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Designing and Constructing an Exemplar Zero Carbon Primary School in the City of Exeter, United Kingdom

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Montgomery Primary School is the UK's first "zero carbon" in use and "climate-change-ready" exemplar school built to the Passivhaus standard. Its design and solar generating electrical power plant enable its electricity bill to be zero each year.

The UK's 2008 Budget announced the government's ambition that all new non-domestic buildings should be zero carbon from 2016. In order to take this goal forward, the Department for Children, Schools and Families (DCSF) established the Zero Carbon Task Force (ZCTF); its objective was to advise on how England can achieve this ambition for new school buildings, to develop a roadmap to zero carbon and make recommendations for its implementation. It was also tasked to oversee exemplar projects in order to increase knowledge and understanding of energy use in school buildings. Montgomery Primary School, a 420-pupil facility, was the scene of one of these projects; the new school was designed to replace the existing facilities which had become outdated and no longer fit for use.

Zero carbon signifies that all emissions from the building and the activities that take place within it must have a net energy balance of zero over a year.

In theory, the simplest way to produce a zero-carbon design would be to build a typical school, replace the gas boiler with biomass for heating and buy electricity via a green tariff for power and lighting. We (the design team that worked on Montgomery School) consider such an approach unsustainable and unrealistic as it relies on continued use of precious resources. We also believe that passive design is not about applying flashy green technology to a standard product: it is an integrated design process, based on a holistic approach that focuses on reducing energy demands. Montgomery has therefore been designed to use the minimum amount of resources, including fossil fuel. Its conception is based on a modular design approach, utilising off-site pre-fabrication techniques with multiple repeatable units where appropriate, and all of the energy required for heating, lighting and power are generated on-site.

As the school design is based on the Passivhaus standard, the heating system will not be able to make up for any wastefulness on behalf of the occupants: if they fail to maintain sensible practices such as shutting windows and doors and cease to control the plant they will notice a drop in temperature. It is hoped that by understanding how the building works and its positive impact on costs, users will be encouraged to change their behaviour in relation to energy and sustainability.

Passivhaus is a leading low-energy design standard, although the design of Passivhaus buildings addresses more than energy efficiency. It includes a set of energy-efficient construction techniques widely adopted in Germany, Austria, Switzerland and Belgium (Flemish Community).

The core objective of the Passivhaus standard is to dramatically reduce the requirement for space heating and cooling, whilst also creating excellent indoor comfort levels. This is primarily achieved by adopting a "fabric first" approach to design, i.e. by focusing on the building fabric, specifying high levels of insulation to the thermal envelope, providing exceptional levels of airtightness, and using mechanical ventilation with heat recovery.

As Passivhaus is a performance-based "energy" assessment, the following targets define the standard to be met in order to qualify for certification.

Specific heating demand	15kWh/m²yr (or) specific heating load – 10W/m²
Specific cooling demand	15kWh/m²yr
Specific primary energy demand	120kWh/m²yr
Airtightness	0.6ach @50pascals (n50)

The standard requires that the primary energy demand target is met in all cases. This figure must include space heating, domestic hot water, lighting, fans and pumps, as well as all the projected appliance consumption. In addition to the primary energy demand, the standard permits that either the specific heating demand (SHD) or the specific heating load (SHL) must be met. Thermal comfort is also a very important issue: a certified Passivhaus should not fall below 16°C, even without heating during the coldest winter months.

OUR DESIGN PHILOSOPHY

Our philosophy was to use on-site renewable energy sources to meet the "zero carbon" in use target, and the first step was to minimise the building's overall energy consumption by pre-construction modelling. Passivhaus has a proven capability of achieving low-energy in use buildings. After consideration, photovoltaic panels were chosen as the most appropriate solution since the site did not lend itself to wind or water-based power generation.

Our experience is that buildings should have the following characteristics if they are to meet the target:

Resource lean	A maximum primary energy demand of 120kWh/m^2/yr, with a limit of 15 kWh/m^2/yr for heating as stipulated by the Passivhaus Institute. (In comparison, a typical school's primary energy demand is 269kWh/m^2/yr.) (CIBSE TM46 energy benchmarks)
Organic	The main heating source will be the teachers and pupils themselves, by radiating heat into the high thermal mass elements (concrete) of the structure.
Super insulated	All components of the building envelope are insulated to a U-value below 0.15 W/m^2/K.
Air tight	Minimal air leakage (target < 0.6 air changes/house volume/hour)
Zero carbon	Predicted overall energy requirement of 166 000kW/hr^2/yr with sufficient on-site photovoltaic panels to provide a neutral balance of imported electricity over an annual cycle.
Robust	It should exceed current ventilation requirements (BB101) and be able to cope with climate variations up to 2080 through the use of high thermal mass and mechanical ventilation heat recovery (MVHR) units. Booster heat will be supplied via simple electrical heating elements in the air ducts.
Comfortable	It should have a predominantly concrete structure providing thermal mass to ameliorate temperature peaks as well as controlled MVHR units.
Educational	Staff and pupils will need to fully understand the philosophy behind the new building and work to minimise energy use during occupation: behavioural change is key.

A precast concrete panel solution was not critical in the desire to achieve a Passivhaus building as it is recognised that a wide variety of construction products and techniques can be used. Where concrete becomes important is that it provides high thermal mass in the step-up from Passivhaus to zero carbon, "future proofed" to 2080 as we needed to ensure that the school would not overheat under the most aggressive climate change criteria. The thermal inertia of concrete allows it to absorb and store surplus heat or cold and then release these back into the air as part of a designed thermal strategy. Concrete also has excellent sound suppression and vibration dampening properties as it absorbs both low and high frequency sounds. It also displays airtightness, safety and security benefits that are related to its massiveness and density, provided wet joints are constructed with cast-in-place concrete poured between the precast panels.

Structural junctions and the interfaces of different building elements can be problematic because of the requirement to provide a continuous insulation wrap around and under the building. Air movement through or around the insulation bypasses its effectiveness and reduces its performance. All insulation has been tightly sealed with tapes and joined with low expanding rate foam. Junctions at the top and bottom of insulation panels are also sealed on a thin bead of foam thereby eliminating thermal bypass. In addition, it was important to ensure that the insulation was continuous and unbroken as even modern products can produce a cold bridge, reducing thermal performance and introducing possible condensation risks. Where it became necessary to break the insulation layer, specialist thermally efficient structural fixings were installed.

Classrooms have integrated services within acoustic ceiling rafts

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A "sample, try, test and dismantle" method has produced many surprising results that may not have been formally recognised in older, more traditional forms of construction. The outcomes have, on occasion, prompted the design team to revise certain details, giving a superior result.

In order to achieve the required airtightness levels, gaps had to be avoided: the uncontrolled leakage of air in or out of a building causes localised discomfort due to draughts, increased energy consumption and increased risks of condensation within the building fabric which may eventually reduce the performance and lifespan of the building. In the past too much airtightness was a worry, sometimes leading to air quality and moisture problems. For a while "sick building syndrome" was known as "tight building syndrome". The Building Research Establishment promotes the maxim "Build tight, ventilate right"; the principle is that accidental air leakage should be avoided and managed air-flows should be designed in. This is where Passivhaus standards excel in promoting the use of a mechanical ventilation system with heat recovery, thereby ensuring that fresh, tempered air is delivered where it is needed, when it is needed, without losing valuable energy in the form of heat.

THE RESULTS ARE THERE

The school's Passivhaus design and solar generating electrical power plant enable its electricity bill to be zero each year, with excess electricity providing a small income to maintain the power cells and equipment.

The Montgomery School was awarded a Quality Approved Passivhaus certificate in February 2012, essentially for "the comfort and quality of the internal environment with extremely low energy consumption". It is the first Passivhaus school in the United Kingdom and is on target to what we believe will be the first "true" zero carbon in use school in Europe. Exeter University will be monitoring the building's energy performance over the coming five years to ensure that the zero-carbon ambition is met and maintained.

Criteria	UK new-build common practice (Building Regulations 2008)	Passivhaus standard	Design standard at Montgomery Primary School
Compact form and good insulation:	Limiting U-values of approximately 0.25-0.35 W/m^2/K	U-Value that does not exceed 0.15 W/m^2/K	Simple rectangular plan, compact form with high thermal mass and excellent insulation. 0.15 W/m^2/K
Southern orientation and shade considerations:	Some consideration is given with regard to north/south orientation, but the improved energy savings resulting from passive site design are often overlooked.	Passive use of solar energy may be a significant factor in Passivhaus design.	Major rooms orientated North to avoid overheating / glare. Use of South facing mono-pitch roof for Photovoltaic array.
Energy-efficient window glazing and frames:	1.8-2.2 W/m^{2}K typical	Windows (glazing and frames) should have U-Values not exceeding 0.80 W/m^2/K, with solar heat-gain coefficients around 50%.	Energy efficient triple glazed thermally broken window. 0.80 W/m^2/K.
Building envelope air-tightness:	Design air permeability of 7 to 10 m^2/hr/m^3@ 50 Pa. Research has also shown that air permeability values for completed buildings frequently exceed these design limits.	Air leakage through unsealed joints must be less than 0.6 times the building volume per hour (this is the equivalent of an air permeability value of less than 1 m^3/hr/m^2 @ 50 Pa).	Air leakage through unsealed joints measured at 0.28 times the building volume per hour.
Passive preheating of fresh air:	The majority of new buildings do not achieve good enough air permeability values to warrant the incorporation of a whole building ventilation system - thus trickle vents, extract fans, or passive stack ventilation is commonly used.	Fresh air may be brought into the building through underground ducts that extract heat from the soil. This preheats fresh air to a temperature above 5°C (41°F), even on cold winter days.	No passive heating of fresh air. Ventilation via controlled MVHR. In winter the cold intake air is warmed by the regenerator units. In the summer natural ventilation is via open-able windows.
Highly efficient heat recovery from exhaust air using an air-to-air heat exchanger:		Most of the perceptible heat in the exhaust air is transferred to the incoming fresh air (heat recovery rate over 80%).	Mechanically ventilated using an ultra-high efficiency heat recovery air handing unit (heat recovery rate over 82%).
Energy-saving appliances:	Dedicated low-energy lights are provided in a number of rooms in a new building. If appliances are supplied they will be generally C-rated or perhaps 'Energy Saving Recommended' in some instances.	Low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc. are indispensable in a Passivhaus.	Low energy A-rated appliances specified throughout.
Total energy demand for space heating and cooling	Typically 55 kWh/m^2/yr	Less than 15 kWh/m^2/yr	12 kWh/m^2/yr
Total primary energy use for all appliances, domestic hot water and space heating and cooling	Typically 269 kWh/m^2/yr (CIBSE TM46)	Less than 120 kWh/m^2/yr	112 kWh/m^2/yr

Breakout teaching areas with informal activity zones

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Credits

Client:	Devon County Council (DCC).
Lead Designers:	NPS Group – Architects, Quantity Surveyors, CDMC, Landscape Architects.
Building Services Engineers:	John Packer Associates (a wholly owned subsidiary of the NPS Group).
Project Manager:	W.T. Hills.
Low Energy Advice:	Centre of Energy and Environment, University of Exeter.
Passivhaus Accreditation:	WARM Low Energy Building Practice.
Main contractor:	Bam Construction.
Prefabricated Concrete:	Buchan Concrete Solutions.
M & E Contractor:	N.G.Bailey Ltd.
Funding:	Devon County Council Primary School Capital Programme (PCP) funding – £7.3 million. Zero Carbon Task Force grant funding – £1.2 million. Devon County Council contribution to the acquisition of new knowledge in this field – £400K.
Project value:	£8.9 million (tender).
Gross Internal Floor Area:	420 pupil Primary School (plus nursery) – 2786m^2.
Contract duration:	Phase 1 – Start date - August 2010. End date - October 2011. Phase 2 - Demolition and external work (Completed March 2012).

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