设备，它仅是一种眩光控制装置——一旦阳光产生的热能进入了使用空间，就需要制冷系统来承担的这一部分热荷载。
- 在被模拟的三个空调系统中地台式送风一般认为是最好的一种节能空调形式，特别是在气候温和和凉爽地区且湿度适中的环境中，每年可能有更多的时间使用非制冷送风方式。
- 在本项研究中，通风腔外墙结构与地台送风系统相结合可以达到最佳的节能效果。
- 日间和年度的昼夜温差变化特性是高层建筑选择最为适合并高效节能空调系统的重要因素——甚至比外墙结构配置更为重要。

为了满足建筑（使用）的需要，外围护结构对空调系统起到了一个补充的作用。为确定外墙结构形式，必须对单体建筑物的设计方案采取更加明确和具体的分析。没有一种“放之四海而皆准”的设计方案。此外，作者注意到，一个成功的建筑设计依赖于建筑师和工程师们的设计和创造力，因此，任何方法都只应作为一个辅助参考，而不是一个决定因素。

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