Release date 2018

Building Bulletin 101 - User Guide

BB101 (2018) guidelines on ventilation, thermal comfort and indoor air quality in schools from the Education and Skills Funding Agency - this User Guide summarizes the changes from the previous guidelines and explains how Breathing Buildings can help you comply with the new standards

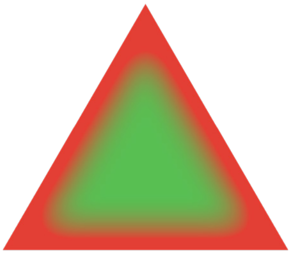
Background

BB101 2018 sets out regulations, standards and guidance on ventilation, thermal comfort and indoor air quality for school buildings. It replaces the 2006 version. The document first describes the factors that affect the design of the indoor environment of schools. It then lays out the regulatory framework for schools and gives the recommended DfE performance standards for compliance with UK regulations. Critically BB101 provides a summary of regulations and recommended performance standards for school designers. The final sections provide detailed non-statutory guidance on how to design schools to achieve adequate performance for ventilation, indoor air quality and thermal comfort.

BB101 2018 is around 150 pages so Breathing Buildings has compiled this easy-to-read User Guide to help you get up to speed quickly. In addition we have developed some online design tools available at www.breathingbuildings.com/services/free-design-tools/

Executive Summary

The document provides a framework which describes the interplay of three key factors – air quality, thermal comfort and energy use.



These factors need to be considered together. For example, it is important to provide sufficient fresh air in winter, but not at the expense of creating cold draughts or high heating bills to try and overcome them. Holistic design is a key feature in BB101 2018 and aligned with the principles of the Breathing Buildings design approach.

Breathing Buildings has compiled this guide to help you quickly grasp the key tenets of Building Bulletin 101 and to explain how we can help you comply with the requirements. We have a wealth of design expertise and modelling tools which can be used during the design stage of a project in order to generate a cost-effective design which meets the requirements for air quality, thermal comfort and energy use. We also have a range of products which can then be used to ensure that the schools deliver the intended results.

For more information get in touch using our contact details on the back page.

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Dynamic thermal mass simulation

Breathing Buildings

BB101

Revised 2018

Air Quality

The first thing to consider in a project is the external environment and the quality of air in the immediate surroundings.

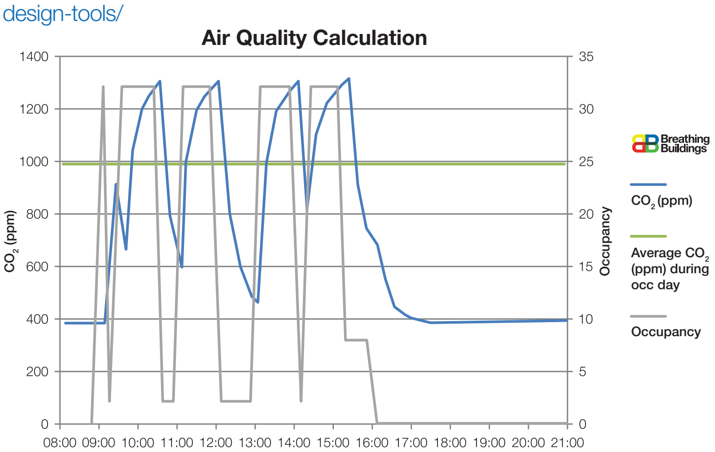
Where outside air pollutants exceed the levels in the National Air Quality Standards consideration needs to be given to means of reducing pollutant levels in the indoor air. This is especially important in Air Quality Management Areas and in Low Emission Zones. Filtration may be needed for two reasons:

1. to prevent dirt accumulating in ventilation equipment such as air handling plant, heat exchangers and ductwork; and
2. to filter out external pollutants if the exterior environment is too dirty to consider unfiltered air. Importantly, the document highlights the fact that filtering out pollutants that have health effects requires more expensive filters.

The air quality in teaching areas is now assessed in the main by monitoring the CO_2 levels. This is because the ventilation rate required in a given space needs to increase with the number of occupants. Occupants generate CO_2 and hence a system which responds to CO_2 levels is a practical way of managing the ventilation rate in accordance with the requirements, and enables ventilation rates to be reduced at times of lower occupancy. However, in some areas such as science laboratories there are further checks because of the potential presence of additional contaminants.

Online CO_2 calculator

Breathing Buildings has developed an online design tool to help determine the flow rates required to meet the new air quality guidelines. The free tool is available for download from www.breathingbuildings.com/services/free-design-tools/



Example output from online design tool CO_2 calculator

For a given occupancy input by the user, the tool provides a graphical output showing whether the chosen flow rate is sufficient.

Normal teaching areas

Mechanical ventilation

Mechanical ventilation is where the driving force for the supply of fresh air and/or extract of stale air is provided by a fan. In general teaching and learning spaces where mechanical ventilation is used or when hybrid systems are operating in mechanical mode, sufficient outdoor air should be provided to achieve a daily average concentration of carbon dioxide during the occupied period of less than 1000ppm, when the number of room occupants is equal to, or less than the design occupancy. In addition, the maximum concentration should not exceed 1500ppm for more than 20 consecutive minutes each day when the number of room occupants is equal to, or less than the design occupancy.

Natural ventilation

Natural ventilation is where the driving force for the supply of fresh air and extract of stale air is buoyancy and/or wind. In general teaching and learning spaces where natural ventilation is used or when hybrid systems are operating in natural mode:

a. Sufficient outdoor air should be provided to achieve a daily average concentration of carbon dioxide during the occupied period of less than 1500ppm, when the number of room occupants is equal to, or less than the design occupancy. In addition, the maximum concentration should not exceed 2000ppm for more than 20 consecutive minutes each day, when the number of room occupants is equal to, or less than the design occupancy; and
b. The system should be designed to achieve a carbon dioxide level of less than 1200ppm (800ppm above the outside carbon dioxide level, taken as 400ppm) for the majority of the occupied time during the year. This is the criterion for a Category II building in the case of a new building; or 1750ppm (1350ppm above the outside carbon dioxide level), for a category III building, in the case of refurbishment or remodelling (see next page for definitions of Category types).

CO_2 should be measured at seated head height in all teaching and learning spaces.

Specialist teaching areas such as science laboratories

In accordance with IGEM standards, gas interlocks by environmental monitoring of CO_2 should operate as follows:

a. During practical activities, the appliances shall not cause the CO_2 level to exceed 2800ppm, which will produce a high level warning signal.
b. An automatic gas shut down shall operate when the level of 5000ppm of CO_2 is reached.

At 2800ppm supply and extract systems should be automatically switched on or boosted and the teacher should be warned that ventilation needs to be increased. Systems to control the ventilation can include individual canopies vented externally, supply air fans or opening windows. When the CO_2 level is below 2800ppm these ventilation systems can be under automatic demand control with teacher or user override, so that noise levels can be easily controlled and energy use can be minimised. Openable windows alone is not an adequate means to control CO_2 levels in these practical spaces.

Building regulation AD F requires local extract of moisture, fumes and dust. BB101 therefore states that additional ventilation is needed in spaces such as laboratories, server rooms, design and technology spaces, kiln rooms, food technology rooms and kitchens, to remove fumes and heat from equipment.

Ventilation rates in practical spaces for normal experimental conditions are given below.

Room type	Area (m²)	Minimum required flow rate
Laboratories and preperation room	>70	4 l/s/m²
Laboratories and preperation room	37-70	11.42 -(0.106 x Area) l/s/m² [note that this is equal to flow rate for the room of 278 l/s/m²]
Laboratories and preperation room	<37	7.5 l/s/m²
Chemistry store room	All	2 air changes/hour, 24 hrs/day
Art classroom	All	2.5 l/s/m²
Metal/wood workshop/ classroom Rooms with 3D printers; laser cutters; and spray booths for spray glue or spray paint aerosols	All	2.5 l/s/m²

These area-based ventilation rates in l/s/m² apply to spaces of 2.7m height or higher. The equivalent air change rate per hour (ach) can be calculated from ach = (l/s/m² rate) x 3.6/(Room height(m)). For spaces below 2.7m in height the equivalent air change rate to a 2.7m high space should be used.

The rates for science rooms have been adjusted to suit school science spaces in the UK and are the result of pollutant tests carried out by the ESFA and CLEAPSS in science labs, with Breathing Buildings in attendance. The exhaust rates are needed during and following experiments and practical activities to purge the room of chemicals and other pollutants.

Thermal Comfort

There are significant changes to the thermal comfort criteria in BB101. The changes are based on a number of factors and learnings. Firstly, it is acknowledged that the level of thermal comfort which can be achieved is dependent upon whether a building project is a new build or a refurbishment. Furthermore, the level of thermal comfort demanded is dependent on the type of activity in a space. The definition of the categories is as follows.

Category	Explanation
I	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young children and elderly persons
II	Normal expectation
III	An acceptable moderate level of expectation
IV	Low level of expectation. This category should only be accepted for a limited part of the year

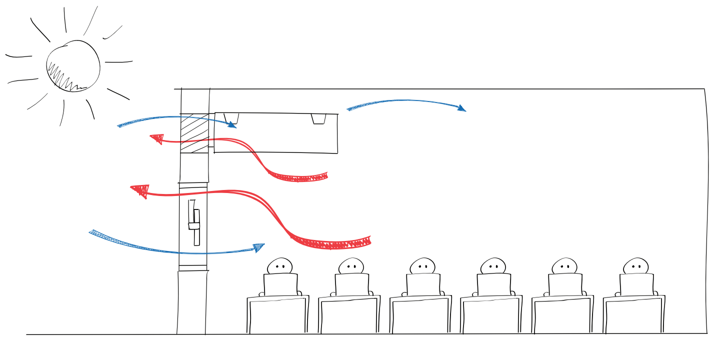
The ESFA has applied categories I-IV for assessment of overheating risk as shown in the following table.

Type of space/activity	New Build	Refurbishment
Teaching and learning, drama, dance, exams, multi-purpose halls	II	III/IV
Practical activities such as cooking	N/A	N/A
Sports Halls not used for exams	III	IV
Working areas, eg, kitchens	N/A	N/A
Offices	II	III/IV
Atria, circulation, reception and corridors - not continuously occupied	III	IV
Areas for pupils with complex health needs	I	I

Note that for refurbished buildings, where III/IV is shown it means that the minimum standard is Category IV where Category III cannot be met for reasons of practicality and due to the extent of refurbishment. However, after refurbishment the criteria should not be worse than before refurbishment in any aspect affecting thermal comfort.

Weather files

BB101 (2018) now stipulates the use of Design Summer Year DSY1 2020 (50th percentile range) weather files. This is a significant change from the 2006 edition of BB101, which required designers to model overheating using the Test Reference Year (TRY) weather file.



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Operative temperature

BB101 sees the use of operative temperature as a measure of thermal comfort. In CIBSE Guide A operative temperature is defined as:

operative temperature = ½ (air temp) + ½ (mean radiant temp)

Breathing Buildings 4DFlo dynamic thermal modelling software calculates operative temperature at every time step. Furthermore, the software automatically assesses the input parameters against the BB101 overheating criteria, and reports the result to the designer without need for post-processing. This greatly streamlines the process and reduces the time it takes to assess a range of design options.

Adaptive comfort

One aspect of the adaptive comfort philosophy is based on the premise that past thermal history modifies building occupants' thermal expectations, preferences and responses to dress code on any given day.

To calculate the acceptable temperatures and the number of hours exceeding these, BB101 requires the use of a number of values from thermal modelling. These are automatically generated by the Breathing Buildings dynamic thermal modelling software 4DFlo:

- Running mean temperature, T_{rm} (calculated from weather files)
- Operative temperature, T_{op} (calculated from dynamic thermal modelling, such as Breathing Buildings 4DFlo)
- Maximum acceptable temperature, T_{max} (calculated from weather files)
- Hours of Exceedance, H_e (calculated from dynamic thermal modelling)
- Weighted Exceedance, W_e (calculated from dynamic thermal modelling)
- Threshold / upper limit temperature, T_{upp} (calculated from weather files)

Overheating criteria

In the previous version of BB101 there were three criteria, of which you had to pass two but could fail one. In general there is a shift from the use of 28˚C, 32˚C and a 5˚C ΔT as a metric, to the use of Adaptive Comfort (EN 15251) to set the maximum desired internal temp (T_{max}) in the space. The Adaptive Comfort criteria are in line with the criteria introduced in CIBSE TM52. For free running (not mechanically cooled) normal school buildings T_{max} is calculated using the equation:

$$T_{max} = 0.33T_{rm} + 18.8 + T_{acceptable\ range}$$

where T_{rm} is the running mean temperature, which is a weighted daily average of external temperatures over the previous 7 days. This can be calculated using the following equation:

$$T_{rm} = \frac{(T_{(od-1)}+0.8T_{(od-2)}+0.6T_{(od-3)}+0.5T_{(od-4)}+0.4T_{(od-5)}+0.3T_{(od-6)}+0.2T_{(od-7)})}{3.8}$$

where suffix od-1 denotes the average external temperature of the previous day, od-2 the day before that and so on. T_{rm} can also be found in CIBSE KS16 or TM52. The acceptable range is based on the category of building.

Category	$T_{acceptable\ range}$ (K)
I	2
II	3
III	4
IV	>4

The operative temperature is to be calculated based on design occupancy 0900-1600 with a 1 hour lunch break 1200-1300, for the period 1 May - 30 Sep.

The following is a brief summary of the three criteria:

Criterion 1 is that the number of Hours of Exceedance must be no more than 40 when the predicted operative temperature exceeds T_{max} by 1K, or more (c.f. number of hours above 28˚C <120 in previous BB101). When sports halls are used for exams this activity shall be taken as weekdays from 1 May to 8 Jul and the number of hours shall be reduced from 40 to 18.

Criterion 2 is the sum of the Weighted Exceedance (W_e) for each degree K above T_{max} (1K, 2K and 3K) and must not exceed 6 on any one day. $W_e = \Sigma h_e \times wf = (h_{e0} \times 0) + (h_{e1} \times 1) + (h_{e2} \times 2) + (h_{e0} \times 3)$, where the weighting factor wf=0 if $\Delta T \leq 0$, otherwise wf = ΔT, h_{ey} = time in hours when wf = y, and $\Delta T = (T_{op} - T_{max})$, rounded to a whole number (i.e. for ΔT between 0.5 and 1.5 the value used is 1˚C, for 1.5 to 2.5 the value used is 2˚C and so on).

Criterion 3 is that the predicted operative temperature should not exceed T_{max} by 4K or more at any time, i.e. T_{upp} = maximum value of **ΔT = 4** (c.f. ΔT<5˚C and T_{max} = 32˚C in previous BB101).

The first of these criteria (Criterion 1) defines a minimum requirement for the overheating risk assessment. In other words, **this criterion must be passed**. The two additional criteria (Criterion 2 and Criterion 3) are primarily measures of short-term discomfort and should be reported for information only. If a school design fails to meet Criterion 2 or Criterion 3 then designers should consider potential overheating mitigation measures and indicate which are viable for the project. The use of these three performance criteria together aims to ensure that the design is not dictated by a single factor but by a combination of factors that will allow a degree of flexibility in the design.

Performance in Use (Effectively Criterion 4, which must be met) is that it should be possible to demonstrate within spaces that are occupied for more than 30 minutes at a time that, during the school day, the average internal air temperature does not exceed the average external air temperature measured over an occupied day by more than 5˚C; both temperatures being averaged over the time period when the external air temperature is 20˚C, or higher, except when the diurnal temperature range (lowest temperature from the previous night to the maximum daytime temperature the following day) is less than 4˚C.

Expert advice

Having been heavily involved in the development of BB101 Breathing Buildings are uniquely placed to help contractors and engineers ensure that their school is designed to comply with the new regulations.

Energy Use and Avoidance of Cold Draughts

One of the most significant changes in the new BB101 pertains to thermal comfort in winter, and in particular the importance of mitigating cold draughts but without incurring excessive heating bills to do so. The new version of BB101 stipulates that in order to reduce the problem of draughts, which frequently prevents windows from being opened in densely occupied classroom spaces with low-level air inlets, the design of ventilation and its control should provide mixing of ventilation air with room air to avoid cold draughts in the occupied zone. Mixing provides heat reuse within the space and is a very energy efficient winter strategy. This is because in new buildings (in the UK) with high levels of thermal insulation the balance point where no heating is required is around 5˚C and the number of occupied hours when the external temperature is below 5˚C is small.

Natural ventilation

For naturally ventilated spaces, when the outside air temperature is 5˚C and the heat emitters are switched off, the minimum temperature of air delivered to the occupied zone at seated head height should be not more than 5K below the normal maintained operative temperature. Seated head height should be taken as 1.1m above floor level for primary and 1.4m above floor level for secondary school classrooms.

The line plume calculator, developed by Breathing Buildings, can be used to estimate the temperature of the incoming plume of air from high level openings when it reaches the occupied zone. Alternatively measurements can be made in test rooms or CFD models can be used.

Mechanical ventilation

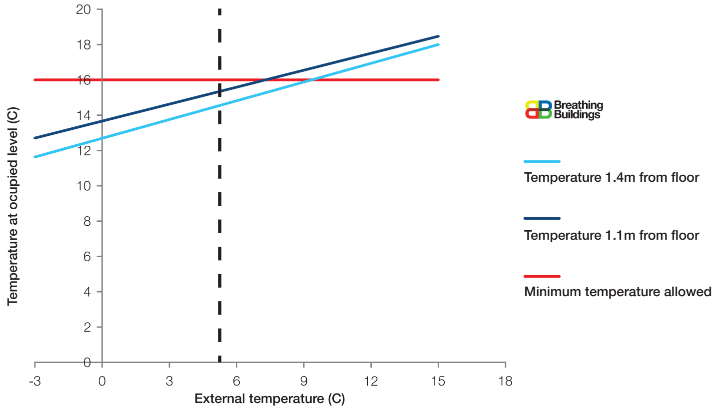
In a mechanical system where the driving force for the supply air is a fan, the design should meet the comfort criteria in BS EN 15251 for mechanical ventilation systems.

Line plume calculator

Breathing Buildings has developed an online design tool to help designers determine when a simple opening is likely to be sufficient to meet the cold draught criterion.

This spreadsheet tool is based on standard plume theory from Turner (1973), Buoyancy Effects in Fluids. It also uses the concept of a virtual origin for plumes following the work of Kaye & Hunt. It shows how the temperature of an incoming stream of cold air through a high level window or damper into a warm room increases as the turbulent plume falls under gravity and entrains warm room air. The entrainment is just from one side of the line plume since the other side is against the window. When the temperature of the plume 1.4m from the floor (represented on the following chart by the light blue line for secondary schools) or 1.1m from the floor (represented on the following chart by the dark blue line for primary schools) is below the minimum acceptable level for schools (given by the red line) for any external temperature above 5C (denoted by the dotted black line), the system **FAILS** to meet the criterion for draughts. When the temperature of the plume (blue line) is above the minimum temperature (red line), the system **PASSES** the criterion for cold draughts.

The model assumes that the flow is fully turbulent the moment air enters the room. This is the most optimistic assumption with regards to the effectiveness of mixing. The modelling results therefore indicate an optimistic view of the mixing effectiveness and colder temperatures at the occupied level may be experienced.

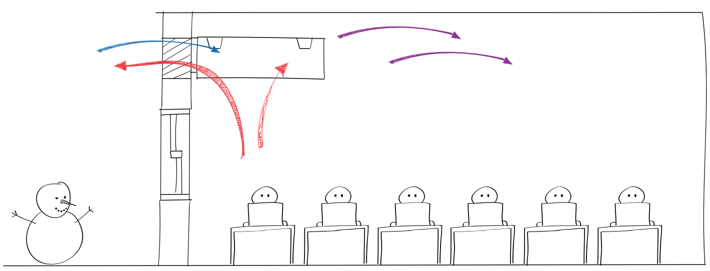


Example output from online design tool Line Plume Calculator (www.breathingbuildings.com/services/free-design-tools/)

The results should be interpreted as follows:

1. If the temperatures predicted show a **FAIL** then it is very likely that draughts will be a serious issue in your design and **alternative solutions such as Breathing Buildings equipment are recommended**.
2. If the temperatures predicted show a **MARGINAL PASS** then anyone using this design should only do so with **extreme caution** as draughts may well still be a problem.
3. If the temperatures predicted show a **CLEAR PASS** then the designer can **proceed**, but note that the results do not guarantee draught free conditions at all times. If completely draught free conditions are desired under all weather conditions then **alternative ventilation solutions such as Breathing Buildings equipment should be used**.

This spreadsheet tool was developed by Shaun Fitzgerald, Breathing Buildings. It is free for designers to use to help them in the assessment of the most appropriate openings for wintertime ventilation. Breathing Buildings is grateful to Prof Malcolm Cook (Loughborough University) and Prof Colm Caulfield (University of Cambridge) for discussions regarding the modelling of plumes. The entrainment coefficient for turbulent plumes is usually taken to be 0.102. However, following work undertaken by Prof Malcolm Cook for a line plume against a solid boundary it has been recommended that the coefficient be 0.09 and this value is therefore used.



Breathing Buildings

Breathing Buildings solution for the PSBP Fingerblock School

Breathing Buildings have used IES-VE software to model their low energy natural and hybrid ventilation solution for the PSBP Fingerblock School.

The 2018 version of BB101 states that;
"for naturally ventilated spaces, when the outside air temperature is 5˚C and the heat emitters are switched off, the minimum temperature of air delivered to the occupied zone at seated head height should be not more than 5K below the normal maintained operative temperature. For mechanically ventilated spaces comfort criteria in BS EN 15251 need to be met."

This functionality is provided by the Breathing Buildings NVHR, R Series and S Series equipment, which offers a lower energy alternative than a classic mixed mode system that operates in natural ventilation in the summertime (when the external temperature is greater than 16˚C) and switches to MVHR when the external temperature is below 16˚C in order to prevent cold draughts.

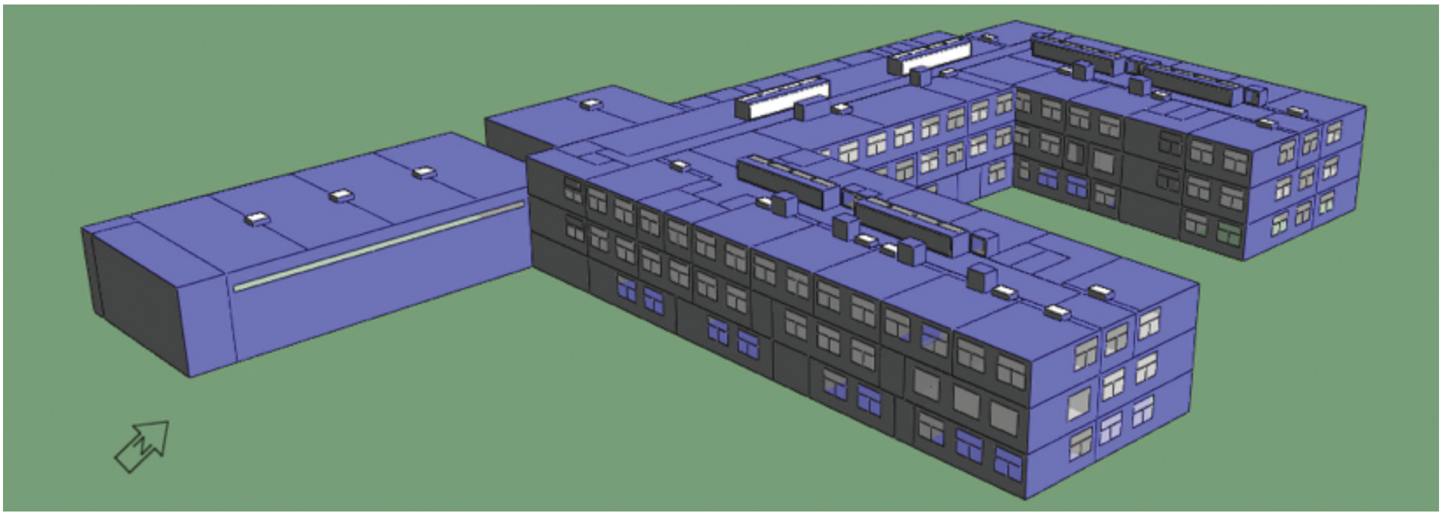
The fingerblock school is well suited to the NVHR system. The rooms on the ground floor and the first floor will use the NVHR units which provide mixing on the facade for use in wintertime. Once external temperatures are sufficiently high that opening windows can be used the NVHR units operate in their passive natural mode. On the hottest summer days the units provide fan assisted inflow to help provide air flow to the rear of the classrooms. The units also provide automatic night cooling of the classrooms in summer. On the second floor, the rooms have easy access to the roof and therefore there are two options for these spaces; either the natural ventilation R Series units can be used or else the hybrid NVHR units can be installed as per the lower floors. Similar to the NVHR units, our R Series units work in conjunction with opening windows in the summertime. In the wintertime, they operate a mixing ventilation strategy, but in this case use sweep fans in the unit.

Some types of room are not suited to natural ventilation, such as landlocked server rooms etc. Breathing Buildings can provide access to mechanical ventilation solutions via partners. Small rooms such as single person offices can usually be ventilated adequately just with opening windows. The rooms using Breathing Buildings natural and hybrid ventilation equipment are shown on the next page. In order to demonstrate compliance with BB101 2018, Breathing Buildings have modelled the building using the following parameters for the typical classrooms.

Hours of Exceedence (H_e)
Daily Weighted Exceedance (W_e)
Upper Limit Temperature (T_{upp})

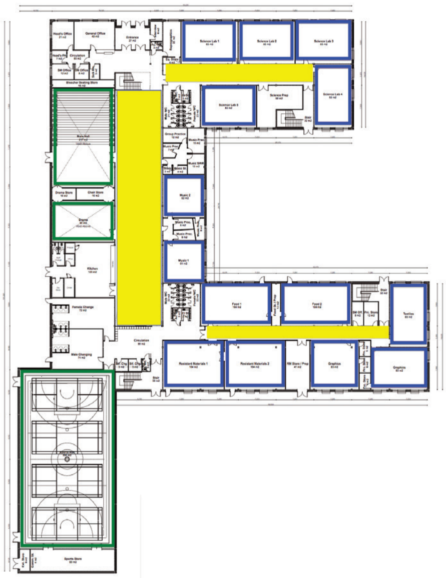
Occupancy (people)	32
Occupancy Heat Gain (W/person)	75
Occupied Hours	9am - 12pm 1pm - 4pm
Lighting (W/m²)	10
Additional Small Power (W)	1,000
Low Level Opening Effective Free Area	0.5m² per std window
Glazing G-value	0.64
Heating Setpoint Classrooms	21˚C
Heating Setpoint Class Pre-heat	18˚C
Heating Setpoint Atria	18˚C
U-value of Walls (W/m²K)	0.35
U-value of Roof (W/m²K)	0.25
U-value of Floor (W/m²K)	0.25
U-value of Windows (W/m²K)	2.2
Infiltration (ach)	0.25
Thermal Mass	100mm exposed concrete soffit

Our modelling demonstrates that each room which uses the Breathing Buildings equipment will meet the necessary summertime overheating criteria, when simulated using the Manchester DSY1 2020 weather file. For more extreme weather files such as London DSY1 2020 it is necessary to reduce internal gains, for example by reducing the glazing G-value to around 0.32.



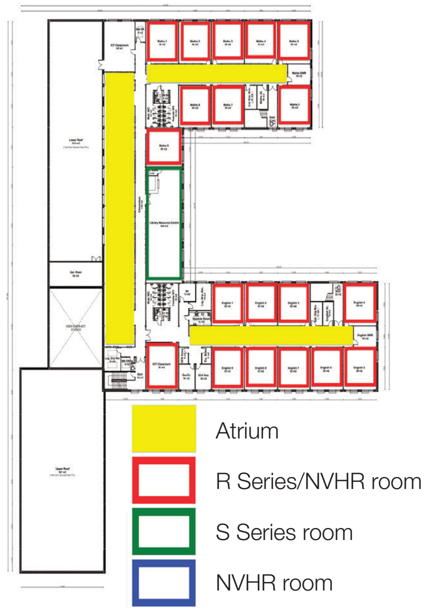
Breathing Buildings natural and hybrid ventilation systems are the best way to ensure compliance with the air quality, summertime overheating, and energy targets/requirements in BB101. In summertime the system uses buoyancy and wind with fan boost and night cooling modes where required. In wintertime, fans in the units are used to mix warm room air with incoming cold fresh air. This is the most efficient way of ventilating buildings because the fan power used for mixing is much lower than that needed in heat recovery systems, and the heat gains in the spaces are sufficiently high that typically additional heating isn't needed until the exterior temperature falls below 5°C.

Ground Floor



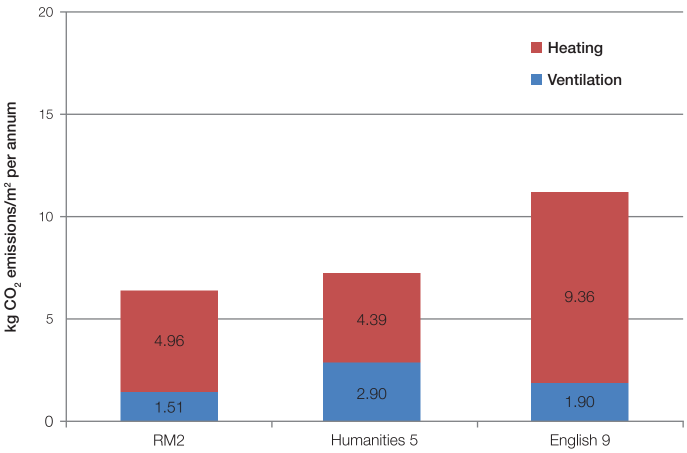
First Floor

Second Floor



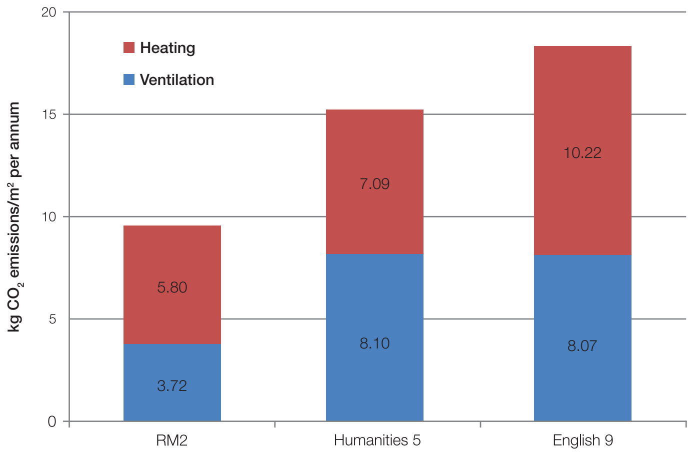
Breathing Buildings System

The carbon emissions of a typical, highly glazed, South facing classroom from the Fingerblock School baseline design can be seen below. RM2 is a ground floor room, Humanities is a first floor room and English 9 is a second floor room.



MVHR System

The Carbon emissions of the same rooms using MVHR can be seen in the chart below.



In addition both systems have identical Equipment (15.63 - 30.05 Kg/m²) and Lighting (13.13 - 27.88 Kg/m²) loads, which have been omitted for clarity.

Summary

A review of a number of schools built under the previous BB101 guidelines found that although many of them were intended to be low energy, the heating bills were significantly higher than forecast. Furthermore, a number of them still overheat. The new edition of BB101 has been created to help overcome these issues. The Breathing Buildings unique approach to natural and hybrid ventilation is the easiest and most robust way of meeting the air quality, thermal comfort and energy targets.

Breathing Buildings

Proving it Works

We are proud of our understanding of natural and hybrid ventilation and our ability to deliver low energy buildings with great internal environments. We have monitored many installations to make sure that they are ventilating properly and mitigating cold draughts. These charts show data from Linton Village College where we installed S Series units.

Winter Supply

In winter it is important to manage the ventilation requirements with heating and thermal comfort. As can be seen from Figure 01 even when the outside temperature is below 5˚C we are able to successfully mitigate cold draughts with the supply temperature remaining at a comfortable level.

Figure 02 looks at the daily average CO_2 levels in the space during the winter months, which BB101 require to be below a daily average of 1,500ppm. The Breathing Buildings system delivers this using CO_2 sensors in the space and our patented winter mixing system. Independent research of our competitor systems has shown that without a draught mitigation strategy occupants simply turn the system off in winter, the space does not ventilate and CO_2 rises significantly.

Modelling

We are often asked what IES shows for natural ventilation and alternative ventilation strategies. The short answer is the Breathing Buildings mixing systems provide significant energy savings not just compared with traditional natural ventilation but also with MVHR, as shown in Figures 03 and 04. But don't take our word for it, let us help you to model your classroom with different ventilation strategies using our 4DFlo and IES software.

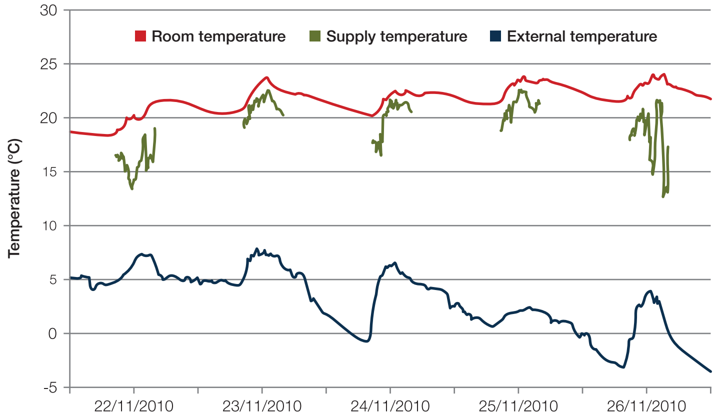


Figure 01

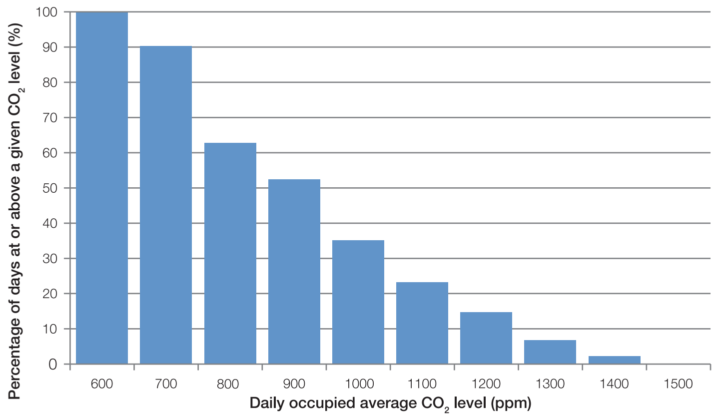


Figure 02

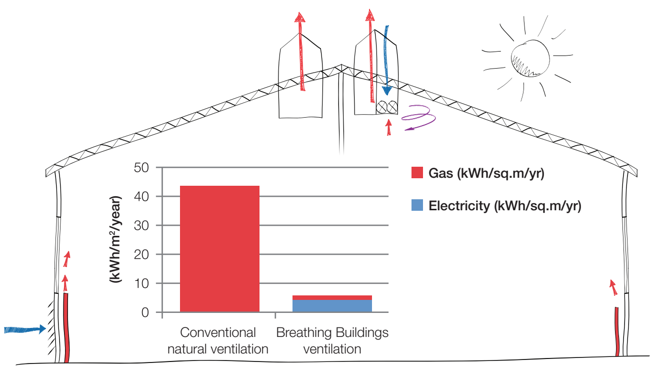


Figure 03

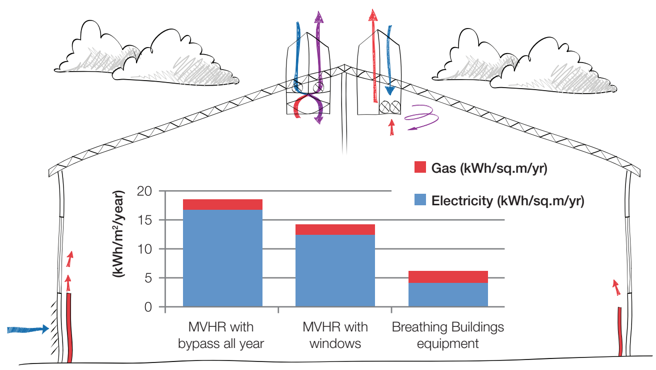


Figure 04

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