8 Building services

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INTRODUCTION

Building services comprises heating, ventilation, plumbing and electrical systems. Energy use by all of these is included in the overall energy use metric in PHPP, Primary Energy Renewable (PER).

Ventilation is critical for Passivhaus to deliver good internal air quality. The importance of heat recovery efficiency means that high quality Passivhaus certified components are required along with a well designed, installed and commissioned system. In-use monitoring has shown the attention to detail paid to Passivhaus ventilation systems pays off – they consistently deliver the best indoor air quality.

Heating is required in a Passivhaus building, just not much, and in practice a modestly sized conventional radiator system can often be the best approach.

VENTILATION

The performance of the ventilation system is an integral element of the primary Passivhaus heating demand calculation, though the rest of the services are not. Heat recovery ventilation is effectively seen as insulation for the fresh air supply. The main intake and exhaust ducts carry air at outside temperature, so form part of the building's external insulated envelope. Thus, in keeping with the emphasis on compact form, the designer needs to be aware of these ducts and how to make them as short as possible at an early stage in design.

The impetus for using MVHR may have come from the opportunity for heat recovery, but now we recognise that the main benefit of these systems is effective ventilation – essential for occupant health. The Passivhaus standard sets detailed criteria for airflow rates, noise levels and commissioning which, if followed, will lead to ventilation that works well. The ventilation section of this guide provides specific details about designing ventilation to the Passivhaus standard.

LEARN MORE

pht.guide/caseforMVHR

HEATING AND HOT WATER

A Passivhaus does need some heating – this is implicit in the standard, which is in terms of annual heating demand or peak heat load, after taking account of solar and internal heat gains. However, the amount of heating is very small – much less than a standard new building, and far less than the twentieth century buildings our heating systems have developed in.

It should be possible to heat a Passivhaus by heating the ventilation supply air, but this doesn't mean you should do it this way. There is often a mismatch between where you want air and where you need to supply heat, so it is usually easier to separate them.

The heating system in a Passivhaus is one area where you can reduce costs compared with a conventional building, and still use conventional suppliers and technologies – the system will simply be smaller.

Heat pumps are well suited to Passivhaus buildings – radiators 'oversized' to work at heat pump temperatures (ideally below 40°C) are not large or expensive in a Passivhaus, thanks to the low heat load. Also, the quality assurance which minimises the performance gap of Passivhaus means the system can be sized accurately without risk of under-heating in cold weather. The minimal heating requirements of Passivhaus mean air source heat pumps with radiators are usually the rational choice rather than ground source with underfloor heating combinations, which are a little more efficient but have a high capital cost. Some Passivhaus buildings are suited to air-to-air split systems, which are cheaper still. Larger buildings such as Passivhaus schools are also ideal for air source heat pumps, and here, the much reduced heat load offers large reductions in plant size.

COOLING

With increasing concern about overheating in the UK climate we expect to see more use of active cooling in dwellings. Being a global standard, Passivhaus already has this covered, with an annual cooling demand limit of 15 kWh/m^2.a (the same as for heating) to ensure a fabric-first approach is used to minimise cooling energy use.

Plant room with ASHP system. Image: Alan Clarke

While building fabric is the key to Passivhaus performance, it is important to pay attention to building services. Mechanical ventilation with heat recovery (MVHR) is the least familiar but it is also important to design heating systems appropriate to the level of heat demand, so they run smoothly and economically. This section looks at the principles of building services design for Passivhaus.

RENEWABLES

Traditionally, solar thermal has been a popular choice for Passivhaus Designers to reduce the total energy demand of a building (i.e. the PER). However, big drops in the cost of solar photovoltaic (PV) generation have changed the landscape, and PV has largely replaced solar thermal as a means of harvesting the sun's energy.

To recognise the use of renewable generation in buildings the Passivhaus standard has three classes. "Classic" is the original Passivhaus standard and has no requirement for renewable generation, then "Plus" and "Premium" have increasing requirements for renewable generation along with reduced PER (Primary Energy Renewable) demand.

To get round the fact that compact multi-storey buildings have less space for PV per m² of floor area, yet provide an efficient built form in most other ways, the on-site generation is assessed in terms of m² of building footprint, so that these build types are not excluded from the Plus and Premium standards.

Note that renewable generation is not simply subtracted from energy consumption in the Passivhaus model: all classes allow some generation to be allocated to on-site consumption, subject to an upper limit of 15 kWh/m² PER. Similarly, the Plus and Premium options allow for this range of reduced PER demand, in lieu of generation.

RETROFIT

When retrofitting a building to the EnerPHit standard the same quality building services are required as for a new build Passivhaus. MVHR can be hard to retrofit given existing floor to ceiling heights, but is still achievable with careful design. In larger buildings this tends to lead to decentralised ventilation being a more common choice for retrofit. Heating systems benefit from the very low peak heat load in an EnerPHit building, not much higher than a Passivhaus. Often existing heating systems can be retained while transitioning from a high temperature fossil fuel system to a low temperature heat pump system, taking advantage of the existing emitter sizes.

do

- **ensure any subcontracted building services designers (eg suppliers providing designs) are aware of and understand Passivhaus requirements**
- **think about MVHR design and location at an early stage**
- **make sure the MVHR is easy to access for filter changes**
- **get a full ductwork design done in time to integrate with the architectural design**
- **allow for a heating system, probably heat pump, but keep it simple**

don't

- **think you have to heat via the air supply**
- **get carried away with expensive heating systems – they won't be used enough to be worth it**
- **think that PV can power a heat pump directly – peak heating demand is in winter when PV generation is lowest**
- **expect that the MVHR will distribute heat from a heated room to an unheated room – it won't**

Left: Photovoltaics on the roof of Hackbridge Primary School, certified Passivhaus Plus. Images: DF Roofing

MVHR

INTRODUCTION

Mechanical ventilation with heat recovery (MVHR) provides whole building ventilation with minimal heat loss, and is an essential component of a Passivhaus in our climate.

LEARN MORE

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MVHR

A domestic MVHR system has a ventilation unit with two fans: one draws outside air in and supplies it to bedrooms and living rooms; the other extracts air from kitchens and bathrooms to exhaust to outside. Inside the unit there is a heat exchanger which transfers the heat from the outgoing air to the incoming air without any recirculation of the air itself.

The fans run all the time, but can be switched to different speeds – usually low, normal and boost – and these rates are adjusted at commissioning to suit the individual house. The unit includes filters which keep dirt out of the heat exchanger. In order to ensure good indoor air quality the intake filter also removes small particulates (PM1, PM2.5 and PM10, which are harmful to health) with high efficiency.

Ducts distribute the air from the ventilation unit to and from the different rooms in the dwelling, and there are also ducts between the unit and outside to bring in fresh air and exhaust stale air.

Large buildings such as schools basically use the same system, though may use a number of ventilation units in one building and may control airflow on a different basis, such as measured CO_2 levels as an indicator of the number of occupants in a space and thus air flow requirements.

Plant room at Old Forge Cottage Passivhaus. Image: Green Building Store

VENTILATION UNIT AND DUCTWORK

Ventilation unit

Ventilation unit location is very important to both the efficiency and also the long term usability of the system. Ducts connecting to outside contain air at the outside temperature, so are effectively outside walls – we use insulated ducts but can't possibly insulate them to the standard of the wall. The ducts therefore need to be as short as possible; basically the unit needs to be located adjoining an external wall, or failing that, within two metres of one. It is also possible to install the unit in a frost free location outside the thermal envelope, such as an enclosed porch, but the connecting ducts still need to be as short as possible and of course the external terminals have to be outside the building altogether. All distribution ductwork on the warm side of the heat exchanger – supply to rooms and extract from rooms – has to be within the airtight thermal envelope.

Old and new MVHR filters – left to right: intake; exhaust; new. Image: George Mikurcik

Access is needed to change filters (every 3–6 months, depending on how dirty the outside air is), so you should be able to walk up to the unit and reach it without needing a ladder. Some units are too noisy to have in a living room or bedroom, so the ideal is a utility room or WC/cloakroom. Allow space for ducts and ancillary equipment when allocating space – look at previous installations for guidance.

Condensate drainage is needed from the ventilation unit – this should be to the internal soil pipe system via a trap and not just straight to outside, otherwise the drain could freeze solid and the unit would flood.

External terminals

External terminals can be close together: it is better to have the exhaust on the same wall as the intake, to minimise impact of wind pressure difference.

Combi MVHR terminals for individual flats at Carlton Chapel House

Placing the terminals vertically one above the other with exhaust 600 mm below intake is a good solution to minimise wall use on a narrow frontage house – there are also “combi” terminals which combine intake and exhaust in a single unit, designed to avoid recirculation from exhaust to intake. Although people can be concerned about such recirculation, for a single house there is little reason to worry – the transfer from adjacent terminals is minimal, and far less than transfer between rooms inside the house.

The position of the intake terminal is however important. Avoid locating the intake near smells or pollution, eg, bins, flues or cars, or the path of exhaust from a neighbouring dwelling. Put the intake two metres or more above ground level to minimise intake of particulates. Intake through the roof risks bringing in hot air in summer – even north roofs can get hot, so walls are a better location. Roof exhaust also causes problems – in this case, with condensate from the damp exhaust air collecting in the duct and needing special drainage.

Ductwork sizing

The basic principles of ductwork systems revolve around airflow rate, air velocity, and pressure. For a particular airflow rate (ie volume per second) the air will move faster in a duct with small cross sectional area than a large one. Higher pressure is needed to push the air at higher velocity, and this is accentuated with small ducts where more of the air is close to the duct walls.

High air velocity has a direct down-side, so called “regenerated” noise, which is the whistling you hear when air is forced through small gaps. However the main impact is due to the higher pressure needed. This increases the energy needed by the fans to move the air, which we don’t want, but also some of that energy is converted to noise, which we also don’t want. Hence Passivhaus ductwork systems are designed around principles of low velocity and low pressure.

For practical purposes ductwork size can be determined initially from the desired air flow rates, calculating the size that will not exceed the limits for air velocity at that volumetric flow rate. In domestic design the usual requirement is velocities <2 m/s, and up to 3 m/s for the main ducts at the MVHR and connections to outside.

With these velocities the ductwork system will have low pressure loss, low energy use and low fan noise. For non-domestic projects the situation is a bit different due to larger and longer ducts, and full design is needed to determine the system pressure drop.

Ductwork type

Ductwork can either be rigid – normally steel – in a branched configuration with larger ducts at the MVHR and smaller branches to each room, or ‘semi-rigid’ systems which use plastic ducts that can be bent round corners, but still have a smooth inner bore. For the latter, the ducts are arranged radially running one or two to each room from supply and extract distribution manifolds. ‘Flexible’ ductwork (like old tumble drier hoses) is not acceptable – it gets squashed and has a high resistance to airflow. Flat channel ductwork is also best avoided since the pressure loss at bends is very high. Semi-rigid systems can be easier for shallow ceiling distribution depths.

Since semi-rigid systems use small ducts right from the MVHR they can run the risk of high pressure drops on the longer ducts to more distant rooms. Pressure drop calculations for these systems – which are straightforward – should be done to ensure pressure drops are low and similar for different terminals so that the system is easy to balance.

For the MVHR units used in dwellings, the test figures for PHI-certified MVHR units only apply up to a maximum system pressure of 100 Pa, though this is usually easy to achieve with good design. Larger ventilation units (for flow rates higher than 600 m^3/h) are certified at a specified maximum external pressure, which is individual to each unit, though there is some scope to trade pressure against flow rate, so long as the specific fan power criterion of 0.45 Wh/m^3 is not exceeded.

Rigid steel (left) and semi-rigid (right) ductwork.
Images: Walled Garden, Nigel Dutt (l); New Forest EnerPHit, Ruth Butler (r)

Noise attenuation

Noise control is needed to make the system unobtrusive – noisy systems get turned down or off. The primary source of noise in MVHR systems is the fans, and the noise level increases with increasing pressure, so well designed low pressure systems are quieter as well as cheaper to run. All systems, whether metal duct or semi-rigid, should include proper silencers on supply and exhaust – these are big (typically 900-1000 mm long and 100 mm larger diameter than the ductwork) so if possible fit them between ceiling joists. Branched systems may also require cross-talk attenuators on the supply to prevent noise transmission between rooms via the duct.

The Passivhaus standard requires design figures of < 25 dB(A) for ventilation noise in living and bedrooms (including in non-residential buildings), and <30 dB(A) for extract air rooms and other rooms in non-residential buildings. These figures are used to calculate attenuation required – they are too low to easily measure accurately, at least during the day on a busy building site. Once the system is running you shouldn't be able to hear the ventilation in bedrooms or living rooms – this is one reason why Passivhaus MVHR is easy to live with.

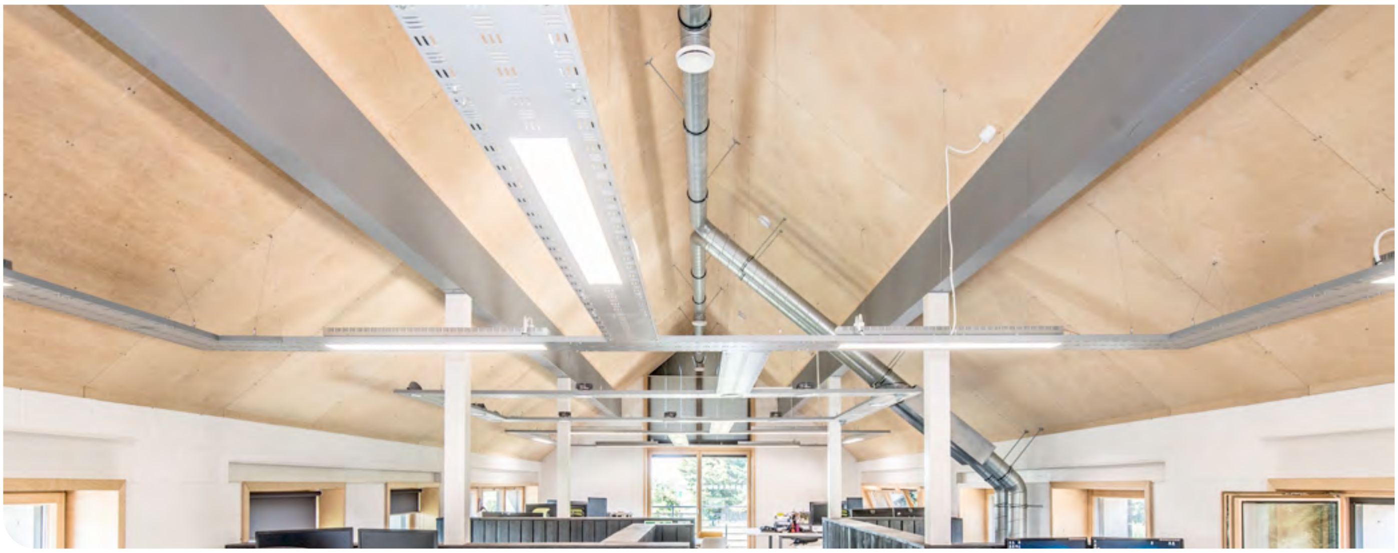
Circular silencers. Image: Earthwise Construction

Internal terminals

Air is supplied to and extracted from spaces using room terminals. These are different for supply and extract, and there are different terminals for wall supply, directional ceiling supply, and all-round ceiling supply. The terminal type used depends on the position in the room: directional terminals are often used to throw air in from above the doorway; standard terminals need to be near the middle of the room – aligned with windows is usually good as the terminals are then unlikely to be obstructed by high furniture. Extract terminals can be put on a wall or ceiling.

In dwellings, door undercuts are the normal way to allow air to flow out of supply rooms and into extract rooms. The minimum undercut is 10 mm above final floor finish. Non-domestic buildings often have to transfer higher airflow rates and purpose-designed transfer grilles or ducts need to be used since the gap under the door is not large enough.

Exposed ductwork with supply terminals positioned along the central spine at Swann Edwards offices. Image: Swann Edwards Architecture



SYSTEM SIZING AND FLOW RATES

There are set criteria for working out how much air to supply in a Passivhaus dwelling; these are provided in the manual for the Ventilation Final Protocol Worksheet, which is supplied with PHPP. Supply air and extract air are worked out differently, but when the system is running they must be equal, that is, in balance.

All projects have to comply with UK building regulations but design teams should always refer to Passivhaus guidance where this gives higher airflow rates. For Passivhaus we recommend supply air is set at 30 m³/h/person (the standard allows for 20 m³/h/person as a minimum but this is not expected to be sufficient for UK homes due to our mild and damp climate) – this should be calculated using the actual number of people expected to live in the house. For under-occupied houses (>40 m² per person) the backstop rate is 0.3 air changes per hour (ACH). This gives the standard airflow rate, which is usually set as the middle fan speed.

Kitchen at Ty Pren Passivhaus. Image: Nick Grant

The lower fan speed is set at 70% of the standard rate, and is used when the dwelling is either unoccupied or occupied by fewer people than usual. The higher fan speed, or boost rate, must be at least 130% of the standard rate. This boost rate also has to provide the extract ventilation rate required for kitchens and bathrooms according to building regulations.

When it comes to deciding air flow to each room, the basic rules are bedroom supply of at least 15 m³/h/person, so 30 m³/h for a double bedroom and the remainder is available for living spaces. Bedrooms can have a higher ventilation rate, especially if also used as a study. Dining rooms can often rely on air passing through to the kitchen and so don't need their own supply, but this depends on the layout of a particular house.

Extract rates are set according to room type but when measured at the standard rate they will typically be lower than the regulation flow rate, with the required flow only extracted at boost rate. Note that supply and extract are both boosted together so that the supply and extract rates are the same as each other at each fan speed.

Stebon Primary School Image: Architype

Non-domestic buildings are usually designed to national ventilation standards. For schools this is according to Building Bulletin 101 which sets performance criteria in terms of CO_2 levels in classrooms. In practice this leads to design flow rates between about 22-30 m³/h/person, depending on the age of the pupils.

Measuring flow rates at Old Holloway. Image: George Mikurcik

Zehnder ComfoSense and ComfoSwitch control panels showing three fan speed rates.

INSTALLATION AND COMMISSIONING

Always use a fully designed ductwork system. For domestic ventilation this would usually be done by the system supplier – however, they may charge for this. Use the ductwork and fittings specified and don't allow shortcuts with flexible or shallow plastic ductwork.

Cleanliness needs to be maintained during construction. Any dirt in the ductwork system will be blown into the building later. Keep ductwork covered before use and cover open ends of ductwork during construction. Do not run the fans at all until after the final clean of the building, to avoid drawing dust and debris into the ductwork.

Above: MVHR unit during installation at Fishleys Passivhaus. Image: Liz Taylor and Mike Hill

Commissioning is the job of setting the system up with the correct flow rates. This can only be done once the house is clean. Traditional branched systems need to have the flow rate for each room adjusted at the terminal, though good ductwork system design will give required settings (in mm). Semi-rigid systems may come designed with specific flow regulating inserts for the duct to each room. It is still necessary to check the flow at each terminal.

don't

- **just stick the ventilation unit in the loft**
- **omit silencers**
- **accept shoddy ductwork installation**

Hand over the system with a clear description, and demonstration of how to operate the controls and how to change filters. Also provide information on where to get replacement filters and written and illustrated instructions on how to change the filters when the time comes 3 or 6 months later.

Housing providers and landlords should highlight ventilation in resident induction, not only the first time but also for all future change-overs. A ventilation system services plan should be set up at the start of any maintenance programme, and ventilation faults should be treated as urgent. Involvement of maintenance expertise at design and specification stages is strongly recommended.

MAINTENANCE

The primary maintenance requirement is changing filters, including any extra on the kitchen grille. Some ventilation units maintain a constant air flow rate when filters get clogged, but in so doing the fans get noisier. Older or cheaper systems just supply less air. So regular filter changes are important. Write the date of install on the filter. Most control units have a filter-change indicator but this is based on number of days.

It is an advantage if occupants can periodically check the system: some systems are so quiet that occupants may not notice if the fans stop running. Over a few years dust builds up on extract valves. These can be removed and cleaned, being careful not to change airflow settings or mix valves between rooms. Terminals should be removed for redecoration, but must be labelled by room if more than one is removed.

Any MVHR error messages and faults should be reported and addressed straight away. An MVHR failure is as much an emergency as a heating system breakdown! The MVHR system should be fully serviced every four to five years.

do

- **make space for the ventilation unit at the start of the design process**
- **provide routes for ducts – think of octopus tentacles not just typical section drawings**
- **fill in the Ventilation worksheet before completing the PHPP**
- **use a PHI certified ventilation unit**
- **get a complete ductwork design before starting installation**
- **have the system commissioned on completion – you need to do this for certification**
- **use a commissioning specialist familiar with Passivhaus systems**

SERVICING CHECKLIST

- Confirm airflow rates are as design - either from MVHR controls or measurement at terminals
- Open MVHR unit, take out heat exchanger & inspect - clean if necessary
- Clean around filter housings
- Check fans for dirt and damage and clean if necessary
- Check bypass valve
- Check preheater and clean if necessary
- Take out condensate trap and wash through, then check condensate is draining properly from MVHR.

RETROFIT

The ventilation system in an EnerPHit building has to have the same performance as that in a new build Passivhaus. Fitting ducts into an existing building is often tricky and for schools it may be appropriate to use one MVHR in each classroom. Some classroom MVHRs are designed to work without ducts, other than short intake and exhaust through the wall.

For dwellings, the lack of designed-in space for ducts can be addressed with lowered ceilings in circulation areas, providing access to adjoining rooms, or routes above kitchen cupboards and through bathroom riser spaces.

CASE STUDY: Carlton Chapel House

Left: PV installation on the roof

Below: small MVHR unit (on the far left) and ductwork discreetly built into and over kitchen cupboards.

This deep retrofit of a three-storey block of 15 flats in Kentish Town to the EnerPHit standard has improved the lives of its residents and contributed to positive climate action.

With energy demand massively reduced, the projected heating load for each flat was just 500W. Direct electric heating using simple wall-hung panel heaters was chosen to heat the homes, avoiding either the expense of a heat pump to meet such a low demand and pipework distribution losses in a communal heating system. Choosing electric over gas made sense for other reasons too: the standing charge alone for gas would have equalled the actual cost of heating. And the roof houses a modest array of solar photovoltaics which provide electricity directly to each flat for domestic hot water.

With the limited space available, careful planning to ensure a compact services installation was key. The flats had no ceiling voids and headroom below 2.4 metres so ductwork routes were limited. The approach used was to run ducts above kitchen wall units, with MVHR in one of the cupboards, and through the bathroom riser space to the bedroom at the rear of the flat.

Heating & hot water

INTRODUCTION

A Passivhaus building can in theory be heated via the fresh air supply – by heating supply air to around 50°C. This idea of doing away with a conventional heat distribution system helped define the Passivhaus standard, but isn't necessarily the best choice. Any heating system can be used; a standard heat distribution will be smaller and cheaper in a Passivhaus than a conventional building. This also results in less embodied carbon.

Passivhaus reduces the need for services! Photo: Nick Grant

To work with renewable generation and minimise carbon emissions, heat pumps are the usual heat source. Small heat loads may be met with direct electricity – especially where this avoids disproportionate heat distribution losses – but running cost needs to be considered.

HEATING

In residential buildings annual hot water demand can exceed heating demand. However, the winter peak of heating demand may be the hardest to address in a renewable energy system. With the PER approach, PHPP weights the impact of different uses according to seasonal renewable energy availability, so despite the low heating demand in a Passivhaus, heat must still be generated efficiently.

HEATING LOADS

PHPP works out an overall heat load, in terms of watts and W/m² at the coldest expected conditions. This gives a continuous heat load – ie, assuming the heating is on 24/7 – and is aimed at seeing if heating via the air is possible. Continuous heating also suits heat pumps, and the small overnight temperature drop in a Passivhaus means there is minimal penalty to heat continuously, even in non-residential buildings.

When using air source heat pumps in domestic buildings there is actually a problem that Passivhaus heat loads are lower than the output of the smallest heat pumps. So in this instance the heat pump may not be running 24 hours a day after all, and also the radiators have to be sufficiently large to dispense the minimum output of the heat pump.

For designing radiator systems, you can use a simple room-by-room steady state heat loss model. Instead of using default ventilation rates (as often used in MCS calculations) it is important to take account of airtightness and MVHR. You can read off the effective ventilation and infiltration rate from the PHPP heat load sheet – for example, a ventilation rate of 0.5 ACH and 90% heat recovery is effectively 0.5 x (1–0.9) = 0.05 ACH for heat loss purposes.

Water tank located in a cupboard. Photo: Alan Clarke

HEATING SYSTEMS

Radiators make for a cheap heating system, and are also an excellent match for a Passivhaus. Thanks to triple-glazed windows, you can put them where you like in a room as there are no downdraught comfort issues. Individual room control with Thermostatic Radiator Valves (TRVs) allows the system to respond to solar and internal heat gains, which provide a far greater fraction of the heating than in a conventional building.

With a heat pump, the heating system temperature is critical to performance – energy usage is roughly proportional to the difference between outside and heating system temperatures, so low temperature systems are better. But the size of radiators needed increases as flow temperature goes down, so a balance must be struck, usually in the 30-40°C range.

Dining room with radiator at the Woodhouse Passivhaus in Presteigne. Image: Charles Grylls

Underfloor heating certainly works in a Passivhaus, but can be an expensive option - it is a radiant source so you need to install it in every room you want to be warm. This then means that the system can be too powerful for the heat load – and needs careful control to avoid overheating. If you can keep the floor temperature down to a degree or two above room temperature, however, the heat output will be self-limiting – once the room is warmer than the floor it will stop heating the room.

The advantage of underfloor heating when using a heat pump is that the flow temperatures required are usually less than 30°C (depending on floor construction and floor coverings) which maximises the performance of the heat pump. This requires no temperature reducing mixing valves at manifolds, which were generally needed in high temperature boiler systems.

COMMUNAL HEATING SYSTEMS

The traditional approach to heating in multi-residential buildings has been to pipe hot water from central boilers (or district heating) to all flats. Here it was used for space heating and to generate hot water via a heat exchanger. The heat loss from the distribution pipework was a significant heat loss for conventional buildings and is proportionally worse for Passivhaus ones, and is sufficient to cause overheating.

Moving away from high temperature heat sources has led to a range of options. Instead of sticking with the conventional approach and trying to minimise the temperature, some are separating out heating and hot water – then the heating circuit can switch to cooling in summer. One new approach is to connect a small water-to-water heat pump to the heating circuit in each flat to generate hot water. More usually, hot water is provided by direct electric heating or central hot water generation. Alternatively, the “ambient loop” approach distributes water at around room temperature for local heat pumps to use to generate both heat and hot water.

Underfloor heating at Bristol Passivhaus Plus. Image: Greenheart Construction

HEATING SOURCES

Air source heat pumps (ASHPs) are a practical option for a Passivhaus. These have an outdoor unit which uses a refrigerant system to generate heat from lower temperature outdoor air. Modern heat pumps are able to heat hot water without needing direct electric boost (immersion heater), which is important considering that hot water often forms the majority of their annual usage in domestic Passivhaus.

Air source heat pump. Image: Alan Clarke

This weighting towards hot water generation also means that the overall performance of the heat pump may be lower than advertised when assessed according to standardised annual usage profiles (as used for the SCOP rating). Remember that some of the heating demand is also met by hot water losses too.

PHPP has a detailed section for heat pumps which takes the test data normally quoted by manufacturers for a range of operating temperatures, and uses the calculated heating and hot water loads specific to the building to estimate the electricity consumption and seasonal performance (SPF) of the heat pump with more accuracy than a standardised SCOP rating.

Ground source heat pumps are also possible, though the advantage of using the ground (as opposed to air) as a low grade heat source in winter is reduced since heating is a small proportion of the total demand, and summer hot water efficiency will be lower than an equivalent air source heat pump. So the high cost of installing ground collectors is not normally justified.

Heat pumps can also heat the air in a room directly – this is actually the usual method around the world, since it lends itself to either heating or cooling, and is generally cheaper than installing a separate water filled heating system. This is known as a split system (see image right), since the refrigerant is transferred from the outdoor unit to the indoor – unlike the usual "Monobloc" air source heat pump which contains all the refrigerant pipework in the outdoor unit. There are also multi-split systems for multiple indoor units connected to one outdoor unit. Large systems for non-domestic buildings may use variable refrigerant flow (VRF) systems, which can be designed to heat some areas at the same time as cooling others.

Hot water can be heated separately by its own heat pump – this is usually using a hot water cylinder packaged with a small air source heat pump on top. Usually in the UK outdoor air is ducted to and from the unit, but in warmer climates the unit may just draw air, and hence heat from the room it is in, so providing some cooling as well.

On a larger scale, hot water is most efficiently generated with a heat pump using CO_2 as a refrigerant. As well as having insignificant global warming potential compared with conventional hydrofluorocarbon refrigerants, CO_2 has unusual properties which lead to high efficiency heating water all the way from cold up to hot, and they can heat to 70°C. There is some scope for using these heat pumps for communal systems, provided the heating return temperature can be kept very low – in effect such systems are often primarily hot water systems anyway.

CO_2 has also been offered as a refrigerant for domestic air source heat pumps. But its poorer performance for heating compared with standard heat pumps has made them unattractive even for Passivhaus. Another refrigerant making a comeback is propane – this had fallen out of favour due to flammability concerns, but is now used in Monobloc heat pumps, including some hot water heaters. This refrigerant has the advantage of very low global warming potential, and can also heat hot water to higher temperatures than the usual refrigerants.

2.5 kW Mitsubishi minisplit installed at Old Holloway – sufficient to heat the whole building. Image: George Mikurcik

HOT WATER SYSTEMS

Hot water often uses more energy than heating in a Passivhaus so it pays to concentrate on designing an efficient system. Use the DHW sheet in PHPP at an early stage in design, since the losses here are included in the summer overheating calculation.

Hot water heat losses fall into three categories:

- cylinder
- continuous (secondary) circulation
- and draw-off dead leg.

In addition there is the primary heat loss between the heat source and the cylinder. Cylinder heat loss is usually quoted in terms of kilowatt hours every 24 hours, so to convert this into watts, multiply by 1000 and divide by 24.

Circulation loss only applies if you have a pumped hot water loop – not normally necessary in houses. If you do have one, then insulation levels and pipe length are the important factors to optimise. Circulation losses can be very significant in non-domestic systems and communal systems. PHPP has detailed entries to ensure this is estimated as accurately as possible. Rule of thumb or percentage losses are not used in Passivhaus designs.

Draw-off losses represent the cooling down of the hot water pipe and its contents after each period of use. Here insulation is not significant – the pipe will cool down anyway: the important factors are pipe diameter and length. Shorter pipes have the advantage of lower pressure loss, which means it may be possible to use smaller diameter pipework. See AECB water standards guidance for details of radial small bore distribution systems.

Cylinder location is the key to efficient hot water distribution. It needs to be as central to the various hot taps as possible in order to minimise the total draw-off pipe length and avoid the need for secondary circulation. A house layout which groups kitchen, utility and bathrooms in one area is also very beneficial. To minimise the primary pipework heat loss the boiler or heat pump also needs to be as near to the cylinder as practical.

Multi-residential schemes with communal heating usually use a heat interface unit (HIU) to generate instant hot water in a similar way to a combi boiler. HIUs traditionally had a bypass valve which let some of the heating system water flow through continually to keep the pipework warm and ready to generate hot water. But this causes high distribution losses, so HIUs with electrically controlled bypass, ie only operated when really needed, are better.

Non-domestic buildings often have much smaller hot water demands than dwellings so for a WC hand wash basin, or a kitchenette sink, it is likely to be more efficient to use local direct electric hot water heating. Instantaneous heating is ideal since there are no storage losses, though the flow rate is limited from such heaters; a cleaner's sink would usually require some storage.

Despite having a large number of taps, schools still have low hot water usage. An example of a Passivhaus school using direct electric hot water heating is Wilkinson primary school. This used a number of storage water heaters, with small bore pipework to distribute to nearby basins and classroom sinks to avoid the proliferation of heaters at every sink.

HOT WATER HEAT RECOVERY

One of the largest uses of hot water is for showers and here there is a good option for energy efficiency. A heat exchanger carrying the waste warm water to the drainage can transfer heat to incoming cold water. This warmed water runs to the shower to reduce the heating needed. With an electrically heated shower the plumbing is simple, but with central hot water storage the pre-heated water would run to the cold tap of the shower and maybe also to the cold feed of the hot water tank – though the latter can only be done for one heat exchanger in the system.

The heat recovery unit may be a long vertical pipe installed in the storey below the shower, or a flat heat exchanger installed under a shower tray – these are less efficient but the only option for flats or ground floor showers. This type may also go under a bath, but they only recover heat when a shower is used over the bath, since they rely on the use of hot water at the same time as the waste water goes to the drain.

Showersave WWHR installation

do

- **use a cheap and simple heating system – the investment belongs in the building fabric**
- **consider radiators as your first option**
- **arrange the layout to keep hot water outlets in a reasonably compact form**
- **put the hot water storage in the same area as the hot water outlets**
- **take care not to oversize heat pumps**
- **fill in the PHPP DHW section before looking at overheating**

don't

- **use fossil fuels**
- **spend a lot of money on a biomass boiler or bore-hole heat pump system**
- **waste money on a wood burner**

Solar thermal and photovoltaics (PV)

PHOTOVOLTAICS

In the past photovoltaic generation was very expensive thanks to the cost of the high tech semiconductor factories needed to make the collectors. Now mass production has brought costs down to a level where PV makes economic sense.

Smart meters allow for measurement of PV export and new tariffs may make simply exporting surplus generation a worthwhile approach for installations with such meters. Traditional electricity meters don't do this, so it has been in the householder's interest to use as much as possible of their PV generation. Immersion heater controllers are available which divert any surplus power to an immersion heater, providing effectively a cheap solar hot water system. However, this approach is not possible if a heat pump uses the immersion heater for high temperature boost. In fact the solar energy would be more efficiently used generating hot water by powering the heat pump. This is now possible, using heat pump controls that link to the PV systems, telling the heat pump to stock up on hot water when the PV system is generating surplus power.

Another way to increase self-consumption of PV generation is to use a battery, especially when decent export tariffs are available, though this is an expensive option and the environmental benefits are debatable. PHPP doesn't account for use of PV power for hot water or in batteries directly, though does allow a fixed share of PV generation to contribute to the PER total.

PV or solar thermal - or both? Renewables installation on a green roof at Ostro Passivhaus. Image: Paper Igloo

SOLAR THERMAL

Solar thermal has traditionally been the cheaper and lower technology way to harvest solar energy, though with current PV prices this is no longer the case. The heat can only be used in the house where it is installed. PHPP recognises this as contributing to reduced primary energy consumption because less fuel is needed for water heating. Systems need to be carefully designed to provide as much useful hot water as possible while avoiding overheating in summer. They may suffer loss of performance if not regularly maintained.

EMBODIED CARBON

While it is important to consider the embodied carbon associated with the energy-intensive manufacture of PV collectors and batteries, it is equally essential to recognise the potential benefits of PV systems at the building level. PV installations enable on-site renewable energy generation, reducing reliance on grid electricity and promoting self-sufficiency. They contribute to the transition towards cleaner and more sustainable energy sources. The suitability of PV systems should be evaluated in the context of local conditions, energy needs, embodied carbon and the broader sustainability goals of the project.

do

- **consider the embodied carbon associated with PV collectors and batteries**
- **consider PV in the roof layout, even if not installing panels straight away. Eg. move any plant and roof access to the north where possible, and minimise parapet heights**
- **use PV panels that have a linear power warranty for at least 10 years**
- **include power optimisation on any PV panels that have any partial shading, or that will be difficult to clean**
- **use MCS products and installers**
- **ensure solar thermal has regular inspection and maintenance**

don't

- **lay PV panels flat – air born dirt will quickly reduce the generation**
- **undersize your PV inverter**
- **specify an over-sized solar thermal system**

Other electrical use

Unlike other UK energy assessment methods, PHPP includes all energy use within a building. For a dwelling this includes appliances as well as lighting, though if these are not supplied with the build, then default figures are used. For non-domestic buildings the assessment of this energy use is both important and onerous. In Passivhaus schools the heating and hot water are a small part of the total energy use. Other key areas are lighting, IT systems, and kitchens. In the latter, the energy use per meal can be assumed as a default but refrigeration needs to be assessed, requiring selection of efficient appliances which are likely to be supplied outside the building contract. Similarly, IT energy consumption will depend on specifications and installations from specialists who work for the client rather than the builder, and often coming to the design relatively late in the process.

Smaller areas of energy use such as fire detection and alarm systems, sprinkler frost protection, lifts, communications systems and controls do usually come under the main contract but are supplied by specialists who aren’t used to addressing energy use and are often not engaged when construction contracts are signed. However, this is a stage when everyone would like to know if the design has reached the Passivhaus standard, so some estimates may be required, along with performance specification to limit the energy use of higher consumption systems.

do

- **consider all energy uses in the building at an early stage**
- **issue an “information request schedule” to contractor and client to specify what information is needed and by when, in order to enable the Passivhaus model to keep up with the design and procurement timetable**

don’t

- **assume Passivhaus is the same as SBEM**

CASE STUDY: Foleshill Health Centre

Foleshill Health Centre in Coventry is the UK's first Passivhaus certified healthcare facility and is the most energy-efficient public building in the NHS estate. Point-of-use heaters were chosen to provide the hot water, so reducing hot water circulation and the concomitant risk of overheating, and also lowering the burden of maintenance for legionella prevention. To get the ventilation strategy right, a detailed room-by-room analysis was undertaken, leading to the solution of separate MVHR systems for each of the two treatment rooms.

The simpler and smaller services required for this Passivhaus health centre have a smaller capital cost than business-as-usual, as well as reducing energy bills. A 40-year cost analysis undertaken by AECOM predicts that the building will save the NHS £450,000 over that period.

Foleshill Health Centre. Images: Tooley Foster.