CARBON TRUST
Making business sense of climate change

Sharing our experience

A natural choice

Lessons learned from low carbon buildings with natural ventilation

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Sharing our experience: About this booklet

A natural choice is part of the 'Sharing our experience' series. These booklets provide advice and tips to help you plan, build and manage cost-effective low carbon buildings that really work to save you money and carbon.

The insights are based on real data from 28 case studies from the Department of Energy and Climate Change's Low Carbon Buildings Programme and our work on refurbishments. The projects cover many sectors including retail, education, offices and mixed use residential buildings.

Further information

To find out how we can help with your low carbon building project, contact us on 0800 085 2005 or visit www.carbontrust.co.uk/buildings

Contents

> "Evidence from our case study buildings showed that naturally ventilated buildings saved an average of £30,000 a year on energy"

MENU

HELP

What is natural ventilation?

We ventilate buildings to keep the indoor environment comfortable and healthy. Natural ventilation systems supply fresh air and remove excess heat, odour, CO_2 and other contaminants. This document looks at two types:

Natural ventilation without mechanical assistance

Natural ventilation exploits the ‘stack effect’, where warm air rises above cold air, and wind, which creates pressure differences across buildings.

Buildings can be designed so that an atrium takes advantage of the stack effect. The atrium allows warmer air from the occupied spaces to rise and escape through vents at the top of the building. This air movement draws cooler air into the occupied spaces through open windows or vents.

Wind-driven ventilation is most effective when there are openings on two different sides of the building. Wind creates a pressure difference and the openings allow air movement through the building. This ‘cross-ventilation’ allows spaces up to 15m deep to be ventilated with a 3m floor to ceiling height. Wind and stack effect ventilation can be combined.

Mixed mode was chosen where additional cooling was needed in some areas (e.g. fitness suites, kitchens in the City Academy project) or as a back-up system in case the office areas got too hot in the summer (e.g. Ceredigion County Council)

Figure 1 Cross-section showing stack effect using a chimney. Buoyancy causes warm, less dense air to rise,exhausting through openings.

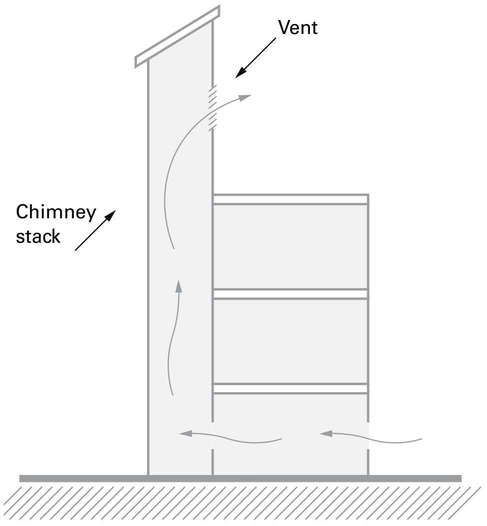


Figure 2 Cross-section showing combined cross and stack ventilation using an atrium

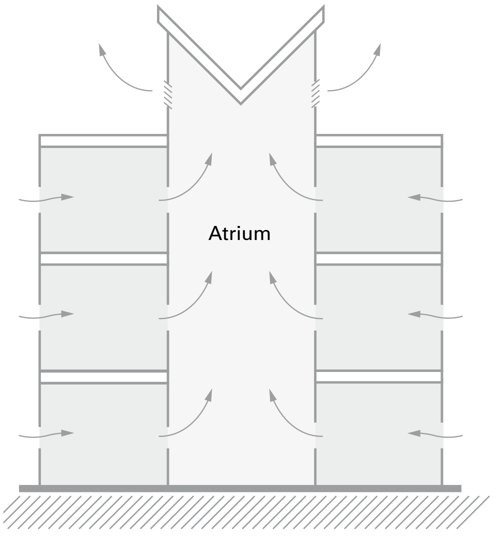
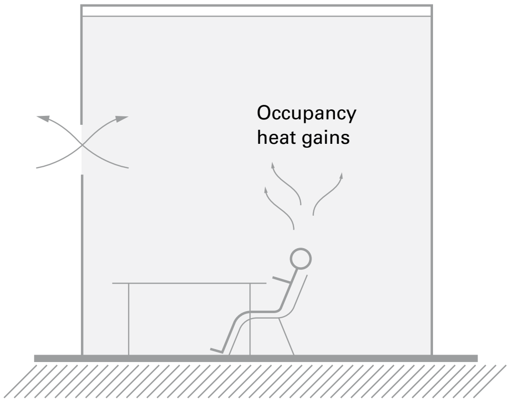


Figure 3 Cross-section showing single sided ventilation aided by wind turbulence



Natural ventilation in tandem with mechanical ventilation

Natural ventilation can be used on its own or in tandem with mechanical ventilation methods. Many of the case study projects adopted this 'mixed-mode' approach, with natural ventilation supported by low carbon mechanical ventilation methods.

Choosing natural ventilation

Before you choose natural ventilation, you need to be sure it will meet your expectations. We asked those closely involved with our case study projects to tell us why they chose natural ventilation, and what they learned along the way.

Motivations

The main attraction of natural ventilation for those we spoke to was the reduction in carbon emissions caused by removing mechanical ventilation. The project teams said they chose natural ventilation as it:

- is cheaper to install and operate than full mechanical plant
- can require less maintenance than air conditioning
- makes occupants feel more comfortable and puts them in control
- changes occupant's expectations and gives them more control of their environment, which means that higher internal temperatures are often accepted in summer
- offers free night cooling, reducing daytime temperatures.

After 12 months, Edge Hill University has reported favourable year-round temperatures in line with design-stage predictions – even with high occupancy.

"The windows open and close depending on the temperature of the room... it never gets too hot and stuffy"

Edge Hill University student

MENU

Universal appeal

Natural ventilation can work in most occupied buildings including offices, universities, schools, visitor centres and council buildings. It can work on its own or alongside other energy-efficient ventilation techniques.

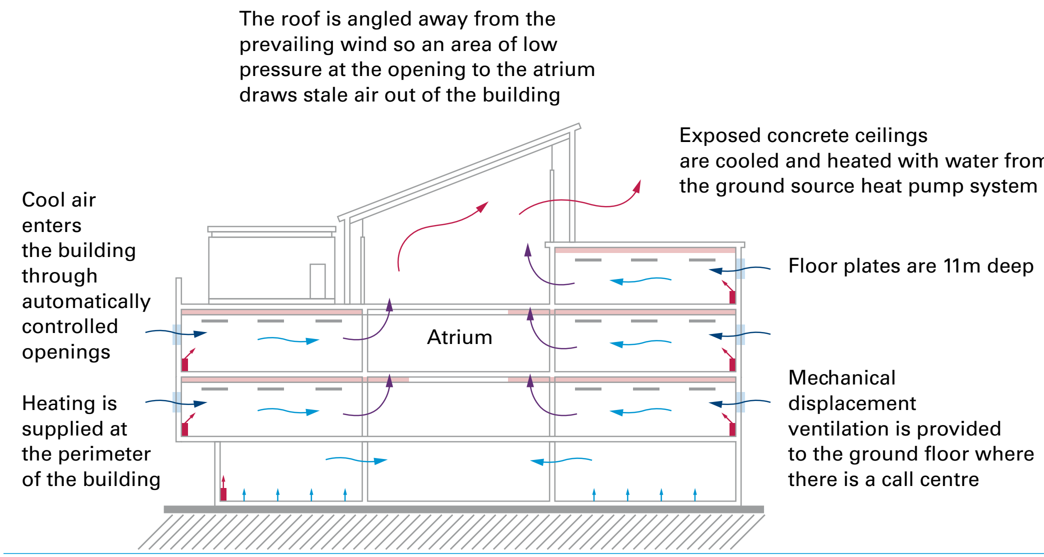
Designing for best performance

Natural ventilation works best when supported by other passive design features or low carbon cooling techniques. For example, internal exposed thermal mass helps regulate temperatures and can also assist night cooling.

Low energy lighting and solar control devices alongside natural ventilation help avoid excessive heat gain in the building.

Ventilation methods should work with the building to optimise air movement. For example, cross-ventilation works with a 'shallow plan', while an atrium can allow air to circulate in a deeper plan building.

Figure 4 The heating and ventilation strategy at St Edmundsbury Borough Council includes natural ventilation.



HELP

MENU

HELP

External noise

Depending on the location of your site, you may be concerned about the noise implications of open windows. City Academy successfully employed natural ventilation despite bordering a busy London street. Horizontal acoustic louvres on the façade, plus extra glazing on the south-west wall created a sound barrier while allowing air flow.

“We tried to plan the building so all areas are naturally lit and naturally ventilated. With a passive approach, you don’t put a particularly large amount of mechanical plant into a building, which reduces costs”

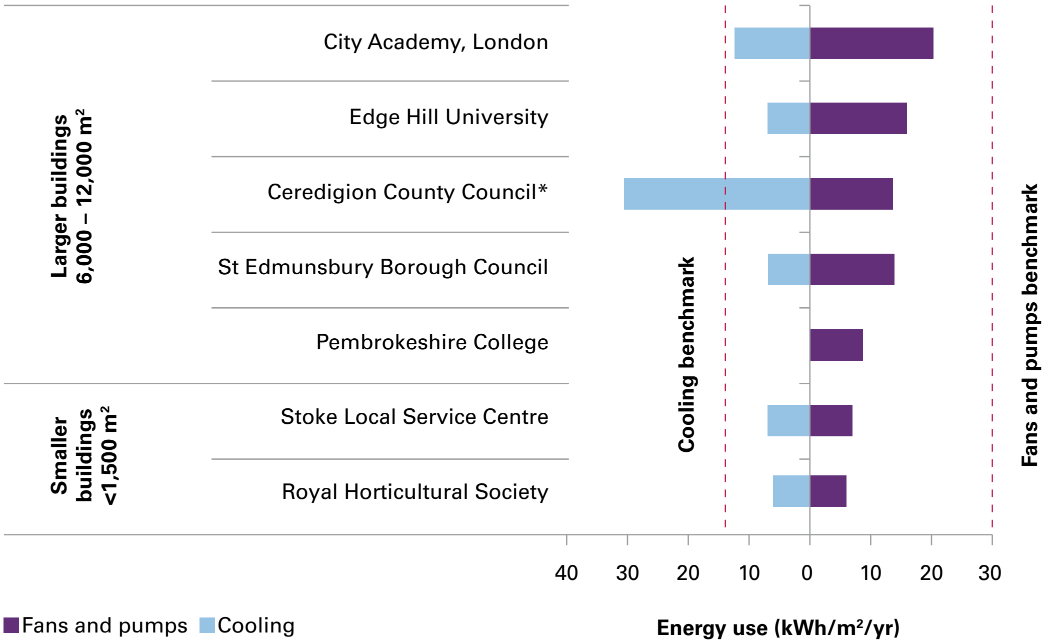
Simon Almond, Project Architect, Edge Hill University

Carbon savings

Four of the six case study projects saved between 24% and 71% of carbon emissions compared to the industry benchmark figures for an average air conditioned building. Carbon emissions from two of the buildings were higher than the benchmarks, but are expected to reduce as the building operation is optimised. Cost savings are between £4,000 and £60,000 a year.

The energy savings for naturally ventilated buildings are associated with reduced use of mechanical cooling (chillers) and fans to move air around the building. All the buildings showed a saving compared to the air conditioning benchmark for fans, and all but one show a saving for cooling.

Figure 5 Energy savings for fans and cooling compared to the air conditioned building benchmark



*High cooling energy use due to large air-conditioned server room

Lessons learned

- A well-designed natural ventilation system can make the building comfortable for occupants.
- Natural ventilation works best as part of a bigger design picture that integrates building fabric, orientation and internal conditions, as well as heating and lighting strategy.
- As natural ventilation leads many aspects of design choices, the decision needs to be made at the earliest stages of a project.
- External noise need not be a barrier to choosing natural ventilation.
- The naturally ventilated case study buildings saved between 24% and 71% of carbon emissions compared to industry benchmarks for an air conditioned building.

MENU
HELP

Designing for optimum results

The success of natural ventilation depends on the building's location, form, fabric, lighting and use. The ventilation strategy should be considered from the earliest stage in the design.

The passive approach

Building form and orientation

New buildings can be orientated to take advantage of prevailing winds and reduce excess solar heat. The St Edmundsbury Borough Council office was orientated to take advantage of prevailing southwest winds by inclining the atrium roof to deliver natural ventilation through the open plan offices.

The building form should allow a simple and effective path for the flow of air, which may mean that the designers need to rethink the layout of the internal space in the building.

One project has a floor with cellular offices ventilated with one window on the façade and a grille above the door. This strategy was not as effective as the open plan areas and the offices were too hot.

Shallow plan

Shallow plan buildings are easier to naturally ventilate. Bideford College was able to locate classrooms on the north side of each learning block and carry air in via large ducting across south-side corridors.

Wind catchers at Stoke Local Service Centre overcome the issue of a deep floorplate

MENU

HELP

The atrium at the City Academy, Hackney

Atriums and deep plan

Deeper buildings, such as at Edge Hill and City Academy, needed atriums to provide cross-ventilation, allowing air from open plan offices to flow in and out of the building.

Stoke Local Service Centre incorporated the library in a wide, older, single-storey building. The floor plate was too deep for cross-ventilation to work so ‘wind catchers’ were used to provide fresh air deep inside the building. These vertical chimneys have compartmentalised vents – one to draw fresh air in, the other to expel stale air out.

Thermal mass in exposed concrete slab at City Academy, Hackney

Thermal mass

Building thermal mass into the design will help regulate air temperature. For example, exposed concrete soffit floors will absorb and release heat.

Allowing cool air into the building overnight can help purge heat built up during the day and cool the thermal mass. Edge Hill achieved this through a combination of manual and automatic window opening.

Ceredigion County Council brise soleil on south facade

Solar shading

All naturally ventilated projects used solar shading to control heat gains from the sun.

Ceredigion County Council assessed how the sun would fall on their building at different times of the year, and designed shading to counter it.

The Royal Horticultural Society’s Bramall Learning Centre avoided overheating on their extensive south façade glazing through the use of an overhanging roof to provide solar shading.

MENU

HELP

Minimising internal heat gains

Most of the projects maximised the use of natural daylight to reduce the level of artificial lighting and associated heat gains. Edge Hill University minimised demand for heating, lighting and ventilation through careful orientation and maximum use of daylight.

Consider the following at an early stage

- Make the decision to naturally ventilate before the building is designed.
- Consider building form, orientation, window opening, solar shading and internal heat gains, and model to predict outcomes.
- Think about the metering and monitoring strategy early in the design process.
- Engage specialists to bring practical experience and costing capability at design stage.

Figure 6 ***Ceredigion County Council office mixed mode features compared to standard air conditioned office***

Default solution	Ceredigion mixed mode solution
Standard lighting, including light fittings in suspended ceilings	Exposed soffits, suspended light fittings and acoustic attenuation Efficient lighting and controls to reduce heat gain
Suspended ceilings	Exposed soffits for thermal mass
Deep floorplates	Shallow floorplates with central atrium to optimise daylight and provide ventilation paths
Standard air conditioning systems	Manual-opening windows, automated windows and vents, displacement ventilation, night-cooling strategy
Highly glazed facade	Reduced glazing areas, external solar shading (brise soleil)
Centralised, automated controls	Openable windows, occupant controlled blinds to manage glare
Enclosed perimeter offices and meeting rooms	Open plan to provide ventilation paths
Standard occupancy levels	Managed occupancy levels

MENU

The mixed-mode approach

Most projects found that natural ventilation was not viable for every part of the building.

Edge Hill University has naturally ventilated teaching, office and communal spaces. However, their lecture theatre is more densely occupied so is cooled by a ground source heat pump supplied by an efficient ventilation system.

Some building types have higher internal heat gains due to large amounts of IT equipment or high solar gain.

St Edmundsbury Borough Council office building delivers extra office cooling through a ground source heat pump feeding into a radiant cooling system in the concrete slab.

The Ceredigion County Council office building also uses displacement ventilation in combination with passive stack natural ventilation to provide additional cooling in the summer, if required.

Controlling and managing mixed mode

Facilities managers have to analyse the energy use in different conditions to effectively manage and control the switch between natural and mechanical ventilation. This analysis is part of the 'bedding-in' period for the building and helps to fine-tune its performance. Once the ventilation strategy has been determined, it needs to be communicated to the building occupants so they know when they should open windows.

Ceredigion has both automatic and manual-opening windows and operates more efficiently when the occupants close windows in cold weather. Similarly, the mechanical ventilation system is a more efficient way to cool the top floors during hot spells.

Design for users

The way that the prospective occupants will interact with the building has to be considered early in the project. This has to go beyond the perception of what designers think is appropriate and actively involve occupants. Designers need to provide local controls for lighting and temperature along with openable windows. The controls need to be simple to understand and provide feedback that they are working.

On one project the local controls for the comfort cooling were being wrongly adjusted by occupants. This was remedied by placing a notice next to them to explain the settings. However, these notices were not concise or clear and were often removed by the occupants. Ideally, the controls should be self-explanatory without the need to add further detail.

HELP

Lessons learned

- The natural ventilation strategy will guide the form and orientation of the building.
- To design effective solar shading, you will need to model how the sun falls on the building at different times of day throughout the year.
- Natural ventilation strategies are more effective when internal heat gains are minimised through the use of low energy lighting, IT systems and equipment.
- If full natural ventilation is not possible, a mixed mode approach can still be highly effective in cutting carbon.
- Consider the needs of users – make sure windows can be opened and closed manually, and controls can be easily understood.

MENU

Successful installation

Finding experienced designers and delivery partners, fostering good relationships and setting up collaborative work practices are all essential if your natural ventilation approach is to succeed.

Building the project team

Creating an effective naturally ventilated building is a team effort. The architect, services engineer, contractor and specialists all need to work together, especially if you are taking a mixed approach to ventilation.

Our case study projects showed that success can depend on the previous experience of the contractors and consultants.

Teams that took early action at key points in the project reaped the rewards later.

At Ceredigion the project team quickly recognised that the proposed natural ventilation strategy was not going to keep the building sufficiently cool in the summer, so they changed the strategy to include additional ventilation and cooling.

Maintaining design performance

A natural ventilation strategy relies on the effective integration of the form and fabric of the building as well as any mechanical systems. After modelling the initial design, you need to consider how any design change, however small, will affect ventilation or heating and cooling performance.

In the case of one project, a value engineering exercise meant that coffered ceiling slabs were replaced with a flat concrete ceiling, reducing the exposed thermal mass. Re-modelling showed that the alteration could leave the building more prone to overheating, so a displacement ventilation system was installed, increasing cost and driving further value engineering in other elements of the building.

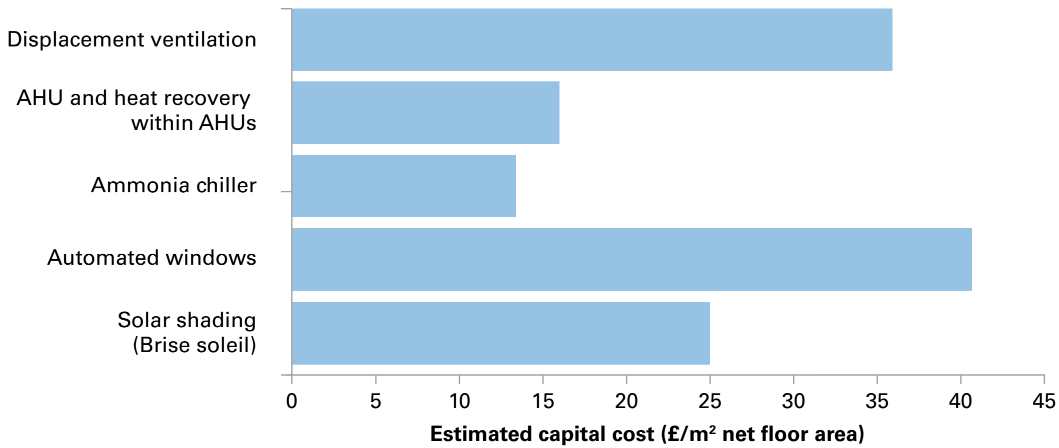
"It did work. It was very much a team effort, and it was on budget as well!"

Andy Brooks, Services Engineer, Scott Wilson, Stoke Local Service Centre

HELP

MENU

Figure 7 ***Estimated capital cost of mixed mode measures for Ceredigion County Council offices***



Note: Exposed soffit, acoustic treatment and suspended lighting compared to standard suspended ceiling not costed

Controlling costs

Naturally ventilated buildings typically have lower capital costs for cooling and ventilation equipment, but some additional capital has to be spent on the façade and building fabric. Mixed-mode buildings require capital to be spent on mechanical services and the façade/ fabric, as shown in *Figure 7*.

Above and top: City Academy windows and actuators

HELP

MENU
HELP

Lessons learned

- To create a successful natural ventilation strategy you need to retain experienced designers and engineers throughout the building process.
- Natural ventilation approaches rely on retaining all building fabric and form measures. If one element is removed, the whole strategy could fail.
- Capital costs for natural ventilation system elements, such as automated windows, can be comparable to air conditioning systems.
- Make sure all relevant suppliers and contractors are briefed on the design intent and bigger vision. They need to understand the natural ventilation strategy as well as the key details.
- Make sure that contractors are familiar with the technologies they are installing and somebody is monitoring the integration of architectural, mechanical and control elements.

Managing the installation process

Installing a whole natural ventilation system may involve sensors, actuators and a BMS system as well as the architectural elements (e.g. windows or vents). The lead contractor needs to co-ordinate the different installers and define responsibilities to make sure that all elements are 'joined up' and deliver the intended design.

You will also need to monitor the quality of the installation process. On one project, the dampers on the intakes weren't correctly fitted, causing draughts, and many window actuators were broken as the installation team weren't aware that they needed to be handled carefully.

Ensuring best performance

Commissioning the building, monitoring performance and engaging with the facilities management team are often overlooked – but are vital if your building is to work. It's also important to make sure the occupants can use the system.

Enhanced commissioning

Rushing commissioning compromises performance. Complex or mixed-mode systems need extra time, but simple systems also need a structured approach. All our case study projects required involvement from the project team for at least one year after completion to optimise operation.

Problems have been experienced when numerous systems are intended to work as one. While in theory this should be possible, extra levels of complexity can be difficult to operate in practice. The entire systems have to be tested to ensure that they are co-ordinated and providing the desired internal conditions.

One case study building has separate control systems operating the heating/ventilation and the cooling in the cellular offices. This results in systems fighting one another and the energy consumption of the entire building increased, with no improvement in comfort levels.

Keep the system as simple as possible. If you design out complications, you design out potential problems

Fine tuning

Commissioning should be treated as an ongoing process. Allow for a certain amount of fine-tuning, particularly in summer and winter, and make sure the team to work together to solve any problems.

When we monitored one office project in detail, we found that a conflict between the natural ventilation and heating controls led to the heating switching on early in the morning after the night cooling mode had cooled the building overnight.

MENU

HELP

Ceredigion County Council uses a natural ventilation strategy with motorised opening windows in the office areas and motorised louvres in the atrium to promote stack ventilation. There was initially a problem when any of the automatic windows on the façade opened slightly, the motorised louvres in the atrium opened fully. This drew too much air through the building and cooled down the building too quickly. The retained controls specialist adjusted the control of the atrium louvres to fix the problem.

Involving the facilities management team

Natural ventilation systems worked noticeably better when facilities management teams were given an in-depth induction about the natural ventilation strategy, including the air flows and performance potential.

Involving building users

Involving building users with the ventilation system helps them feel in control of their environment.

Classroom windows at City Academy are motorised, but manually operated. A 'traffic light' display shows when the windows should be opened or closed, depending on air quality (CO_2 levels). This display is a good example of providing occupants with information on how to control the building. However, the display is small and does not show what action needs to be taken when the lights go on.

Edge Hill University trained natural ventilation 'champions' to understand the system and explain it to others.

Building user guides are extremely important in showing how the building is designed to operate. A well-designed building user guide is something people can return to, and new occupants can use it as a reference.

Ceredigion atrium showing the motorised louvres in the atrium (at high level)

A 'traffic light' display at City Academy shows air quality in the room and indicates when the windows should be opened

Monitoring and measuring performance

Optimising performance is likely to take at least a full year. Feedback about temperature, air quality and comfort can be gathered in various ways:

- **Occupant feedback** – Edge Hill University asks for regular feedback from building users to check that people are comfortable.
- **Temperature sensors and energy meters** – Pembrokeshire College's Building Management System lets the facilities management team see temperatures in each room, allowing them to control comfort and energy use.
- **Soft landings** – City Academy has engaged the design team and constructors on the BSRIA Soft Landings framework agreement. This helps fine-tune the systems and ensures that facilities management teams and building users know how to operate the building as it was designed.

Maintaining the system

Where natural ventilation systems are supported by air intakes, fans, radiant cooling, shading devices or simply open plan spaces, it is important that these are not inadvertently removed, obstructed or covered up later in the building's life. Make sure your maintenance schedule includes key elements such as window actuators and window seals.

Lessons learned

- Commissioning takes time and the system will work best if it is fine-tuned throughout the first year. Ideally the design team should be accessible during this time.
- In-depth training for facilities teams can reduce operating problems later on.
- By recording temperatures, energy use and gathering occupant feedback it is possible to identify any problems and their solutions early.
- Many building features work together to support the natural ventilation strategy. It is important that they are checked and maintained.

Figure 8 ***Project summaries***

	City Academy, London	Ceredigion County Council, Wales	Stoke Local Service Centre, Stoke-on-Trent	Edge Hill University	St Edmundsbury Borough Council	Royal Horticultural Society, Harlow Carr	Pembrokshire College
Description of project	New build school academy	New build office building	New build extension to community building	New build educational building including lecture rooms and offices	New build office building	New build education centre	New build technology training centre for existing college
Features of natural ventilation system	Cross-flow natural ventilation with Mechanical ventilation to areas (fitness suite, kitchen, music rooms etc).	Mixed mode: natural ventilation with back-up displacement system in case of overheating.	Cross-flow natural ventilation with wind catchers and automated windows. Mechanical ventilation to internal rooms.	Natural ventilation plus efficient mechanical displacement ventilation for high-occupancy lecture theatre.	Natural ventilation for office areas with radiant cooling. Mechanical ventilation and cooling for ground floor.	Natural ventilation automatically controlled windows with manual override. Heating integrated with vents.	Natural ventilation for office and classroom areas with automatic opening windows and rooflights. Mechanical ventilation for workshop.
Low or zero carbon technologies used	Photovoltaics, ground source heat pump	Biomass boiler, solar thermal	Photovoltaics, ground source heat pump	Ground source heat pump	Ground source heat pump and solar thermal	Ground source heat pump, solar thermal, wind turbine	Biomass boiler, solar thermal
Monitored electricity use (kWh/m²/year)	82	108	125	88	154	48	36
Monitored gas and biomass (kWh/m²/year)	62	67 (gas) 42 (biomass)	–	5	48	–	33 (gas) 59 (biomass)

Further information

MENU

HELP

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Applications Manual AM10 Natural ventilation in non-domestic buildings. 2005.

This covers the development of a design strategy, a review of ventilation components and how they should be integrated into an overall design philosophy.

Applications Manual AM13 Mixed mode ventilation. 2000.

This includes guidance on mixed mode design, operation and maintenance.

BSRIA

The Illustrated Guide to Ventilation. 2010.

Describes the basics of ventilation and covers natural and mechanical ventilation, the mixed-mode approach, minimising cooling loads, thermal mass, control strategies, commissioning, maintenance, and ventilation standards and requirements.

Controls for End Users. 2009

Concentrates on the strategy, implementation and the user interfaces of control devices for heating, cooling and ventilation, located in occupied spaces and operated by individual users.

Soft landings framework for better briefing, design, handover and building performance in-use, Building Applications Guide BG 4/2009.

This provides a programme of post-occupancy evaluation that the project team can use to improve a building's performance and make it sustainable over the long term.

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Focused on reduction, it is awarded to organisations that measure, manage and reduce their carbon footprint. It is managed by the Carbon Trust Standard Company, which was set up by the Carbon Trust in June 2008. Find out more at www.carbontruststandard.com

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This is managed by the Carbon Trust Footprinting Company, which was set up by the Carbon Trust in 2007. Any product that has had its carbon footprint calculated and verified by an accredited verifier can have the label on its packaging or marketing material. It shows the total greenhouse gas emissions arising from every stage of the product's life cycle, including production, transportation, preparation, use and disposal. Find out more at www.carbon-label.com

Helpline

Call 0800 085 2005 for independent, authoritative advice from our experts. Lines open 8.30am-5.30pm, Monday to Friday.

MENU

HELP

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We help to cut carbon emissions now by:

- providing specialist advice and finance to help organisations cut carbon
- setting standards for carbon reduction.

We reduce potential future carbon emissions by:

- opening markets for low carbon technologies
- leading industry collaborations to commercialise technologies
- investing in early-stage low carbon companies.

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The Carbon Trust receives funding from Government including the Department of Energy and Climate Change, the Department for Transport, the Scottish Government, the Welsh Assembly Government and Invest Northern Ireland.

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 4190230 with its Registered Office at: 6th Floor, 5 New Street Square, London EC4A 3BF.

Published in the UK: July 2011.

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