Guidelines on ventilation, indoor air quality and thermal comfort for schools

Launch of revised Building Bulletin (BB)101

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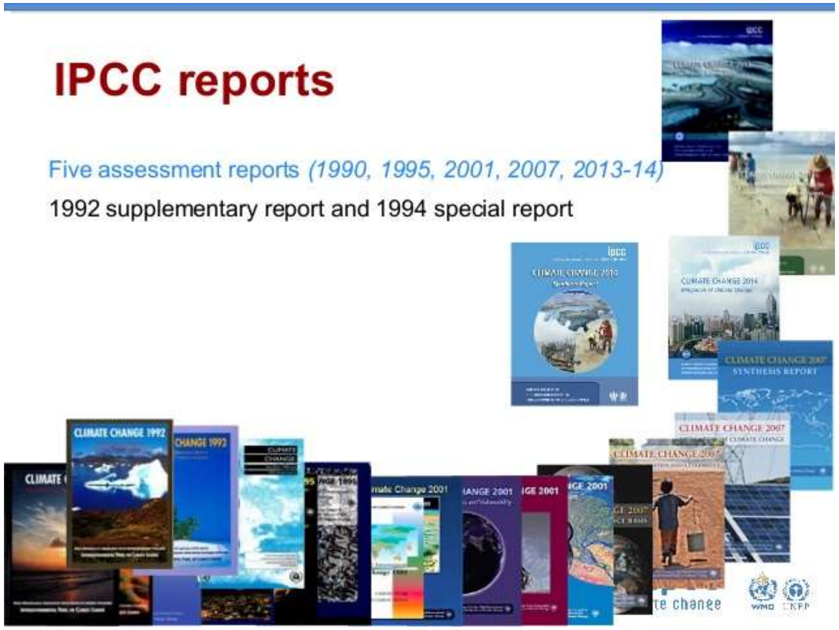
Department
for Education

Timeline

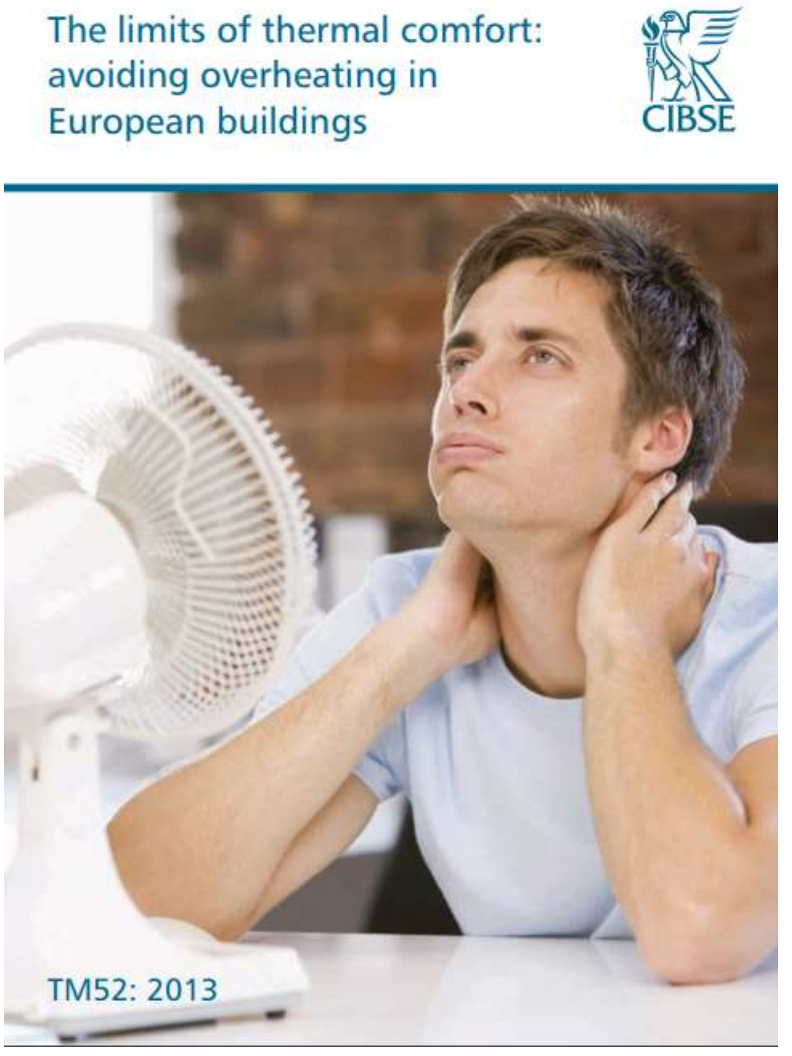
- Previous BB101 was published in 2006. Much has changed in the interim
- UK Climate Change Act, 2008
- IPCC Fourth Assessment Report, 2007; and Fifth Assessment Report, 2013-14
- National Adaptation Plan for Climate Change resilience, 2018
- UKCP18 new climate projections published in November 2018



Timeline

New industry guidance relevant to overheating risk assessment

- CIBSE TM 52 The Limits of Thermal Comfort: Avoiding Overheating in European Buildings, 2013
- CIBSE TM 48 The use of Climate Change Scenarios for Building Simulation, 2014
- CIBSE TM 49 Design Summer Years for London, 2014
- CIBSE TM 59 Design methodology for the assessment of overheating risk in homes, 2016
- New CIBSE weather data, include future climate weather files (based on UKCP09), released in 2016



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The DfE Output Specification, 2017 is fully aligned with BB101, 2018

- Priority School Building Programme, Facilities Output Specification (FOS) 2013 already included updated overheating criteria aligned with CIBSE TM 52
- The ventilation, thermal comfort and indoor air quality design requirements in the revised BB101 are the same as those published in the revised OS in 2017

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Areas covered by BB101

- Indoor Air Quality
- Ventilation
- Local Exhaust Ventilation
- Thermal comfort

Indoor air quality

Carbon dioxide concentration is the indicator used to provide enough fresh air in teaching spaces.

BB101 Guidance on pollutants has been brought up to date.

The guidance covers:

- particles and the range of indoor and outdoor pollutants
- Sources of indoor air pollutants and source control
- advice is given on reduction of pollutants by positioning of air intakes and use of filters
- extensive references are provided to research on air quality in schools

Indoor Air Quality and children's health

- The UK has one of the highest prevalence rates of childhood asthma among European countries, with almost 10% of children (1.1 million) suffering from symptoms (WHO, 2010)
- More research is needed on the reasons why
- Data indicates that a sub-population of school-aged children with asthma receive challenges when returning to school that trigger their asthma (Julious et al. 2007)
- Only a few studies address the epidemiological associations with exposure to PM10 in school children and the health impacts of PM2.5 and PM1.
- Particulate matter monitoring (PM) in classrooms is complicated by large differences in studies' design, including duration, number of schools monitored and instrumentation used.

BB101 requirements on CO_2 level (Ventilation)

In addition to the general ventilation requirements of Section 4 of Approved Document F 2010 (ADF), the following DfE performance standards for teaching and learning spaces are set out in BB101.

Sufficient outdoor air should be provided to achieve:

1. Mechanical ventilation or hybrid systems:

- daily CO2 concentration < 1000 ppm (when occupied)
- max CO2 concentration < 1500 ppm (for more than 20 min, each)

2. Natural ventilation

- daily CO2 concentration < 1500 ppm (when occupied)
- max CO2 concentration < 2000 ppm (for more than 20 min, each day)

3. - CO2 concentration < 800 ppm above the outside CO2 level for the majority of the occupied time during the year (ie the criteria for a Category II building in the case of a new building)

   - CO2 concentration < 1350ppm above the outside CO2 level (ie, a category III building, in the case of a refurbishment).

See Table 3.7 of BB101 for definitions of comfort categories.

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Occupant density of classrooms and perceived IAQ

Average primary class size (Eurostat, 2011)

- EU countries and US: average 20.8 ± 2.0 pupils; density ranging from 2 to 3.1 ± 0.3 m^2/person.
- UK recently built classrooms: density of 1.72m^2/person

High occupancy densities in school classrooms result in high internal gains, emissions of body odour together with various indoor pollutants.

The ventilation must be well designed to cope with high occupancy densities.

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Recommendations on IAQ

- WHO Indoor Air Quality Guidelines (WHO, 2010) &
  UK ambient air quality guidelines (DETR, 2007);
- ADF performance levels (2010);
- Indoor air pollutants (including Sinphonie's project, 2014);
- Sources of indoor air pollutants and source control.

References

WHO (2010) WHO Guidelines for Indoor Air Quality: Selected pollutants.

DETR (2007) The Air Quality Strategy for England, Wales and Northern Ireland

Approved Document F1 (2010) Means of ventilation

Kephalopoulos et al. (2014) *Guidelines for healthy environments within European schools, Sinphonie project;* ISBN 978-92-79-39151-4

Chatzidiakou et al. (2012) *What do we know about indoor air quality in school classrooms*? Intelligent Buildings International, 4:4, 228-259

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Key points – Ventilation

Cold draughts in wintertime

Window and ventilation design needs to allow large volume flow for summertime ventilation and prevent dumping of cold air onto occupants during winter.

Blinds and restrictors

Windows, vents and blinds need to be robust and easy to operate:

- Window ventilation openings should not be obstructed by blinds or curtains when these are opened
- Blinds should not cut off all daylight and views out
- Where dim-out blinds are required, they should provide a suitable daylight illuminance in the space and should not restrict ventilation.

Ventilation standards

- Building Regulations Approved Document AD F
- ASHRAE 62-1
- EN 13779 standards for filtration of outside air
- CIBSE AM10 will also be revised soon
- IGEM UP11 Gas safety in educational buildings, Revision was published this year and the two documents are aligned;
- European guidelines on air quality
- Other standards

Ventilation design

Fresh air is critical for health and hygiene

Poorly ventilated rooms see concentration levels fade within 10mins

- Typical solutions use hybrid ventilation
  to provide ventilation in winter (draft free) and
  to boost summertime ventilation (on still days)

- Single-sided natural ventilation is relatively ineffective

- Climate resilient designs use the combination of thermal mass and cross ventilation

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Ventilation

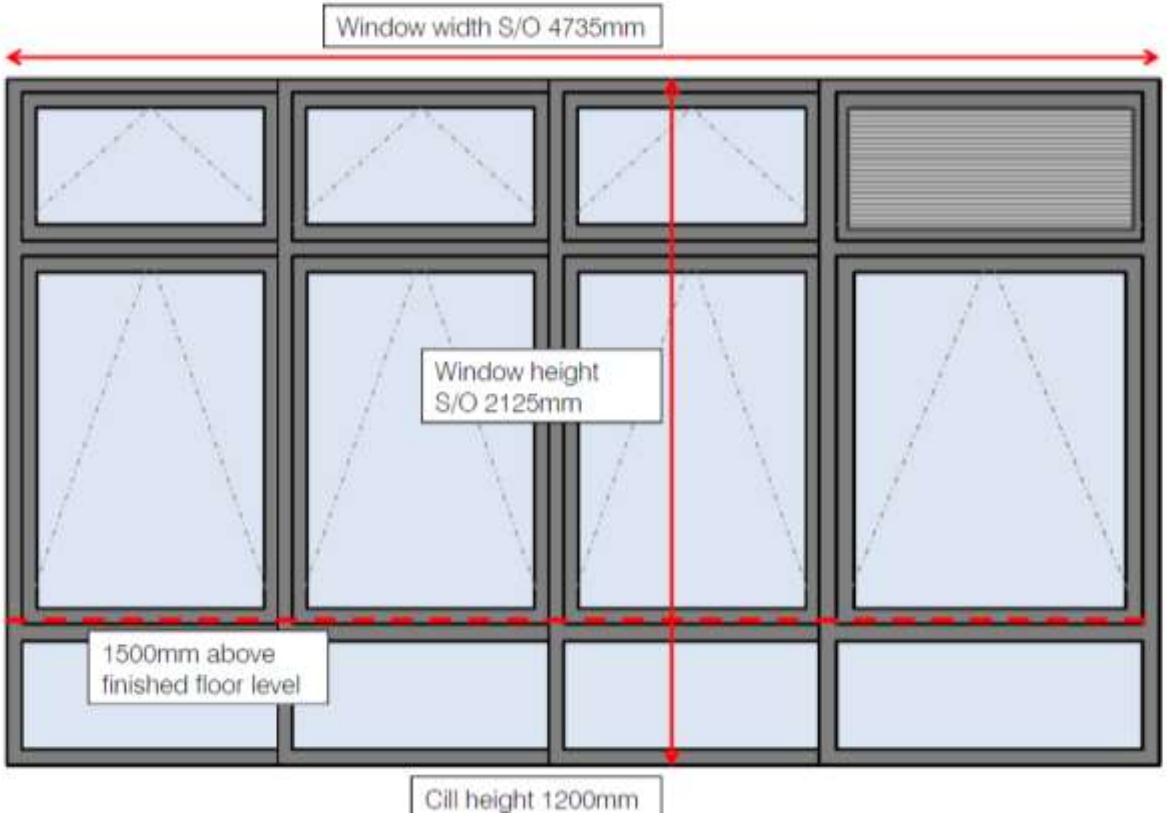
Fresh air is critical for learning, health and hygiene

The CO_2 levels required of 1000ppm-1500ppm in classrooms can be exceeded within 20 minutes of the start of a lesson.

What can go wrong?

- *Levels in poorly ventilated classrooms of over 2500ppm throughout the day are common in schools. At these levels concentration fades.*
- Openable areas too small and single sided ventilation does not provide adequate ventilation in summertime mode. Restrictors are often too short.
- Lack of user/management control

Typical window elevation and restrictors



Windows that are accessible, ie with a cill or furniture adjacent on which children can stand or with the opening at 1500 mm above finished floor level or below need to be restricted to 130 mm maximum clear opening

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Louvres provided on classroom vent units

Rubber seals coming out - louvres are screening type not rated as weather louvres

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Ventilation louvres

Screening type of weather louvre which leaks on many projects where fitted

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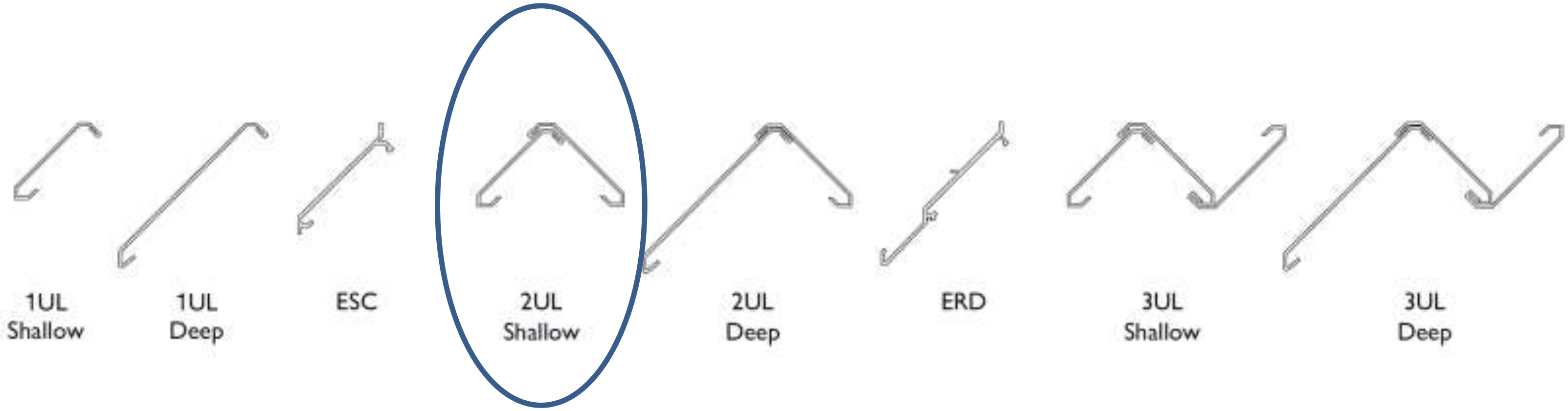
Profiles of louvres made by Colt



2UL is the minimum recommended for classroom protection

NB: Waterloo grilles catalogue on line does not feature any external louvres that are rated as weather louvres to the BS EN 13030: 2001

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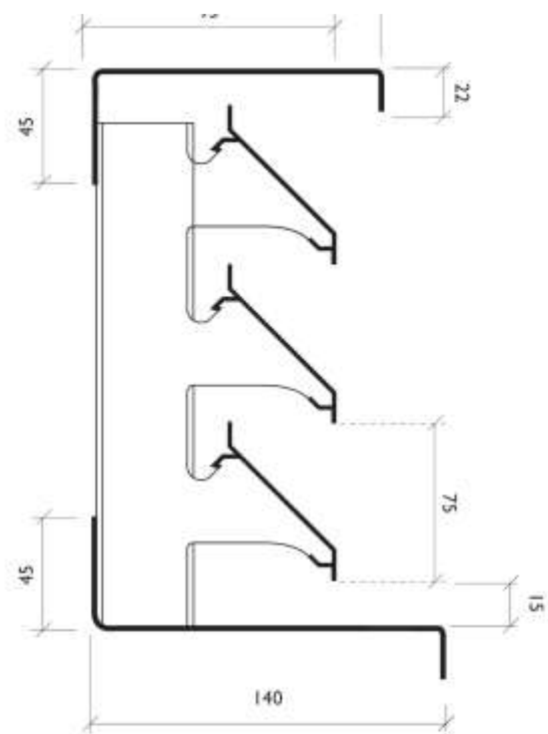
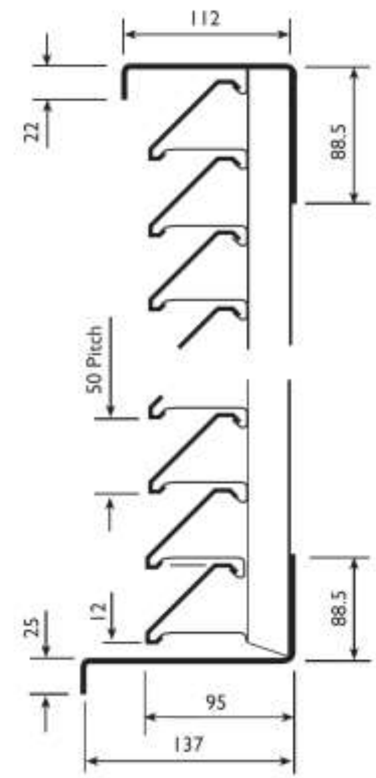
Screening type louvres used to hide plant on roofs or where rain penetration is not important

Class D

Colt screening louvres providing only limited protection from driven rain





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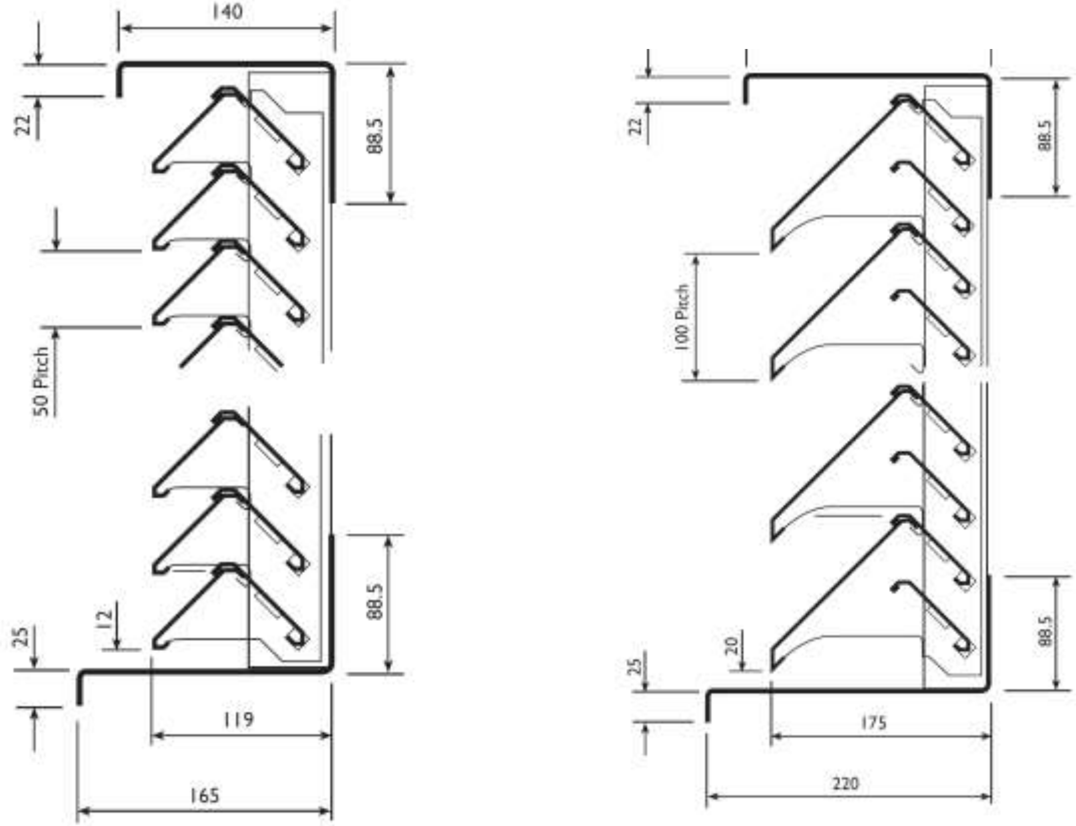
Weather louvres



Class A : Colt louvres that provide weather protection

Weather louvres

Weather louvres should be Class A rated to BSEN 13030:2001

Classes to BS EN 13030:2001			
		Max allowable rain penetration litres/hour per square metre	
Class			
A		0.75	Performance (or weather louvre) to protect the room beyond from rain penetration
B		3.75	Standard louvre
C		15	Screening louvre used to screen unsightly plant on roofs
D		>15	Screening louvre used to screen unsightly plant on roofs Screening louvre

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Blinds

If light transmission is too high there will be too much glare to see the whiteboard. If it is too low the room will be too dark.

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Ventilation Design – specialist ventilation

BB101 contains detailed guidance on:

- Science Labs and fume cupboards (Practical spaces)
- Kitchen and food room vent/windows/doors
- **Design and Technology spaces**
    - Local exhaust ventilation (LEV) to practical spaces
    - LEV required in rooms with 3D printers/laser cutters/ reprographics rooms
- See IGEM UP/11 "Gas safety in educational buildings" - published in 2018
- We are now working on a guide for school teachers and managers IGEM UP1101 to be published in 2019

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BB101 requirements for Specialist ventilation

Practical space ventilation rates in new BB101 - based on $l/s/m^2$ not air changes per hour – following ASHRAE 62-1 2014 methodology for calculation of minimum exhaust rates

Fume cupboard extract - chimney heights increased to 3m minimum.

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Thermal Comfort

Thermal comfort considerations involve a range of factors

- Operative temperature range
- Categories of thermal comfort for different activities and types of pupils – e.g. SEND
- Adaptive thermal comfort criteria for the avoidance of summertime overheating for free running buildings
- Cold draughts - Use window and damper draught calculator
- Radiant temperature difference - Use radiant panel calculation table and calculator
- Vertical Temperature Difference (stratification)
- Hot or cold feet caused by floor surface temperature

Thermal Comfort standards

Values in BB101 are derived from experience but related to EN 15251, PPD related research (Fanger work for adults) and the following thermal comfort standards.

- Workplace Regulations on Ventilation and Temperature
- PD CR 1752: 1999 Ventilation for buildings – Design criteria for the indoor environment
- BS EN ISO 7730: 2005 Ergonomics of the thermal environment (PMV and PPD indices) –local comfort criteria
- EN 15251 for adaptive thermal comfort is being revised and will supersede what is CIBSE TM52
- ASHRAE 55
- DfE cold draught criterion

Operative temperature vs air temperature

- BB101 specifies operative temperatures for design
- But uses air temperatures for performance in use checks

Heating demand

Classrooms have high internal gains – 30 pupils at 80W each in a 60m^2 classroom is 40W/m^2. Add some equipment and the total quickly gets to 50W/m^2

If design day heating is 60W/m^2, internal gains provide all the heat that is needed until the outside air temperature is <5ºC.

How many school days are colder than 5ºC each year?

Around 30? So heating energy in occupied hours is only needed 30 days/year. If your heating boilers are going to be hot for 200+ days/year – that will waste a lot of energy.

Thermal comfort in summer

High temperatures affect student performance

What can go wrong?

- Design to fixed temperature limits in BB101 e.g. max. 28^{0}C is inadequate for mechanical and hybrid systems.
  - Since 2013 the FOS has requiresd design to CIBSE TM 52/ European Standard EN 15251 Adaptive thermal comfort criteria
- High solar gain due to too much glass
- Lack of thermal mass and less openable area than needed for summertime ventilation
- Ineffectiveness of single sided ventilation for summertime ventilation.

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Changes to BB101 summertime thermal comfort calculations

2006 Edition

- Fixed temperature threshold criteria
- CIBSE TRY
- Defined analysis period and hours of occupation

2018 Edition

- Adaptive thermal comfort criteria
- CIBSE DSY1 2020 50%
- Detailed guidance on internal gains and more

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Key changes - detail

- Criterion 1 of CIBSE TM52 is used as the minimum requirement for demonstrating compliance with BB101 (threshold of 40 hours exceedance)
- Occupied throughout summer period, 09:00 to 16:00, Monday-Friday
- No internal gains in teaching spaces during the lunch period 12:00 to 13:00

Primary School
Equipment: 5W/m^2
Lighting: 7.2W/m^2
People: 60W (pupil), 70W (teacher)
Secondary School
Equipment: 10W/m^2
Lighting: 7.2W/m^2
People: 70W/person

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Key points – thermal comfort

- Mechanical cooling should not be necessary in classrooms and teaching spaces and minimised elsewhere, e.g. in server rooms.
- We are not designing for legacy equipment but for the loads specified in the OS of 25W/m^2 for practical spaces and IT rooms and 15 W/m^2 for general teaching spaces.
- Where legacy loads are higher the performance in use criteria for overheating do not apply.
- Criterion 2 is currently a problem as designs usually fail. BB101 revision advisory group is looking at how to deal with this. An option is to revise the criterion to make it a weekly weighted average rather than a daily weighted average. This will resolve the effect of one hot day making the design fail in some locations.

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Thermal Comfort – avoidance of summertime overheating

BB101 uses adaptive thermal comfort criteria for summertime overheating for free running buildings
(NB This does not apply to air conditioned spaces)

- To achieve the overheating criteria, thermal mass and increased ventilation rates need to be considered, especially in the heat islands of cities
- Limiting solar gain and cross ventilation need to be considered at an early stage of the development of the design

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Avoidance of summertime overheating

Building designs are assessed for overheating and ventilation

- Openings are sized using dynamic thermal modelling using:
  - CIBSE DSY 2020 (50^{th} percentile range) weather file most appropriate for the location of the projects

  Note: The 2020 year uses the 30 year average of weather years from 2009 to 2039.
- For climate resilience it is also advisable to model against predicted future DSY weather years for 2050 and 2080
- DfE will be reporting on the resilience of school designs in the Climate Change Adaptation National Adaptation Plan published annually by DEFRA on behalf of the UK government

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Impact – Results of Testing

- We have modelled some PSBP1 schools to examine performance when assessed against CIBSE future weather files in different geographical locations (Nottingham, Swindon, Manchester, London)
- Primary and Secondary school designs outside London complied with new criteria
- Additional passive design measures required to comply in London, but technically feasible using hybrid ventilation systems
- Compliance is more challenging in SW England, particularly in London because of the Urban Heat Island
- Testing demonstrated that changes in BB101 are cost-neutral whilst bringing BB101 up to date with latest industry research and development

Avoidance of summertime overheating

Clients and designers benefit from a standardised overheating risk assessment methodology that is consistently applied to school designs

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Avoidance of summertime overheating

We are working with CIBSE Schools Design Group and have set up a Climate Change Adaptation in Schools Working Group to assess the climate resilience of current designs. The initial report on this will be in October 2019.

DfE will be reporting on the resilience of school designs in the Climate Change Adaptation National Adaptation Plan published annually by DEFRA on behalf of the UK government

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Systems that are effective in summertime

- adaptive teaching environments with easy to understand and responsive user controls
- passive design using thermal mass
- cross and stack ventilation
- shading to prevent summertime overheating
- ability for occupants to increase air movement
- systems that are well designed and installed and commissioned and easy to monitor and control by the school
- air conditioning for peak lopping

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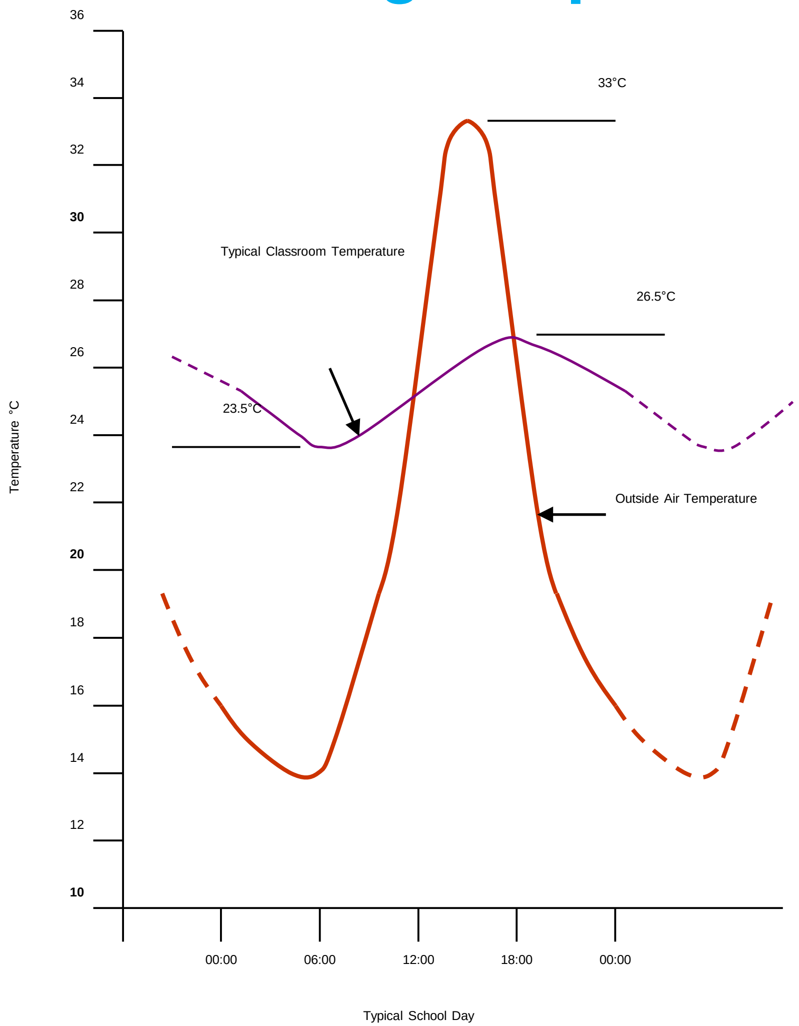
Design to prevent overheating



Output from BMS 15th July 2006

English Classroom 6

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Concrete ceilings and timber-frame external walls

Typical classroom held at 26.5°C when outside temperature 33°C

High mass structure and the high levels of thermal insulation mean building damps down the internal temperature variations

Graph is from Whitecross School, Worcestershire

Design to prevent overheating

Ventilation close to ceiling level is effective for cooling the slab

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Underfloor heating

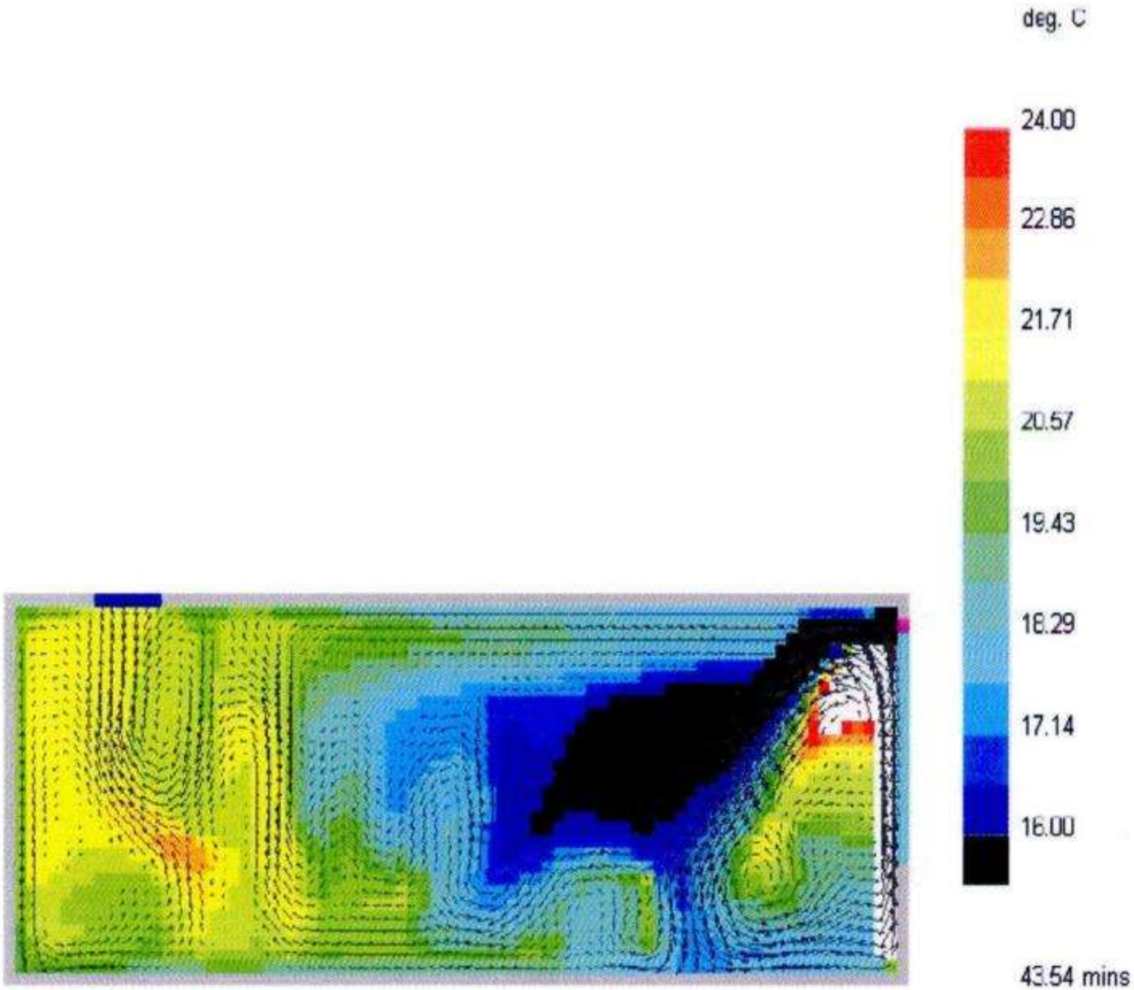
Underfloor heating can cause overheating.

Under-floor heating with surface temperatures above 23ºC can seriously over-heat a room. Floor emitter 'slope' is 11W/m^2 per ºC. A floor at 27ºC will give >60W/m^2.

When a class (40W/m^2) walks in, it will get so hot that the windows will be opened to dump paid-for heating energy.

Screeded underfloor heating has a thermal time constant far longer than a working day. If you turn the heating off at 9am, the floor is still hot at 4pm – A lot of energy can be wasted because the emitter response is too slow.

Thermal comfort in colder weather



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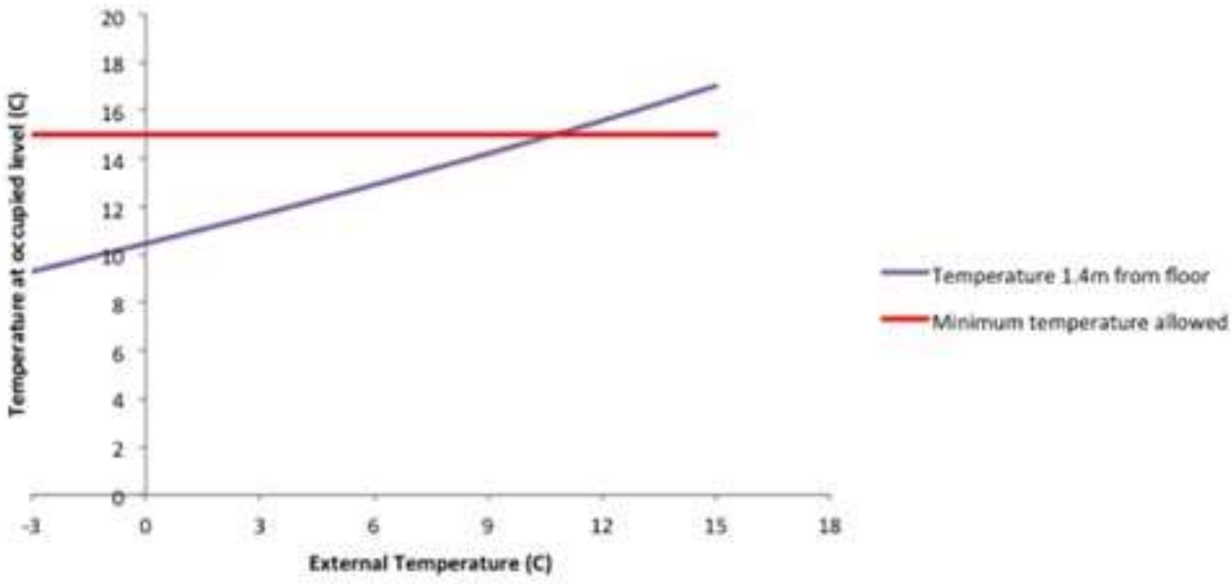
Window and damper draught Calculator



The tool asks for several simple inputs:
Dimensions of the room
Type of inlet (window / damper)
Occupancy
Flow rates

Distance to reach fully turbulent flow	0	m
Width of opening window/damper	4	m
Average temperature of classroom	21	C
Height from floor to ceiling	3	m
Vertical height of opening high level window/damper	0.5	m
High level opening type	Top hung window	
Number of occupants	32	
Minimum fresh air rate per person	5	l/s

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Radiant temperature assymetry

- Radiant panels overhead can be too hot overhead.
- What is the right temperature?
- Calculate the radiant temperature increase at head level due to the panels and limit this.
- BS7726 gives a calculation method that can be used in two ways to calculate:

   1. either the maximum width of a panel directly overhead in a room with a low ceiling; or
   2. the percentage of the room ceiling that can be covered by panels in a room with a high ceiling.

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Hybrid ventilation unit with cloth duct and lighting raft with acoustic baffle

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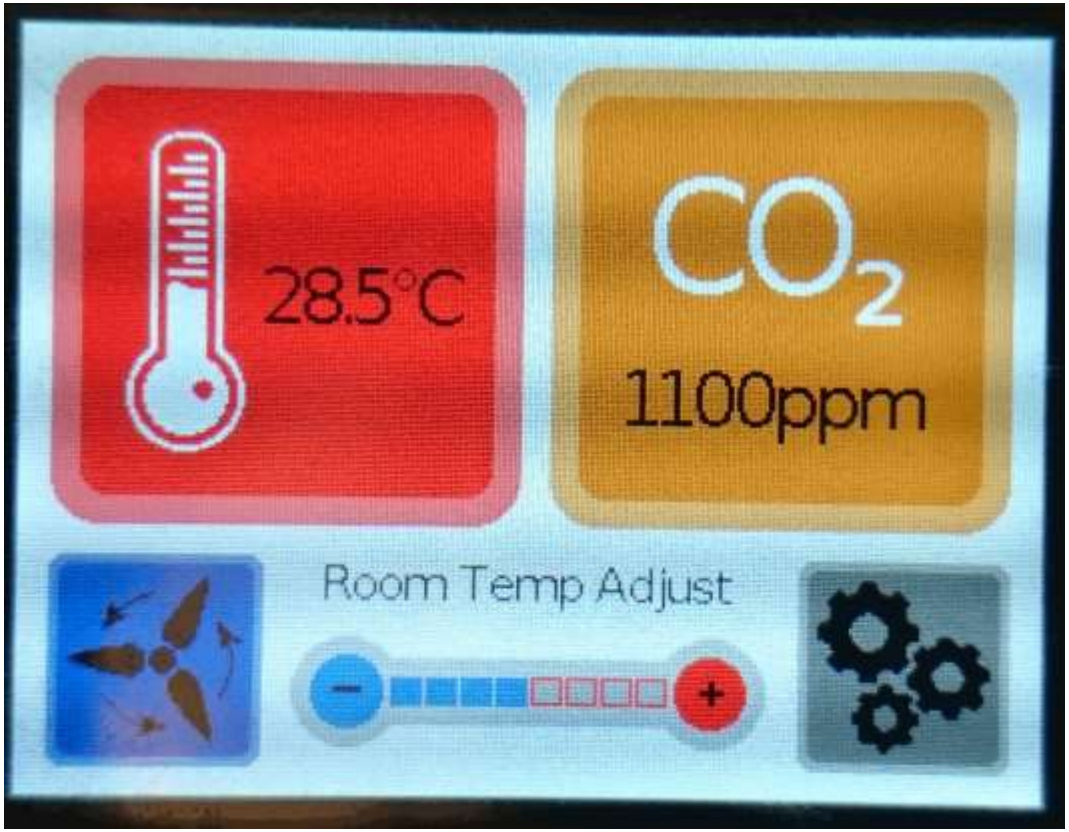
Digital temp and CO2 room controller



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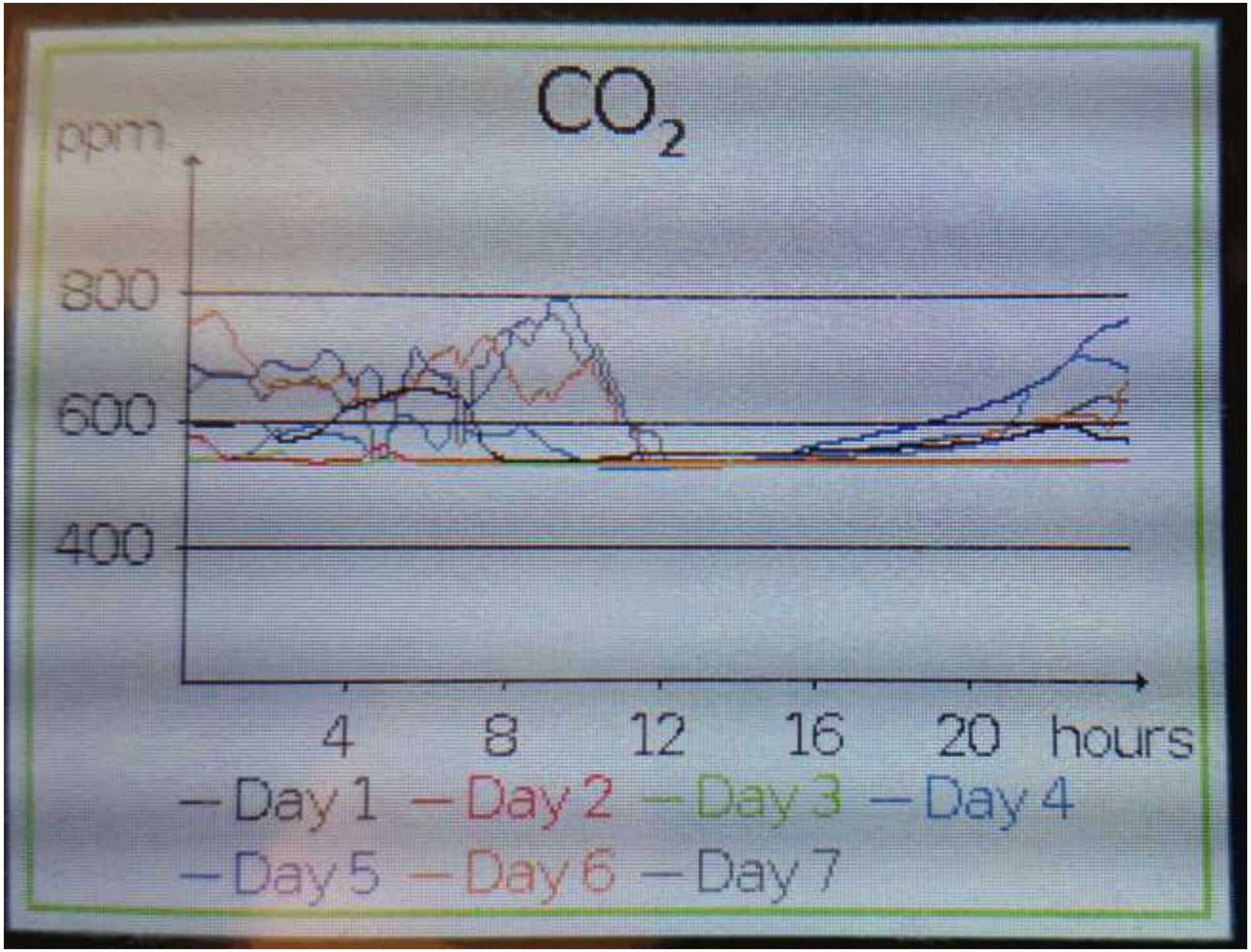
Digital controller data logging



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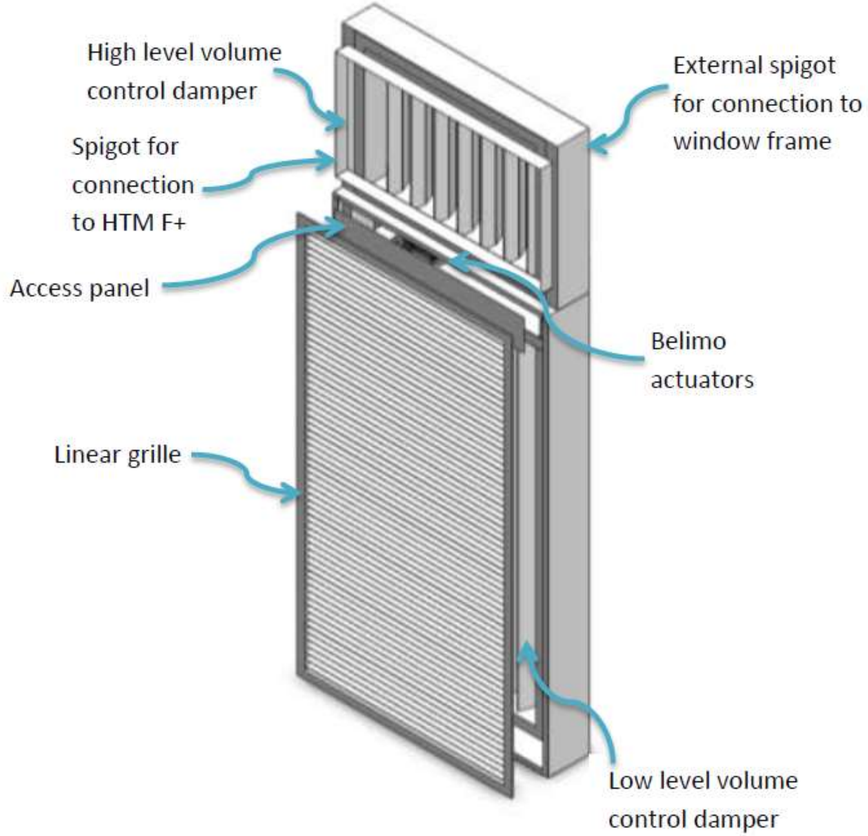
1.2m wide automated natural ventilation louvre

Automated ventilation louvre



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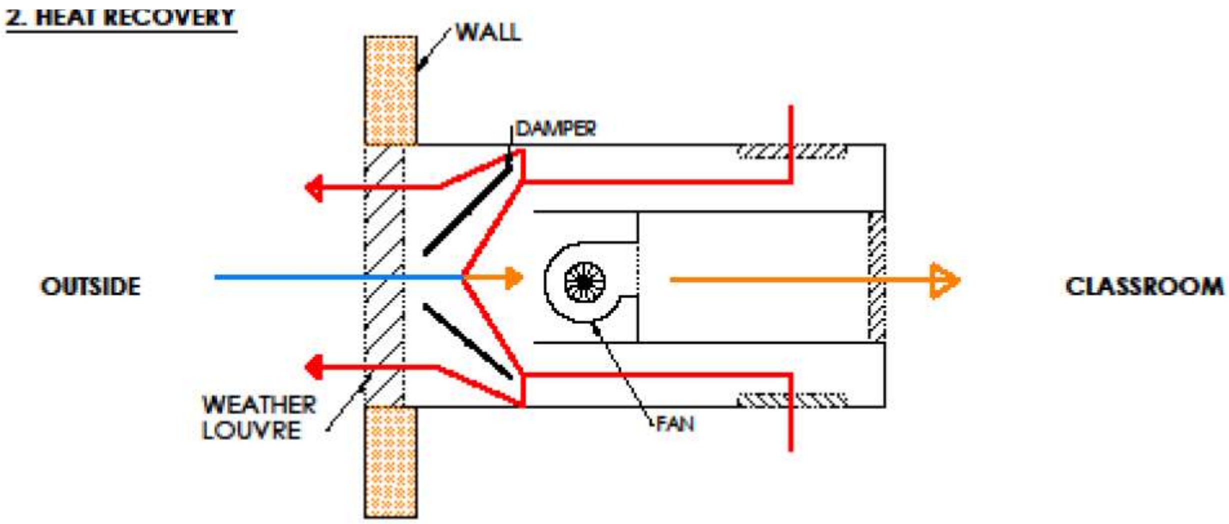
Hybrid mixing unit room controller

CONTROLS AND USER INTERFACE

Wall mounted user controls with:

- Room Temperature and CO_2 sensor.
- On/Off control.
- High, Medium(auto) and Low fan speed settings.
- LED wall panel to indicate when to open windows.

Hybrid mixing unit in heat recovery mode



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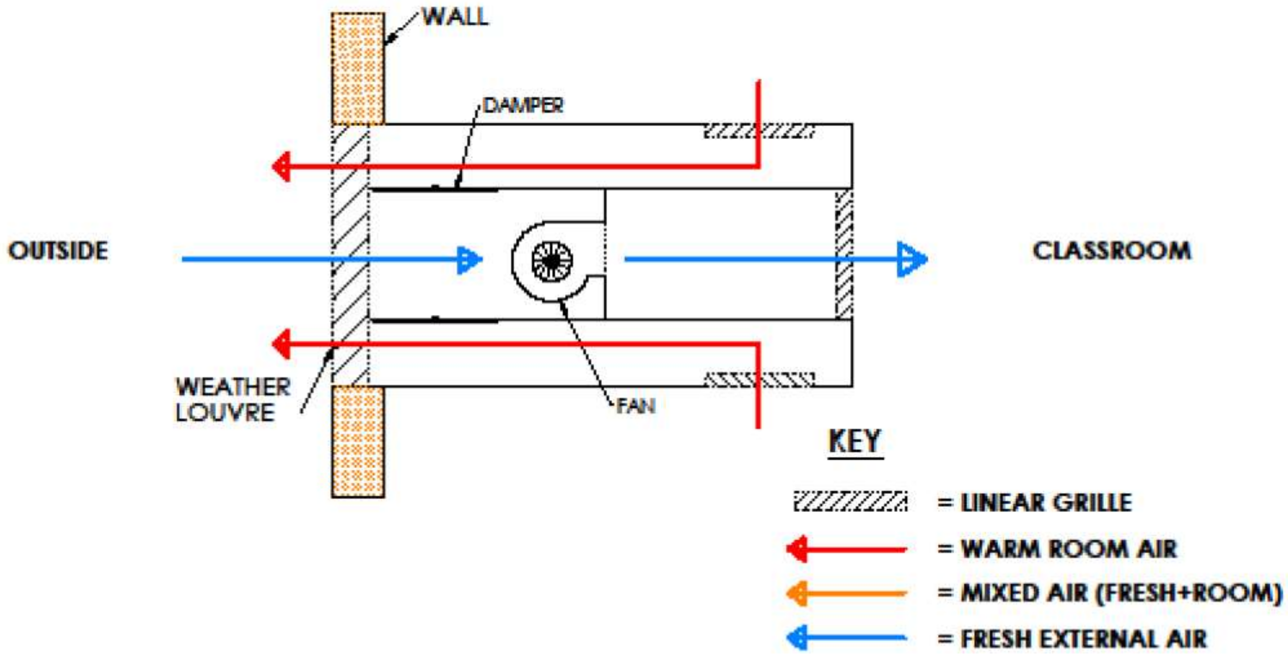
Hybrid mixing unit in full fresh air mode



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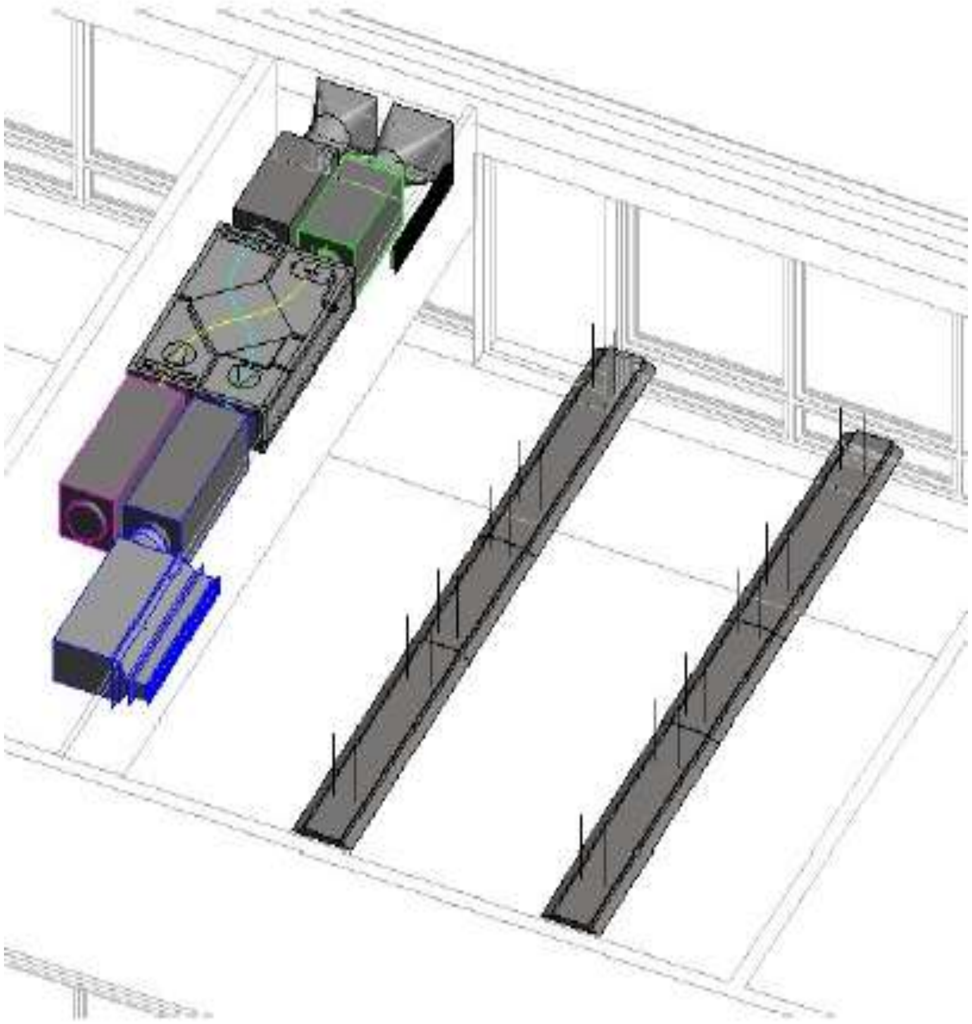
Mechanical Ventilation with Heat Recovery



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MVHR units

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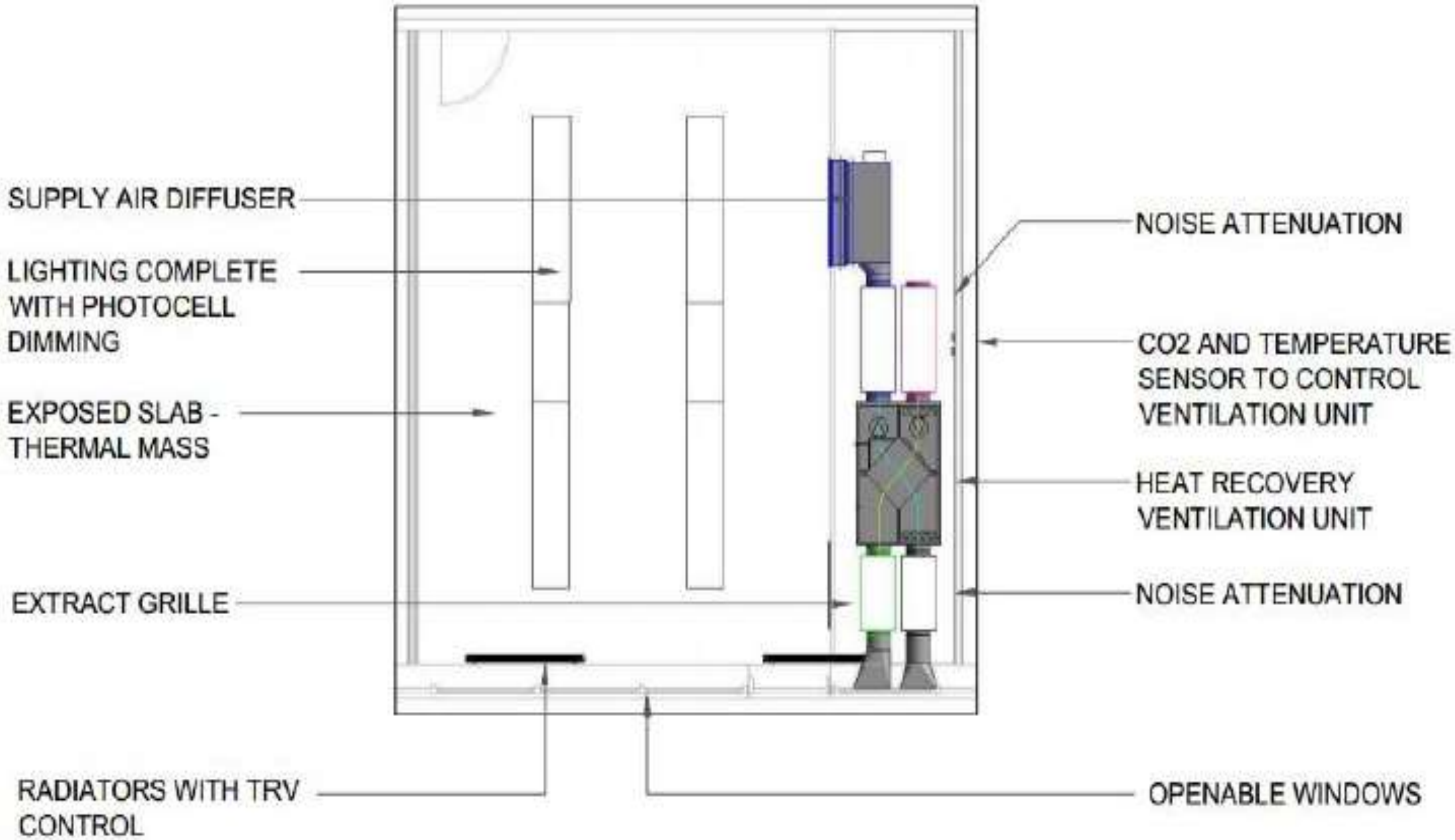
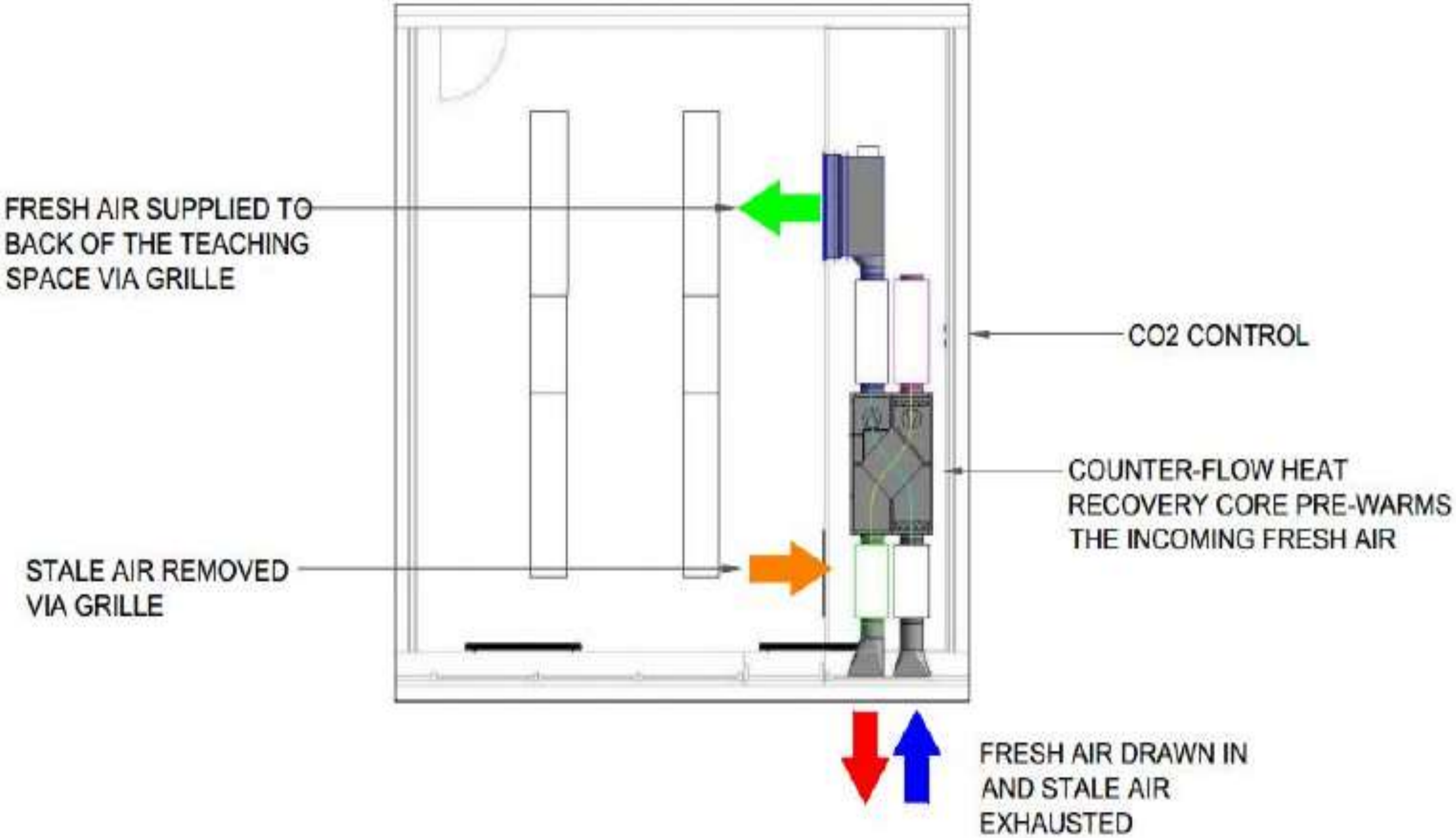
Classroom based mechanical ventilation system with heat recovery



Wintertime ventilation



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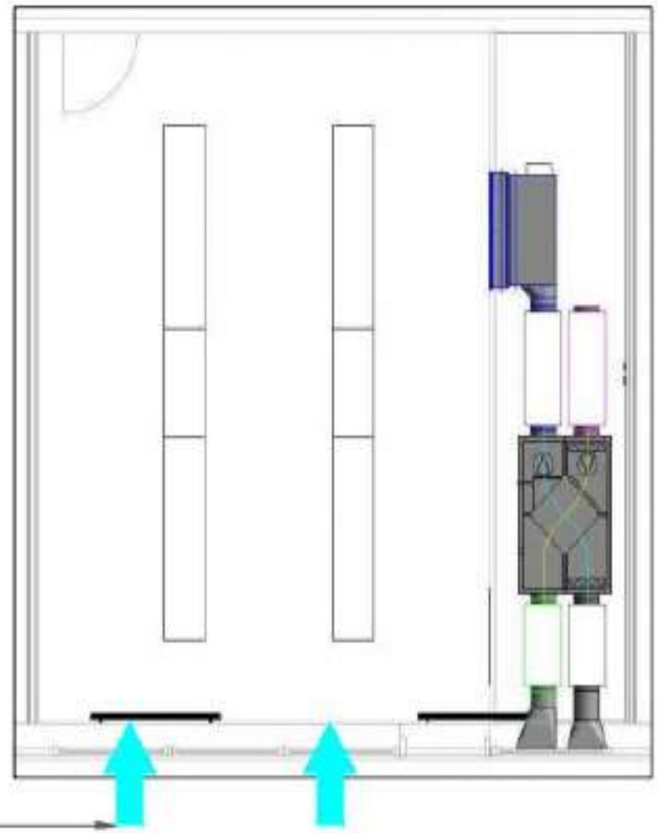
Mid-season ventilation



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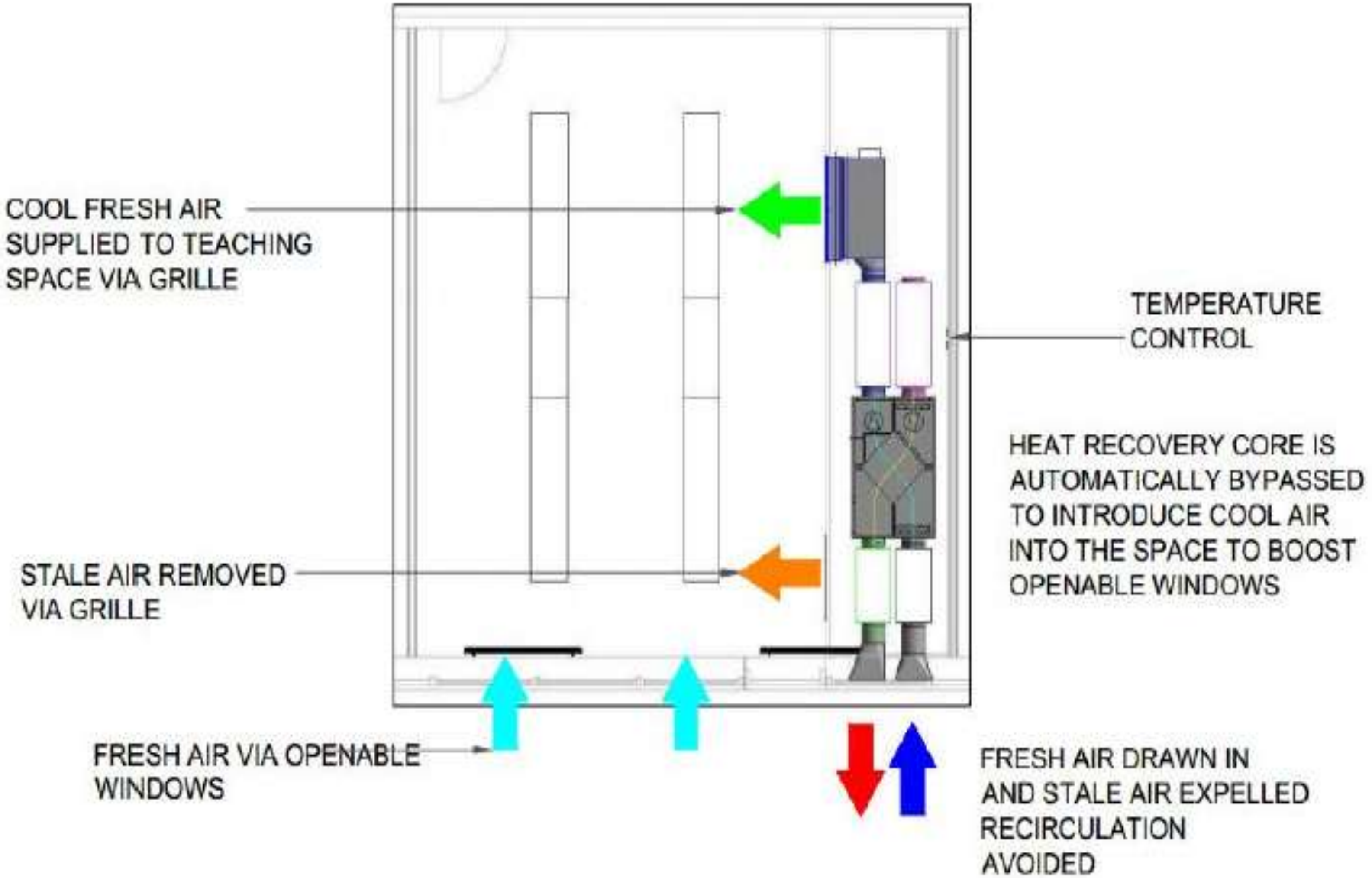
Summertime Ventilation



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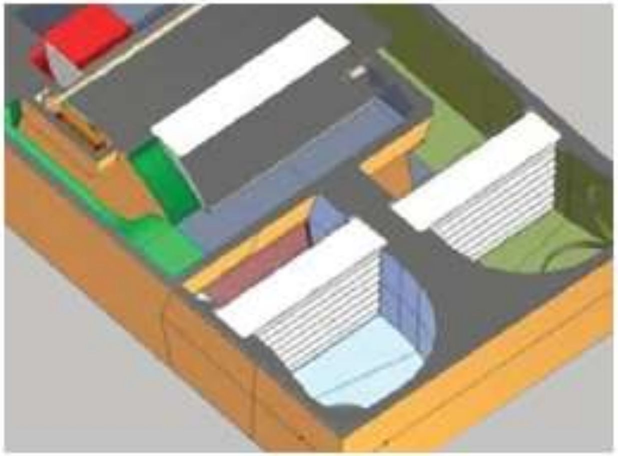
MVHR unit with quick release panel for maintenance

MVHR units require air filters

EN 13779 - M5 Filters as Standard / F7 Optional

Indoor air quality

AirMaster AHU units are provided with filters in both the fresh air intake and exhaust pathways. The filters conform to the requirements of EN 13779, (European Norm which includes guidance on filter selection - ventilation equipment installed in non-residential buildings). M5 Class filters are included as standard, with F7 offered as an alternative where external environments are expected to have a high burden of contaminants.



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Things to look out for

- Window restrictors wrongly designed. Restrictors that are 100mm in length. Should be designed to provide 130mm free opening dimension clear of cills etc.
- Windows that are poorly designed and do not allow control over ventilation and produce cold draughts, eg one big bottom opening pane.
- Louvres on classroom vent units that are not Class A rated weather louvres to BS 13030 but are simple screen louvres and allow rain to enter the classroom.
- Flimsy blinds and mechanisms that are not robust enough for school use and obstruct the air paths.
- Over sized and badly designed air conditioning for summer use.

Window restrictors

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Challenges

Climate change and heat waves

Reduction in capital budgets

Inexperienced client bodies, trusts and sponsors

Lack of experience of contractors and construction industry

Clarity of design brief

Centralised delivery and procurement remote from the users

CLIMATE CHANGE REFERENCE DOCUMENTS

- **Climate Change Risk Assessment CCRA1**
- **NAP1**
- **Climate Change Risk Assessment 2 CCRA2**
- **NAP2**
- **EAC Inquiry on adaptation 2015 EAC 2015 report and government response**
- **EAC Inquiry on heatwaves 2017/18 EAC Inquiry on Heatwaves 2017-18**
- **and government response Government response to EAC Inquiry on Heatwaves**
- **ASC 2015 report ASC 2015 report to Parliament and 2017 Report EAC 2017 Report to Parliament**
- **Not inclusive!**

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OVERHEATING IN BUILDINGS

- **Work on overheating co-ordinated across government. Impacts on buildings as well as health. No one department owns it.**
- **MHCLG – Buildings Regulations and set up Project Board for delivery of overheating research project. Consultation on a method for reducing overheating risk in new homes. To be done in conjunction with Government's review into energy efficiency standards of Building Regulations.**
- **DHSC and partners (PHE) consider public health impacts of overheating**
- **Cross Government group on overheating**
- **Work being done by Good Homes Alliance.**

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COMMITTEE ON CLIMATE CHANGE & ADAPTATION SUB-COMMITTEE

Committee on Climate Change

- **jointly sponsored by BEIS, Northern Ireland Executive, Scottish and Welsh Governments**
- **comprises a Chairman and eight independent members.**

Adaptation Sub-Committee - part of the CCC,

- **also established under the Climate Change Act 2008 to support the CCC in advising and reporting on progress in adaptation. Work is led by a Chair, who also sits on the main Committee, and six expert members.**
- **jointly sponsored by Defra, Northern Ireland Executive, Scottish and Welsh Governments**
- **Audit Committee supports the main Committee and the Chief Executive (as Accounting Officer) in respective responsibilities for control and governance, risk management and associated assurance.**

Benchmark design

- Passive design using thermal mass
- Cross and stack ventilation
- Shading to prevent summertime overheating
- Adaptive teaching environments with easy to understand and responsive user controls
- Systems that are well designed and installed and commissioned and easy to monitor and control by the school

Guidelines on ventilation, indoor air quality and thermal comfort for schools

- includes spreadsheet calculation tools for early design
- published August 2018 on GOV.UK

Please contact the DfE Design Team mailbox for design and technical advice and queries

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