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Feasibility Study to Implement the Passive House Standard on Tall Residential Buildings
关于被动式房屋标准应用于高层居住建筑的可行性研究

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Dan Kaplan is widely recognized for integrating design excellence, sustainable innovation and an urban point-of-view into noteworthy architectural and urban design projects. His passion and preoccupation is sustainable city building. Dan has principally served in a design and leadership capacity for many of the firm's significant projects – from individual buildings to large scale urban plans.

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Ilana Judah leads sustainability strategies for local and global projects of multiple scales and typologies. She served as co-chair of the AIA New York's Committee on the Environment and on Mayor de Blasio's 80x50 Task Force on the Leading Edge Standards subcommittee.

Ilana Judah 她在多种尺度和类型的本土及国际项目中领导可持续发展战略。她曾担任美国建筑师协会（AIA)纽约委员会的联合主席和de Blasio市长的80x50工作组（80 x50 Task Force)下属的领先标准委员会（Leading Edge Standards subcommittee)。

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Daniel Piselli's extensive portfolio of educational, cultural, and residential projects combine an innovative and questioning perspective with a rigorous and methodical design process. With assistance from The New York State Energy Research and Development Authority, Daniel co-led research to determine the viability of implementing the Passivhaus standard for tall residential buildings in New York.

Daniel Piselli 他将自己在教育，文化，住宅项目中广泛的经验、创新和批判性的视角以及严密系统性的设计过程相结合。在纽约州能源研究和发展管理局（The New York State Energy Research and Development Authority）的协助下，Daniel共同领导研究，用以确定在纽约高层住宅楼实施Passivhaus标准的可行性。

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As one of Dagher Engineering's primary sustainable design specialists, Josephine is well-versed in energy conservation strategies that promote efficiency while meeting budgetary requirements. Josephine has distinguished herself by seamlessly managing her studio to provide MEP systems that are fully integrated within the architecture of buildings.

作为Dagher工程公司的首席可持续设计专家之一，约瑟芬精通于既能提升能源效率同时满足预算需求的能源节约战略。约瑟芬对历史敏感和复杂的项目有深刻的认识，有别于其他人的是，她带领工作室提供可以和建筑设计完美结合的MEP系统。

Abstract | 摘要

A FXFOWLE lead team is near completion on a research grant funded by The New York State Energy Research and Development Authority to determine if the Passive House Standard can be implemented on a tall residential building in the megacity of New York City. The research study is noteworthy because it considers a building that is taller and larger than the biggest Passive House building in the world. The study considers a climate with humidity that is more globally relevant to countries like China than the temperate central European setting for which the Passive House Standard was developed. The study currently results in drastic energy reductions in line with those expected by the Passive House Standard.

We propose a paper that will present the results of the study. The paper will include a viable design for a tall Passive House residential building, and analyze its impacts from multiple perspectives.

Keywords: Energy Efficiency, Façade, Passive Design, Sustainability, Sustainability Certification

FXFOWLE公司的领导团队将于近期完成一个由纽约州能源研究和发展管理局（The New York State Energy Research and Development Authority）资助的研究项目，用以确定Passive House Standard是否能够应用于纽约大都市的高层住宅楼。这项研究是值得关注的，因为它考虑了比目前世界上最大的Passive House更高更大的建筑。相比于Passive House Standard被开发出来时设定的欧洲中部的温带气候，该研究考虑了对于中国这些国家更具相关性的潮湿气候 。该研究目前造成了大幅的能源消耗减少，这符合Passive House Standard的预期。

我们将提交一篇可以呈现研究成果的文章。文章将包含一座高层Passive House住宅建筑的可实施性设计，并从多角度对它进行分析。

关键词：能源效率、幕墙、被动设计、可持续性、可持续性认证

Introduction

Highly energy efficient and resilient buildings are crucial to the success of megacities. As populations grow and cities become larger and denser, problems related to energy inefficiency are magnified and threaten megacity sustainability. Pollution, urban heat island effects, energy resource uncertainty and other energy related stresses cause health problems, discomfort, economic hardship and other challenges. Global climate change may be the ultimate energy related problem, posing an existential threat to large urban areas and all human habitation. Fortunately, it is possible to make buildings with the level of energy efficiency needed to address these issues. Passivhaus is a standard for energy efficient buildings that results in energy reductions for heating and cooling of approximately 70%–90% compared to typical buildings (BEEX, 2015). This standard was originally developed for small buildings in the central European climate, but it is now

介绍

高效节能及弹性建筑对于特大城市的成功至关重要。随着人口的增长，城市变得更大更密集，城市中涉及到能源效率低下的问题被放大，并威胁到大城市的可持续发展。污染、城市热岛效应、能源资源的不确定性，以及其他能源相关的压力导致健康问题、不适、经济困难和其他挑战。其中全球气候变化可能是关于能源的终极问题，它对城市空间以及全人类的居住地构成了现实威胁。幸运的是，我们可以设计达到一定能源效率水平的建筑以应对这些问题。Passivhaus作为一种节能建筑标准，可使房屋供暖和制冷的能源消耗相较常规建筑减少约70%–90%（BEEX，2015）。该标准最初是为适应中欧气候的小型建筑开发的，但现在在各国被广泛应用于各种类型、形状和大小的建筑，其中包括新建建筑和旧建筑改造。

FXFOWLE最近启动了一项适应性研究，用以评估Passivhaus标准在纽约市区（NYC）中高层住宅楼的应用状况。这

Figure 1. Aerial view (Source: FXFOWLE)
图1. 鸟瞰图（来源：FXFOWLE）

in use internationally for buildings of all types, shapes and sizes, including new construction and retrofits.

FXFOWLE recently lead research to evaluate the applicability of the Passivhaus standard to tall residential buildings in the megacity of New York City (NYC). The study is a comparative analysis of a base-case building design that targets LEED Silver to a Passivhaus version of the same building. The base-case building is a large mixed-income housing project currently under construction (Figure 1). Preliminary results indicate that the Passivhaus design can significantly reduce primary energy use with virtually no aesthetic changes and common construction methods (Figure 2). (At the time of publication the percentage of primary energy use reduction was not verified.) Additional construction costs are estimated to be less than 5% more than initial first costs. Energy use is projected to be so low that utility cost savings will result in a payback period of approximately three years per the preliminary results. These results

项研究对达到LEED 银制级别的基本类型建筑设计和Passivhaus标准下的相同房屋进行了比较分析。基本型的大楼是目前正在建设一个大型混合收入住房项目（图1）。初步结果表明，该Passivhaus设计能减少一次能源消耗，且几乎不在美观上产生影响，并且使用常见的建造方式（图2），截止出版之时，一次能源的使用量减少的百分比并没有得到确认。附加施工成本大约只比初始第一成本不多于5

Key FIndings
70% primary energy reduction
Less than 5% initial cost increase
3 year payback
No major aesthetic changes
Reduced mechanical equipment size
Improved resiliency, acoustic performance and thermal comfort
Typical New York City high-rise construction methods

Figure 2. Key findings (Source: FXFOWLE)
图2. 重要发现（来源：FXFOWLE）

%。能源用量预计为如此之低，节约能耗成本可以达到大约三年的投资回报期。这些结果有力地表明， Passivhaus可适用于纽约高层住宅楼。由于纽约拥有极具挑战性的气候，冬天寒冷夏天炎热且潮湿，这些结果表明，Passivhaus可广泛适用于多种气候的大城市。

这篇论文简略描述了该项研究。该报告的完整版将出版于2016年年中。

Passivhaus

德国术语Passivhaus通常在英语被引用作为“Passive House”。本文采用德国词，是因为英文单词“house”会造成误解认为该标准仅适用于单个家庭的房子。德文Passivhaus可以翻译成更适用的英文词组“Passive building”。

该Passivhaus标准是在德国开发，并在1990年代初出台。它是基于一些简单的原则和基本的建筑处理方法来创建超低能耗

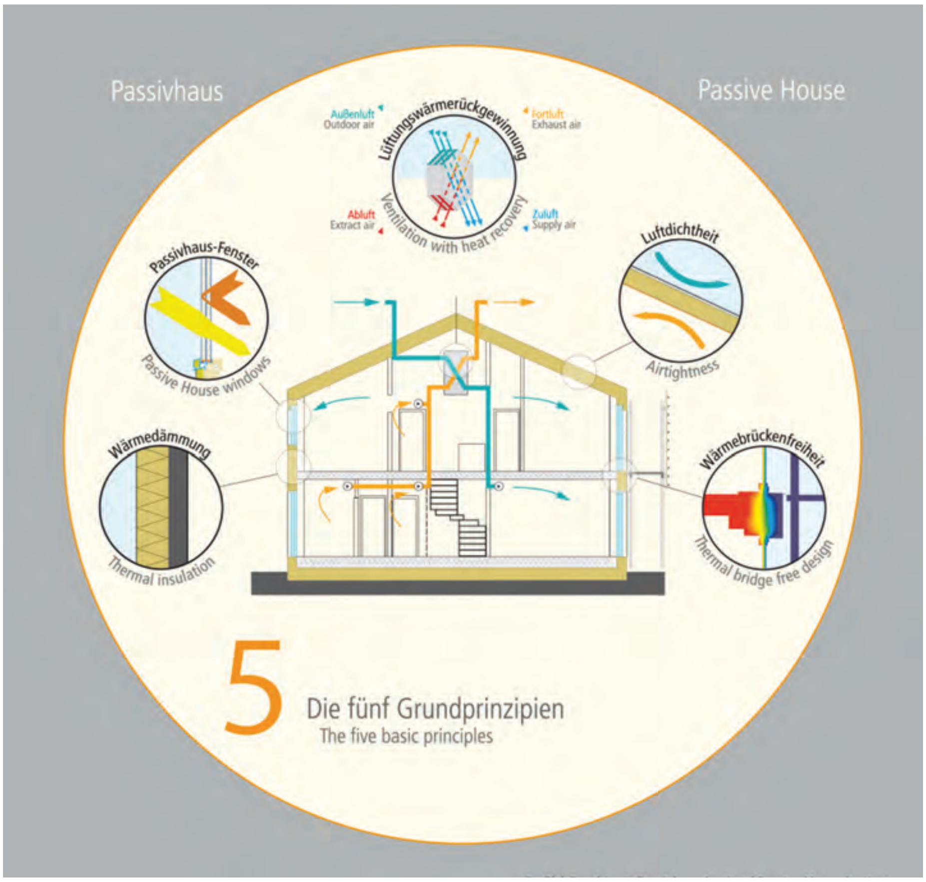

Figure 3. Passivhaus principles (Source: Passivhaus Institute)
图3. Passivhaus 原则（来源：Passivhaus Institute）

strongly suggest that Passivhaus is applicable to tall residential buildings in NYC. Since New York has a challenging climate with cold winters and hot & humid summers, these results suggest that Passivhaus is broadly applicable to megacities in many climates.

This paper describes the research study in an abbreviated form. A full version of the report will be published in mid-2016.

Passivhaus

The German term Passivhaus is often referred to in English as "Passive House." This paper uses the German term because the English word "house" can cause misperception that the standard is only for single family houses. Passivhaus can be translated from German to a more applicable English phrase "Passive building."

The Passivhaus Standard was developed in Germany and introduced in the early 1990s. It is based on a few simple principles and primarily architectural solutions to create ultra-low energy buildings. Strategies include optimized orientation and shading, passive solar gain, excellent building enclosure performance, exceptional air-tightness, and reduced mechanical system sizes with increased efficiency. These concepts are often represented as 5 main principles: 1. Thermal insulation, 2. Thermal bridge-free design, 3. Air-tightness, 4. Passivhaus windows, and 5. Mechanical ventilation with heat recovery (Figure 3).

Certification is based on a few crucial performance criteria as calculated by the Passivhaus Planning Package (PHPP) energy modeling tool. Main criteria include very low energy consumption limits on heating demand (4.75 kBtu/{ft2yr}, 15kWh/{m2yr}), cooling demand (5.39 kBtu/{ft2yr}, 17.02 kWh/{m2yr}) and total building primary energy demand (38.0 kBtu/{ft2yr}, 120kWh/{m2yr}). In addition, a strict air-tightness limit must be achieved (0.6 ACH@50Pa, or 0.036 CFM/ft2 of surface area for large buildings) and proven through blower door testing. Buildings constructed to the Passivhaus Standard also benefit from improved indoor thermal comfort through reduced temperature asymmetry, better acoustic performance through enclosure upgrades, and higher air quality through increased ventilation and filtering of all supply air.

Additional information on Passivhaus can be found in the document "Active for more comfort: Passive House" published by the International Passive House Association (IPHA, 2014).

建筑物。策略包括建筑朝向优化和遮阳，被动式太阳能获取，出色的建筑围护结构性能，优异的气密性，并降低了机械系统尺寸，提高了效率。这些概念通常被表示为5个主要原则：1.热绝缘，2.热桥自由设计，3.气密性，4. Passivhaus窗户，5.具备热量回收的机械通风（图3）。

认证是基于几个关键性能标准，这些标准是由Passivhaus规划包（PHPP）这一能源建模工具计算出的。主要标准包括非常低的加热能量消耗限额标准(4.75 kBtu/{ft2yr}，15kWh/{m2yr}）、制冷能耗限额标准(5.39 kBtu/{ft2yr}，17.02 kWh/{m2yr})、总建筑一次能源需求(38.0 kBtu/{ft2yr}，120kWh/{m2yr})。另外，也要达到严格的气密性的限制(0.6 ACH@50Pa, or 0.036 CFM/ft2 of surface area for large buildings)或对于大型建筑表面0.036 CFM/ft2），并通过鼓风机门测试证实。构建基于Passivhaus标准的建筑也可通过减少温度不对称提高室内热舒适性，并通过优化建筑表皮达到更好的声学性能，通过增加通风并过滤提升室内空气质量。

关于Passivhaus的更多信息可以参看由国际被动式房屋协会（IPHA,2014）出版的文件“Active for more comfort: Passive House”。

政府间气候变化专门委员会（IPCC，2014）认为，对于建筑行业，Passivhaus是唯一能够降低建筑的能耗并足以实现温室气体减排目标的整体建筑策略（IPCC，2014年）。在德国，奥地利，比利时和西班牙市政当局都以不同的方式授权Passivhaus建造。Passivhaus目前在美国，中国和许多其他非欧洲国家，基于不同气候条件下进行推广。迄今为止，全球大约有60000符合Passivhaus标准的建筑物（Passipedia，2016)。这其中包括许多类型的建筑，如写字楼，住宅，学校，消防局，卫生保健设施，会展中心，使馆，研究机构，和其他人。

一批大型的Passivhaus开发案和高层建筑都大量出现在过去的几年里。德国的海德堡新Bahnstadt区是一个部分建成的全Passivhaus社区。开发包括各种建筑类型，包括住宅，商业，教育等。已建成的最高的Passivhaus建筑是栋高达256英尺（78米）的办公楼，位于奥地利的维也纳。另一栋更高的Passivhaus大楼正在建设中，是位于纽约高达270英尺（82.3）的CornellTECH宿舍楼。从纽约到布鲁塞尔到中国，还有更多高层和大型的Passivhaus建筑方案被提出（图4）。大城市必将受益于各类型的Passivhaus建筑物在世界范围被全方面应用。

The Intergovernmental Panel on Climate Change identified Passivhaus as one of the only whole-building strategies capable of reducing building energy use enough to achieve greenhouse gas mitigation targets for the building sector (IPCC, 2014). Municipalities in Germany, Austria, Belgium and Spain have mandated Passivhaus construction in various ways. Passivhaus activity is now underway in the United States, China and many other non-European countries with different climatic conditions. To date, there are approximately 60,000 buildings built globally to the Passivhaus Standard (Passipedia, 2016). These include many typologies such as office, residential, schools, fire stations, health care facilities, convention centers, embassies, research facilities, and others.

A number of large Passivhaus developments and tall buildings have emerged in the last few years. The new Bahnstadt district in Heidelberg, Germany is a new all-Passivhaus neighborhood that is partially complete. The development includes many building types including housing, commercial, educational, and others. The tallest built Passivhaus building is a 256ft (78 meter) tall office tower in Vienna, Austria. A taller Passivhaus building is under construction, the 270ft (82.3) tall CornellTECH Residential dormitory in NYC. Multiple other tall and/or large Passivhaus buildings are proposed for locations from New York to Brussels to China (Figure 4). Megacities will surely benefit as Passivhaus buildings of all types are shown to be viable throughout the world.

Figure 4. Passivhaus tall building examples (Source: Clockwise from upper left: Atelier Hayde Architekten, Architekturbüro Rombach, CREE, Ateliers Jean Nouvel, WuXing Real Estate Co. Ltd., Local Design Institute Tianjin, Rongen Architekten, Rongen Architekten, ALTIPLAN° architects, Handel Architects)
图4. Passivhaus 高层建筑范例（来源：Clockwise from upper left: Atelier Hayde Architekten, Architekturbüro Rombach, CREE, Ateliers Jean Nouvel, WuXing Real Estate Co. Ltd., Local Design Institute Tianjin, Rongen Architekten, Rongen Architekten, ALTIPLAN° architects, Handel Architects）

Figure 5. West view (Source: FXFOWLE)
图5. 西视图（来源：FXFOWLE）

Base-Case Building for Comparative Analysis

The purpose of the comparative analysis is to present a feasible model for the design of high-rise residential apartment buildings in NYC to achieve the Passivhaus standard. High-rise residential apartment buildings are a ubiquitous building type and many are expected to be built in the future. In fact, this building type is a common housing solution in many megacities around the world. The comparative analysis examines the impacts of achieving the standard from architectural, enclosure detailing, mechanical, constructability, resilience, zoning, and code and cost perspectives.

The base-case building is a 593,000 sf (55,092 sm), 26-story multifamily, mixed income, high-rise building with retail in Jamaica, Queens, New York (Figure 5). Jamaica is well-served by transit. It hosts a regional transportation hub that includes bus, rail, and direct access to John F Kennedy International Airport. The area is currently undergoing regeneration, and the central district was recently up-zoned to enable higher density development. The base-case building is in the central district and immediately adjacent to the transportation hub. The building will serve as model for mixed-income development with a combination of inclusionary and work-force housing.

While the neighborhood context around the base-case building is currently low-rise construction, the study assumed built-out adjacent properties to represent a fully developed future condition. This step was necessary to approximate a typical NYC building site, and potential future overshadowing from adjacent buildings

用于对比分析的基本型建筑

对比分析的目的是提供一个用于纽约市高层住宅公寓楼设计的可行的模型，用以实现Passivhaus标准。高层住宅公寓楼是一个无处不在的建筑类型，并且将在未来的城市中兴建更多。事实上，这种建筑类型在世界各地的许多大城市是普遍的住房解决方案。比较分析检测达到节能标准对房屋从建筑，围护结构细节，机械，施工，回弹性，规划分区，建筑规范，成本各方面的影响。

基本型建筑是一个593000平方英尺（55092平方米）26层的具有多户、混合收入居住类型，带底商的高层建筑，位于纽约皇后区的Jamaica（图5）。Jamaica具备良好的公共交通。它承载了区域交通枢纽，包括巴士站，火车站，并直接进入

(Figure 6). The site is fortunate to have a rail line to the south which ensures adequate exposure for passive solar gain in winter.

The base-case building is currently under construction. The design targets LEED Silver Certification. The building includes a 3-story retail podium and a 450-unit residential rental apartment tower with amenity spaces on the 4th and 25th Floors. A Passivhaus boundary was selected to include all fully enclosed, conditioned space including retail, residential and other areas. Below grade parking is the only area excluded from the Passivhaus Boundary since it is not fully enclosed, conditioned space.

The compactness ratio of the base-case building was found to be a very favorable floor area to volume ratio of 0.07. In comparison, a good compactness ratio from the point of view of energy savings is considered to be 0.2. Low compactness ratios signify less surface area relative to building volume, and less opportunity for heat to move through the enclosure. Large buildings generally have lower compactness ratios than small buildings, making it easier for large buildings to meet Passivhaus requirements.

Glazing is distributed on the building in all solar orientations based on apartment layouts. Shading devices are not used for specific south, east or west solar conditions. The window to wall ratio is approximately 36%. This ratio is lower than many market-rate residential buildings in NYC and the current prescriptive code ratio of 40%. But this ratio is higher than many inclusionary housing developments and the future NYC prescriptive code ratio of 30%.

The predominant base-case exterior wall system is a cement panel rain screen assembly supported on a metal frame backup wall. The residential tower has aluminum windows with double glazed insulating glass units (IGUs) and operable in-swinging casement windows. Storefront and curtain wall fenestration occurs at the podium levels.

The central plant of the base-case building provides space heating, space cooling and domestic hot water. It consists of a combined heat and power (CHP) cogeneration system that operates in conjunction with hot water condensing boilers and absorption chillers. There are ten 100kW CHP natural gas generators, three 350 ton (1,231 kW) absorption chillers and eight natural gas boilers along with associated pumps and accessories. In addition to domestic hot water, depending on the season, the central plant provides chilled or hot water that

约翰•F•肯尼迪国际机场。该地区目前正在进行区域再生，而中心区最近被向上规划，使得可以进行更高密度开发。基本型建筑位于中心区，紧邻交通枢纽。该大楼将作为用于混合收入居住开发且兼具适应性和劳动力住宅的典型模型。

而目前该建筑物周围是低层建筑，研究采用自带的相邻属性来代表一个充分开发的未来状态。为了接近典型的纽约城市建筑场景以及潜在的未来会存在的来自周边建筑物的遮挡，这一步是必要的（图6）。很幸运的是，在场地中有一个铁路线通向南部，保证了冬季建筑也能获得充足的光照，并获取被动式太阳能。

目前的基本型建筑正在建设中。设计达到LEED银级认证。该建筑包括一个3层的商业裙房和一栋出租公寓楼，在4层和25层设有便利设施空间。Passivhaus边界被选定包括所有全封闭、可调节的空间，包括零售、居住和其他地区的空间。停车场是唯一被排除在Passivhaus边界的区域，因为它不是完全封闭并可调节的空间。

基本型建筑的紧凑度是很有利于容积率的0.07。相比之下，从节约能源的角度来说，良好的紧凑性比率被认为是0.2 。低紧凑比率表示相对建筑体积较小的表面面积，以及热量通过表皮流失的机会较小。大型建筑一般有比小楼房更紧凑的比例，使得大型建筑更容易以满足Passivhaus的要求。

依照建筑平面，玻璃分布在建筑物的每个朝向立面上。遮阳装置不用于特定南、东或西的光照条件。该窗墙比例约为36%。这个比率比纽约市中许多符合市场利率的居住建筑和现行的建筑规范要求的40%都要低。但是这个比例比许多适应性居住开发和未来的纽约市建筑规范要求的30%要高。

基本型建筑主要的外墙系统是支撑在金属框架靠墙上的水泥面板雨幕组件。该住宅楼设置有双层中空玻璃（IGUs）的铝制窗户和可操作的内开窗。店面和幕墙门窗设置在裙房层。

基本型大楼的中央控制设备提供空间加热，空间制冷和生活热水。它包括，一个热电联产（CHP）联供系统，操作热水冷凝锅炉和吸收式制冷机。设备包括十个100kW的热电联产天然气发电机组，三个350吨（1231千瓦）的吸收式制冷机，八个天然气锅炉以及与之相关的泵和配件。除了生活热水，根据不同的季节，中央设备提供了一个通过整个建筑的双重温度水循环回路，循环冷水或热水。在需要制冷的季节，热电联供系统提供的热水作为生活热水并且提供吸收式制冷机。在供暖季，它与锅炉一起工作，提供为供暖和作为生活用水所需的热水。对于住宅单元，垂直叠层风机盘管机组可获得中央设备供应的用以加热和冷却房屋的冷热水。通风是通过经由外墙开口到风机盘管的管道完成的。中央屋顶风机排出厕所和厨房的废气。住宅的走廊利用专用的燃气封装空气冷却屋顶单元并通风能量回收。能量回收是通过公寓的厕所废气排放实现的。生活设施区域由水平和/或垂直风机盘管调节，获取中央设备供应的冷热水。 LED照明和能源之星（Energy Star）额定电器在整个基本型建筑的住宅部分使用。

Passivhaus设计

Passivhaus再设计的初始目标是使它可以实现并可以复制，并且最大限度的避免其发生变化。它使用符合当前纽约建筑工业技术的产品与建造方法。该设计并不需要使用外部系统或特别的产品。

基本型的PHPP模型被再次应用达到Passivhaus的能量平衡。对基本型设计的围护结构进行具有挑战性但可以实现的优化升级，以达到高性能围护结构目标。利用PHPP模型不断的分析机械，电气和管道（MEP）系统，直到Passivhaus实现能量平衡（图7）。

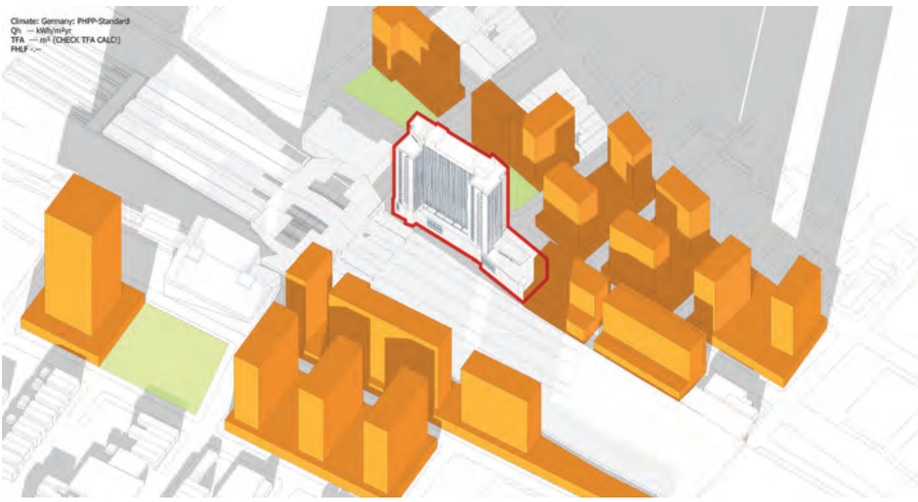

Figure 6. Site context (Source: FXFOWLE)
图6. 场地环境（来源：FXFOWLE）

				Base-Case Building	Passivhaus Design
Architectural	Airtightness	CFM/SF@50Pa		0.263	0.036
	Insulation (Effective R-Value)	Roof		R 33.06	R 42.12
		Ground Floor Slab		R 18.50	R 18.52
		Basement Slab		R 0	R 16.52
		Rainscreen Wall (Avg.)		R 12.02	R 26.00
		Brick Cavity Wall		R 10.71	R 26.10
		Lot Line wall		R 15.90	R 17.32
		Foundation Wall		R 4.34	R 16.52
		Basement Wall		R 0	R 13.12
	Windows	"U-Value Frame"	Residential	0.42 (R 2.4)	0.14 (R 7)
			Curtain Wall	1.00 (R 1)	0.14 (R 7)
		"U-Value Glass"	Residential	0.29 (R 3.4)	0.175 (R 5.7)
			Curtain Wall	0.24 (R 4.2)	0.175 (R 5.7)
		SHGC	Residential	0.38	0.38
			Curtain Wall	0.62	0.62
	Thermal Bridging	ψ	Typical	0.15	< 0.006
		ψ	Foundation	0.15	0.02
		ψ	Columns	1.2	1.0
		ψ	Balconies	0.556	0.03
		ψ	Windows & Doors	0.15	0.023
		χ	Typical	1.2	< 0.018
Mechanical	Ventilation	System Type		Energy Recovery Ventilator (ERV) for Corridors; Outside air provided directly to mechanical units without energy recovery for all other spaces	Multiple ERVs for all spaces (Semi Centralized System)
		System Efficiency		Approximately 75% for Corridors; Not Applicable for all other spaces	85%
	Mechancial System	System Description		Absorption Chillers, Hot Water Boilers and Combined Heat and Power System serving Two Pipe Fan Coil Units	Water-cooled Electric Chillers and Natural gas condensing Hot Water Boilers serving Two Pipe Fan Coil Units
		Central Plant Equipment		Absorption Chillers, Hot Water Boilers, Combined Heat and Power System and Cooling Towers	Electric Chillers, Hot Water Boilers, and Cooling Towers
		Cooling Efficiency		0.75 COP for Absorption Chiller	Peak condition: 0.61 kW/ton (COP 5.76); NPLV 0.352 kW/ton for Electric Chiller
		Heating Efficiency		85% Thermal Efficiency for Boilers, 56% Efficiency for heat output for Combined Heat and Power Units	94.5% Thermal Efficiency for Boilers
		Domestic Hot Water System Description		Indirect heat exchangers and storage tanks served by Combined Heat and Power Units	Natural gas condensing Water Heaters
		Domestic Hot Water System Efficiency		56% Thermal Efficiency for heat output of Combined Heat and Power Units	95.5% Thermal Efficiency
	Lighting	Installed & Recptacle Lighting in Apartments & Common Areas		0.5 W/ft2 Avg.	0.3 W/ft2 Avg.
		Lighting in Retail Spaces		1.6 Watts / sq. ft.	1.6 W/ft2 Avg.

Figure 7. Base-Case Building vs. Passivhaus Design (Source: FXFOWLE)
图7. 基本型建筑设计 与 Passivhaus 设计（来源：FXFOWLE）

is circulated through a dual temperature water loop throughout the building. During cooling season, the CHP system provides hot water for domestic hot water consumption and the absorption chillers. During heating season, it works in conjunction with the boilers to provide hot water for space heating and domestic hot water consumption.
For residential units, vertical stack fan coil units are served with chilled and hot water from the central plant provide heating and cooling. Ventilation is provided through ducted openings in the exterior wall to the fan coil units. Central roof fans exhaust the toilets and kitchens. Residential corridors utilize dedicated gas-fired packaged air cooled rooftop units with energy recovery for ventilation. Energy recovery is achieved through toilet exhaust from apartments. Amenity areas are conditioned by horizontal and/or vertical fan coil units, provided with chilled and hot water from the central plant. LED lighting and Energy Star rated appliances are used throughout the residential portion of the base-case building.

Passivhaus Design

The Passivhaus redesign began with basic goals to make the result practical and replicable. Changes were avoided to the extent possible. A concerted effort was made to use products and construction means and methods familiar to the current New York construction industry. No exotic systems or speculative products were required.

The base-case PHPP model was used to iterate possible Passivhaus energy balances. Enclosure performance targets were developed based on aggressive but achievable upgrades to base-case enclosure systems. Mechanical, electrical and plumbing (MEP) systems were analyzed in PHPP until a system achieved a Passivhaus energy balance (Figure 7).

Architectural aspects of the Passivhaus redesign result in virtually no aesthetic changes. Architectural upgrades mostly occur at the level of details and specifications. Improved performance is achieved through additional insulation, reduced thermal bridging, simplified air barrier installation strategies, and triple glazed insulated windows. These changes allow mechanical systems to be substantially reduced or eliminated.

The base-case window to wall ratio of 36% is preserved. Windows were upgraded to include high performance Passivhaus Certified

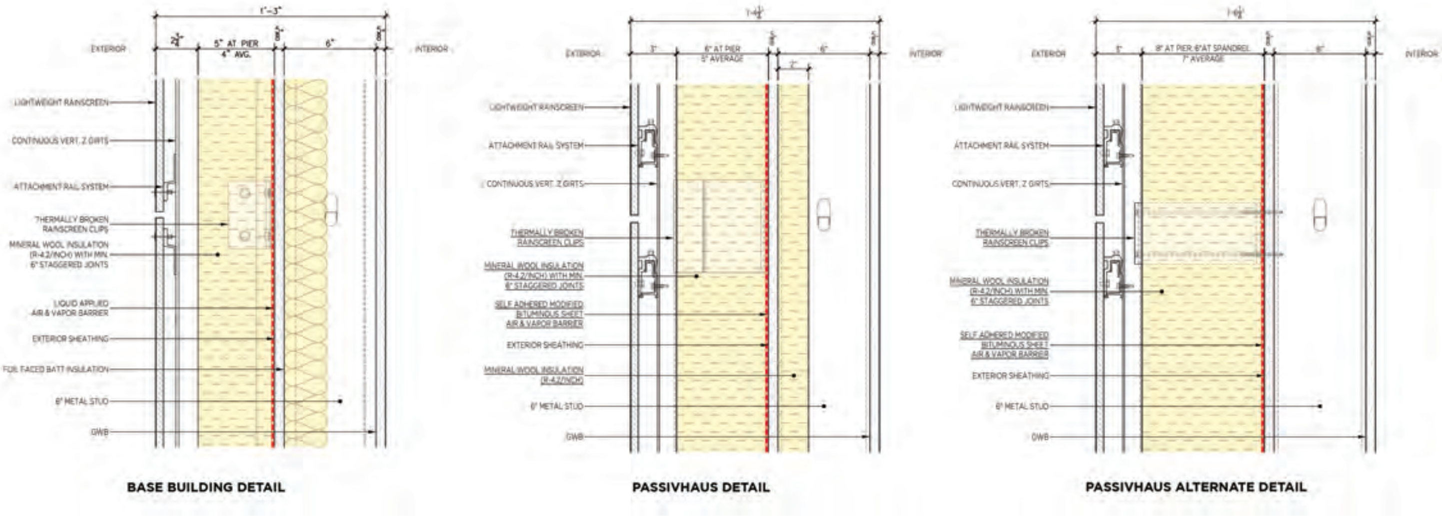

Figure 8. Rainscreen assembly: Base-Case, Passivhaus, and Passivhaus Alternate (Source: FXFOWLE)
图8. 雨幕组件：基本型，Passivhaus 和Passivhaus替代品（来源：FXFOWLE）

triple glazing and enhanced thermally broken frames. Increased performance allowed window sizes and locations to remain unchanged despite uncontrolled solar exposures and lack of shading devices. This achievement dispels a misperception that Passivhaus buildings do not have sufficient vision glass for views or daylight. Further, this result suggests that optimal building orientation, window exposure, and the addition of shading devices may allow Passivhaus buildings at the scale of the base-case building to achieve better performance with the same glazing ratio, or to have higher glazing ratios.

All major assemblies in the base-case building are redesigned to achieve the required performance. The predominant lightweight rain screen was an area of focus (Figure 8). The base-case assembly is considered to perform better than average due to the use of intermittent aluminum attachment clips and more exterior continuous insulation than stud cavity insulation. This type of assembly has been shown to result in a 45% to 55% reduction of insulation effectiveness due to thermal bridging (Payette, 2014). The Passivhaus energy balance required an effective insulation value of R-26 (IP U-0.0385, SI U-0.2184) for this assembly after accounting for thermal bridge reductions. A Passivhaus version of the assembly uses thermally improved fiberglass attachment clips and additional all-fully continuous insulation. The improved assembly results in a lower, 20% reduction of insulation effectiveness (Payette, 2014). This represents a 60% increase in insulation effectiveness over the base case. While this assembly achieves better performance, it is 3" (7.62 cm) thicker than the base-case assembly, and causes additional gross area and/or decreased usable area. To address this undesirable impact on area, an alternate version of the assembly is considered. The alternate is based on a different fiberglass attachment clip that is reported to result in a lower 3%–7% loss of insulation effectiveness. This represents a 90% increase in insulation effectiveness over the base-case. This alternate approach allows some insulation to be shifted back into the metal stud cavity. The resulting assembly is only approximately 1" (2.54 cm) thicker than the base-case assembly, and minimizes additional gross and/or decreased usable area. Both improved assemblies reduce the potential for interior condensation by minimizing thermal bridging, and relocating insulation to the exterior. These measures shift the location of potential cold surfaces where condensation may occur to the exterior side of the weather barrier.

NYC has a zoning incentive called Zone Green to encourage high performance enclosures among other energy savings measures. This incentive enables the area of some additional exterior wall insulation to be excluded from zoning calculations. Up to 8" (20.32 cm) of exterior wall can be deducted based on the level of performance. The proposed Passivhaus details would enable full use of the incentive. This kind of incentive is very helpful and can be emulated in other jurisdictions.

All major details in the base-case building are redesigned to enable air-tight installation

从建筑角度来看， Passivhaus再设计在视觉上并没有造成美学的损失。建筑性能的改善大多发生在细节和一些特定的方面。通过额外的隔离构造，减少热桥，简化的空气阻隔安装策略以及三层玻璃隔热窗来实现Passivhaus改善的目标。这些设计改变可以减少或消除一些机械设备。

基本型建筑的基本开窗和墙36%的比例被保留下来。Passivhaus利用高效的Passivhaus 认证的三层玻璃以及改善的阻断热传导的窗框来提高窗户的节能效率。其提高的性能可以使它设计的窗口大小和位置保持不变，尽管它不可避免的暴露在太阳下并缺乏遮阳设备。这一设计成果消除了之前外界对Passivhaus建筑设计没有足够的开窗或日照的一种误解。这一结果还表明，最佳建筑朝向，窗口朝向，并增设遮阳装置可使Passivhaus和同等规模的基本型建筑相比可以更好的实现节能，或比其具有更高的窗墙比。

Passivhaus重新设计基本型建筑中的所有主要组件以达到设计要求。轻巧的雨幕是一个关注点（图8）。由于基本型建筑使用铝制固定夹和连续的外墙保温而不是双头中空隔热材料的组件，其被认为高于当前的平均水平。由于热桥这种类型的组件可以导致减少45%至55%的隔热效果（Payette，2014）。因为减少了热桥的出现，Passivhaus能量平衡标准达到的有效隔热值为R–26（IP U–0.0385，SI U–0.2184）。其中一个类型的Passivhaus使用了热改良玻璃纤维固定夹和额外的连续的完全隔热材料。改进后的Passivhaus组装结果使其产生了一个更好的隔热效果（Payette，2014）使导热再次降低了20%。该结果显示其隔热保温效率和基本型建筑相比提高了60%。虽然此装配具有

and reduce thermal bridging. Common air and vapor barrier products are used. Base-case building window closure details rely on sealant which may crack over time. The Passivhaus design proposes self-adhered membrane flashing instead of sealant to improve the consistency of workmanship at joints between window frames and rough openings, and similar construction joints. Thermal bridge reduction strategies include the use of structural thermal breaks at balconies and parapets, proper positioning of window thermal breaks with assembly insulation layers, stand-off metal shelf angles, discontinuous through-wall flashings, and other strategies (Figure 9). Calculated thermal bridge values were used in the PHPP when Passivhaus thermal bridge maximums could not be achieved.

The Passivhaus MEP design is a modification of the base-case building system. Similar components are used such as vertical fan coil units, water cooled chillers, cooling towers and condensing boilers. However, greatly reduced heating and cooling loads enable the HVAC equipment to operate at optimum efficiency and to be specified at reduced sizes. While the base-case building design utilized a cogeneration system to increase overall efficiency, the Passivhaus design efficiency was high enough that the cogeneration system was eliminated. Energy recovery ventilation units with a minimum efficiency of 85% are used for ventilation of all conditioned spaces. Chillers are changed from an inefficient absorption system (Coefficient of Performance (COP) 0.75) to high efficiency magnetic bearing compressors with Variable Frequency Drives (COP 5.76). With reduced envelope heat losses, fan coil units in the apartments are capable of providing adequate heating even with low hot water temperatures of 105° F (40.56° C) supply and 95° F (35.0° C) return. These low temperatures enable the condensing boilers to operate at an optimum efficiency of 94.5%, compared to 85% efficiency in the base-case building.

Ventilation with energy recovery is a key component to the Passivhaus design. The tower portion of the base-case building utilized louvers on the façade to provide outside air to fan coil units in apartments. Apartment fan coil units did not utilize energy recovery. This inefficient system for ventilation was revised to Passivhaus Certified energy recovery units mounted on the roof, with each unit serving multiple apartments. A small amount of additional shaft space was needed in each apartment to accommodate ventilation ducts. Amenity, lobby and retail spaces are served by separate ERV units

较好的性能，但是它比基本型建筑的装配厚了3英寸（7.62厘米）由于比基本型装配厚，导致其额外的占地面积或降低了有效的使用面积。为了解决这一问题，新的装置被设计出来用以替代它。替代方案是利用一个新的证明可以减少3%-–7%隔热效果的玻璃纤维固定夹替换之前的固定夹。该结果显示其效率和基本型建筑相比提高了90%。这种替代方法可以使一些隔热区域位于金属钉的空腔内。其所得到的装配只比基本型建筑大约厚1英寸（2.54厘米），减少了额外需要的的空间和降低的使用面积。所有部件最大限度地减少热桥并把保温区域移到外部以减少内部结露的可能性。这些措施使可能出现冷凝的表面转移到到外面的位置。

纽约有一个名为绿色区域划分的规划分区策略，其鼓励在设计中使用性能良好的围护结构。该策略允许附加的外墙保温面积不参与分区的占地面积的计算。根据节能性能，可以使建筑物减少计算最高可达8英寸（20.32厘米）厚外墙的面积。Passivhaus在细节方面将充分利用这个优惠政策。这个政策实施的非常有效，并可以在其他地区推广实现。

Passivhaus对基本型建筑所有主要的细节进行重新设计并进行气密装置的安装同时减少热桥。设计中使用常见的空气和水蒸气阻隔构件。基本型建筑的窗口的密封依赖于会随时间消解的密封剂。Passivhau的设计提出了使用自粘卷材条来代替密封胶来改善交接的位置的状况，比如说在窗框和开口，以及类似的施工缝缝。减少热桥的设计手法也包括在阳台和护栏使用热桥阻断装置，在正确的窗户位置安装热桥阻断装置和隔热层，调整金属构建的角度，使用不连续的穿墙防水条等方法（图9）。当Passivhau不能实现热桥减少的

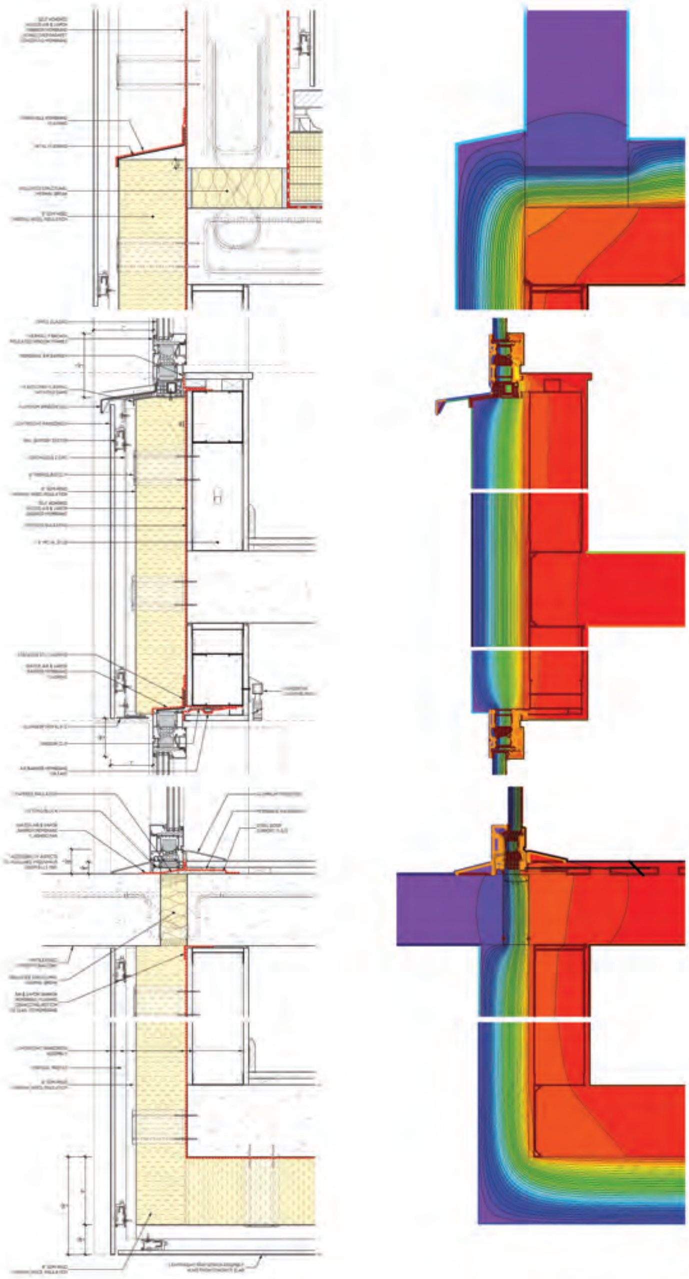

Figure 9. Rainscreen details and thermal bridge analysis (Source: FXFOWLE)
图9. 雨幕细部和热桥分析（来源：FXFOWLE）

(Figures 10 & 11). Balancing of the ventilation system is assisted by the use of spray sealant inside ducts and constant airflow regulators. The regulators also help limit potential stack effect disruption of ventilation flows.

最大值的时候，在PHPP模型中计算其热桥的值。

Passivhaus 的MEP设计是基于基本型建筑系统的修改。它仍然使用常用的构件比如垂直风扇盘管机组，冷却水机组，冷却塔和冷凝式锅炉。它大大降低了加热和制冷负荷从而使HVAC设备可以以最佳效率运行，特别是它还可以减小构建的的尺寸大小。基本型建筑设计利用热电联产系统以提高整体效率，然而Passivhaus设计的节能效率足够高以至并不需要使用热电联产系统。所有空调空间的通风使用效率最小为85%的高性能通风组件。采用变频驱动器（COP为 5.76）的高效磁轴承压缩机代替使用原有的低效吸收的冷却水机组（性能（COP系数）为0.75）。因为减少了空间内的热损失，公寓的通风机盘管能够提供足够的热量即使只提供温度为105°F（40.56℃）的温水并且循环回收的热水温度有95°F（35.0℃）。在这个低温度下，冷凝锅炉可以以94.5%的最佳效率运行，而一般基本型建筑物它的运行效率为85%。

通风中的能量回收使用是Passivhaus设计的关键点。基本型建筑的塔楼部分在立面上使用百叶窗给公寓里的风扇盘管机组提供外部空气。公寓的通风盘管机组不能循环使用能量。Passivhaus安装在屋顶的标准能量回收单元改变了原有效率低下的通风系统，并且每个单元可以同时服务多个公寓。每间公寓只需要少量的管道井空间用来安装通风管道。公共设施，大堂和商业空间使用单独的ERV单元（图10、11）。管道中的喷雾密封剂和恒定气流调节器可以帮助调节通风系统的平衡。恒定气流调节器还可以防止烟囱效应破坏气流流动。

分析

PHPP分析展示了一种成功的Passivhaus设计（图12）。总的一次能源节约是符合Passivhaus标准的总体预期。由于基本型设计和纽约市气候的具体性质，相比于基本型建筑，Passivhaus设计造成的能量削减在加热中比冷却更显著。所以其它具备不同机械设备或生长于不同气候环境的建筑物，可能对加热和冷却的能量减少比例要求是不同的。

建造

在建造一个类似于上述期望设计的Passivhaus建筑的主要挑战是，达到气密性要求所需的做工质量。而在基本型建筑和Passivhaus设计中应用了同样的施工技术，工作人员的专注和行业间的协调性是成功安装空气阻隔层中的关键。该研究提出通过利用美国空气阻隔协会（ABAA）的质量程序，专业认证和审计程序来增加空气阻隔层的审查，以确保正确的设计，安装和测试。 ABAA建议包括使用第三方空气阻隔层顾问，和气密层施工图纸等措施。鼓风机门测试是必要的，用于控制质量和证明的性能。该研究认为用于空气阻隔层的监测、修复和其它Passivhaus措施需要额外的施工时间。

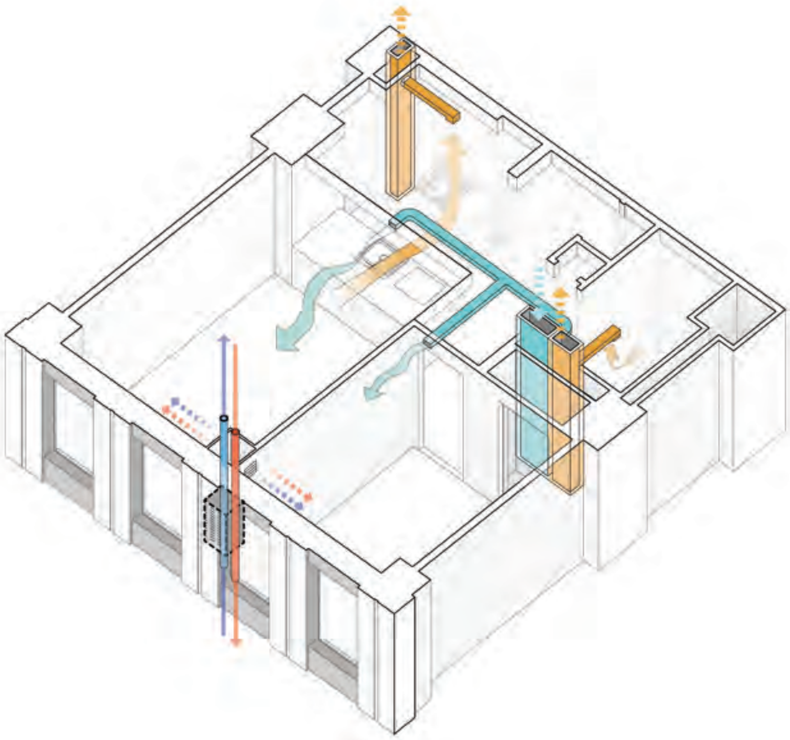

Figure 10. Apartment HVAC diagram (Source: FXFOWLE)
图10. 公寓暖通空调（HVAC)分析（来源：FXFOWLE）

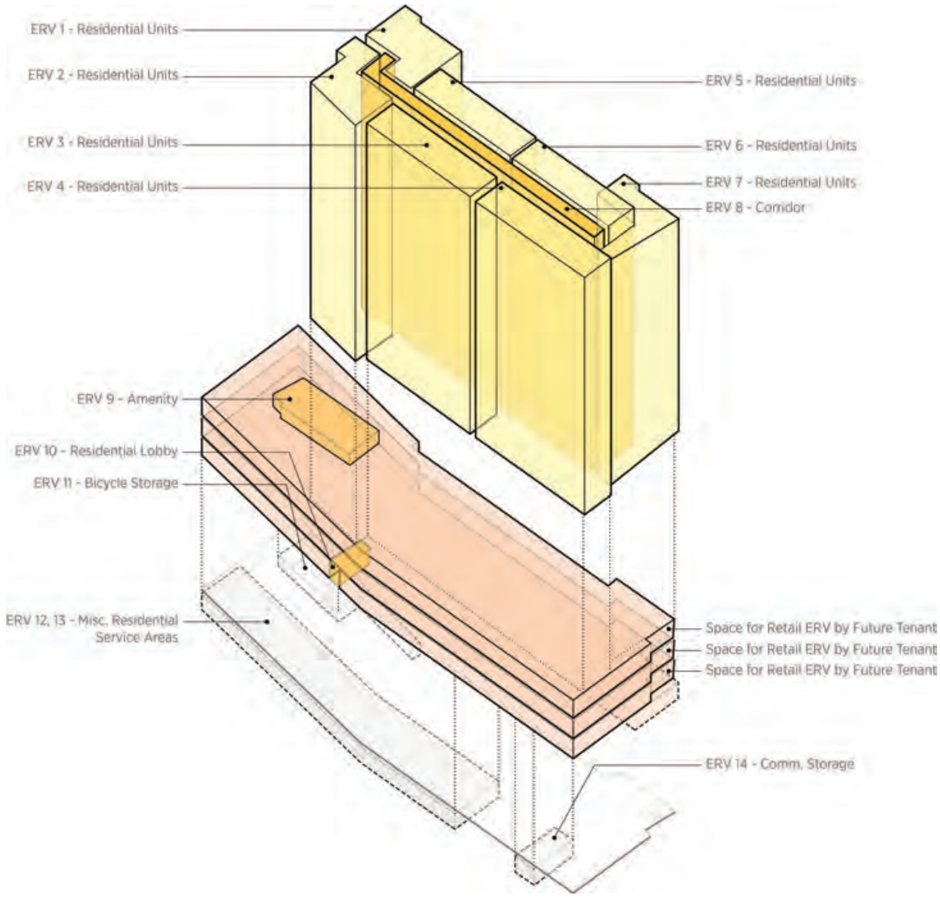

Figure 11. Ventilation zone diagram (Source: FXFOWLE)
图11. 通风区分析（来源：FXFOWLE）

Analysis

PHPP analysis shows a successful Passivhaus design (Figure 12). The total primary energy savings is in line with general expectations of the Passivhaus standard. Compared to the base-case building, the Passivhaus design resulted in greater energy reductions in heating than in cooling due to the specific nature of the base-case design and the NYC climate. It is likely that buildings with different mechanical systems or buildings in other climates will require different proportions of heating and cooling energy reductions.

Construction:
The main challenge in constructing a Passivhaus building similar to the proposed design is expected to be the quality of workmanship required to achieve airtightness requirements. While the same construction techniques are used in the base-case and Passivhaus design, attentiveness of the workforce and coordination between trades is crucial to the successful installation of the air barrier. The study proposes increased scrutiny of the air barrier through the use of the Air Barrier Association of America (ABAA) quality procedures, accredited professionals and auditing procedures to ensure proper design, installation and testing. ABAA recommendations include utilizing a third party air barrier consultant and air barrier shop drawings, among other measures. Blower door testing is necessary to control quality and to prove performance. The study assumes additional time for construction for air barrier testing, repair, and other Passivhaus measures.

Resilience:
The Passivhaus design will improve overall building resilience. Increased insulation, thermally broken triple-pane windows and significantly improved air-tightness will enable buildings to remain comfortable during a power outage for a longer period of time than typical construction. A study was recently undertaken after Hurricane Sandy caused power outages and unsafe building conditions in NYC. The study concluded that an extended power outage in summer or winter would cause typical high-rise apartment buildings to reach unsafe temperatures in one to three days while high-performance buildings similar to the proposed Passivhaus design would remain habitable for a week or more (Urban Green, 2014). Passivhaus strategies such as operable windows, increased insulation, improved air tightness, and other upgrades help control passive heat gain in power outages.

Financial Analysis:
A cost analysis was performed by Dharam Consulting to compare the base-case building and Passivhaus design. Specific energy conservation measures were identified and costs for those items were assigned for both the base-case and Passivhaus design options. This side by side comparison enabled a clear cost analysis. The Passivhaus design was found to increase capital cost by less than 5%. Generally, additional costs for the building envelope were counterbalanced by savings for MEP systems. The largest cost increase was for the Passivhaus Certified windows. It should be noted that very expensive windows were selected to test their cost, and that less expensive, non-Passivhaus Certified, slightly lower performing windows can also be used to achieve Passivhaus.

Conclusion

The findings of this study suggest that high-rise residential buildings in NYC can be designed to very high Passivhaus levels of energy efficiency and resilience. Passivhaus is applicable to the high-rise residential building typology and NYC climate. Technical challenges can be overcome with little aesthetic compromise and good glazing ratios. This approach is also shown to be financially viable with minimal up-charges and reasonable pay-back periods.

A number of challenges confront the implementation of Passivhaus in NYC and globally. As the standard was developed in central Europe, local issues must be addressed for widespread application around the world. Varying climatic conditions, construction practices, labor quality, product availability, codes, use patterns and other nuances are important factors that must be integrated into strategies for high performance buildings.

弹性
该Passivhaus设计将提高建筑物整体弹性和复原能力。相比于基本型，被动式节能建筑增加保温，热破三窗格窗口和显著提高气密性将使建筑室内空间在停电时更长时间的保持舒适。在纽约Sandy飓风造成断电和不安全建筑隐患之后，一项新的研究已于最近完成。该研究认为，在夏季或冬季长时间断电会造成普通的高层公寓楼在一至三天中达到不安全的温度，而类似于上述Passivhaus设计的高性能建筑将维持适宜居住一周以上（Urban Green, 2014）。Passivhaus战略，如可操作的窗户、增加保温、提高气密性，及其它措施都有助于在断电时控制被动产生的热量。

财务分析
Dharam咨询对基本型建筑和被动式节能节能建筑进行了成本分析。具体的节能措施被逐个确认，其成本根据基本型和Passivhaus的设计方案进行计算。这种并排比较使得成本分析一目了然。Passivhaus的设计增加总资金成本不超过于5%。一般来说，建筑围护结构的附加成本可以在MEP设备节约的成本中得到平衡。造成最大的成本增加的是Passivhaus认证窗户。但应当指出的是，在测试中应用的非常昂贵的窗户来测试成本，但是其它相对更便宜，非Passivhaus认证，略低成效的窗户也可以被应用且可以达到Passivhaus标准 。

结论

研究结果表明，纽约市高层住宅可设计达到能源效率和弹性都非常高的Passivhaus水平。 Passivhaus可适用于高层住宅建筑类型和纽约市的气候。技术上的挑战是可以攻克的，并且可以保证较好的外观和良好的窗墙比。这种方法也体现出财务上的可行性，包括最小的额外成本以及合理的投资回收期。

PHPP Modeling Comparison

	Passivhaus Requirement	Passivhaus Design PHPP	Fulfilled?	Savings Over Base-Case	Base-Case PHPP
Heating Demand	4.75 kBtu/(ft2yr)	3.56 kBtu/(ft2yr)	Yes	80%	17.88 kBtu/(ft2yr)
Heating Load	3.17 Btu/(ft2hr)	2.64 Btu/(ft2hr)	Yes	75%	10.76 Btu/(ft2hr)
Cooling Demand	5.39 kBtu/(ft2yr)	3.71 kBtu/(ft2yr)	Yes	50%	7.38 kBtu/(ft2yr)
Cooling Load	3.17 Btu/(ft2hr)	2.40 Btu/(ft2hr)	Yes	41%	4.10 Btu/(ft2hr)
Primary Energy*	38.0 kBtu/(ft2yr)	36.6 kBtu/(ft2yr)	Yes	70%	120.20 kBtu/(ft2yr)
Airtightness**	0.036 cfm/ft2@50Pa	0.036 cfm/ft2@50Pa	Yes	86%	0.263 cfm/ft2@50Pa
Passivhaus?			Yes		

*Primary energy includes heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, and electrical applicances.
**Pressurization test result n50

Figure 12. PHPP Results (Source: FXFOWLE)
图12. PHPP 结果（来源：FXFOWLE）

This study shows how Passivhaus can be implemented in NYC for one building typology in NYC. Similar studies and pilot projects are needed around the world to prove that this approach is globally viable. Many such projects are already under way.

Passivhaus represents a breakthrough in energy efficient building design that offers a big opportunity for megacities to become more sustainable, healthier places. European cities are already starting to include Passivhaus in building codes. As Passivhaus is proven to be feasible globally, municipalities around the world can also consider this highly energy efficient and resilient approach.

Passivhaus在纽约市和全球的实施面临着许多挑战。由于该标准是在欧洲中部开发出来，随着它在世界各地广泛应用，地方性问题必须得以解决决。不同的气候条件，施工方式，劳动力质量，产品的可达性，建筑规范，使用模式等细微之处都是必须结合到高性能建筑策略的重要因素。这项研究显示了Passivhaus可以应用于纽约市某一种特定的建筑类型。类似的研究和试点项目需要在世界各地进行，以证明这种方法是可行的全球通用的。很多这样的项目已经在进行中。

Passivhaus代表了节能建筑设计上的突破，它提供了一个机会，使特大城市变得更加可持续，更舒适。欧洲的很多城市已经开始将Passivhaus写入建筑规范。只要Passivhaus在全球范围内被证明是可行的，世界各地的市政当局都可以考虑这种更节能且具备弹性的建筑方式。

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