Original Paper

Indoor Built Environment

Indoor Built Environ 2000;9:87–96

Accepted: June 30, 2000

Super-Efficient Mechanical Ventilation

John Berry

Ove Arup & Partners, Consulting Engineers, London, UK

Key Words
Low energy · Mechanical ventilation · Evaporative cooling · Heat recovery · Wind assistance · Photo-voltaic

Abstract
A novel ventilation system has been installed in buildings constructed for the New Campus of the University of Nottingham. Super-efficient mechanical ventilation has been used as part of an integrated environmental strategy and operates with fan input powers below 0.5 $W \cdot l^{-1} \cdot s^{-1}$ of airflow. The complete plant was assembled from innovative low-pressure components and has exceptional performance. A key element of the design is that components of the system are bypassed when not in use. At the heart of the system is a low-velocity, high-efficiency thermal wheel. Evaporative cooling reduces summertime peak temperatures. A tracking wind-assisted exhaust cowl further reduces the dependence on fan power. The low fan power requirement is matched by a 450-m^2 photo-voltaic array effectively giving zero energy ventilation.

Introduction

Super-efficient mechanical ventilation (SEMV) can be described as a total design approach which takes account of: (1) thermal comfort, (2) energy consumption and (3) optimal plant operation.

The key features of such a design are low-pressure-loss plant components and distribution systems coupled with optimal control strategies to bypass the high-pressure components whenever possible. If advantage can be taken of natural phenomena such as wind or solar power in the design strategy then so much the better. Fan power should be less than 1 $W \cdot l^{-1} \cdot s^{-1}$ of airflow. In reality, it is far easier to define the criteria for such a system than to apply the design to a real situation. Components which have low pressure loss and work at low velocity must be large and at the present time innovative. To design such a system, conventional wisdom has to be abandoned in favour of radical new thinking for the integration and application of SEMV into a building.

This paper describes the application of SEMV to the faculty buildings at the new 'green' campus for the University of Nottingham which are due for completion for the academic year 1999–2000. The campus has been constructed on a former industrial site within a mile of the existing university campus. Construction is underway, and the first buildings became available for occupation in August 1999. The new campus was planned on the site of the old Raleigh bicycle factory, a brown field site separat-

KARGER
Fax +41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

1420–326X/00/0092–0087$17.50/0

Accessible online at:
www.karger.com/journals/ibe

John Berry
Ove Arup & Partners, Consulting Engineers
13, Fitzroy Street
London W1 P 6BQ (UK)
Tel. +44 20 465 3405, Fax +44 20 465 3673

ing an intensely industrial area from suburban housing. At completion, the site will be landscaped with a new lake and wilderness area, designed to maximise both public amenity and re-introduce wildlife. The university intends to make the new campus a model sustainable development for the Midlands, setting an example to the large number of students passing through the campus, making this project of unique value by disseminating both environmental awareness and state-of-the-art civic solutions.

The New Campus with SEMV in Context

The principal innovative feature of the SEMV system used for the campus buildings is the operation in mixed mode. The background to the design is the recent completion and subsequent monitoring of one of the largest naturally ventilated office building complexes in the UK – the 50,000-m^2 Inland Revenue Office in Nottingham. Feedback from the operation of this building, together with the conclusions of two successive EEC 11 Solar House Joule research projects [1, 2] into low-energy work space, indicated that both internal comfort conditions and annual energy consumption could be improved through mechanically assisted ventilation with heat recovery.

The addition of low-pressure-drop air distribution systems and heat exchangers assists with providing adequate minimum ventilation to deep-plan areas and partitioned cellular rooms, simultaneously minimising energy loss through heated or cooled ventilation exhaust air.

In the design, providing the fresh air intake at roof level avoids street level pollution, and the addition of a heat recovery unit enables 100% fresh air to be supplied to all interior volumes without any re-circulation. This avoids excessive energy penalties and creates a healthier internal environment. All the faculty buildings incorporate tracking wind cowls to reduce the requirement for electric fan operation to supply the motive power for air extract.

Photo-voltaic cells were incorporated into the glazed roof of the atrium. These are of a size to meet the annual electrical consumption of the supply and extract fans. The addition of a climatically responsive facade system with light/shade shelves was made to increase internal daylight levels, at the same time reducing overheating through solar gain in the summer. Daylight sensors were used to minimise the use of artificial light and so reduce the heating and cooling loads at the same time as reducing the amount of electrical energy used for lighting.

In summer, exposed thermally massive concrete floor slabs will be used to store coolness from night to day, creating cooler internal conditions than outside the building. Evaporative wet-pack humidifiers integrated within the low-pressure-drop air distribution system will provide passive summer comfort cooling.

It is expected that the mixed-mode ventilation systems will combine all the advantages of natural ventilation, without the penalty of high electrical consumption normally associated with mechanical ventilation, because the annual electrical energy demand for the air distribution fans is provided by the photo-voltaic cells. This combination of low-pressure-loss components should result in a building that uses no more electricity than a naturally ventilated building, minimises the thermal energy loss through ventilation in winter due to the heat recovery facility, stays cooler in summer through passive evaporative cooling systems and provides significantly improved comfort conditions all year round.

Working towards Zero-Energy-Intake Buildings

The environmental control strategy was conceived around current research and development in buildings that require minimal energy to be imported in order to maintain a comfortable internal working environment.

The results from dynamic thermal modelling and work on the Joule 11 Solar House project have shown that 'forced' ventilation systems are the most efficient way to ventilate densely occupied buildings in winter and summer. They provide greater control of ventilation rates in all areas of the building, ensuring that adequate air movement and hygiene standards are maintained. Energy consumed in winter can be minimised because the heat generated by the sources (people, machines, lights, solar gains) can be recovered and used to heat the incoming fresh air.

In summer, the evaporative cooling and thermal wheel heat transfer system, working with the under-floor air supply and thermally massive slabs and night cooling ventilation, provides up to 5 °C of passive cooling.

It would be difficult in a naturally ventilated building to provide these benefits. In such buildings, ventilation rates are inconsistent and difficult to control, and heat recovery is not possible.

In the mixed-mode ventilation system, the forced ventilation systems are supplemented by the ability of the building's occupants to open windows when desired. Occupant briefing sessions advise that they should not do this during peak summer and winter conditions since keeping windows shut will actually provide a more comfortable internal working environment.

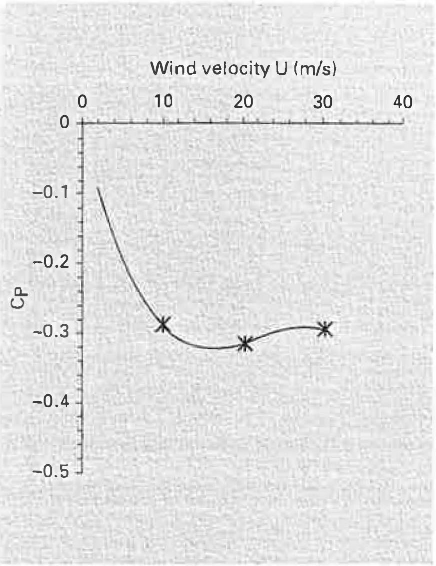


Fig. 1. Pressure coefficient versus wind speed in the DERA wind tunnel tests. Reaction, $Cp = 2(P - P_o)/\rho U^2$; P = static pressure measured on the downstream side of the wind cowl; P_o = atmospheric pressure.

Table 1. Benefits from the passive wind cowl

Wind speed $m \cdot s^{-1}$	Hours per year	Cp	Pressure gain, Pa	Annual energy, kWh
0.5	3.0	−0.02	0.0	0.0
1.5	667.0	−0.07	−0.1	0.3
2.5	759.5	−0.11	−0.4	1.4
3.5	606.5	−0.14	−1.1	2.8
4.5	604.5	−0.17	−2.1	5.7
5.5	555.5	−0.20	−3.7	9.0
6.5	424.0	−0.23	−5.8	10.8
7.5	284.0	−0.25	−8.4	10.5
8.5	193.5	−0.27	−11.6	9.9
9.5	142.5	−0.28	−15.3	9.6
10.5	75.0	−0.29	−19.5	6.4
11.5	31.5	−0.30	−24.3	3.4
12.5	20.0	−0.31	−29.5	2.6
13.5	6.0	−0.32	−35.1	0.9
14.5	3.5	−0.32	−41.2	0.6
15.5	2.0	−0.33	−47.6	0.4
16.5	2.0	−0.33	−54.4	0.5
Total	4,380.0	–	−300.0	74.7

See also legend of figure 1.

Experience has also shown the benefit of using a pressurised floor void as an integral part of the ventilation system. Passing air over the top surface of a concrete slab has a significant effect in stabilising room temperature by effectively using the thermal inertia of the concrete to transfer heat or coolness into the air supply. In summer, the slab is pre-cooled at night using fresh air which reduces the peak daytime supply air temperature and hence the resultant room temperature.

A further element of the Joule 11 Solar House project was the demonstration of how it would be possible to use the prevailing wind pressure to overcome the air resistance within the ventilation system. The proposals adopted were based upon this theoretical research, but the systems used also include mechanically driven fans, modulating bypass dampers and a control system which ensures that ventilation rates can be maintained when there is insufficient wind pressure.

To maximise the effect of the prevailing wind, tracking wind catchers working on the exhaust system were found necessary. These devices were designed to ensure that the maximum negative pressure coefficients are obtained. Their design was based on wind tunnel tests of devices completed as part of the Solar House project. The facility used for these was an atmospheric low-speed wind tunnel with a 24-ft open-jet working section (DERA, Farnborough, UK). Tests were conducted on a full-scale model of a cowl (prepared by Gill Air Ventilation) at wind tunnel air velocities (U) of U = 10, 20 and 30 $m \cdot s^{-1}$ (fig. 1). These showed that the cowl would rotate at wind speeds down to U = 2.0 $m \cdot s^{-1}$. Its performance could be sustained under a wind speed in excess of 40 $m \cdot s^{-1}$ for 5.0 min, and it was structurally stable under all examined wind speeds.

The benefits from the passive wind cowl are shown in table 1. Only the suction effect for daytime operation was used in the calculations. To calculate the fan energy benefit, banded wind velocity data for the University of Nottingham was used.

An integral part of the system is a photo-voltaic array whose output matches the annual absorbed power of the supply and extract fans. Stand-alone photo-voltaic cells do not have an attractive energy payback period in the UK. However, they become more attractive if they are integrated into the building's cladding systems. In this instance they were integrated into the sloping atrium roof glazing to reduce the need for solar shading in the atrium itself and to optimise the performance of the cells.

The ability to avoid the need for conventional air conditioning or comfort cooling is only possible because of the use of 'passive' elements within the building design to control internal conditions. Exposed concrete ceiling units have a high thermal capacity which stabilises the

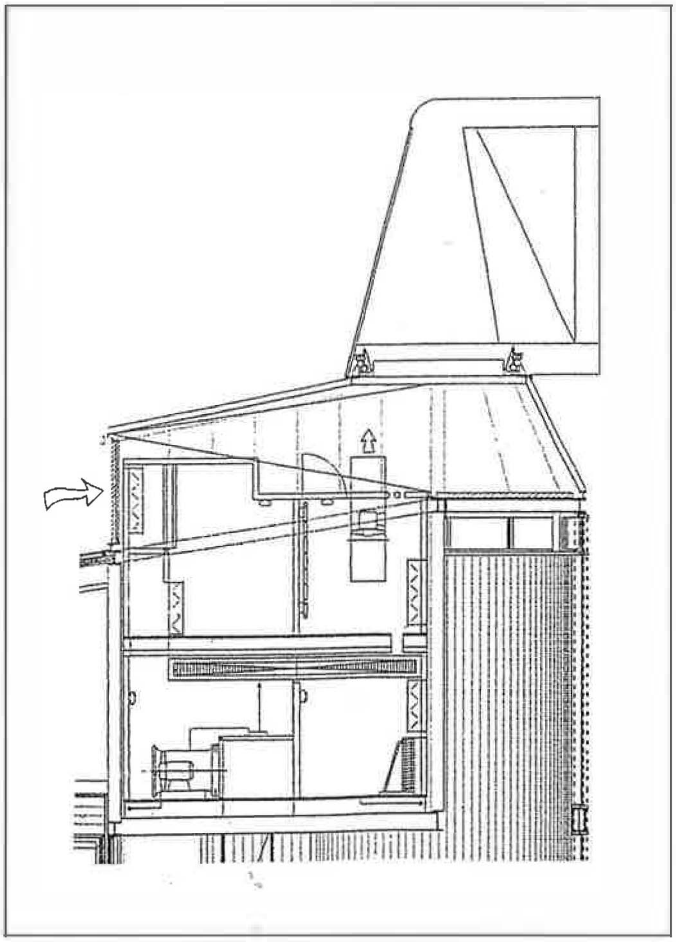


Fig. 2. Section through an AHU.

Table 2. Principal components in each AHU

Electrostatic filter		
Manufacturer	Engineering Dynamics Ltd.	
Type	Dynamic Electronic Panel (non-ionizing)	
Efficiency, %	EU3	
Power, W	28	
Thermal wheel		
Manufacturer	ABB	
Type	Rotary Econovent	
Diameter, m	2.9	
Efficiency, %	84	
Evaporative cooler		
Manufacturer	Munters	
Type	mains water wet pack	
Efficiency, %	85	
Fans	Supply (2)	Extract (2)
Manufacturer	ABB	ABB
Type	–	–
Blade angle, degrees	56	51
Efficiency, %	72	67
Normal speed, rpm	1,410	1,410
Power input, kW	0.47	0.62
Air volume, $m^3 \cdot s^{-1}$	2.2	2.2
Total pressure, Pa	153	190
Heater		
Manufacturer	Reznor	
Type	Euro-C (compact gas-fired unit heater)	
Output, kW	30	
Efficiency, %	82	

room environment by damping temperature swings. The large exposed surface has the added benefit of providing radiant cooling in the summer. The building envelope has a high level of thermal insulation to reduce peak heating loads and summer heat gains. The specification for the construction of the building was that it had to be highly weather-tight, i.e. resistant to uncontrolled infiltration of outside air. The facade seeks to find a balance between the seemingly conflicting requirements of view, day-lighting, solar and glare control. Light shelves provide shade to areas of glazing, whilst redirecting useful daylight deeper into the building and reducing the contrast in light levels at the very edge of the building. This, coupled with an energy-efficient lighting system and a lighting control system which ensures artificial lighting is switched off when daylight levels are sufficient, reduces lighting energy consumption and unwanted heat gains. Lighting controls in areas not directly under the control of an individual – that is, large classrooms rather than private offices – will use passive infrared controls to ensure electrical energy for lighting is only used when the area is occupied.

Compact Air-Handling Units Installed in the Faculty Buildings

The faculty buildings are ventilated by rooftop air-handling units. These units, generally known as the compact air handling plants (AHU) are of an innovative design and provide a high energy-efficient performance (fig. 2). The principal areas of innovation are the way in which the components are arranged, the very low pressure drop of the unit, the bypassing of components when not in use, and avoiding a pressure drop across any heater or cooler batteries in the supply air train. The components used to construct the system are as follows (table 2):

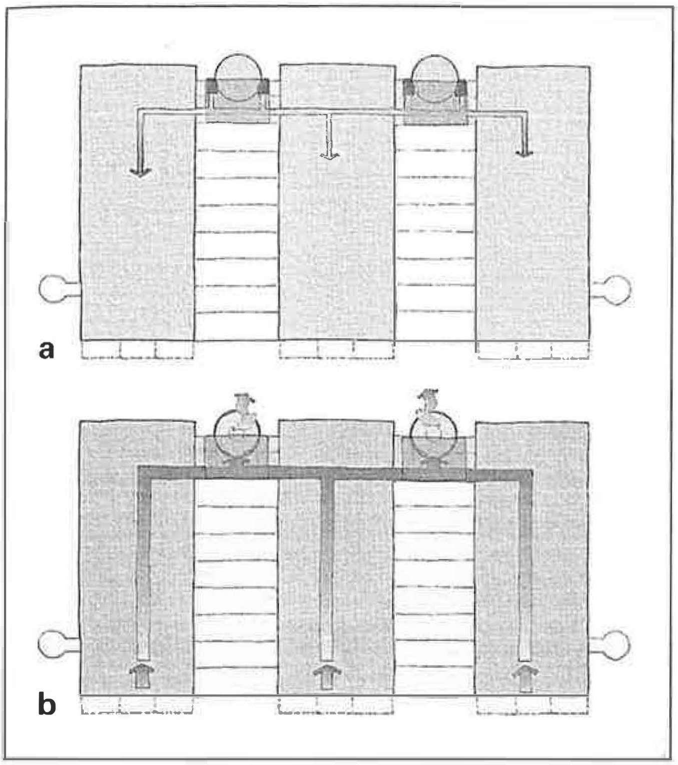


Fig. 3. Schematic plan showing the position of the AHUs on a building. **a** The supply air route. **b** The exhaust air route.

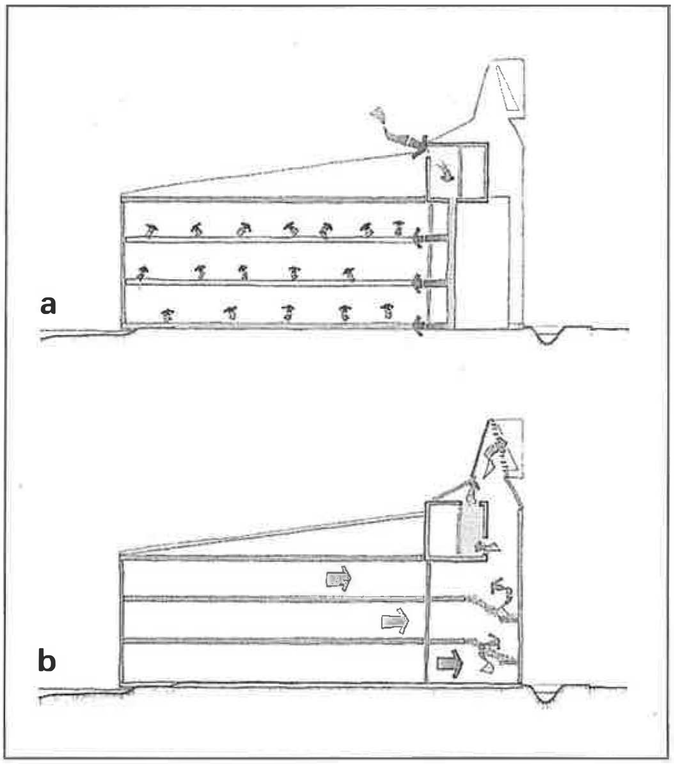


Fig. 4. Schematic section showing the position of the AHUs on a building. **a** The supply air route. **b** The exhaust air route.

Components Making Up the Supply Air Train

(1) Intake louvre. (2) Air filter (electrostatic type to reduce the degree of air pressure drop caused by conventional bag filters). (3) Thermal wheel (and bypass to reduce pressure drop when the thermal wheel is not required). (4) Backup gas-fired heaters (used only at very low ambient temperatures and not forming part of the system resistance network). (5) Variable-speed supply air fans. (6) Acoustic attenuator.

Components Making Up the Extract Air Train

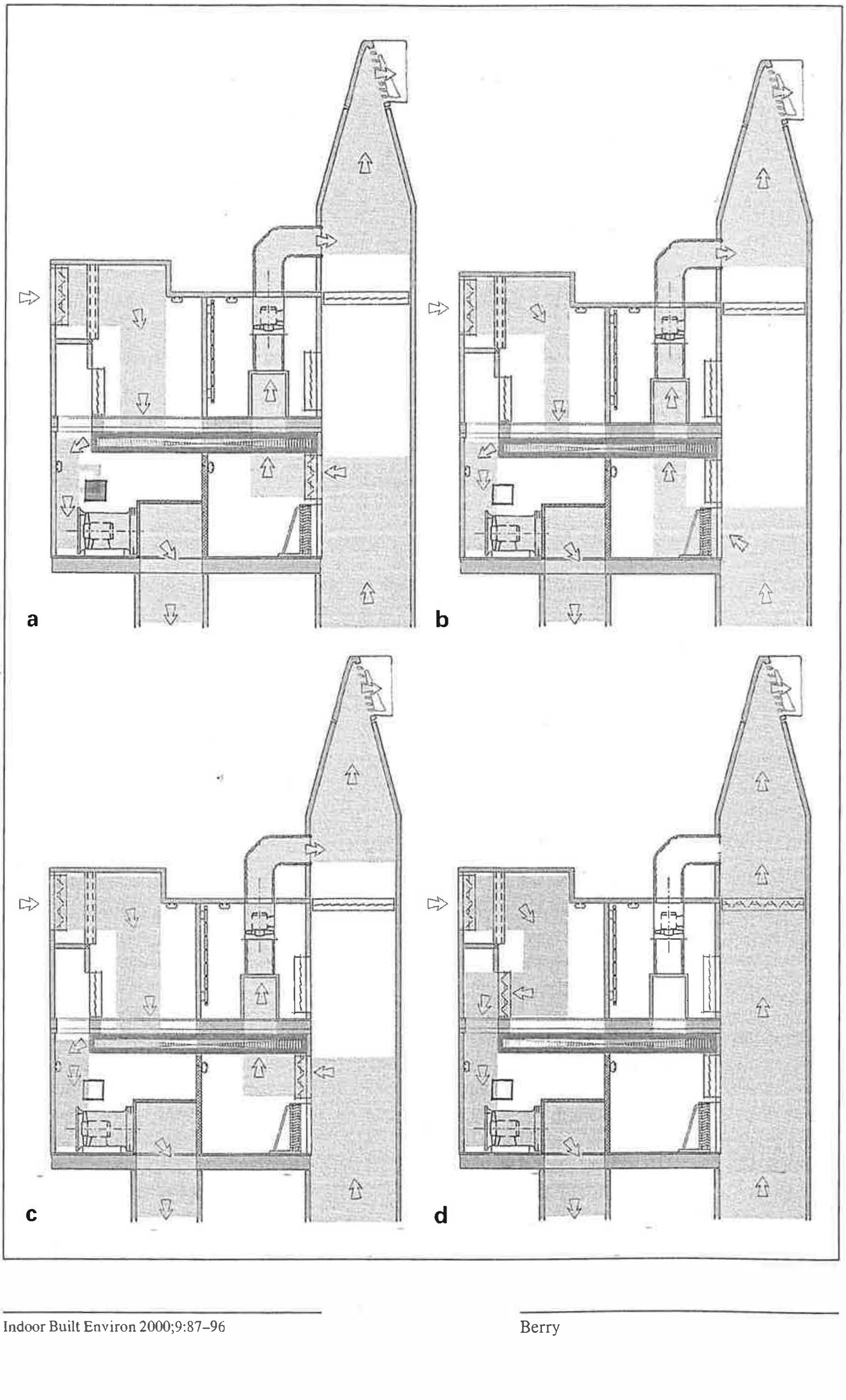
(1) Return air dampers (bypassing evaporative humidifiers to reduce pressure drop for the majority of the year). (2) Evaporative humidifier (to reduce extract air dry bulb temperature). (3) Thermal wheel (+ bypass to reduce pressure drop when the thermal wheel is not required). (4) Variable-speed exhaust air fans. (5) Acoustic attenuator.

Six AHUs have been installed on the three faculty buildings on the site. One of these, a unit of 4.4 $m^3 \cdot s^{-1}$, located on the Faculty of Management and Finance, is described in some detail below as an example. The daytime duties of the other faculty units range from 4 to 7.2 $m^3 \cdot s^{-1}$, but the principle of using low-pressure components applies equally to them. The overall dimensions of 4.2 m wide × 4.785 m long × 5 m high is the same for each AHU, but the component sizes vary to give a similar pressure loss profile across the range. Total air volume of all the faculty building AHUs is 35.6 $m^3 \cdot s^{-1}$.

The arrangement and location of the AHUs on the Faculty of Management and Finance building and the principles of the airflow in the building are shown diagrammatically in figures 3 and 4.

Ductwork Distribution: Description

The use of conventional ductwork distribution and terminal design would have meant high pressure loss. In systems constructed in this way, velocities in the range of 7–8 $m \cdot s^{-1}$ are common, and high impedance terminals are often employed to balance the pressure differences inherent in medium velocity-systems. SEMV, on the other hand, requires a holistic approach, where elements of the building – whether fabric or structure – are utilised as low-velocity, low-pressure air paths. Thus, each compact



5

Table 3. Plant room data for operating modes

Components	Pressure drop, Pa	Av. velocity, m·s^{-1}	Fan power, W	Annual fan energy kWh
Winter (peak)[1]				
Supply side				
Intake louvre	17.0	1.4	103.9	45.3
Air inlet shut-off damper	3.0	1.2	18.3	8.0
Electrostatic filter	16.0	1.0	97.8	42.6
Thermal wheel	60.0	1.5	366.7	159.9
Thermal wheel bypass damper	–	–	–	–
Supply fan	37.0	–	226.1	98.6
Attenuator	9.4	2.3	57.4	–
Ducts and outlets	10.6	<1.5	64.8	28.2
Extract side				
Exhaust ducts	1.0	<0.5	6.6	2.9
Evaporative humidifier	–	–	–	–
Evaporative humidified bypass damper	3.4	1.2	22.3	–
Thermal wheel	60.0	1.5	394.0	171.8
Thermal wheel bypass damper	–	–	–	–
Extract fan	48.0	–	315.2	137.4
Attenuator	9.7	3.7	63.7	–
Exhaust air shut-off damper	–	–	–	–
Stairtower outlets	3.7	0.8	24.3	0.3
Total	279	–	1,761	695

Components	Pressure drop, Pa	Av. velocity, m·s^{-1}	Fan power, W	Annual fan energy kWh
Mid-season[3]				
Supply side				
Intake louvre	17.0	1.4	103.9	405.7
Air inlet shut-off damper	3.0	1.2	18.3	71.6
Electrostatic filter	16.0	1.0	97.8	381.8
Thermal wheel	60.0	1.5	366.7	1,431.8
Thermal wheel bypass damper	–	–	–	–
Supply fan	37.0	–	226.1	883.0
Attenuator	9.4	2.3	57.4	224.3
Ducts and outlets	10.6	<1.5	64.8	253.0
Extract side				
Exhaust ducts	1.0	<0.5	6.6	25.6
Evaporative humidifier	–	–	–	–
Evaporative humidifier bypass damper	3.4	1.2	22.3	87.2
Thermal wheel	60.0	1.5	394.0	1,538.7
Thermal wheel bypass damper	–	–	–	–
Extract fan	48.0	48.0	315.2	1,230.9
Attenuator	9.7	3.7	63.7	248.8
Exhaust air shut-off damper	–	–	–	–
Stairtower outlets	3.7	0.8	24.3	94.9
Total	279	–	1,761	6,877

Components	Pressure drop, Pa	Av. velocity, m·s^{-1}	Fan power, W	Annual fan energy kWh
Summer (peak)[2]				
Supply side				
Intake louvre	17.0	1.4	103.9	3.5
Air inlet shut-off damper	3.0	1.2	18.3	0.6
Electrostatic filter	16.0	1.0	97.8	3.3
Thermal wheel	60.0	1.5	366.7	12.5
Thermal wheel bypass damper	–	–	–	–
Supply fan	37.0	–	226.1	7.7
Attenuator	9.4	2.3	57.4	2.0
Ducts and outlets	10.6	<1.5	64.8	2.2
Extract side				
Exhaust ducts	1.0	<0.5	6.6	0.2
Evaporative humidifier	68.4	2.9	446.6	15.2
Evaporative humidifier bypass damper	–	–	–	–
Thermal wheel	60.0	1.5	394.0	13.4
Thermal wheel bypass damper	–	–	–	–
Extract fan	48.0	–	315.2	10.7
Attenuator	9.7	3.7	63.6	2.2
Exhaust air shut-off damper	–	–	–	–
Stairtower outlets	3.7	0.8	24.3	0.8
Total	343	–	2,185	74.3

Components	Pressure drop, Pa	Av. velocity, m·s^{-1}	Fan power, W	Annual fan energy kWh
Summer (night)[4]				
Supply side				
Intake louvre	68.0	2.8	831.1	68.2
Air inlet shut-off damper	7.0	2.4	85.6	7.0
Electrostatic filter	41.0	2.0	501.1	41.1
Thermal wheel	–	–	–	–
Thermal wheel bypass damper	8.0	3.0	97.8	8.0
Supply fan	74.0	–	904.4	74.2
Attenuator	37.6	3.8	459.6	37.7
Ducts andoutlets	41.4	<3.0	506.0	41.5
Extract side				
Exhaust ducts	5.0	<1.0	65.7	5.4
Evaporative humidifier	–	–	–	–
Evaporative humidifier bypass damper	–	–	–	–
Thermal wheel	–	–	–	–
Thermal wheel bypass damper	–	–	–	–
Extract fan	–	–	–	–
Attenuator	–	–	–	–
Exhaust air shut-off damper	0.2	1.6	2.8	0.2
Stairtower outlets	15.3	1.6	200.7	16.5
Total	297	–	3,655	300

Volume flow rate: 4.4 m^3·s^{-1}; operating hours per year: 436 h (summer and winter peak), 39,056 h (mid-season and summer night); fan efficiency: supply 72%, extract 67%. Temperatures: winter (peak) <2.3 °C; summer (peak) >25 °C; mid-season >2.3 °C, <25 °C; summer (night) >23 °C.

Fig. 5. Plant room data for the 4 operating modes. **a** Winter (peak). **b** Summer (peak). **c** Mid-season. **d** Summer night.

AHU has two large builders work supply air ducts either side of the stair tower. A typical daytime velocity is less than 1.5 $m \cdot s^{-1}$. The large builders work shafts connect to the 350-mm air plenum void formed between the concrete structure and the raised floors of the faculty building. Low pressure outlets connect the floor to the room.

Extract air flows from the room to the interconnecting corridors and up the stair tower before exhausting directly to the outside via the wind-assisted tracking outlet, or is returned to the AHU. Full-height fire doors into each stair tower are held open by magnetic interlocks to ensure an unencumbered flow path. The doors close automatically in the event of a fire. A special low-pressure attenuated flow path is incorporated into the corridor ceiling effectively to connect the room to the corridor while maintaining acoustic separation.

This design approach gives the lowest possible pressure loss whilst maintaining balanced airflow to each room.

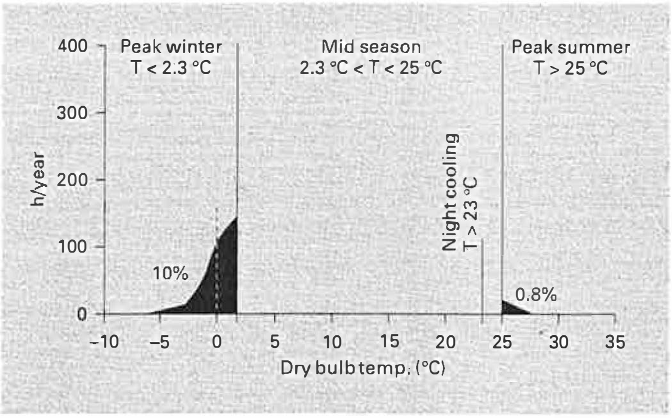


Fig. 6. Banded temperature data for Nottingham; 7.00–18.00 h.

The supply air outlet is the dominant pressure element between the supply duct and the room, and results in equal air distribution.

Basic Control Strategy

Operating Modes

The operation of the plant has been determined for 4 operating modes: (1) winter (peak) – figure 5a, table 3; (2) summer (peak) – figure 5b, table 3; (3) mid-season – figure 5c, table 3, and (4) summer night – figure 5d, table 3.

The configuration of the various components in the AHUs for each operating mode is summarised in table 4.

Banded temperature data for Nottingham (fig. 6) were used to calculate the operating hours for each mode. The total fan input energy can be determined for a typical year from the data in table 3 (table 5). The measure of performance of fan input power divided by air volume can be calculated as an average value for the operating year. Averaging this performance indicator over the year is important when high-pressure-loss components which only operate 'on-line' for a short period are bypassed. The evaporative cooler is an example of this.

Supply Air Temperature Control

The supply air temperature sensor modulates the speed of the thermal wheel and gas heater in sequence via a P + I control loop in order to maintain the supply air temperature set point.

The thermal wheel is only allowed to operate providing the wheel and stair bypass dampers are in the closed position, as determined by the damper closed-end switches.

Table 4. Configuration of the AHU components for each operating mode

AHU component	Winter (peak)		Summer (peak)		Mid-season	
	day	night	day	night	day	night
Supply fans	on	off	on	on at 2 × day rate	on	off
Thermal wheel	max. rpm	off	max. rpm	off	rpm varies	off
Thermal wheel bypass	shut	shut	shut	open	shut	shut
Evaporative humidifiers	off	off	on	off	off	off
Evaporative humidifiers bypass	open	shut	shut	open	open	shut
Extract fans	on	off	on	off	on	off
Backup gas-fired heater	on	off	off	off	off	off
AHU bypass damper in stair tower	shut	shut	shut	open	shut	shut

Spray Humidifier Control

To improve the cooling capacity of the thermal wheel, a spray humidifier is used during higher ambient temperatures.

If the global outside air temperature is above a high limit, then the supply air temperature control loop is disabled, and the speed of the thermal wheel is set to 100%. The spray humidifier bypass damper is closed. After a time delay to allow the dampers to reach their respective open and closed positions, the water supply is switched on.

If the global outside air temperature is below a low-limit set point, then the supply air temperature control loops are enabled, the spray is switched off, and the spray humidifier bypass damper is opened.

Summer Night Cooling

To pre-cool the building during the summer, it is ventilated during the unoccupied period if ambient temperatures are advantageous.

Night cooling is initiated if the space temperature sensor registers above the space temperature set point.

When night cooling is required: (1) the stair and thermal wheel bypass dampers are opened; (2) after a time delay to allow the dampers to reach their open position, the supply fans are started; (3) the fan tracking control loop is disabled and the supply fan operated at maximum speed, and (4) the supply air temperature and spray humidifier control loops are disabled.

The night cooling is allowed to continue provided all the following conditions are satisfied: (1) the return air temperature sensor is above the global outside air temperature by a pre-set differential; (2) the return air temperature sensor registers above the space temperature set point, and (3) the global outside air temperature is above a low-limit set point.

If night cooling has operated for at least 5 successive nights, then it is continued for a further 2 successive nights after the global outside air temperature is below the low-limit set point.

Night cooling is stopped if any one of the above conditions are not satisfied, or if the plant is required to operate for normal start-up. In either case, the AHU is shut down and, after a time delay, reconfigured to operate in the next required mode.

Fan Tracking

Differential pressure sensors measuring across the thermal wheel in the supply and extract air ducts are used to measure the supply and extract volumes.

The supply differential pressure sensor, via a P + 1 control loop, modulates the speed of the supply fan to maintain the supply air volume set point. The supply differential pressure sensor resets the set point of the extract differential pressure sensor and maintains an offset between the supply and extract volumes. The extract differential pressure sensor, through a P + 1 control loop, modulates the speed of the extract fan to maintain the extract air volume set point.

As the filters in the AHU become dirty, the supply fan speed increases to maintain the supply volume set point.

Conclusions

An annual operating fan input energy of 7,871.6 kWh coupled with a low power to volume ratio of 0.4 clearly confirms the construction described in this paper as mer-

Table 5. Annual fan energy and power to flow rate ratios[1]

Mode	Total pressure drop, Pa	Operating hours h/year	Fan input power, kW	Annual energy rate, kWh	Fan peak power/ flow rate, $W \cdot l^{-1} \cdot s^{-1}$
Peak summer	343	34	2.18	74.3	0.50
Peak winter	279	436	1.76	695.0	0.40
Mid-season	279	3,905	1.76	6,877.0	0.40
Summer night	297	82	1.60	300.0	0.18
Total	1,198.0	4,457.0	7.30	7,946.3	0.4 (av.)

[1] Wind benefit is 74.7 kWh. Total fan energy is 7,871.6 kWh.

iting the description of SEMV. It is worth noting that as the static pressure loss in the system reduces the dynamic loss at the fan, discharge becomes a significant proportion of the total pressure loss in the system. The next generation of SEMV will need to consider ways of recovering this loss.

The tracking wind cowl contribution to the annual fan energy consumption is small; a total of 75 kWh or about 1% of the total.

A more conventional design operating under similar conditions would have a much higher fan energy requirement because the total pressure loss in such a system is typically 1,200–1,600 Pa for the supply and extract.

The thermal performance of the system and building will be the subject of a separate paper.

Acknowledgment

This project has been supported by a THERMIE grant from the EEC. As well as contributing towards the component costs, a portion of the grant is also to be used for performance monitoring by the Department for the Built Environment at the University of Nottingham.

References

1 Joule II Contract No. JOU2-CT93-0235 (1991–1994). Engineering Research into Prototype Development for Low-Energy Buildings.
2 Joule II Contract No. JOU2-CT93-0351 (1991–1994). Office and Public Buildings Incorporating Wind/Solar Buoyancy/Photovoltaic Powered Ventilation Systems.