Passivhaus school kitchens

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1 Introduction

Schools in the UK provide a mid-day meal, usually cooked at the school. Accommodating a commercial kitchen within a Passivhaus school has significant energy impacts on both ventilation heat loss and catering energy consumption. For two of the first Passivhaus schools to be built in the UK we adopted a strategy to minimise this energy use.

The schools

Two Passivhaus primary schools, Oak Meadow and Bushbury Hill, were completed in Wolverhampton in 2011. [Hines 2012] Oak Meadow is 2400 m^2 (TFA 2200) with 420 pupils aged 4-11 and Bushbury Hill 1900 m^2 (TFA 1700) with 240 pupils, aged 3 to 11. The school day is from 8:45 to 15:15, and lunch is prepared in the morning, served from 12:15 till 13:15, with dishwashing completed by around 14:30. Hot meals are eaten by around half of pupils, 170 at Oak Meadow and 110 at Bushbury. For these projects we were the Passivhaus consultants to architect Architype Ltd and M&E consultant E3 Consulting.

The problem

To achieve the 15 kWh/(m^2.a) heat demand limit the schools have mechanical ventilation at 18m^3/h/person with 80% heat recovery for the classrooms and hall, so for example for Bushbury this was 5400m^3/h. The standard kitchen design requires another ventilation unit of 3600m^3/h with no heat recovery. In simple terms this additional ventilation heat loss looked like adding up to 10 kWh/(m^2.a) to the school heating demand – although with no actual heat loss impact on the teaching areas. In fact the heat demand comes from the need to ensure the fresh air supply to the kitchen is not so cold as to cause discomfort.

The approach

We aimed to firstly examine the requirement for ventilation in the kitchen, and see how this could be minimised without adverse affect on safety or comfort, and then to estimate how much heat input kitchen ventilation actually required, and what we could do to minimise this.

2 Kitchen ventilation in schools

Kitchens are ventilated for a number of reasons:

- fresh air for gas combustion
- removal of products of combustion

- removal of heat both convective and radiant from cooking equipment
- removal of vapour and particulates, mainly water but also oil or fat

Generally air is extracted from a hood over the cooking equipment and fresh air supplied either from the face of the hood or separate supply air grilles.

UK designers follow the guidance of the Specification For Kitchen Ventilation Systems DW/172 [HVCA 2005]. This quantifies ventilation rates required for various items of equipment depending on the type of equipment and usually the horizontal area. For equipment under the hood the aim is to capture the plume of hot air that rises naturally from the hot surface by extracting in excess of this quantity of air from the hood so that heat and vapour do not spill out into the kitchen. This requires higher ventilation rates for equipment with hotter surfaces, so ovens being insulated have lower ventilation rates than hobs, and charcoal grilles and deep fat fryers have high ventilation rates.

In addition to the primary cooking equipment other heat sources are hot cupboards where batch cooked food is kept hot ready to be served; heated server counters; dishwashers; refrigeration equipment. In a school kitchen the heat from these is generally removed by air transfer from supply grille to extract hood.

Cooking equipment for schools

The good news for us is that schools do not use deep fat fryers or grills – most food is either steamed, baked or roasted, with some use of hobs for boiling, e.g. for pasta, and for frying and making sauces. Most Wolverhampton schools use gas-fired kitchen equipment. With the standard requirement of two gas ovens and one gas hob the required ventilation rate was 3600m^3/h. However at other new schools there had been problems of overheating so the engineer wanted to specify a higher ventilation rate than this.

With a switch to electric appliances and in particular an induction hob, total ventilation rate was reduced to 2400m^3/h. Also without gas combustion it is permissible to reduce the ventilation rate further at times of low heat output, whereas with gas cooking the airflow must remain at the design level to ensure it will always dilute combustion products. Also an interlock is required since the ventilation must be running before the gas can be turned on.

The decision was taken to follow the all-electric route of minimum heat output and variable ventilation volume as basis for a more economical and comfortable kitchen.

3 Kitchen energy balance

To aid understanding of the heat flows in the kitchen we built a steady state spreadsheet model to combine the main heat sources and the air movement. This drew on detailed measurements of actual heat emissions of various appliances [Kosonen 2005] and the equations developed by kitchen ventilation specialists Halton [Halton 2007].

(These papers showed for instance that when cooking the heat lost to the kitchen from a gas hob is around 100% of the heat used, whereas the heat to the kitchen with an induction hob is only 25% of the useful heat. At idle the heat gain to the kitchen from some hobs, such as an iron range or gas left burning can actually be higher than when in use, but is close to zero for an induction hob.)

The model assumes a percentage of maximum cooking power, with around 15% radiant heat to the kitchen, and 15% convective heat extracted via the hood. 100% of other heat gains of lighting, refrigeration, occupants and hot cupboard go to the general kitchen area. (Note that a large fraction the cooking heat input is retained in the food and some goes to generating vapour in addition to convection.) Ventilation rate is also variable, from design maximum down to a minimum set by the fan characteristics. The air supply temperature of 12°C is considered the minimum for comfort below supply air terminals.

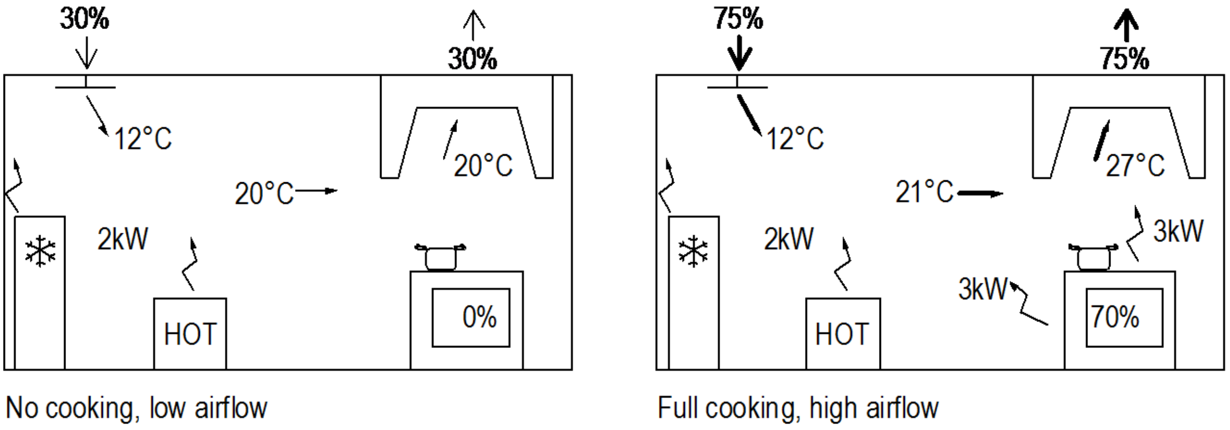

Figure 1: illustration of heat and airflow in the model

We can see that at full cooking load (70% diversity assumed for school kitchens) the gains to the kitchen are such that a 12°C supply air temperature will lead to comfortable working conditions, and with 20°C outside (summer mornings in Wolverhampton) and maximum airflow the room should be limited to 28°C – acceptable for kitchens. When there is no cooking a minimum ventilation flow rate of 50% leads to a requirement for supply temperature higher than 12°C, but not if air flowrate can be reduced to around 30%.

Space heating requirement

The level of building insulation in Passivhaus indicates there is no requirement for background heating in the kitchen so all heat input is via the supply air to maintain a minimum comfort temperature in the kitchen during use. The requirement for a minimum supply temperature of 12°C clearly indicates a requirement for heating as external daytime temperatures drop to -2°C here. However by establishing that we only need to heat the supply air to 12°C does mean the heat demand can be calculated for a much lower heating degree hours than for general space heating.

However it was also apparent that the total heat production of the kitchen was sufficient to heat the fresh air to comfort conditions at all times – and we wanted to solve the dilemma of supplying air in order to remove heat and then having to pre-heat the air as well. Clearly heat recovery is the solution and although a counter-flow heat exchanger is not considered robust enough for the hot, moist and greasy air from a kitchen, a simple air-to-water heat exchanger is OK. So a run-around coil heat recovery system was used, with glycol mixture circulating between a coil in the extract air and a coil in the intake air. This was calculated to have a design heat recovery efficiency of 50%, which was close to removing all additional heat demand. The fluid circuit includes a mixing valve so that proportion of heat fed to the supply air can be modulated on air temperature control.

The system still includes a heater coil from the main heating system because of uncertainty of maintaining comfort temperatures in winter design conditions and during food preparation when cooking heat gain is minimal.

4 Monitoring

The schools opened in October 2011 and have been monitored via the Trend Building Management System (BMS). There was no specific funding for in-depth monitoring so we used the standard types of monitoring available in the BMS plus site visits with interviews with kitchen staff and energy measurements of refrigeration using plug-in kWh meters:

Temperatures:	Power:	Other:
Outside	Total kitchen electricity	% run-around valve
Kitchen	Total hot water generation	% fan speed
Extract hood	Refrigeration	Numbers of meals
Air off run-around		Menu
Air off heater		
Run-around fluid		
Heater coil		

Table 1: data points monitored

Generally data points are collected every 15 minutes, but the default used for the electrical meters is 30 minutes and this was not changed for our study. It was not practical to monitor the actual hot water supplied to the kitchen, so we have estimated on basis of the gas submeter supplying the hot water generators. Unfortunately at the time of writing the Bushbury electric submeter is faulty, due to be replaced at next school holiday.

Results

The monitoring showed the daily trend as shown in figure 2 (here all results relate to Oak Meadow school), note that as hood temperature increases so does exhaust with only the quanitity of heat needed to maintain the supply temperature being recovered.

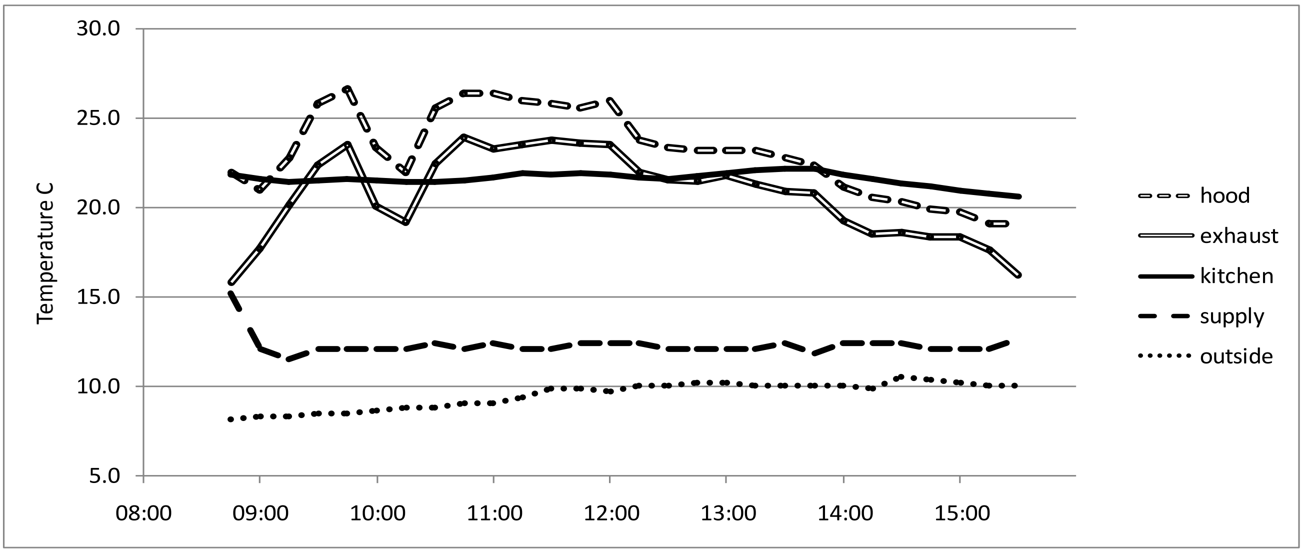

Figure 2: room and ventilation system temperatures over typical day

At around 9:30 the hot cupboard is turned on to start warming up food containers, then ovens are used for batch cooking starting around 10:00. The result is that the heat recovery was more effective than anticipated, and we think with good airflow control the additional heating would not be needed. However with the manual speed control currently provided in the kitchen the staff tend to leave the fans at a particular rate for several days, not adjusting them until they feel noticably too warm or too cold (on/off time is controlled automatically).

Heat recovery

The heat recovery efficiency was inferred from temperature rise and seen to reach a maximum of approximately 45%, modulating down to 10-15% as hood temperatures increase. This modulation is clearly important for control of room temperature.

Kitchen Equipment

The induction hob was new to the kitchen staff, luckily they are very happy with performance. Previously the handles of pans would get too hot to touch – now they are cool and easier and safer to lift. Control of heat is good.

The combi steam ovens are used for most cooking. It appears that the bulk of the heat release to the hood is some time after the start of cooking.

The fridges and freezers (600 litre upright fridge and freezer in kitchen, chest freezer in store) use a total of 5kWh/day. This represents around 1kWh/m^2.a of electricity so not a major impact on primary energy or on kitchen heat gain.

Cooking energy use

Over a two-week menu cycle, the average daily electrical power consumption for Oak Meadow is 55kWh for 170 meals. Taking the cooking energy use as running from 8am until

13:00 (the hot cupboard and heated servery are still in operation at this time) and subtracting refrigeration, the daily power consumption ranged from 43kWh to 49kWh, with average of 46kWh. This gives an average figure of 0.27kWh per meal.

Dishwashing energy use

The passthrough dishwasher used has a 21 litre wash tank with 2kW element and 7.5 litre rinse tank with 7kW boost heater, operating at 85°C. Water usage is 3.5 litres per cycle.

The average dishwasher electrical use is estimated as kitchen power from 13:00 until 15:00. Hot water use is not separately metered so has been estimated on the basis of the increase in gas consumption by the hot water generators for this period.

The electrical use ranges from 7kWh to 11kWh, with average 9kWh, and hot water from 4kWh to 13kWh, average 8kWh Total washing up energy usage is estimated on average at 16kWh, 0.09kWh/meal – though with some uncertainty as hot water usage wasn‘t metered.

5 Conclusion

The use of cooking equipment with low heat loss to the kitchen enables the use of lower ventilation rates, with associated reduced need to heat incoming air and reduced plant size and fan power. A low efficiency heat recovery system using air-glycol heat exchangers is sufficient to provide most of the heat that the supply air requires.

A change of control to vary the supply air volume automatically in response to kitchen temperature would allow the omission of the boiler heater coil in the fresh air supply. Such variation of air volume is only possible with all-electric cooking.

Energy demand for cooking was measured and found to be close to the assumptions made in the design PHPP calculations.

6 References

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[Kosonen 2005] R Kosonen, H Koskela, P Saarinen, An analysis of the actual thermal plumes of kitchen appliances during cooking mode, Proceedings: Indoor Air, pages 2624-2629 (2005)

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