Building a Better Passivhaus School

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1 Introduction

Elemental Solutions worked with Architype to deliver three of the first Certified Passivhaus schools in the UK, Oak Meadow and Bushbury in Wolverhampton, and Swillington in Leeds. The Wolverhampton schools were monitored in detail over the first two years during a “soft-landings” [BSRIA 2014] handover period to tune the building services systems. Architype were commissioned to design another school in Wolverhampton, Wilkinson Primary School. The earlier schools were built without additional budget for Passivhaus [Hines 2012], but the square metre budget for Wilkinson School was about 10% lower than the previous schools. As with the earlier schools the construction is timber frame with taped 18 mm OSB for airtightness, blown cellulose insulation and ventilated rain-screen cladding. The flat structural slab floats on EPS insulation and the roof utilises I joist cassettes.

2 Internal Heat Gains (IHGs)

When using PHPP to inform the design of the first three schools, generous areas of south glazing and high-g glass helped meet the 15 kWh/(m^2a) annual heating demand target. Once occupied, we soon realised that the first schools had higher internal gains than assumed by PHPP. There was no problem meeting the heating demand in practice, but controlling overheating was harder, especially in spring and autumn.

We assume that the PHPP IHG figure has worked as a basis for designing typical German Passivhaus schools but our comparison showed that the average occupant density of UK primary schools was 5.7 m²/child compared with 10.5 m²/child in the German schools we had visited. In addition, the UK school day is approximately 1 hour longer. Considering only the metabolic gains we calculated that this amounted to an additional 1.3 W/m² on average, and the new school was designed in PHPP to an internal heat gain figure of 4 W/m² rather than the default 2.8 W/m^2.

We did not assume any increase in internal gains due to computers – these are fairly insignificant in a primary school. Clearly this is a small sample but the UK Schools Building Bulletin 103 [DoE 2014] recommends gross area for primary schools to equal 400 + 4.5 N as a maximum size and 350 + 4.1 N as a minimum size (N being the number of pupils). (ie 5.1 - 5.8 m²/p for a school of 300 pupils) - very close to our TFA figure.

2.1 Fenestration

The major implication for the design of using this higher IHG figure was the reduction in south facing glazed area. Glazing below the work surface height of about 800 mm provides no significant increase in useful daylight. However if this lower glazing is added to capture additional winter solar gain, and we use fixed shading, the shading must be extended to control summer overheating. This actually reduces the sky view and daylight penetration. Thus reducing the amount of floor to ceiling glazing actually improved daylight, and results in simpler and cheaper window installation.

3 Ventilation


Figure 1. windows and night vent. Photo Juraj Mikurcik Architype.

Useful feedback from the first schools concerned summer ventilation. The system of motorised opening of classroom windows with automatic control was frustrating for teachers to use and prone to faults. The reasons for such a system were firstly to enable automatic control of window opening for over-night ventilation for cooling, and also to provide safe operation of windows considered too big and heavy to open by hand. The automatic controls introduced algorithms to protect against rain and low outdoor temperatures, which were also applied when teachers wanted to open the window with the manual over-ride switch. In practice this meant the window openers appeared not to be working at times.

The new school only uses windows in classrooms that can be opened by hand. Some have fixed external shutters so they can be left open in rain and overnight. Tilt action windows were found to provide little free area. A more effective solution for night purge ventilation in classrooms is manually operated side-hung windows opening flat against an internal wall, see figure 1.

To ventilate the central “hub” spaces which have high level clerestory windows, side-hung vents open under the control of the Building Management System (BMS) with local manual override. The side-hung design means that actuators do not have to carry the weight of the window and the window can open further. External louvres mean that rain can be ignored.

It was expected that the mechanical ventilation would be switched off outside the heating season to save electricity and prolong filter life. To this end, an auxiliary WC summer extract fan and additional dampers were included in the designs of the first schools (the extra fan only ran in summer). For Wilkinson the summer fan was omitted and the MVHR was to be used at a reduced flow rate, with extraction from the hub area shut off by damper.

However feedback from the first schools showed that it was difficult to decide when the system should be in summer mode and teachers didn't know if they needed to open windows or not. The result was better classroom air quality in winter than spring and autumn because only the MVHR provided consistent ventilation rates. In practice it has proved useful to run the MVHR whenever the school is occupied to ensure background ventilation. Architype's latest Passivhaus school is designed to have the MVHR run all year with windows opened manually whenever teachers want.

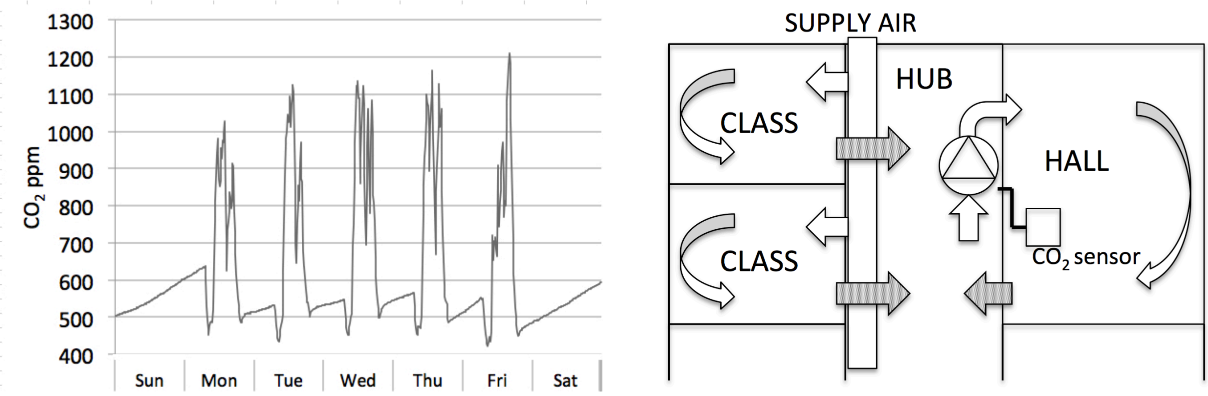

Figure 2. Schematic supply air strategy for the schools and CO2 for a classroom week 2-8th Nov 2014.

The simple cascade concept of supplying air to classrooms and extracting from the WCs and 'hub' area as implemented in the first three schools has proved very effective and was repeated for Wilkinson. The 'hub' is used for teaching and is ventilated by overflow air from classrooms via low pressure-loss acoustic vents that also serve for passive night purge air transfer. The fresh air is supplied to classrooms at a fixed rate whether occupied or not. If there are lots of children in the hub then there must be fewer in the classrooms and so the overflow air from them will still be fresh. A CO_2 sensor in the hall activates a shunt fan to circulate air from the hub through the hall when enough children are in the hall rather than the classrooms. The graph in Figure 2 shows CO_2 concentration (ppm) in a north facing classroom at Wilkinson School. Such monitoring shows that achieved ventilation rates maintain satisfactory indoor air quality with peaks typically below 1200 ppm [KEEN 2015].

A CO_2 sensor in the extract air stream at the central MVHR unit allows the BMS to modulate the ventilation rate. This feature was never actually commissioned on the previous schools so we have yet to discover how it will fail. As with the previous schools, heat recovery is by thermal wheel, which provide some moisture recovery when the outside air is cold and allows simple control of supply air temperature. The whole school ventilation rate is set based on the total design number of occupants and a fresh air supply rate of 15 – 20 m^3 per occupant, per hour whilst occupied, plus an hour purge before the day starts.

3.1 Kitchen Ventilation

The successful approach to kitchen ventilation is outlined in an earlier paper [Clarke 2012]. The main refinement introduced for Wilkinson was the removal of the fresh-air heating coil. The run-around-coil heat recovery unit had proved capable of maintaining a minimum supply air temperature of 12° C, ideal for comfort in a commercial kitchen. An electric heating coil was included in the air-handling unit as a fall back measure but was not to be connected unless this was found to be necessary. The authors were disappointed, but not surprised, to discover that the heater had in fact been wired in and was masking the failure of the run-around-coil pump, and also causing overheating of the kitchen.

4 Heating and Domestic Hot water

It was clear that previous systems had been oversized, so a single boiler and smaller radiators were used. The long time constant and stable temperatures in the first schools convinced the client that a standby boiler would not be required. As with the other schools, the heating system has a single zone with thermostatic radiator valves (TRVs). A single radiator per room is preferred to simplify user control. Typically the radiator is behind the door to each room minimising distribution pipe length and saving more valuable wall space.

Contrary to Passivhaus practice, the first schools were designed with weather compensating boiler temperature control. It was apparent that the impact of solar and internal gains meant that this wasn’t a relevant way to control the heating. These controls were reprogrammed to turn the boiler temperature down as the average room temperature approached the desired set point, and to turn the heating off when the building was above the set point. This approach was adopted for Wilkinson.

The Authors have previously explored the importance of hot water system design in Passivhaus dwellings [Clarke 2010]. Monitoring of the first schools had shown that at least 60 % of the hot water energy use was circulation loss – the pipes were well insulated, but the usage is low. Distribution losses were even higher than expected as our calculations (and the PHPP) ignored the daily cooling and reheating of the long secondary circulation loop.

For Wilkinson, to minimise these losses and unwanted heat gains, we used a gas instantaneous water heater for the kitchen, and local electric water heating for the rest of the school. Instantaneous electric water heating was rejected because of the high peak load, instead small local storage heaters were used. In order to minimise the number of units and associated standing losses, these were located to serve as many outlets as possible with un-insulated micro-bore pipe to minimise dead legs. The contractor was skeptical and so constructed a test rig, which successfully proved the concept. Figure 3 shows the test rig and a graph of maximum flow rate for lengths of 10 mm PEX pipe (6.5 mm bore) for a 1 Bar pressure drop. The final installation utilised 8 mm copper pipe (6.8 mm bore) and 7 electric water heaters to serve the whole building. Pipework volumes are below 1 litre so there are no concerns with Legionella in the distribution pipework. The total standing loss of the local storage is estimated at 2.7 kWh/(m^{2}a) primary energy.

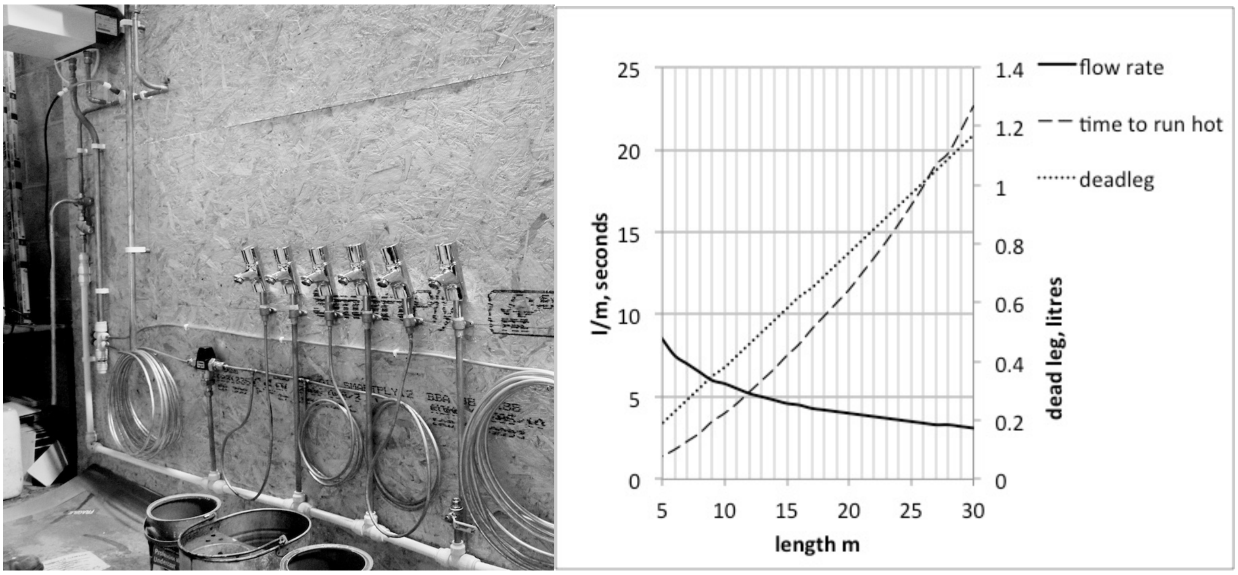

Figure 3. Test rig to prove the 8mm microbore pipe distribution concept and graph for 10mm PEX pipe. Time to run hot is at the maximum flow rate for that pipe length.

Hand basin taps were fitted with 1.7 litre/minute, flow-regulated multi-column-laminar-flow outlets, commonly referred to as ‘spray taps’ which implies aerosols, raising fear of legionella. This had led to the Council banning spray taps. A risk assessment was carried out before we could proceed with this key component of the hot water strategy.

For Bushbury school we avoided hot water supply to individual classrooms but we failed to win that argument for Wilkinson. Also we chose to store water at the standard 60° C and use thermostatic mixing valves. A more elegant solution, that seems to be acceptable outside the UK, would be to store the hot water at the temperature required at the tap. This would save energy, reduce scale build up and eliminate troublesome mixing valves. However it would go against current UK practice in terms of legionella control – something to re-visit on a future project.

5 Building Management System (BMS)

The control strategy for Wilkinson is simpler than for the other schools but a BMS is still employed and this is where most problems have been encountered. Bretzke [2014] seems to be recommending that the BMS is replaced by timers and basic boiler control. This would save capital cost but also reduce user frustration and wasted energy caused by inevitable errors in a complex system. The MVHR has proved effective in controlling supply air temperature in response to exhaust air temperature but communication with the BMS has been problematic. Similarly we have experienced considerable problems with sophisticated lighting controls and now, like Bretzke, favour simpler controls.

6 Comfort

Comfort and internal conditions are being monitored in an on-going Architype and Coventry University KEEN (Knowledge Exchange & Enterprise Network) research project, funded by Architype and ERDF via University of Wolverhampton. This includes monitoring of hygrothermal conditions in classrooms of the three Passivhaus schools and three other new schools, and a building user survey. Although average summer temperatures appear similar in the three Passivhaus schools, in Wilkinson the south facing classrooms experience less temperature variation and the survey showed that Wilkinson was rated more comfortable in summer than the previous Passivhaus schools, and is the highest rated of the six schools in the study.

7 Conclusions

The new school has been open for a year and initial monitoring shows that the energy performance is as expected. Also the summer conditions have been more stable than the previous schools – with less solar gain and simpler ventilation the temperature is easy to control. According to the head teacher Tina Gibbon: “The school feels very airy and it’s very quiet. It’s warm in winter, but it also performed very effectively in hot weather.” It is clear that there is still potential for further simplifications which we expect will reduce costs, simplify operation and reduce energy wastage caused by unforeseen control errors.

8 References

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