Passivhaus
Schools & Larger Buildings
Some lessons learnt

Building Carbon Zero
Santa Cruz March 2014

Nick Grant
Elemental Solutions
Technical Director UK Passivhaus Trust
3 schools with the same team
An opportunity to practice

<table>
<thead>
<tr>
<th>Acoustics</th>
<th>Ion Acoustics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architect</td>
<td>Architype West</td>
</tr>
<tr>
<td>Client</td>
<td>Wolverhampton City Council</td>
</tr>
<tr>
<td>Contractor</td>
<td>Thomas Vale</td>
</tr>
<tr>
<td>M&amp;E</td>
<td>E3 Consulting engineers</td>
</tr>
<tr>
<td>Passivhaus</td>
<td>Nick Grant &amp; Alan Clarke</td>
</tr>
<tr>
<td>QS</td>
<td>Jerry Thomas</td>
</tr>
<tr>
<td>Structures</td>
<td>Price &amp; Myers</td>
</tr>
</tbody>
</table>

And many other companies and individuals
Bushbury Hill Primary School - Architype

Type: Mainstream Primary School
Build type: Timber frame
Location: Wolverhampton
Occupancy: Occupied since Oct 2011
Budget: £4.2 million

Standard budget, no extra funding or time for Passivhaus.
Oakmeadow Primary School - Architype

Type: Mainstream Primary School
Build type: Timber frame
Location: Wolverhampton
Occupancy: Occupied since Oct 2011
Budget: £5.2 million

Standard budget, no extra funding or time for Passivhaus.
Details
Learning from Others
### PHPP Tools

**Custom parametric sheet**

### House version

<table>
<thead>
<tr>
<th>Building</th>
<th>Weather region (BRE)</th>
<th>Monthly method</th>
<th>Fabric &amp; Form</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Midlands</td>
<td>Lightweight</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0% summer heat</td>
<td>2.7 K</td>
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<tr>
<td></td>
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<table>
<thead>
<tr>
<th>GF floor to ceiling</th>
<th>FF floor to ceiling</th>
<th>Slab insulation thickness</th>
<th>Slab thickness</th>
<th>FF thickness</th>
<th>Wall thickness</th>
<th>Wall pitch</th>
<th>Roof pitch</th>
<th>Roof insulation thickness</th>
<th>Roof pitch</th>
<th>Depth internal (E&amp;W)</th>
<th>Stair width</th>
<th>Internal wall width</th>
<th>Internal wall length</th>
<th>Party wall width</th>
<th>No of units (terrace)</th>
<th>MVHR efficiency</th>
<th>Blower door test n80</th>
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</thead>
<tbody>
<tr>
<td>2.40 m</td>
<td>2.00 m</td>
<td>0.20 m</td>
<td>0.25 m</td>
<td>0.20 m</td>
<td>0.40 m</td>
<td>35</td>
<td>35</td>
<td>0.166 W/m².K</td>
<td>0.63</td>
<td>7.00 m</td>
<td>1.50 m</td>
<td>0.15 m</td>
<td>20.00 m</td>
<td>0.25 m</td>
<td>2</td>
<td>90%</td>
<td>0.80 m</td>
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</table>

<table>
<thead>
<tr>
<th>Win Description</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Number of windows per dwelling</th>
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</thead>
<tbody>
<tr>
<td>opening</td>
<td>1.00</td>
<td>1.50</td>
<td>4</td>
</tr>
<tr>
<td>fixed picture</td>
<td>2.00</td>
<td>1.50</td>
<td>2</td>
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<tr>
<td>other</td>
<td>0.70</td>
<td>0.50</td>
<td>1</td>
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<tr>
<td>South overhang</td>
<td>0.05</td>
<td>0.50</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Skylights</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Number</th>
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</thead>
<tbody>
<tr>
<td>North</td>
<td>1.00</td>
<td>1.20</td>
<td>6</td>
</tr>
<tr>
<td>South</td>
<td>1.00</td>
<td>1.20</td>
<td>6</td>
</tr>
</tbody>
</table>

### Energy balance (annual method)

- **KWh/(m².a)**
  - Heat
  - IHG
  - Solar
  - Infiltration
  - Vent
  - Windows
  - Roof
  - Floor
  - Wall

### Window energy balance

- **KWh/(m².a)**
  - Loss
  - Gain

### Window properties

- **Sky**
- **West**
- **South**
- **East**
- **North**

### MVHR efficiency

- **90%**
PHPP Tools  Simple scenario tracker

Simple results sheet (c) Elemental Solutions 2014

- Energy balance heating (annual method)
- Non-useful heat gains
- Exterior wall - Ambient
- Roof/Ceiling - Ambient
- Floor slab / Basement ceiling
- Church wall
- Windows
- Thermal bridge loss
- Ventilation
- Solar gains
- Internal heat gains
- Heating demand

<table>
<thead>
<tr>
<th>Scenario</th>
<th>TFA m²</th>
<th>Dwell units</th>
<th>Form factor</th>
<th>Annual demand kWh/m².a</th>
<th>Heat Load W/m²</th>
<th>Daily temp swing °C</th>
<th>Mass W/m².K</th>
<th>Glazing m²</th>
<th>Glazing % of TFA</th>
<th>Glazed fraction</th>
<th>Window gain kWh/m².a</th>
<th>Window losses kWh/m².a</th>
<th>Net solar gain kWh/m².a</th>
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<tbody>
<tr>
<td>1</td>
<td>690</td>
<td>0</td>
<td>2.21</td>
<td>15.6</td>
<td>19.3</td>
<td>3.9</td>
<td>60.0</td>
<td>35.3</td>
<td>9%</td>
<td>64%</td>
<td>0.95</td>
<td>0.00</td>
<td>5.2</td>
</tr>
<tr>
<td>2</td>
<td>691</td>
<td>0</td>
<td>2.17</td>
<td>13.1</td>
<td>17.7</td>
<td>3.7</td>
<td>60.0</td>
<td>35.3</td>
<td>9%</td>
<td>64%</td>
<td>0.95</td>
<td>0.00</td>
<td>5.2</td>
</tr>
</tbody>
</table>
Ground beam between piles

Air tight layer

Structural slab

Load

Ground beam between piles
Standard details made airtight

Contractor’s standard detail with airtightness added: internal walls keyed into external walls.

Expensive on tape, time consuming on site & some unresolved junctions.

Lesson learnt.
Schools 2&3 followed the drawings!
- Much easier
Walls split where single storey attaches
No penetration of wind barrier
Simple Cascade Vent Strategy

Occupation constant but people move around.
Street as transfer zone.
Hall fed from street when used

School hall

Hub / street

Hall transfer fan

Air to street

Air from street

HALL -> STREET VENTILATION
Window opening limited by UK Code
An unwelcome constraint

Ambiguous interpretation of 100mm opening
Stunts: Alan Clarke
Kitchen ventilation

Initial design
- Main MVHR: 5400 m$^3$/h
- Kitchen ventilation: 3600 m$^3$/h
- No heat recovery on kitchen system – grease

Engineer concerned this wasn’t enough
- risk of overheating based on previous experience - preferred kitchen rate of 4800 m$^3$/h!

Passivhaus energy balance cannot be achieved.
Our low energy strategy

- Only provide as much air as needed to remove excess heat
  - This was not compatible with gas cooking

- Recover heat to temper fresh air for comfort
  - A robust heat exchanger possible if no frying

- How to model in PHPP?
  - Developed multivent sheet
## Passive House Planning

### Multi-ventilation Unit Calculation

**Building:** Wilkinson Primary School

<table>
<thead>
<tr>
<th>Building</th>
<th>Main School</th>
<th>Kitchen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. ambient temp, heating p. (°C)</td>
<td>10080</td>
<td>2880</td>
</tr>
<tr>
<td>MvHR speed MAX m3/h</td>
<td>9.0</td>
<td>5.0</td>
</tr>
<tr>
<td>MAX h/day</td>
<td>4050</td>
<td>1871</td>
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<tr>
<td>MvHR speed NORMAL m3/h</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>NORMAL h/day</td>
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<td>0.0</td>
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<tr>
<td>MvHR speed MIN m3/h</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>MIN h/day</td>
<td>10080</td>
<td>2880</td>
</tr>
<tr>
<td>Set Average m3/h through unit</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Room temperature (°C)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Balanced PH ventilation</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pure extract air</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Heat recovery unit within the thermal envelope</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Heat recovery unit outside of the thermal envelope</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Temp. of plant room (Enter only if the heat recovery unit is outside) °C</td>
<td>60%</td>
<td>38%</td>
</tr>
<tr>
<td>MVHR manufacture and unit name</td>
<td>Bwegen gold</td>
<td>run around coil?</td>
</tr>
<tr>
<td>Efficiency of heat recovery η</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>MVHR manufacture and unit name</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Electric Efficiency Wh/m³</td>
<td>733</td>
<td>733</td>
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<tr>
<td>Nominal width (mm)</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Insul. thickness (mm)</td>
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<td>150</td>
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<tr>
<td>Reflective? Please mark with an &quot;X&quot; Yes</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Reflective? Please mark with an &quot;X&quot; No</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Thermal conductivity W/(m·K)</td>
<td>0.038</td>
<td>0.038</td>
</tr>
<tr>
<td>Conductance supply duct</td>
<td>1.615</td>
<td>1.134</td>
</tr>
<tr>
<td>Length supply air duct</td>
<td>16</td>
<td>16</td>
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<tr>
<td>Ψ-value Supply or Ambient Air Duct</td>
<td>1.134</td>
<td>0.006</td>
</tr>
<tr>
<td>Nominal width (m)</td>
<td>733</td>
<td>733</td>
</tr>
<tr>
<td>Insul. thickness (mm)</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Reflective? Please mark with an &quot;X&quot; Yes</td>
<td>X</td>
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<tr>
<td>Ψ-value Extract or Exhaust Air Duct</td>
<td>0.006</td>
<td>0.006</td>
</tr>
</tbody>
</table>
Lessons learnt: school kitchens

Use of induction hobs and low energy appliances to reduce surplus heat and primary energy
It works!
June-July 2013

25° C 77° F
Simple radiators with thermostatic valves, one per room, not all rooms.
DHW

• Optimised pipe sizes and good insulation
• No hot water in classrooms for Bushbury
• Losses reduced to about 70%!!
Daylight and lighting - theory

What worked:
- Target 2W/m²/100lux & max 300lux, so classrooms etc are limited to 6W/m²

Less successful:
- Daylight optimised by 3D modelling
- Consideration of localised shade for whiteboard
- State of the art energy saving lighting controls
Practice
North classroom
Practice
Lights on when sun out
Measured Energy Use
Bushbury School (Oakmeadow very similar)
- 90% less than the old school

Figures are based first year readings.

**Gas (x 1.1 for PE):**
- Space heating*: 14kWh/(m².a)
- Hot water: 7kWh/(m².a)

**Electric (x 2.7 for PE):**
- Lighting: 12kWh/(m².a)
- Power & plant: 22kWh/(m².a)
- Kitchen: 7kWh/(m².a) Sprinkler frost protect: 14kWh/(m².a)

**Total primary energy:** 169kWh/(m².a)

**Comment:**
Primary energy is higher than the target 120 kWh/(m².a)
Sprinklers = 38kWh/(m².a) PE (‘frost’ protection)

**Main success:**
Kitchen energy & comfort

**Main lessons:**
Issues with automatic lighting controls and sprinkler systems.
South classroom summer comfort

Indoors

25°C 77°F

Outdoors

35°C 95°F
“We feel that our children are more alert and attentive in lessons due to the amount of daylight in classrooms and the fresh air throughout the school. The fact that the new school is built to passivhaus standards means that learning has been enhanced; our pupils love coming to school and enjoy their impressive surroundings. They are comfortable, secure and stimulated by their new environment; hence they learn very well!”

Sara Morris: Head Teacher, Oak Meadow Primary School
School Number 4, Wilkinson

1. Council specified Passivhaus
   - Based on previous experience and the boast of no extra cost!

2. Planning require 10% renewables
   - Successfully challenged – negawatts

3. Contractor with no experience of PH
   - Experienced sub-contractor engaged

4. Timescale tight, Architect has new baby & not sleeping and 10% less budget
Classrooms clustered around two hub spaces, school also includes community use facilities
KiddyWatts
# Metabolic Heat Gains

<table>
<thead>
<tr>
<th>School</th>
<th>Children</th>
<th>TFA m²</th>
<th>m²/child</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bushbury Hill (UK)</td>
<td>240</td>
<td>1707</td>
<td>7.1</td>
</tr>
<tr>
<td>Oakmeadow (UK)</td>
<td>450</td>
<td>2205</td>
<td>4.9</td>
</tr>
<tr>
<td>Montgomery (UK)</td>
<td>446</td>
<td>2367</td>
<td>5.3</td>
</tr>
<tr>
<td>Swillington (UK)</td>
<td>240</td>
<td>1344</td>
<td>5.6</td>
</tr>
<tr>
<td>Wilkinson (UK)</td>
<td>459</td>
<td>2500</td>
<td>5.4</td>
</tr>
<tr>
<td>LH Hannover (D)</td>
<td>300</td>
<td>3507</td>
<td>11.7</td>
</tr>
<tr>
<td>Gronau (D)</td>
<td>336</td>
<td>2953</td>
<td>8.8</td>
</tr>
<tr>
<td>Reidberg (D)</td>
<td>500</td>
<td>5540</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Average for UK examples: 5.7 m²/child  
Average for German examples: 10.5 m²/child  

Difference: +1.32 W/m²  
+ 5-6 kWh/(m².a) of useful heating  
Against 15 kWh/(m².a) target
Less reliance on solar gain

Don’t confuse Passivhaus & Passive solar – solar costs 10-20x gas!!
3.8W/m² v 2.8W/m² IHG
Means we designed a different building
An aside – mall dwellings & IHGs

To be presented at Aachen, 2014
Small Buildings Sorted!

IHG = 71 TFA^{-0.73} (curve fit for PHPP calculated IHGs)
“You sure we got the right boiler?”

2,400m² school, boiler still twice the size needed!
Summer vent and opening windows

Less and simplified actuators.
More manual operated windows and night vents
Glazing to ground omitted

- Big cost & time savings
- Better daylight
- Less overheating
- More useful space
- Architect likes it!
Simpler PH skylights
Big cost saving, less overheating, no leaks
Windows replace curtain wall

- Big cost & time savings
- Quicker install
- Easier to make airtight
- Simplified structure
- Worked better with actuators.
Local Hot Water
Electric DHW storage shared between several areas. 8mm microbore, 0.5 gpm (1.7 l/min) sprays
Optimised MVHR ducts
Optimised MVHR layout
Effortless, robust air-tight details

Design team, contractor & sub-contractors learn how to overcome previous construction issues
Hereford Archive & Records Centre

A very Eco-Minimal passive approach
Archive energy balance
No passive solar, no heat recovery ventilation, no cooling. Some dehumidification of supply air.
River Studio
Sjölander da Cruz Architect’s Office
Sjölander da Cruz
Lancaster Cohousing Project

Passivhaus Community Housing Project

Andrew Yeats (Eco Arc Architects) & Alan Clarke
Project Overview

Name: Lancaster Cohousing Project

Type: 41 Owner Occupied Houses

Build type: Masonry & Timber frame

Location: Halton Lancaster

Occupancy: Phased Handover
Occupied since August 2012

Budget: £ 5.4m Inclusive of 41 Passive Houses / Shared Community buildings & site civil engineering works.

Terrace A Passive Houses & Common House Veranda
Measured Energy Performance

Measured Performance:
(average across all houses)

DHW: 26kWh/m².a

Space heating: 13kWh/m².a

Electricity: 22kWh/m².a

Extra use in common facilities: 5kWh/m².a

Primary energy (at boiler room): 77kWh/m².a

Heating and hot water house demand are meeting predictions

Electricity use in the houses is unusually low, possibly thanks to communal usage.
Occupant Feedback

Building User Survey (BUS) was undertaken with 100% return of questionnaires.

Residents were very positive about how well it performs. Responses for all eight main categories: air quality, comfort, design, perceived health, lighting, needs, noise and temperature were all higher or better than the UK 2011 BUS Housing benchmark.

In five of the categories the project was either the highest or second highest performer when compared against other studies.

"An exceptional achievement"

Professor Fionn Stevenson.

Occupant Feedback Quote

"The Lancaster passive house I live in has exceeded all my expectations with regard to comfort, warmth and air quality. The utility bills are exceptionally low and the systems are easy to use. From my personal experience I would have no hesitation to recommending these Passive House Designs to others"

Dr Jan Maskell Lancaster Cohousing Resident
Aesthetics
Key lessons learnt

• Get the basics right early on
• Keep it simple
• Have confidence in Passivhaus performance
• Keep the same team, commit to learning!
• Small budget & more constraints can help!
“Making the simple complicated is commonplace, making the complicated simple – that’s creativity”  Charlie Mingus
“What you put in may make a building good but it’s what you leave out that can make it great.”