High-Rise Testing of Drainage Systems on Two of the World's Tallest Test Towers | 在世界上2座最高的测试塔测试高层排水系统

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Abstract | 摘要

The drainage systems in tall buildings are being subjected to greater loadings. The effect of negative and positive transients is, therefore, becoming a larger issue. The vents to the atmosphere are further away, and the increased communication time for the pressure regime within the pipe leads to the system pressure exceeding +-400Pa, with the loss of water trap seals. National codes do not provide sufficient information to engineers, due to many of the codes being based on steady state flows versus the real inherently unsteady state discharges that occur. This paper presents findings of physical testing carried out on two testing towers located in the UK and China. The testing subjects both systems to unsteady discharges to determine the maximum loadings for both 100mm and 150mm sized pipe systems, with the key criteria being that all the traps seals are maintained.

Keywords: Active Drainage Ventilation, Drainage Ventilation, National Codes, Unsteady State Discharges, and Water Trap Seals

高层建筑的排水系统负载越来越严重。负压与正压瞬变的影响愈来愈大，伸顶通气管伸展加长，使系统内空气传送时间加长，导致系统内气压超过+−400pa和水封破坏。 各个国家的排水标准不能提供明确的信息给工程师应用，是基于稳定流速计算,与现实中非稳定器具排水流有很大差别。 本文演示的研究结果是分别在英国和中国实验塔进行采集，测试100,150mm排水系统在不稳定的情况下可以达到的最高负荷度'同时水封不受到破坏. 测试目的是为国家标准更新提供可靠根据.。

关键词：主动排水通气、排水通气、国家标准、非稳定流排水、水封

Introduction

Tall buildings are using 21st century, cutting-edge research and design tools in their architecture, structural design, and buildings services, but there is one service that is still way behind the other disciplines. The above ground drainage system remains fundamentally based on late 19th and early 20th century calc¬ulations and practices used in many national building codes today.

Research and product innovations have only been developed in the late 20th and early 21st century that meet the demands of modern high-rise buildings in above ground drainage. The conservative nature of the discipline and the reliance on national codes as being fit for purpose sometimes leads engineers to disregard the research findings, and can inhibit the use of innovative products that will ensure that drainage systems will function correctly.

One of the key requirements of above ground drainage is to protect the occupants of the building from the drainage in the pipework, which is achieved by water trap seals. These seals can be lost when the system pressure exceeds +- 400Pa.

介绍

高层建筑在建筑工程、结构设计以及建筑服务方面，均已采用21世纪最新的研究和设计工具，但有一项服务标准却远远落后于其他方面。那就是建筑的地上排水系统，如今许多国家建筑标准在这一领域依然普遍采用19世纪末20世纪初时的计算和操作手法。

关于地上排水系统的研究和产品创新，一直到20世纪末和21世纪初时才取得进步，能够满足现代高层建筑的设计需求。由于行业标准的老旧，以及对于国家标准适用性的依赖，有时工程师会忽略最新的研究发现，从而妨碍能够保证排水系统正常运行的创新产品的应用和实施。

地上排水系统设计的一个关键要求，就是要在管道工程的设计上让大楼的使用者不受排水系统的影响，这主要依靠存水弯水封来完成。当管道系统内的压力超过+−400Pa的时候，这些水封就会脱落。

为了保护这些水封，传统的方法是使用通气管网；在学术界，这被称作"被动式通气"。现代研究发现，现有国家标准对高层建筑中使用被动式通气的要求，在许多情况下是无法起到应有作用的，主要原因有三个方面：1）通气管直径过小；2）高

To protect the traps, traditional methodology is to use a vent pipe network; in the academic world, this is known as "passive venting." Modern research has found that the principles of venting requirements for tall buildings located within many national codes using passive venting will fail for three main reasons a) the vent pipe diameters are too small, b) in tall buildings the transient communication time is too long, and c) that the loading criteria is based on steady state calculations.

To meet the demands of water trap seal protection in tall buildings, Active Drainage Ventilation has been developed that uses Air Admittance Valves (AAV's) and Positive Air Pressure Attenuators (PAPA™). The active system negates the requirement for the vent pipes and reduces the communication time and transient pressure within the system, and that active ventilation has been researched on the actual unsteady state discharges of a drainage system. Active ventilation has approvals in some codes and the components of the system have recognized product approvals.

- Australia: AS/NZS3500, AS/NZS4936, ATS5200.463, ATS5200.483
- Europe: EN12056-2, EN12380
- USA: ASSE1030, ASSE1049, ASSE1050, ASSE1051
- Australian WaterMark: WM-20006, WM-22085, WM-22122, WM-22193, WM-22415
- European CE marking to: EN12380
- European KEYMARK: 011-7B002, 011-7B003, 011-7B005, 011-7B008, 011-7B009, 011-7B010
- UK: BBA Technical Approval 89/2139, 15/5225

Active ventilation has been installed on hundreds of towers around the world since it came into the market in 2004: first in problem solving existing buildings, and then as a specified solution in new buildings. The full system was installed at the Trump Ocean Club – the tallest and largest building in Latin America which overlooks the Pacific from Panama City. The tower houses 650 residential units and bay lofts, 369 five-star hotel rooms and suites, together with office lofts and a state-of-the-art business center. Arranged over 70 floors, the building is a total of 284 meters in height. More recently, it was installed in Abu Dhabi's Nation Towers – a world-class development comprising high-rise, residential apartments and penthouses; first class office spaces; the Nation Galleria (a chic, boutique-style mall); and the deluxe St. Regis Hotel. From a tapering podium base, the two towers, constructed from steel and glass,

层建筑中瞬时通信时间过长；3）负荷标准是基于稳态计算的。

为了满足高层建筑中保护存水弯水封的要求，研究人员通过采用“吸气阀”（Air Admittance Valves）和“正压衰减器”（Positive Air Pressure Attenuators，PAPA™），创造出了“排水系统主动通风技术”（Active Drainage Ventilation）。主动通风系统取消了对通气管道的要求，并缩短了系统内的瞬时通信时间，同时降低了瞬时压力，并且主动通风系统是在排水系统真实的不稳定状态下进行研究和计算的。主动通风系统在一些技术标准中得到了认可，而系统中所使用的配件全部都有相应的技术认证。

- 澳大利亚： AS/NZS3500，AS/NZS4936，ATS5200.463，ATS5200.483
- 欧洲：EN12056-2，EN12380
- 美国：ASSE1030，ASSE1049，ASSE1050，ASSE1051
- 澳大利亚排水认证标志：WM-20006，WM-22085，WM-22122，WM-22193，WM-22415
- 欧盟CE标志：EN12380
- 欧盟KEYMARK认证：011-7B002，011-7B003，011-7B005，011-7B008，
- 011-7B009，011-7B010
- 英国：BBA Technical Approval 89/2139，15/5225

自2004年面市以来，主动通风技术已经被应用在全世界成百上千的高楼大厦之中：一开始用来解决现有建筑中存在的问题，后来作为定制解决方案被新建筑采用。特朗普海洋俱乐部（Trump Ocean Club）大厦也安装了全套系统，这座拉丁美洲最大、最高的建筑位于巴拿马城，可以俯瞰太平洋美景。该大厦拥有650套住宅和湾景阁楼、369间五星级酒店客房和套间，以及写字楼和最现代的商业中心。建筑总高284米，楼层超过70层。前不久，阿布扎比的国家塔（Nation Tower）广场也采用了这套系统，这座世界级的大型建筑综合体包括摩天公寓和阁楼、一级写字楼、国家广场时尚精品购物中心以及奢华的喜达屋酒店。在锥形的墩座基础之上，两座钢架玻璃塔楼直冲天际。1号塔楼高64层，2号塔楼高51层。每幢建筑都配备了各自的奢华设施，和其他许多建筑一样，这两座塔楼在研究和模拟的基础上，为主动通风技术可以有效运转提供了实证。

使用AIRNET模拟活性气压瞬变控制

赫瑞瓦特大学（Heriot-Watt University）的研究小组，通过在一座50层高的大楼中使用AIRNET进行了一系列研究，你会发现研究所取得的成果十分出人意料（如图1和图2所示），特别是在考虑到该分析中的传统系统在高层建筑排水设计中十分普遍这一点之后。

存水弯C在第8秒时产生虹吸，此时系统内的流量大约为4.5l/s。这一模拟表明尽管排水系统设计已经采用了100mm直径的排气竖管和100mm直径的通气横管以及150mm直径的低湿度立管，建筑最低端的水封依然在瞬时负压的情况下被冲开。

图3和图4显示在同一座50层的建筑中，在一半的水力负荷即6.5l/s的条件下，使用AIRNET进行瞬时正压模拟的情况。模拟结果显示，存水弯C在瞬时正压的作用下水封也被冲开。这一结果表明设计中采用的100mm排气管，其直径不足以将320m/s流速时的瞬时正压疏散，以保护系统中的存水弯水封，而如今在设计中普遍采用这种直径的排气管。

当50层的建筑被设计成一套主动控制系统时，可以认为整个系统都为水封提供了保护（如图5、图6所示）。通过在整个系统中采用AAV和PAPA，AIRNET提供的模拟结果显示，无论在正压还是负压状态下，系统中的所有水封都得到了有效保护。正是由于同时使用了AAV和PAPA，系统压力被控制在-110Pa以下，因此，系统中的水封不会受到破坏性的+-400Pa的压力冲击，从而得到保护。

相关的研究说明了两大要点：第一，传统的高层建筑设计会受到瞬时正压和瞬时负压的影响；第二，通过和业界合作，可以为高层建筑的排水和通风系统提供安全和切实可行的设计方案。

试验塔

既满足特定的高度要求，又能反映出世界各地目前高层建筑的各个类型，并能达到测试的目的，这样的场地想要找到并不容易。要么是在建筑寿命即将结束的建筑上（例如赫瑞瓦特大学在邓迪市一座17层建筑上所做的实验）或即将新建的大楼（例如大冢制药（Otsuka）2010年在一座34层高的摩天大楼上所做的实验）进行测试，要么是利用现有的建筑（通过实际的实验流程，而不是模拟估算，例如2009年Wong and Mui在香港一座居民大楼上所做的实验）。Fernandes 和Goncalves在2006年就巴西国家标准中AAV应用的相关规定，对学生校园建筑的实施情况展开了调查，但在很多情况下，测试往往是由大学在自己的研究场地和设施中进行

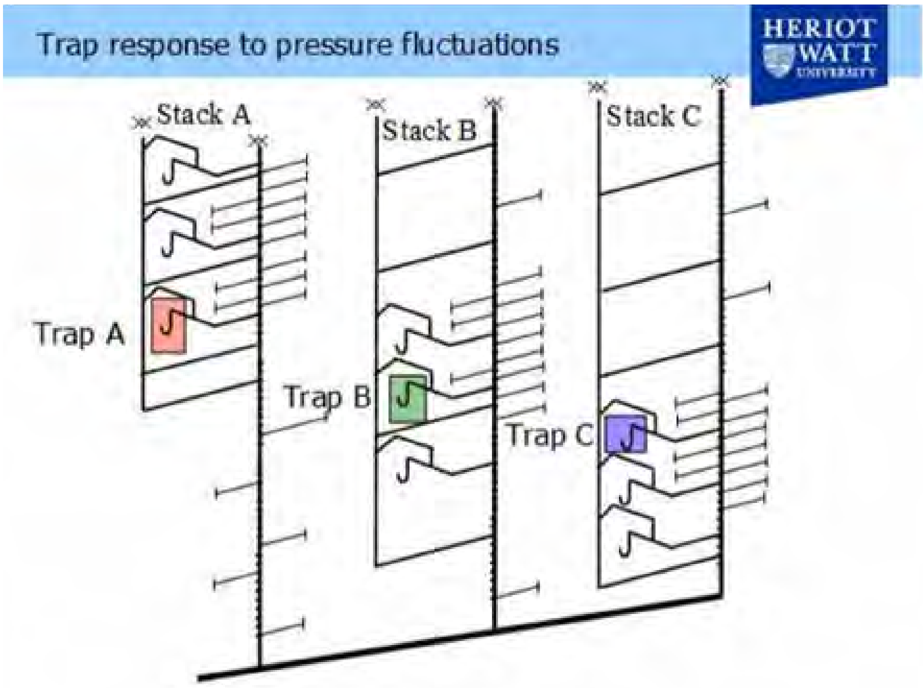

Figure 1. A 50-story building with 150mm wet stacks and a 100mm vent pipe network (Source: Studor)
图1. 50层，150mm排水管，100mm通气管（来源：思都得）

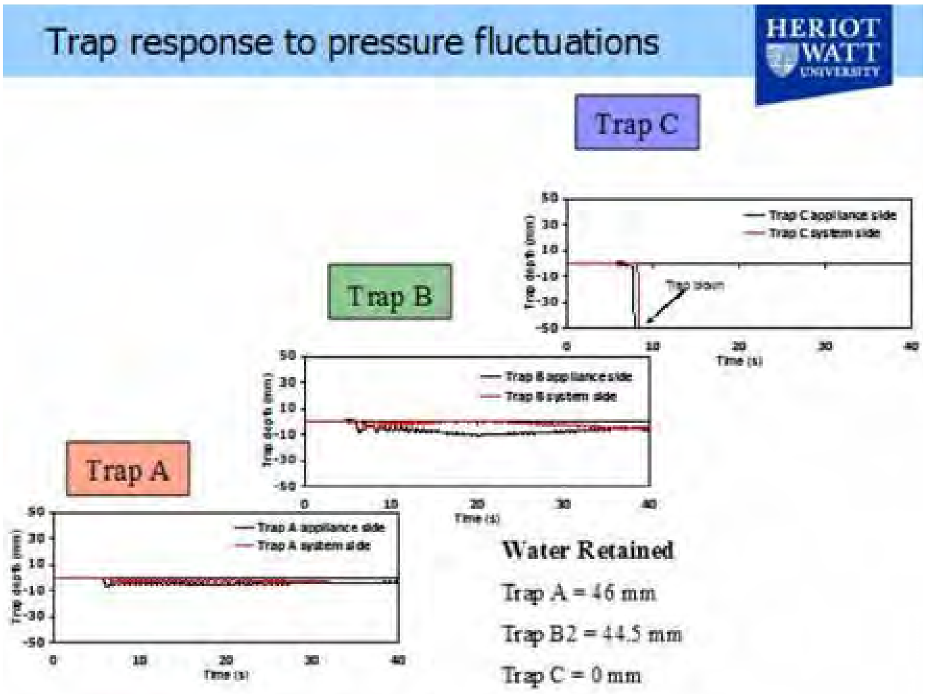

Figure 2. Results of the trap seals when subjected to a discharge of 12.4l/s over a 35-second period (Source: Studor)
图2. 水封承受水流12.4l/s 超过35s（来源：思都得）

extend skywards. Tower 1 is made up of 64 stories and Tower 2 features 51 stories. Each offering its own blend of luxurious facilities, these and many other towers were approved on the bases of the research and simulations undertaken to prove active ventilation works.

Simulated Active Air Pressure Transient Control using AIRNET

Research carried out by the drainage research group of Heriot-Watt University, using AIRNET for a 50-story building, produced some surprising results (illustrated in Figures 1 and 2), especially considering that the conventional system analyzed is quite typical of high-rise drainage designs.

Trap C has siphoned at eight seconds, at which point the system has approximately 4.5l/s. This simulation has demonstrated that although the drainage system design is fully vented with a 100mm relief vent pipe and 100mm cross vents with a 150mm wet stack, the trap seal at the lowest point of the building is subjected to negative transients that have depleted the trap.

的。例如大家制药（2012）在关东大学（Kanto Gakuin University）高层模拟建筑、Cheng（2008）、NTUST 13号试验塔以及Sakaue（2014)中提到的108米的URA实验塔上所做的一系列测试。

2012年，在爱丁堡的学术研讨会上，CIBW062被推荐给中国的一座试验塔，该建筑位于中国广东省东莞市，实验由国家住宅与居住环境工程技术研究中心和万科建筑研究中心共同主持完成（图7）。

2013年和2014年，Z Zhang（2013/2014）和 L Zhang（2013/2014)向CIBW062提交了两篇论文，主要探讨关于排水立管中的瞬时水流问题。2015年，这座试验塔上还进行了活性排水测试，旨在为中国的排水专家提供数据，以评估现有建筑标准中的排水系统相关规定。

在欧洲，最高的试验塔为10层，而英国建筑研究院使用的是一个5层高的试验塔。伦敦未来五年将要建造超过230座从20层到80层甚至更高的摩天大楼，每平方英尺的平均建筑成本为472美元，为了满足这一新的建筑需求，大型建筑公司都在想方设法为增加大楼内的可售空间找到最佳的解决方案。

活性排水通风系统成为大型建筑上取代传统管道设计方法的替代方案。这一新的技术能为他们节省更多的管道空间。除了这个梦寐以求的优点以外，新的系统还能尽可能限制排水和通气立管穿透建筑房顶，这也是建筑设计师一直所要实现的一点。然而，尽管最新的研究和项目都表明活性排水通风系统是高层建筑最佳的技术解决方案，想把传统的排气管道设计和施工方法剔除出行业准则，使用新技术代替传统方法，依然面对着重重阻力，即使传统设计在保证高层建筑排水系统正常运转方面存在着很大风险。

Principle Place是伦敦一座50层的摩天大厦，在与其承建方的一次讨论中，他们要求证明活性排水通风系统的实际效果。唯一的解决方案就是在欧洲找到一座合适的场所来为这一新技术提供支撑。用来测试系统性能的试验塔National Lift Tower位于北安普顿（图8）。塔高128米，塔基宽14.6米，塔身逐渐变细，塔尖处宽度为8.5米。

测试目的

鉴于现在已有海量的关于瞬间正压和瞬间负压以及PAPA™ 和AAV的研究成果发表，本次实验的目的是为了测试现实中的数据和状态是否与第二章中研究结果相互一致。

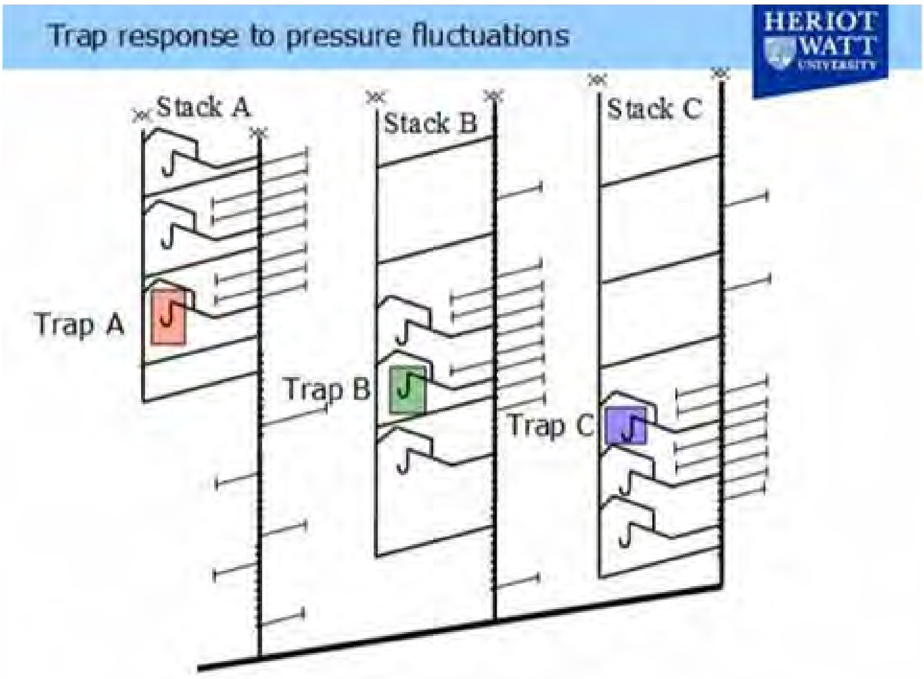

Figure 3. A 50-story building with 150mm wet stacks and a 100mm vent pipe network (Source: Studor)
图3. 50层，150mm排水管，100mm通气管（来源：思都得）

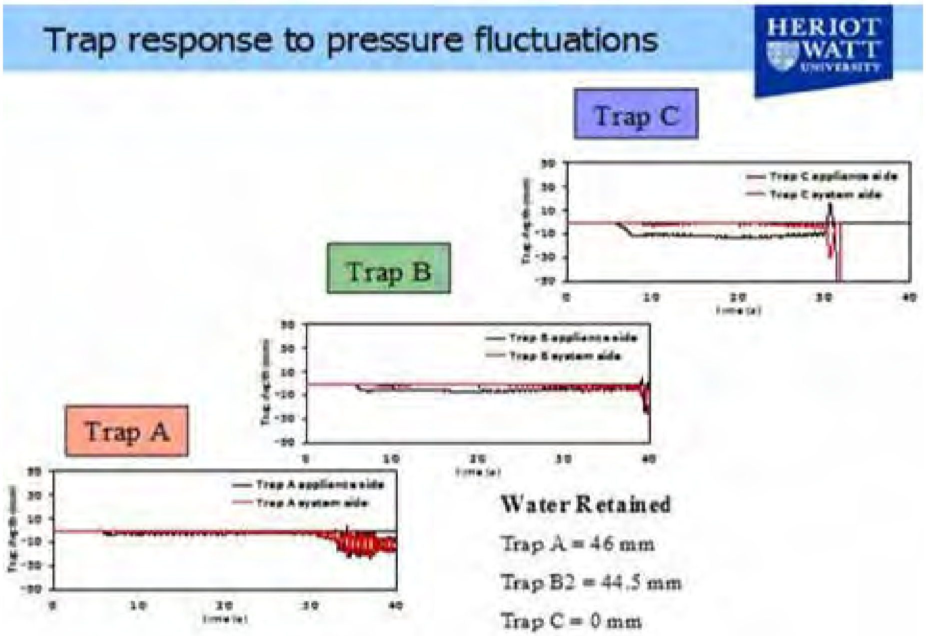

Figure 4. Results of the trap seals when subjected to a discharge of6.5l/s over a 35 sec. period and a surcharge placed downstream after a 30 sec. period with the load at that point of 3.5l/s (Source: Studor)
图4. 排水6.5l/s，35s，下游排水3.5l/s，30s后（来源：思都得）

Figures 3 and 4 show the results when the same 50-story building is simulated by AIRNET for positive transients with half a hydraulic loading of 6.5l/s. It can be seen by the simulation results that trap C has depleted due to positive transients. This indicates that the 100mm relief vent which is in the design – and is commonly used – is insufficient in diameter to divert the positive transient that is moving at 320m/s away from the trap seals in the system.

When the 50-story building is designed as an active controlled system, it can be seen that protection is provided throughout the system (as illustrated in Figures 5 and 6). By using AAVs and PAPA placed throughout the system, the

- 对比符合国家标准的传统排水通风系统与活性排水通风解决方案

- 在极端的负荷和使用场景下对排水系统进行检验，并在系统内加入污水，这是正常高层建筑通常都会存在的状况，通过观测现实建筑中的真实状况，以对比不稳定排放状态以及稳定排放状态的相关数据。

- 主要关注排放到系统的过程中和排放到系统之后两个时间段存水弯水封的保存状况，这也是建筑排水通风系统的主要目标（以保证存水弯中隔离物的存在）。

- 将WC作为主要排放通道，以密切关注系统中的动态排放数据。

中国实验测试塔

由Studor™和中国建筑设计研究院（国家级工程技术研究中心）人居环境设计研究所签订协议，在这一试验塔上进行了相关测试。

试验塔塔基设置如图9所示。全部楼层都安装了存水弯水封，AAVs 和 PAPA™也全部配置了闸阀，这样在实验的各个阶段就可以按照要求打开和关闭。

测试流程的设置主要是为了证实提交给中国排水专家的活性排水通风系统数据是有效的，并使系统获准进入中国建筑的相关标准。

根据实验设置，系统的不同区域都将承受高频率排放，以检测在高负荷状态下通风系统对于水封的保护效果，同时在系统中排入厕纸、湿纸巾、卫生纸以及固体物来检测这些污水对系统的影响。

中国试验塔测试结果

系统描述
对系统的两次实验性测试使用DN110单立管，这种传统单立管系统由开放式排气管直接对外排气，每个分支都安装有AAV，每三层安装了一组PAPA™，立管顶部安装了Maxi-Vent™。

测试：在30-33F进行排放（christen 6l），每层有一个单元。测试时同时有两个和四个单元进行排放，以分析系统中的压力反应。

结果：在同样的测试条件设置下，活性排水通风系统中的负压要明显小于传统单排立管系统中的负压。在没有安装AAV的系统中当四个单元同时排放时表现尤为明显，系统负压超过-1100Pa，同时存水弯水封被破坏。安装了AAV的系统，负压回落至-310Pa，符合国家标准规定的-400Pa以内的限制。在两个单元同时排放的测试中，传统单立管系统中的压力超过-400Pa，并有部分水封被破坏；但是如果加装了AAV，系统压力降低到了-150Pa，水封也得到有效保护。

英国实验性测试塔

128米高的National Lift Test Tower被证明是测试、演示高层建筑排水系统运行效果的最佳设施和场所。这里的场地和设施

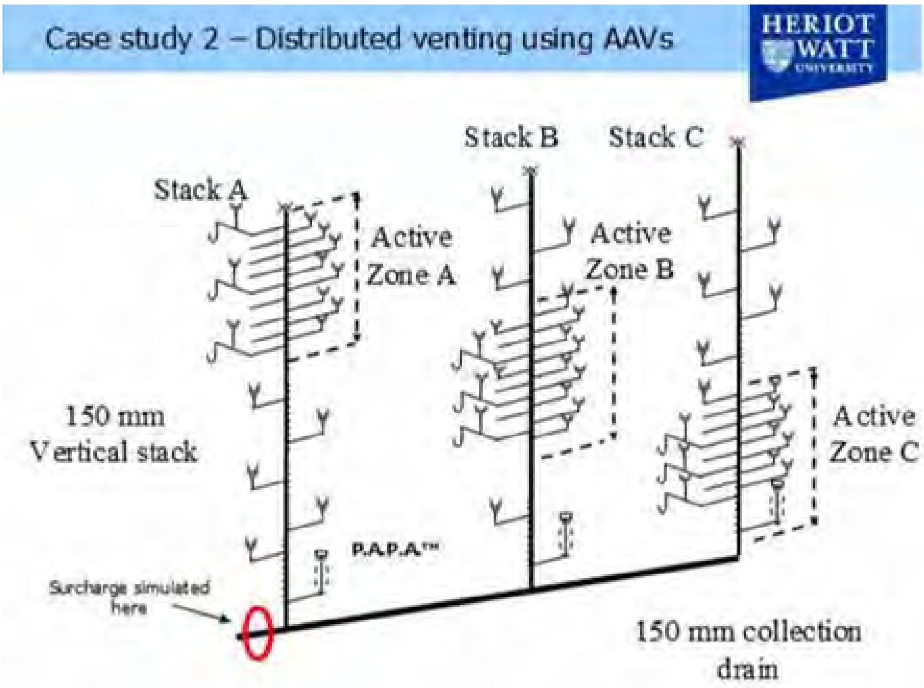

Figure 5. Results of the trap seals when subjected to a discharge of 6.5l/s over a 35-second period, and with a surcharge placed downstream after a 30-second period with a load, at that point, of 3.5l/s (Source: Studor)
图5. 50层，150mm立管,6.5l/s水流,使用吸气阀与正压缓减器（来源：思都得）

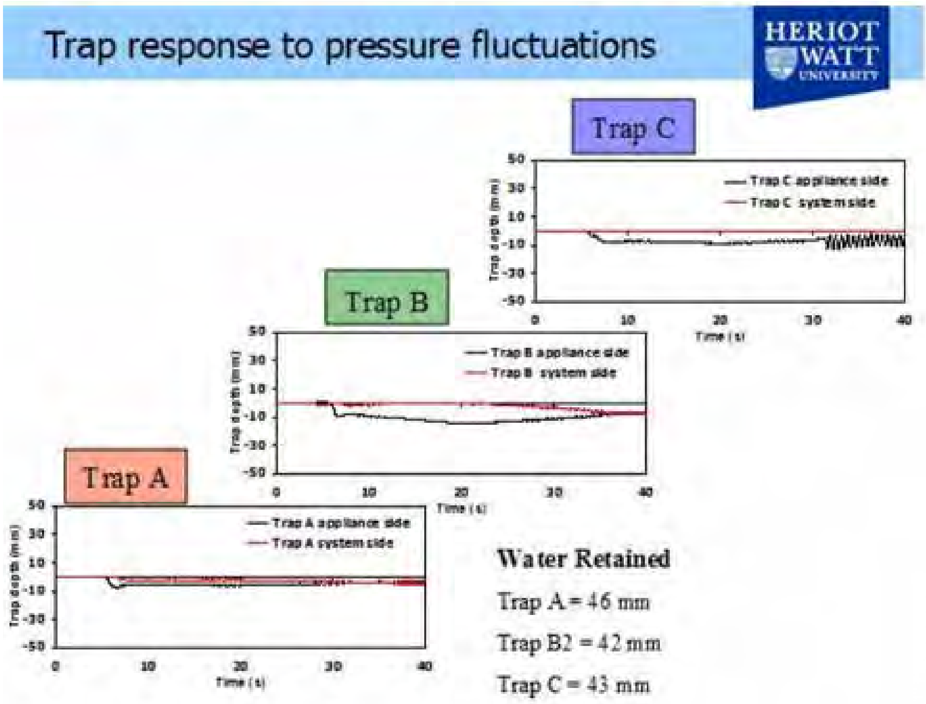

Figure 6. Results of the trap seals when subjected to a discharge of 12.4l/s over a 35-second period (Source: Studor)
图6. 水封承受水流12.4l/s 超过35s（来源：思都得）

simulation results provided by AIRNET show the provision of the trap seals throughout the system with protection from negative and positive pressures. It is the act of using AAV's and PAPA together that keeps the system pressure below -110Pa, and thus, the trap seals within the system are not subjected to the harmful pressures of over +- 400Pa.

The involvement of research has demonstrated two major factors: firstly, that high-rise buildings designed conventionally can be affected by negative and positive transients; and secondly, that working with the industry, there is a safe and practical solution to designing a high-rise building drainage and vent system.

Test Towers

Finding suitable facilities of a certain height that reflect the types of high-rise construction occurring around the world is limited, in terms of testing purposes. It is done either through testing on buildings at the end of their life (as Heriot Watt University undertook at the 17-floor building in Dundee) or new construction (as

极为便捷，健康安全要求很少，并且由于是开放性场地，整个系统的运行过程都十分便于观察。

系统的设计是基于英国BS EN 12056-2的标准规定和流程来完成的。FUZE HDPE 110mm 立管和FUZE HDPE 56mm 排气管道是由Polypipe® Terrain提供的。在英国，商业高层建筑中更倾向于采用HDPE材质的管道材料。

受测试的排水系统高84米，底部四层排放至主下水系统，其中一层和二层的办公室厨房（一1个下水槽）和卫生间（2个厕所下水和1个脸盆下水）并不在本次测试的观测范围内。

测试的安装部分包含一个从一层到二层的短立管，其中有1个WC，2个40mm P型存水弯，以及一个瓶式存水弯。 管道连接在主立管底部下水方向3.5米处的水平管上。主立管底部的水平管延伸5米后以90度弯向下与建筑的初始下水管网相连接，并承担办一楼二楼公室厨房和洗手间的排水任务。

每个测试的楼层平面都安装了1个5L的WC，2个40mm P型存水弯和1个75mm瓶式存水弯。如图10所示，这些配件被安装在4楼、6楼、12楼、16楼、19楼、21楼、25楼、29楼和38楼。每个测试楼层都安装了带闸阀的AAV，这样在需要的时候可以将选中的楼层与主管道系统隔离开来。2套PAPAs™被有序安装在测试楼层第二层的主立管上。单个PAPA™被安装在测试楼层的7楼、11楼、20楼、24楼和30楼，同样也配备了闸阀，需要时可以与主管道系统隔离。56mm排气管被横向连接安装在1楼、5楼、10楼、14楼、20楼、24楼、30楼上，所有楼层也都配备了闸阀，需要时可以与主管道系统隔离。

每个有WC的楼层都有压力计与立管相连接，每次测试前所有存水弯都会重新存水。试验中使用视频记录测试楼层的压力表读数，并监控立管底部及存水弯水封的状态。测试中使用了Dyteqta® Pressure TEQ™（一种数据和分析系统，采用了Sensor Technics CTEM7NO23G7压力传感器）来记录测试楼层和16层的压力读数。

在立管的底部和中部安装了透明的管道，这样可以观察并记录管道内部的水流状况。一些PAPAs™被打开，以便在排放时可以观察到内部的情况。

系统测试对比了活性排水通风系统与封闭的排气管网之间的差别。在排气管网打开的状态下，又在两者之间做了一次对比测试。

the 34-floor high-rise tower by Otsuka (2010)), or an existing building (on actual rather than assumed flows on a Hong Kong housing tower block by Wong and Mui (2009)). Fernandes and Goncalves (2006) investigated the application of AAV within the Brazilian national codes on the student campus blocks, but in many cases, the testing has been undertaken by the university's own research facilities. For example, Otsuka (2012) on the high-rise simulation tower of Kanto Gakuin University Cheng (2008), the NTUST 13 experimental test tower, and on the 108-meter URA experimental tower mentioned in Sakaue (2014).

In 2012, at the symposium in Edinburgh, CIBW062 was introduced to the Chinese experimental test tower located in Dongguan, Guangdong Province, and operated by the China National Engineering Research Centre for Human Settlements' Vanke Building Research Centre (Figure 7).

In 2013 and 2014, two papers were submitted to CIBW062 focusing on the instantaneous flows in drainage stacks by Z Zhang (2013/2014) and L Zhang (2013/2014). In 2015, active drainage was also being tested on this tower, with the aim to provide data to allow Chinese drainage experts to assess the system for Chinese building codes.

Within Europe, the tallest test tower was 10 floors, and in the UK, at the British Research Establishment, a five-floor rig was used. Due to the new building demands in London, with over 230 high-rise buildings being constructed over the next five years ranging anywhere from 20 floors up to 80 floors or more, and with floor space costing USD$472 to 4720 / ft^2, major building firms are looking for new solutions to maximize sellable space within these buildings.

Active drainage ventilation has been submitted to the major builders to provide them with an alternative system to traditional pipe methods. This will give them the space saving in the ducts that they are seeking, as well as limiting the roof penetrations of the stacks at the top of the building which the architects do not want to see on their designs. Alongside this, despite the research and project references on why active drainage ventilation should be used as the best technical solution for taller buildings, there has still been a resistance to move away from the traditional vent pipe method that is in the building code, and traditional methodology, even through the systems are at risk of failing due to the nature of the high-rise designs.

In one discussion with the builders of Principle Place – a 50-floor project in London – they requested that active drainage ventilation

Figure 7. China Test Tower (Source: Studor)
图7. 中国测试塔（来源：思都得）

be proven to them. The only solution was to find a suitable facility in Europe to back up the research. The tower that was used for testing in Europe is the National Lift Tower in Northampton (Figure 8). It is 128 meters tall, with 14.6 meters at its base, and tapers to 8.5 meters at the top of the building.

Testing Aims

Due to the significant amount of existing research that has already been published over the years on negative and positive transients, and on the PAPA™ and AAVs, testing has been carried out to see if physical testing is in line with the researched findings as in Chapter 2:

- To compare traditional pipe vented systems designed to national codes with the active drainage ventilation solutions;
- To subject the drainage systems to extreme loadings and usage, and to introduce waste into the system that a normal high-rise may be subjected to in everyday usage, keeping to the principle of unsteady state discharges verses steady state discharges, as this is the reality of the system in a real building;
- To focus on the trap seal retention during and after discharging into the system, as this is the main goal of drainage ventilation (to ensure that the barrier is maintained);
- To focus on dynamic discharges by using WC as the principle discharge route into the system.

Figure 8. UK National Lift Tower (Source: Studor)
图8. 英国测试塔（来源：思都得）

英国测试塔实验

测试包含对三种不同类型系统从立管中部和顶部进行的单次和多次冲水以及最后阶段的超载测试，三种系统类型为活性系统、排气管网系统和混合型系统。冲水时使用了净水和固体物的混合物。

多次冲水演示了活性通风系统在配备了AAV和PAPA时的运行状态，AAV和PAPA分别连接到立管排水系统和环形水流管道，同时展示了固体物下行速率以及系统底部固体物的减速情况和水跃的产生状态。整个立管系统不同区域的水压都由4个HZ传感器全程记录。测试还见证了在AAV和PAPA在正压和负压的影响下对水封的保护，以及避免水封破坏的情况。

所有结果在不同区域都被客观验证。WC和P型存水弯中水封的轻微移动都被观察和记录下来，水压也由安装的压力计监测记录。对活性通风系统、传统排气设计和混合系统都进行了高负荷测试，测试包括从立管中部到立管顶端每个部位15秒内冲水24升。据估算这一负载下的排放流量达到3.2L/S，系统底部经受了过载负荷。测试结果如图11所示，测试结论如图12所示。

需要注意的是，低湿度立管的底部压力读数是在入口处PAPA连接之前采集的，所有正压都会有衰减。在之前的测试中，同样读数和结论的测试结果也可根据要求提供。

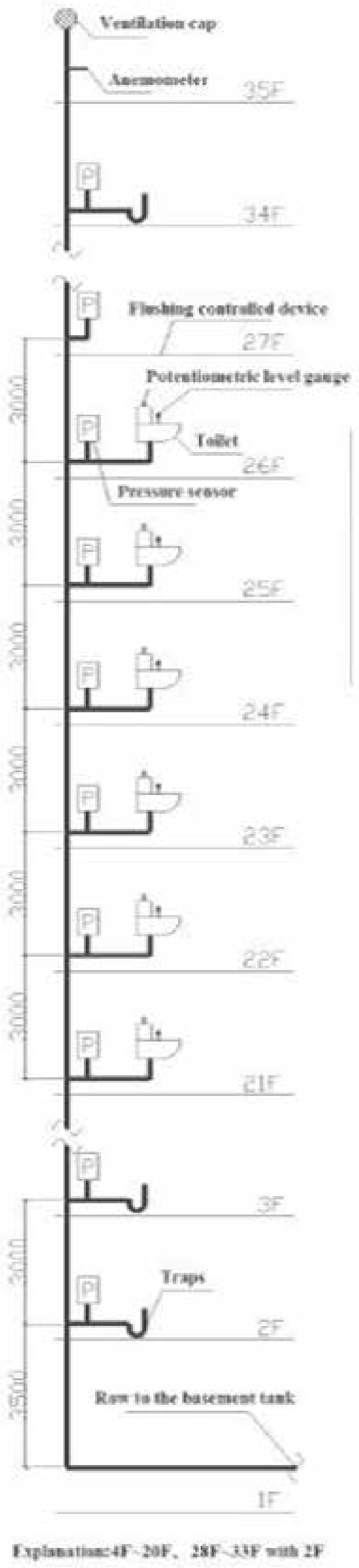

Figure 9. China layout of test system (Source: Studor)
图9. 中国测试塔结构（来源：思都得）

Chinese Experimental Test Tower

The testing on this tower has been undertaken by contract between Studor™ and the China Architecture Design and Research Group (CNERC) for Human Settlement.

The test tower base setup is seen in Figure 9. Water trap seals have been installed throughout the floors, and AAVs and PAPA™ have been installed with gate valves so that they can be switched in and out as required through the testing phases.

The testing procedure being undertaken focuses on proving the active drainage ventilation data to be submitted to the Chinese drainage experts for discussion and approval of the system into China building codes.

The test sets loaded the system to a high rate of discharge at different zones to see how the ventilation solution protects the water traps seals under high loadings, as well as introducing toilet paper, wet wipes, sanitary towels, and solids to see the effect that they would have on the system.

Chinese Experimental Test Tower Results

System Description

Two experimental tests of the systems are using DN110 single stack pipe, a traditional signal stack system with open vent to atmosphere, AAVs installed on each branch, PAPA™ installed every three floors, and Maxi-Vent™ installed at the top of the stack.

Test: Discharged (christen 6l) at 30-33F, as each floor has 1 unit. Tests were carried out with two and four units discharge at the same time to analyze the pressure response.

Result: Under the same test configuration, the maximum negative pressure within the active system was significantly smaller than the maximum negative value of the traditional single-riser system. In particular with the four discharges done without the AAVs, the system exceeded -1100Pa and included the loss of the water trap seal. With the AAVs, the system only went -310Pa and fell within national code limits of -400Pa. In the two discharge tests, the traditional system exceeded -400Pa with the partial loss of the water trap seal; but, with the AAVs engaged, the system pressure reached -150Pa and the trap seal was maintained.

UK Experimental Test Tower

The 128-meter National Lift Test Tower proved to be the ideal facility in which to test, as well as demonstrate, drainage systems in operation on a tall building. It provided ease of access with minimal health safety requirements and, due to the open floors, the whole system was observable when testing was carried out.

The design of the system was based on standard UK principles derived from BS EN 12056-2. Polypipe® Terrain supplied FUZE HDPE

活性通风系统可以根据排水管网中的水流要求来平衡整个系统。尽管正压读数很高，在320m/s的正压速度下最近的PAPA只有7.5米远，反应时间也会在0.02秒之内。正是由于超短的反应时间保证了系统处在安全压力之下。

通风管道系统的压力读数是在第一个排气立管连接后面采集记录的。这显示了有相当大的气压穿过了排气立管，可以毫无阻拦的顺着低湿度立管向上威胁到水封的安全。

混合系统底部和中部的正压测试全都失败了。

讨论和总结

现在已经有足够多的研究来支撑一套国际高层建筑准则的制定，但是有时候建筑行业却不愿意接受新的研究成果，不愿改变自己现有的理念，也不愿确认自己执行的国家标准能够满足世界各地超高层复杂建筑的需求。活性系统已经得到了澳大利亚的AS 3500官方认可，但这一准则是一个高低层建筑通用的普通下水系统设计标准。这套系统可以被用作大楼的工程解决方案，并已经在英国未来即将开发的102个项目中得到应用。问题在于这一系统需要得到工程师们的认可，而在很多情况下，新的系统是与他们执行的现有下水系统标准相冲突的。

在中国，他们已经意识到了这一点，并且开始和行业进行合作，他们建造了测试设施来证明自己的产品和系统能够满足国家和人民的需求。这在其他许多地区是没有的，以至于新的产品需要数年才能批准上市，甚至需要数十年时间才能改变现有的行业准则。活性排水通风系统的实验测试结果，与此前发表的研究结论是一致的，使用了AAV和PAPA™的活性排水通风系统的表现也要优于现有国家行业标准中高层建筑的排水系统。

在欧洲，对于高层建筑排水系统测试设施的需求和中国是一样的，然而却没有第三方机构有能力或者有意愿来运营这一项目。建造一座测试塔，一方面是出于商业需求，另一方面则是要实际证实新系统的运行情况，这样在很多时候，人们就可以更容易接受现有研究成果和实验结果。

英国的测试塔于2015年5月完工，迄今为止，有超过250位公共健康专家前来亲眼见证了这里的系统测试，有些还亲身参与其中。许多人评论说，他们从来没有在系统底部见到过水跃现象，在过载状态下立管底部的运行情况依然稳定，这可以当作一种实用工具用来教育下水系统的设计师和安装工人们，他们有时会忽略大量有价值

110mm stack and FUZE HDPE 56mm vent pipes. The HDPE pipe is the preferred pipe material for commercial high-rise projects in the UK.

The drainage system tested was 84 meters, with the lower four floors discharging into the main sewer system with the office kitchen (one sink) and bathrooms (two WC and one basin) on floors one and two, which were not monitored as part of the test.

The tested installation consisted of a stub stack on floor test levels one to two, with one WC, two 40mm P traps, and one 75mm bottle trap. It was connected to horizontal run 3.5 meters downstream of the base of the main stack. The horizontal run at the base of the main stack was five meters before it turned via a 90 bend into the original building drainage network, picking up the office kitchen and bathrooms on floors one and two.

Each test level floor was installed with a 5L WC, two 40mm P traps, and one 75mm bottle trap. These were installed on test level floors four, six, 12, 16, 19, 21, 25, 29, and 38, as shown in Figure 10. Each of the test floors was installed with an AAV that had a gate valve so that they could be selected or isolated from the system. Two PAPAs™ were installed serially at test level two on the main stack. A single PAPA™ was placed on test level floors seven, 11, 14, 20, 24, and 30 with gate valves to isolate them from the system. The 56mm vent pipe was cross connected at test level floors one, five, 10, 14, 20, 24, 30, and 39; these also had gate valves to isolate from the system as required.

Each test level floor with a WC had a manometer connected to the stack, and traps were replenished when required before each test. Video was used to monitor different tests on various test levels and to record the manometer readings and monitor the base of the stack and trap seals. In the testing, the Dyteqta® Pressure TEQ™ (a data and analysis system using Sensor Technics CTEM7NO23G7 pressure transducer) was used to record the pressure readings at test levels four and 16.

Clear pipe was installed at the base of the stack and midway up the stack, allowing the flow in the pipes to be monitored and recorded. A number of the PAPAs™ were opened so that the action could be observed when discharging was taking place.

Testing of the system was carried out comapring the active drainage ventilation with the isolated vent pipe network. The tests were repeated with the active drainage ventilation isolated and the vent pipe network opened.

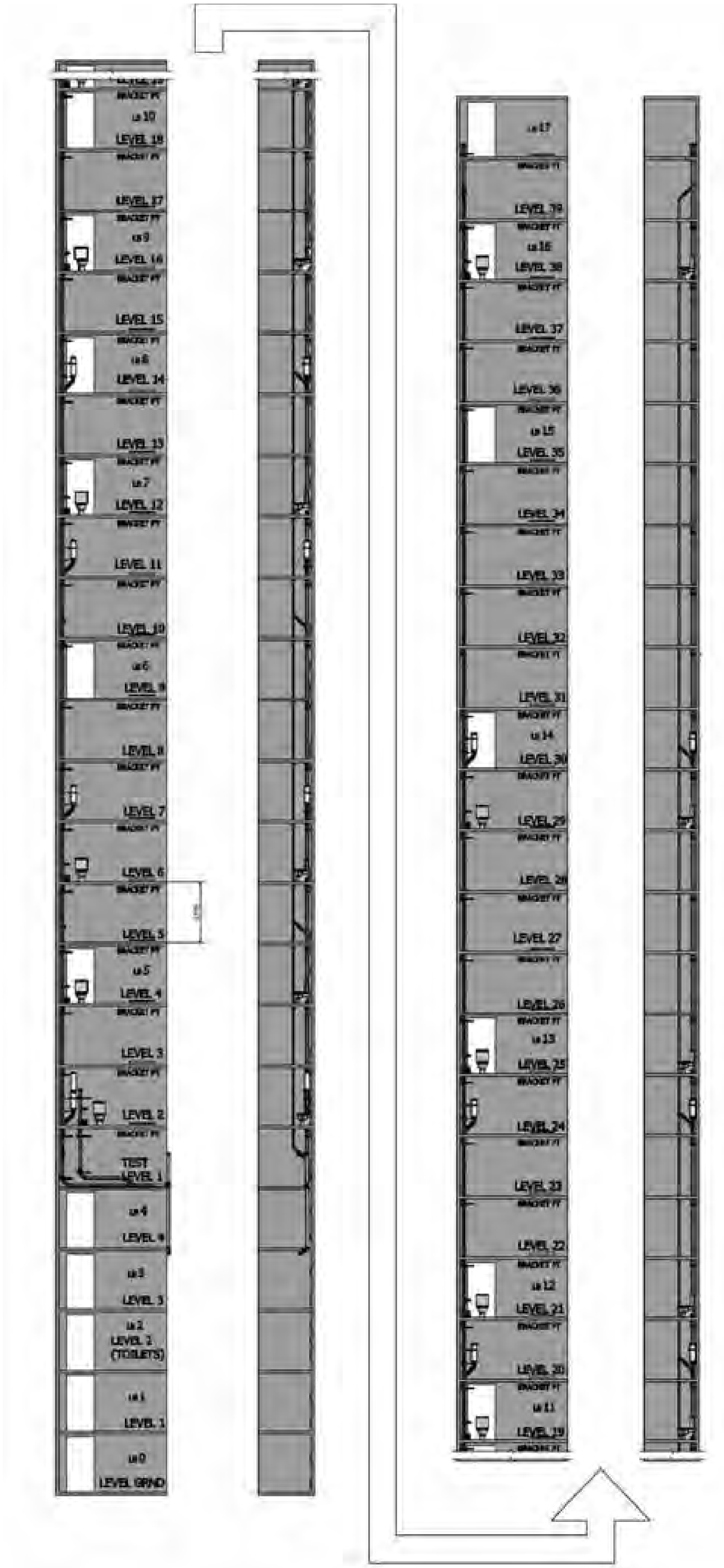

Figure 10. UK layout of test system (Source: Studor)
图10. 英国测试塔结构 （来源：思都得）

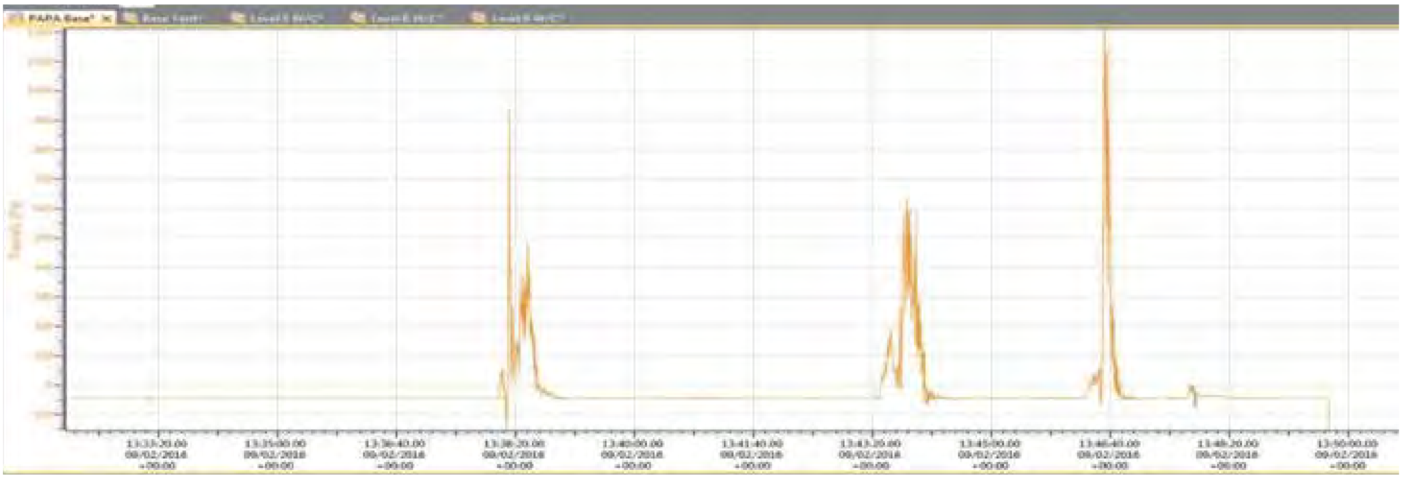

Figure 11. UK testing result (Source: Studor)
图11. 英国测试结果 （来源：思都得）

UK Test Tower Testing

The testing consisted of single and multiple flushes with a final surcharge into the three types of systems – Active Venting, Vent Pipe, and Hybrid – from the mid-way and top of the stack. This was a mixture of clean water and solids being flushed.

A number of flushes demonstrated the active ventilation working with the Air Admittance Valves and PAPA, connected to the single stack drainage system as well as annular flow, a solids drop rate, and the deceleration of solids at the base and the hydraulic jump. The system pressures at various locations throughout the stack were recorded with four Hz pressure transducers. The protection of the trap seals from both positive and negative pressures by air admittance valves and the PAPA was witnessed, and worked without the loss of trap seals.

This was physically witnessed at various locations. Minimal trap movement was observed in the WC and P traps, and the pressure was monitored by the installed manometers. High load testing of active ventilation, the traditional vented design, and hybrid systems was undertaken, and the test consisted of flushing from the mid-way point and top of the stack with 24 liters from each location within 15 seconds. This activated the discharge giving an estimated discharge rate of 3.2 L/S, witnessed as a surcharge to the system at the base. The results can be seen in Figure 11, with the conclusion of the tests in Figure 12.

It is to be noted that the base pressure readings are taken on the wet stack at the entry point before the PAPA, and any positive pressure will be reduced on attenuation. In previous tests, the results have shown the same readings and conclusions which are available upon request.

Active ventilation works to balance the system in harmony with the demands of the flows active within the drainage network. Despite high positive readings, the closest PAPA will only be 7.5m away at 320m/s of positive pressure speed, and the reaction time would be within 0.02 of a second. It is this response time that keeps the system within safe pressure limits.

Vented system pressures were recorded after the first vent stack connection. This shows that a greater amount of pressure has bypassed the vent stack, and is free to travel up the wet stack and put trap seals at risk.

The hybrid System fails at the base and midpoint due to positive pressures.

Discussion and Conclusion

There is sufficient research already generated to design an international high-rise building code, but the industry is sometimes unwilling to accept the research, change their beliefs, and ensure that the national codes they follow meet the demands of tall, complex designs being built all over the world. The active system has been approved in Australian code, under the AS 3500; but, this is a general plumbing

System | 系统	Pressures | 气压(pa)			
	Base of Wet stack 立管底部	Mid way point Wet stack | 立管中部	Vent stack at base | 辅助通气立管底部	Trap seal | 水封
Active Venting 主动系统单立管	+936Pa - 152.6Pa	+510.7Pa -131Pa	0 0	Pass
Vented | 传统通气	+632.5Pa -66.7 Pa	+486.7Pa -329.3Pa	+239Pa -301Pa	Fail / At Risk
Hybrid | 主动通气混合	+12203.5Pa -66.2Pa	+856.6Pa -192.7Pa	+136Pa -445Pa	Fail

Figure 12. Conclusion of Tests Table (Source: Studor)
图12. 测试结果表（来源：思都得）

的研究结果，而通过学习他们可以改善工程质量，为客户提供更好的服务。

北安普顿的测试塔正在建设中，在未来六个月会有更精细的规划——在系统中部增加一套支管以及一个测试区域，并在立管上增加管道三通。

另外需要特别强调的是，为高层建筑所设计的活性排水通风系统比传统排气管网性能更加卓越，这一点已经被一再证实，不论是研究或是模拟，或是在试验塔上进行实际测试，或是解决问题的能力，或是世界各地已经安装了活性通风系统的成千上万的高层建筑，都能提供强有力的证明。

由于论文篇幅所限，我们将会在CTBUH大会上使用PPT详细展示这套系统，包括一组关于试验塔的动画和视频文件。另外我还增加了目前我们获得的认证和符合的行业标准，以及一些项目的资料（主要集中介绍了巴拿马城的特朗普大厦（2011）和阿布扎比的国家塔（2013））。截止今天，还未发生过一次系统失灵的情况。我还会对制定行业标准的官员作进一步的解释——这也是我们目前最缺乏共识的地方，我们需要让他们理解高层建筑中排水系统的工作原理，以及在高塔上进行试验的必要性。

code for low and high-rise buildings. The system can be installed as an engineered solution and has been specified in over 102 projects being developed in the UK in the coming years. The issue is that the system puts the requirements on the engineers to approve the system, and this in many cases contradicts the established plumbing codes that they have to follow.

In China, they have recognized this, and in partnership with the industry, they have established testing facilities to prove that their products or systems meet the demand for China and their people. This is sometimes lost in other regions where it can take years to gain product approval, or sometimes decades to change an existing code. The testing of active drainage ventilation has followed the expected outcomes of the research that have already been published in the past, and the performance of active ventilation using AAVs and PAPA™ performs better than required by the guidance in the existing national codes for taller projects.

Within Europe, the need to have a tall testing facility is the same as China, and yet there is no third party testing institute able or willing to operate such a project. The need for the test tower has come from a commercial requirement and the need for industry to physically witness the system in operation, so in some cases they can accept the research and testing that has already been done.

The test tower in the UK was completed in May 2015 and, to date, over 250 public health engineers have come to witness the testing and even partake in the tests themselves. Many have commented that they have never seen a hydraulic jump at the base or what happens when there is a surcharge at the base of the stack, so this can be used as a practical tool to help educate drainage system designers and installers who are sometimes unaware of the amount of valuable research out there that can help them improve what they do for their clients.

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