Passive solar PassivHaus paradigm for Scotland in zero-carbon quest?

Lessons from study tour in Switzerland and Germany, August 2009

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The main title of this article is deliberately somewhat provocative in that many proponents of the brand ‘PassivHaus’ seek distance from the concept ‘passive solar’. The context of the sub-title also immediately invites comparison between the Swiss Minergie-P standard and PassivHaus. Minergie-P is purportedly harmonised with PassivHaus, yet it retains specific passive solar criteria. The tour also included two passive solar houses that explicitly challenge PassivHaus orthodoxy with regard to active heat recovery, but easily comply with PassivHaus standards for total primary energy consumption. Moreover, all the projects visited sought to go beyond the PassivHaus requirements in terms of building-integrated renewable energy (BIRE), all had other ecological credentials and all were passive solar buildings. This article will seek to rationalise key similarities and differences, with a view to applicability in our more temperate and less sunny climate; and also to posit alignment with statutory and voluntary standards in Scotland as well as future targets.

PassivHaus, Minergie-P, Minergie-P-eco and building-integrated renewable energy

The Swiss Minergie standard is somewhat younger than PassivHaus. The Minergie idea first developed in 1994 and the Minergie Association was founded in 1998; whereas the first PassivHaus development in Darmstadt dates back to 1990 and the Passivhaus-Institut was founded in 1996. Minergie-P was established in 2002, both to align with a Swiss target of 80% reduction in heat demand and to harmonise with Passivhaus [1]. Today, through the Promotion of European PassivHaus (PEP), the Building Research Establishment (BRE) is promoting ‘PassivHausUK’ with the sub-text ‘towards sustainable design’. Moreover the Scottish PassivHaus Centre (SPHC) is active as an independent PassivHaus certifier in Fife, and the University of Strathclyde is running courses in certification using PassivHaus Planning Package (PHPP) as the predictive tool.

The basic requirements for PassivHaus certification are quite simple: annual heating (or cooling) demand of no more than 15 kWh/m² floor area, or peak heat load of 10 W/m²; maximum total primary energy load (heating, hot water and all electricity) of 120 kWh/m²; air leakage not to exceed 0.6 air changes per hour (ac/h) at a pressure of 50 Pa. The first of these implies U-values for the solid parts of the envelope between 0.1-0.15 W/m²K and 0.7-0.85 W/m²K for windows, including the frame. Overall the standards are intended to make normal central heating redundant, with most if not all of the heating supplied by low-volume ‘mechanical heat recovery ventilation’ (MHRV). With efficiencies of at least 80%, MHRV may also involve earth tubes to temper the initial supply, depending on ambient conditions, and/or a small auxiliary heating coil. Although the average design rate indicated is 0.4 ac/h, rates required in practice may vary significantly depending on room volumes, intensity of occupation and specific ‘wet’ activities. Indeed, in terms of healthy building a range of 0.4-0.8 ac/h has been indicated [2]. Related issues are automated versus manual control, noise transmission and ease of access in order to change filters.
Minergie-P, as one might expect for a standard that aimed to harmonise with PassivHaus, has very similar requirements [1]. The Swiss heating limit of 15 kWh/m² only differs in that it measures gross area rather than net; and includes an upper limit of another 15 kWh/m² for hot water, pumps and fans, including fuel weighting factors. The weighting factors expressing conversion from primary to secondary or delivered energy represent another difference since they take account of national conditions. Although values for natural gas and heating oil are relatively similar, those for electricity are significantly different - 2.97 for PassivHaus and 2.0 for Minergie-P (reflecting Swiss hydropower) - and wood of any form greater still - respectively 1.01 and 0.5. It may also be noted that values published for the UK by the Association of Energy Conscious Building (AECB) as part of its CarbonLite Programme [3] are quite close to those for PassivHaus - respectively 1.10 and 1.08 for oil, 1.06 and 1.07 for natural gas, 1.05 and 1.01 for wood and 2.78 and 2.97 for electricity. In Switzerland matters are complicated further by the existence of factors by the Swiss Society of Engineers and Architects (SIA) that are different compared with those of Minergie-P, in particular for wood and electricity. The SIA value for the latter is close to that for PassivHaus at 2.9, while that for wood is very low at 0.1 - respectively one fifth and one tenth of those for Minergie-P and PassivHaus. This means that if an architect has used the SIA factor for a log stove, the primary energy will appear to be significantly smaller than if the post-2002 Minergie-P standard were applied.

Perhaps the most significant difference between Minergie-P and PassivHaus is that the latter treats solar gain as secondary to having low U-values and being airtight, while the former has the three aspects in full partnership. The U-values stipulated are the same except that Minergie-P windows, including their frames, are allowed up marginally to 0.9 W/m²K. The pressure test requirements are identical. However, Minergie-P requires that the main façade should face from southeast through to southwest, be 30% transparent and stresses the importance of realising solar gains usefully, rather than simply concentrating on minimising losses [1].

Several of the Swiss projects visited on the tour had a further suffix, Minergie-P-ECO. This introduces environmental criteria that are relatively soft-edged - a high proportion of daylight, ostensibly a health factor, but it will also displace electricity; limiting ‘off-gassing’ from materials, ionizing radiation (radon gas) and non-ionizing radiation (electromagnetic) in order to improve air quality; more local sourcing of raw materials, designing to reduce the quantity of them, avoiding ones that pollute during manufacture, and designing for easy separation and recycling or re-use. These criteria are hardened by certain exclusions - for example, certain solvent based products, large areas of timber products that emit formaldehyde, materials containing heavy metals, and absence of recycled concrete.

Moreover, several of the projects visited in both Germany and Switzerland had other specific aims - ‘zero heat energy’, ‘zero total energy’ and ‘plus energy’ (or Energy-Surplus-House®), being the main ones. The second of these also implies zero carbon emissions, at least from energy usage, ‘Zero-haus’ being a 2005 German certification scheme for zero emission buildings. The third implies negative emissions, and all such terms are prefaced by the words ‘net annual’, allowing energy exports and imports to iron out the intermittency of renewable supply, often out of phase with demands of occupants.

When relating to UK and Scottish definitions, standards and targets, the key message to be taken from the above is that housing providers must be transparent when describing their intention, and should also be careful to ‘read the small print’ when it comes to comprehending the intentions and achievements of others. For example, in the 2006 ‘Building a Greener Future’ [4] the Department of Communities and Local Government (DCLG) ‘zero carbon’ definition initially accepted that all renewable generation could not be expected to occur on site, but was clear in including all power use by occupants. It later aligned with Her Majesty’s Revenue and Customs (HMRC) definition [5], which requires all renewable power to be generated on site, the only softening being that renewable, zero-carbon ‘private wire arrangements’ are acceptable. In Scotland, the so-called Sullivan Report [6], defined ‘low-carbon’ as 30% less than in the Scottish Technical Handbook 2007 (TH07), ‘very low carbon’ as 60% less than TH07, and finally ‘total life zero carbon’, which holds the building responsible for net zero carbon emissions, but not all of what people choose to do inside buildings. In other words, it conforms to the TH07 regulated energy uses - space heating, water heating, lighting and ventilation, on which the 30% and 60% reductions are based - and excludes other power use. An added complication is that while Sullivan’s definitions omit the power used by appliances, its ‘total life’ requirement includes the embodied energy of the building, which both DCLG and HMRC leave to one side. Hence direct comparison with DCLG and HMRC definitions are difficult, although one may assume that both of these closely align with the continental ‘zero total energy’ and German ‘Zerohaus’ labels. A final point to note is that TH07 and the Sullivan report, by concentrating on proportional carbon reductions, lack the clarity of PassivHaus and Minergie-P with respect to specific energy standards related to floor area. Instead one has to rely on default U-values for components of the envelope, associated with various fuel packages, and which correspond with the target emissions rate (TER) for CO₂. This strategy makes no allowance for complexities of design, such as passive solar gain, and sets an agenda for subsequent percentage emissions reductions where the relationship with predicted energy loads, including renewable contributions, is unclear.
Introduction to projects visited during tour and appraised in this article

All projects visited on this tour were to Minergie-P or PassivHaus standard, apart from two individual solar houses and one housing refurbishment project. Three of the Minergie-P projects also have the ECO accreditation; one was the first in Switzerland to be net annual ‘zero heat energy’; one by the same architect is designed to be net annual ‘zero total energy’ (the only non-domestic project, and should achieve this during an extended post occupancy evaluation phase); one claims to be, and another has been shown to be, net annual ‘energy plus’; and one is approaching Zerohaus (zero emissions) standard.

Nearly all of them had PV arrays, the net annual output of which in many cases met the demand for some form of heat pump, plus fans and circulating pumps. Heat pumps were often also linked to solar thermal collectors, and the degree of aesthetic integration was impressive for PV arrays and flat-plate panels or evacuated tubes, with bespoke design quite usual. Utilizing renewable electricity from PV in this way to meet a small residual thermal demand is not a common technique in the UK. However, assuming we insulated to the same PassivHaus standard, we would have a lower heat demand, which would offset the lower solar supply to the PV. The author has already shown that a small 70 m² dwelling to PassivHaus standards, having a 4 m² flat-plate collector and a modestly efficient heat pump with a Coefficient of Performance (COP) of 3.0, could have a total annual thermal load of 820 kWh/m² [7]. This can be met in Scotland by a PV array of no more than 12 m².

Given that the areas of PV per dwelling in the Swiss and German projects visited averaged 23.5 m², and if it is also assumed that a similar market pump-primer to the German ‘feed in tariff’ (FIT) were established in the UK, such a proposition seems viable. But a critical proviso would be a shift in culture for our building industry.

Another point to note in terms of such knowledge transfer is that housing floor areas are typically considerably higher in Germany and Switzerland compared with the UK. In total primary energy terms, this means that it is relatively easier to attain low values per m², with correspondingly low rates of air change - i.e. of the complete internal volume per hour. It also means that larger footprints, or rather ‘roof-prints’, tend to offer greater scope for solar collection; and this would inhibit the UK reaching ‘Zerohaus’ or ‘energy plus’ standard.

Among all the projects, the entire Vauban district in Freiburg is a seminal paradigm for holistic, sustainable urban regeneration. This includes a district CHP system burning wood pellets, as well as a tram network running through grass, vehicular access curtailed and managed to a safe level, luxurious greening irrigated by run-off from roofs and hard surfaces, large investment in building-integrated PV (BIPV), and so on.

As far as possible, the descriptions of projects that follow in ‘tech-note’ form include useful comparative data with respect to performance, and comparative contextual information.

October 2008 Minergie-P-ECO block of 6 apartments, Dubendorf (southeast Zurich suburb)
by Architektburo Beat Kampfen

Access to first floor flat (home) and a 2nd floor attic flat (photography studio) to west of stairs;
guide Esther Ramseier (Kampfen office) (Fig. 1)

The context is suburban and the form is a tenement, with two main floors above a cellar and an attic floor keeping the height in sympathy with neighbouring buildings. The street runs east to west, with the entrance conveniently facing north to the street, so that main rooms are on the south and more private edge, and active solar collection is also on the pitch of the roof that is not visible from the street. This is the rational environmental solution, but it is surprising how many housing association projects in Scotland face main rooms towards the street regardless of orientation (often a requirement built into briefs).

Its roof-mounted 81.43 m² PV array, 11.1 kWp, generated 9,820 kWh from 16/10/08 to 01/10/09; 28.06 kWh/day, implying 10,241 for completion, or 125.8 kWh/m² - 6.4% above prediction of 9,627 kWh/a or 118.2 kWh/m². Over 125 kWh/m² or 1,707 kWh per flat is impressive compared with typical expectations in Scotland, perhaps of the order 70-80 kWh/m², depending on size of system and the number and reliability of inverters. 11.7 m² evacuated tube solar thermal collectors, shading south tilted surface of stairwell and neatly design-integrated above the roof glazing, are predicted to yield 8,277 kWh/a or 1,376 kWh/flat - a contribution towards space heating and DHW via the air-to-water heat pump (located in bike shed). For the flat to be net annual zero-heat energy, the PV would have to meet the entire electrical load for the heat pump, plus any pumps and fans for the MHRV system located in the basement. This should be feasible as triple glazing is 0.5 W/m²K (assumed excluding frame) and solid timber envelope 0.09-0.15 W/m²K and circa 40-50 cm thick; with overheating controlled by automated external solar blinds with manual override. Their black colour does raise the issue of compromised outlook when rooms are occupied and blinds are down. Although the ‘veil effect’ allows fairly good visibility, the darkened visual editing is undeniable.

The stairwell is concrete (Swiss requirement), but the entire superstructure, mainly timber, was prefabricated and erected in one week. This sophisticated and very accurately dimensioned Swiss prefabrication industry only dates back to the mid-1990s.
Fig. 1: South façade from garden in morning, noting solar blinds and PV; evacuated tubes above roof glazing over central stairwell.
June 2007 Minergie-P-ECO housing blocks, total 136 rented apartments, Eulachhof, Winterthur by Architekt Dietrich Schwarz

Unguided external visit, technical data acquired from websites (Fig 2).

Located on former industrial land, the regenerated context here is distinctly urban and relatively dense. Although it claims to be first in Minergie-P-ECO housing in Switzerland, certified 04/12/07, a 2006 Liebefeld project by Peter Schurch of Halle 58 Architekten, Berne www.halle58.ch seems to beat this and also lays claim to ‘first’ status [8].

The 6-storey high main slab of each of the two Eulachhof blocks are again tenements (lift/stair access to pairs of flats), with main rooms facing south to communal gardens and access from the north. Terraced variants are in shorter 2-storey wings at east and west ends of the long main block. The floor area is some 20,400 m² (average 150 m²).

Passively, this project utilises 910 m² special phase-change glazing, ‘GLASSXcrystal’ (www.glassx.ch) - approx. 6.7 m² per dwelling. This has plastic containers of salt hydrate between the two inner layers of glass in a quintuple-glazed unit. A prismatic pane between two outer layers of clear glass allows low angle winter sunlight to be transmitted but reflects high angle sunlight, whilst providing diffuse light transmission. Similarly the phase-change material (PCM) temporarily captures and stores any heat transmitted through the first four layers of glass, while transmitting up to 45% light in its liquid state (up to 28% in its crystalline state). Note that Dietrich Schwarz also heads this company and used another GLASSXcrystal product with paraffin PCM in an early 21st C Swiss house at Ebnat-Kappel so that there has been a development lead-in period of several years to ‘GLASSXcrystal’ as a more transparent PCM component in this project.

Web articles claim that 1,240 m² roof-mounted PV arrays (880 No Kyocera, 176 kWp, with 2 No Solarmax 80C inverters) generate about 164,000 kWh annually or 132.3 kWh/m². The higher value compared with Dubendorf may be due to the larger scale, with only two inverters. These are designed to meet the electrical load of heat pumps (also associated with waste water), and thus all thermal loads for space and water heating, plus lifts and communal lighting and ventilation. The average annual energy loads for the apartments are as follows; space heating 13.3 kWh/m² (29%); water heating 16.1 kWh/m² (35%); electricity 17.0 kWh/m² (37%). Wall U-values are 0.13 and roof 0.10 W/m²K; while the GLASSXcrystal U-value is given as 0.48 W/m²K, and windows assumed to be 0.8 W/m²K. External venetian-type metal shading blinds on windows will help to control overheating and daylight distribution internally in tandem with the GLASSXcrystal panels.

Checking what proportion of the total PV output will be required to meet the space and water heating: 13.3 + 16.1 = 29.4 kWh/m² x 150 m² x 136 units = 599,760 kWh, divide by 4.0 COP for heat pumps = 149,940 kWh = approx. 91% predicted 164,000 kWh output. Is 4.0 COP feasible and is the 9% balance adequate for the communal loads - lifts, stair lighting etc?
March 2007 Minergie-P-ECO Marché International Support Offices, Kemptthal, near Winterthur by Architektburo Beat Kampfen

Tour of building, including plant room with Urs Kelder, the building’s Project Manager as guide. Fig. 3, 4.

This is the only non-domestic building to be included in this article - a rural company HQ located next to the highway between Zurich and Winterthur and adjacent to one of the Marché service stations, with a cafeteria and shop serving commendably organic and local produce. It has also been published [9] and is a pioneer in terms of its design aim to be entirely zero-energy, and again uses GLASSXcrystal. In other words the net annual contribution of PV-generated electricity is intended to be enough to fund all heating (from heat pump), ventilation (mechanical heat recovery) and power for lights and equipment.

That aim has not quite been achieved. The thin-film, First Solar PV performance has been almost exactly as predicted - circa 4,000 kWh/a from 485 m², 12.5 degree pitch, thin-film large-tile roof. This corresponds to 82.5 kWh/m² PV. Marché has a contract with a power company who own the PV system and associated plant. The total energy demand for the first year was circa 45,000 kWh, which would have required a PV performance of 92.8 kWh/m² (indicating a deficit of 12.5%). Demand in the second year reduced to circa 42,000 kWh, which would have required a performance from the PV of 86.6 kWh/m² (deficit of 5%). The aim is now to reduce consumption to 40,000 kWh, partly be changing to more efficient equipment (e.g. printers) and partly by persuading occupants not to use artificial lights unnecessarily (some lights on when not needed during our visit). What is most remarkable is the levels of consumption are already so low - annual heating of circa 10.1 kWh/m² floor area; total energy 1st year of 35 kWh/m² and 2nd year of 32.7 kWh/m², when divided by the total area of 1,286 m² - 29 m²/person for 45 occupants.

Apart from low U-values - walls 0.104 W/m²K (44 cm thick overall), lowest floor 0.095 W/m²K (56 cm thick overall), roof 0.084 W/m²K (ceiling 52 cm thick overall) and windows 0.5 W/m²K** - the system of ventilation is key. Air enters at the northeast end travels below the ground floor (passively cooling in summer and pre-heating in winter) to a vertical duct at the west end, rises to a heat recovery unit in attic, is distributed down hollow H-shaped columns on south and north outer edges of workspaces, and finally returns via central columns to the attic. Two fans operate the entire system. The air quality during our visit was excellent and the temperature perfectly comfortable while it was sunny and warm outside. A green wall on one bay of each floor by the toilets takes 3 litres of water per m² and helps to oxidise and moisten the air.

There are many tactics to keep the internal temperature steady apart from the rate of mechanical air change: opening doors to veranda until 10.30 in morning; dense timber-cement flooring; GLASSXcrystal glazing (roughly 46% south façade); solar blinds on normal glazing; fixed shading from veranda; ability to circulate cool water at 17ºC in summer. Water for hygiene as well as that for winter space heating is provided by a ground-source heat pump with two boreholes 180 metres deep, such heat pumps reputedly having a COP as high as 4.5.

Fig 3: South façade, circa midday
Sunny Woods has been published in some detail [10]. The third Kampfen building to be included here, it predates the use of Minergie-P by one year, but was acknowledged as a PassivHaus scheme and set the bar high for his later projects such as those described above. Indeed, as the first net annual zero heat energy apartment block in Switzerland (6 fairly luxurious maisonettes), it of course exceeds PassivHaus and Minergie-P standards.

The roof has a 202 m² (33.7 m²/house), virtually flat Unisolar-Baekert PV array (triple thin-film amorphous silicone), 16.2 kWp, which provides a net annual yield of 15,000-16,000 kWh - i.e. 74.3-79.2 kWh/m² of collector area; 15,000 kWh being the combined predicted demand for heat pumps, 9,420 kWh, and pumps and fans, 5,580 kWh. The rate per unit area is predictably somewhat lower than at Marché with its more favourable tilt.

An active solar thermal contribution is provided by toughened glass evacuated tubes, which also function as semi-transparent balustrades to two floors of balconies (total 18 bays, approximately 36 m²). These are predicted to yield 17,340 kWh/a, 482 kWh/m² or 2,890 kWh/a for each dwelling feeding into a 1,400 litre storage tank. Since the annual water and space heating demand is 6,615 kWh/dwelling, this leaves 3,725 kWh to be funded by the water-air heat pump - i.e. 22,350 kWh for all six units.

It may be noted that the estimated yield from the toughened tubes of 482 kWh/m² compares with 707 kWh/m² predicted for Dubendorf, where longer tubes lie above roof glazing and reflected light could possibly enhance performance. The number of separate arrays at Sunny Woods, the longer distance from the thermal stores (next to entrances on north side of building), and the number of thermal stores (six compared with one centralised calorifier in the basement at Dubendorf) may also partly explain the discrepancy. Detailed design differences of the tubes themselves may be another factor, with a seven year difference in age.

**Note: it seems likely that the U-value of 0.5 is for the glazing, rather than the window including its frame. Detail Green 02.09 provides more in-depth information with regard to the windows for a Minergie-P-Eco housing project by Peter Schurch of Halle 58 Architekten where the frame has a U-value of 1.6, triple glazing 0.5, and average 0.65 W/m²K. Its G-value (solar heat gain value = shading coefficient x 0.87) is given as 0.55 or 55%. Another housing development, 'solaR2' in Munich by Joachim Nagel quotes 0.76 W/m²K for the frame and 0.5-0.6 W/m²K for the glass. If the frame were 15% of the total, and the average U-value for the glass 0.55 W/m²K, the average thermal resistance for glass and frame would be 1.74 m²K/W and the average U-value 0.57 W/m²K. These examples also correspond with what Beat Kampfen told us for Dubendorf and Sunny Woods (below).**

Fig 4: looking out through south façade, with diffused light through GLASSXcrystal and visual editing through solar blind

2001 pre-Minergie-P ‘net annual zero heat energy’ block of 6 apartments Sunny Woods, Rutihof (west Zurich suburb) by Architektburo Beat Kampfen

Access to upper maisonette with Beat Kampfen as guide. (Fig. 5)
Warm air ducts set into intermediate floors supply heating to rooms (up through floor grilles for upper floors, and down through ceiling grilles for lower floors). There is a heat recovery unit and supply air is preheated via 150 mm diameter polythene pipes at a depth of 1.5 m and 30 m long for each apartment. A small radiator is also located in bathrooms. Although Enz and Primas (Hastings and Wall eds.) give a U-value of 0.8 W/m²K for windows, and 0.24 W/m²K the average for the external envelope [10], Beat Kampfen claims that windows are lower at 0.5-0.6 W/m²K, a similar number to the G-value (solar energy transmitted)**.

Windows also have vertical automated solar blinds fitted externally, but with manual override - i.e. similar to those at Dubendorf and at Marché - and it is a matter of subjective sensitivity as to how this edits perception of the outside. Regardless of this, there is no doubt that the generosity of fenestration - 100% of the south façade - is welcome given the outlook over Zurich, and will also contribute useful passive solar heat gain during winter months to the near-black stone floor finish (exposed throughout in the apartment visited). Individual U-values vary from 0.1 (roof, 40.5-64.5 cm thick overall, variation due to sloped mineral wool below PV), 0.12 (walls, 50 cm thick overall) to 0.16 W/m²K (floor above cellar).

Fig: 5 view of south façade of Sunny Woods, late morning with all blinds down.
These two individual houses by Peter Dransfeld are both hybrid (part passive, part active), naturally ventilated solar buildings (i.e. no MHRV) with opaque envelope U-values of circa 0.2 rather than 0.1-0.15 W/m\(^2\)K. Therefore they do not conform to Minergie-P, but rather are aiming to provide energy-efficient models for rural houses with log stoves that inevitably do not sit easily with MHRV in terms of their air supply and flue-gas exhaust.

The consumption for heating and hot water at Oberburen is estimated to be 21 kWh/m\(^2\). The total heated floor area of some 200 m\(^2\) is fairly typical for such dwellings in Switzerland, here including a self-contained wing for the daughter of the owners.
This contributes both to hot water, with draw off top of two stratified storage tanks of 1,500 litres each at 65-70°C, as well as floor heating coils with draw off bottom of tanks at 40-45°C. A large custom-built log stove in the main room obviates the need for floor heating in this part of the dwelling and consumes about 1,500 kg timber annually - a notionally carbon-neutral fuel, meeting most of the thermal demand typically from the second half of October through to the end of March (sometimes into April, but sometimes stopping at end of February). Winter design temperature is 22°C. The stove itself and the dark slate-tile floor finish add to thermal capacity, the entire timber superstructure being prefabricated and erected to roof level in one day. Since the solar collectors will meet most of the hot water demand from spring till autumn, the electrical back-up for hot water is minimal. The overall primary energy consumption has been estimated as 64 kWh/m², only 53% of the allowable maximum for PassivHaus or Minergie-P. Commendable as this is, the low 0.1 SIA weighting factor for logs is undoubtedly significant, as is the relatively large floor area.

The monitored consumption over one year for heating and hot water at Herisau came to 11 kWh/m² for a floor area of 218 m², significantly lower than at Oberburen. The total electricity consumption during the same period was 13 kWh/m². Although only one person occupied the house during this period, these are remarkably low values, totalling just over 5,000 kWh for a substantial house. Part of the success was due to transparent insulation or TI on the south façade [11]. This will give an average effective U-value below zero - i.e. gaining more energy than is lost [12]. A critical aspect of the TI is avoidance of overheating, especially in summer.

To that end three types of outer glazing have been used to complement the fixed shading louvres above the top stratum of TI. Apparently, in peak conditions, the 240 mm sand-lime brick wall behind the TI does not average more than 33°C and the inside temperature does not exceed 28°C. There is also a substantial array of evacuated tubes located behind the dwelling, which feed into a large thermal store located behind the staircase inside; and again a log stove contributes to heating and hot water. In this case the overall primary energy consumption has been estimated as an even lower range of 40-45 kWh/m², down to one third of the allowable maximum for PassivHaus or Minergie-P. Apart from the single-person occupancy in the initial monitored year, the construction provides significantly greater thermal capacity than at Oberburen, with two concrete floors and brick internal walls on the lower floor.

The experience in these two houses does tend to challenge the orthodoxy of MHRV as a prerequisite of low-energy design. The way occupants use their homes in terms of setting thermostats and opening windows is critical to their performance, regardless of other ventilation control such as fan-driven or passive stack. Although log stoves could not be applied readily as a heating solution for mass housing, a wood-pellet communal boiler would be viable (as for the Berne and Munich projects mentioned above [8]); and could align with natural or mechanical ventilation. A question therefore remains - could PassivHaus and Minergie-P standards be achieved with a system of natural ventilation, the absence of two fans mitigating rather coarser passive control?


Full guided access to upper flat and office, including plant, by owners. (Fig. 8)

The Miloni household occupies roughly half of a two-dwelling, flatted development on quite a tight suburban site. Their upper flat is accessed by a single flight of stairs at the north side facing a quiet residential street, and two floors above a small office at the east end of lower ground floor level. Meanwhile their neighbours enter at the corresponding west end and rise up to their main floor, underneath and matching the Miloni apartment, but accessing the garden directly at ground level along the south edge. This is designed as a ‘plus-energy’ house (i.e. produces more energy annually than its total demand). Most of the electricity is generated from 33 PV panels on the flat roof (each 0.998 x 1.65 m) totalling 54.3 m². In addition there are innovative perforated PV spandrel panels on each of his 5 upper floor windows, amounting to about 9.0 m². The total area of PV thus works out at an average of 31.65 m² per household, more than twice as much as at Dubendorf and three and a half times as much as at Eulachhof.

A ballpark figure of 10,000 kWh generated annually has since been revised to that amount in the 18 months from August 2008-January 2010 - say 7,500 kWh in a year. Assuming the roof-mounted PV matches that at Dubendorf at 125.8 kWh/m², it would generate 6,830 kWh to which one might reasonably add 670 kWh from the spandrels. The combined input, however divided, represents a significant contribution to both upper and lower apartments. There is also an annual expectation of some 2,000 kWh of heat from a solar thermal array. The main demand, apart from lighting and appliances, will be for the MHRV fans and the air-source heat pump. Depending on the total air heating and hot water load, the COP of the heat pump, and the frugality of consumption for appliances and lighting, plus-energy status seems feasible. Reto Miloni has taken great care to eliminate all cold bridging in the construction, which in this case is heavy masonry encased in thick insulation - 20 cm rock-wool on walls, 46 cm rock-wool on roof and 20 cm extruded polystyrene under the floor.
Therefore it has a very high thermal capacity that will damp down temperature fluctuations to solar heat gains through windows and block any though the solid envelope. Peak temperatures were apparently no more than 27°C inside, and Reto Miloni is sensitive to summer control issues, restricting window opening to overnight and early morning. Moreover, all supply ducts are embedded in the concrete floor slabs. The initial supply to the heat pump is embedded in sand - 28 m x 20 cm diameter - while the 10 cm diameter floor ducts deliver via floor grilles close to the window wall. As at Sunny Woods, there is no other floor heating, whilst, in contrast to slate-finished floors of timber structures seen earlier, the floor is veneered in timber to give a warm haptic feel. Windows are the usual Minergie-P or PassivHaus standard - U-value of 0.8 W/m²K including the frame, and vertical solar blinds outside the glazing were similar to those used at Dubendorf, Sunny Woods and Marché.

Fig. 8 Inside Miloni apartment, showing blind half down and PV spandrel.

2006 PassivHaus, Energy-Surplus-House® Solarsiedlung am Schlierberg (59 dwellings), Vauban, Freiburg by Rolf Disch Solar Architektur

External guided access by Innovation Academy, plus information by Tobias Bube, Rolf Disch Solar Architektur. (Fig. 9)

Rolf Disch Solar Architektur has a substantial record in promoting projects that provide a net annual gain of energy: http://en.wikipedia.org/wiki/Rolf_Disch_Solar_Architecture This site explains the Energy-Surplus-House® or plusenergiehaus® concept; and specific information about the 1994 Helioprote as a precedent for Solarsiedlung am Schlierberg can be found on www.rolfdisch.de. Further, a useful background to the regeneration of Vauban is found on www.vauban.de. This has English translations under various key headings, totalling 12 pages plus two of publications, reports and contacts.

Solarsiedlung am Schlierberg, a development of 59 dwellings, consists mainly of a series of low-rise, south-facing terraces lying at right angles to, and east of ‘Sonnenschiff’ (Sunship), a commercial spine that buffers the housing from a busy street. There is also a number of penthouse maisonettes on top of Sonnenschiff, with construction details published [13]. Rolf Disch is both architect and developer; the entire project completed 2006 having overcome major financial hurdles - see www.pvupscale.org/IMG/pdf/Schlierberg.pdf.

A monitoring programme of twenty dwellings [14] has measured a net primary annual energy surplus of 36 kWh/m², which includes all power used for lighting and appliances. The average floor area of homes in this group was 137 m², occupied by 2.9 persons, each with 49 m² PV or 6.3 kWp - i.e. each m² floor area equates to 0.36 m² PV of 46 Wp. There are approximately 445 kWp of PV roofs overall, with generous overhangs for façade shading in summer. This generates some 420,000 kWh/a, corresponding to an income of over 220,000 Euros or circa 300 Euros monthly for a typical roof (sold @ 0.545 Euros per kWh at ‘Feed In Tariff’ or FIT rate).

Assuming a linear proportional relationship between kWp (denoting area) and generation of electricity, the total area of PV in the project comes to 3,483 m², which gives an output rate of 120.6 kWh/m². This is 4% less than measured at Dubendorf, Zurich, and the spacing of cells and calculation of productive PV areas may be relevant in this regard. In turn this implies that the average PV output for each dwelling is 5,909 kWh of electricity, but the monitored group of 20 indicates a slightly lower value - see next paragraph. Space heating demand was predicted to vary between 10-20 kWh/m², depending on location and orientation, and the Vauban district biomass and natural gas CHP plant meets the supply for this. Triple glazed, argon-filled windows meet 0.8 W/m²K U-value PassivHaus standard, and opaque envelope conforms to 0.1-0.15 W/m²K - roof with 35.6 cm mineral fibre insulation (0.1 W/m²K) and external walls 30 cm (0.12 W/m²K) and envelope average 0.38 W/m²K [13]. All dwellings have their own MHRV per PassivHaus requirements.
The average total primary energy consumption in the monitored group was found to be 79 kWh/m$^2$ [14], adjusted down by 19 kWh/m$^2$ to take account of the CHP plant (i.e. 98 kWh/m$^2$ without the CHP). Net demand was met from the PV with 36 kWh/m$^2$ surplus - primary values obtained applying an average heat factor of 0.9 and electricity factor of 2.7. This means that thermal demand for heating and hot water averaged 21 kWh/m$^2$ (19/0.9), and that for electricity 29 kWh/m$^2$ (79/2.7) - a total demand of 50 kWh/m$^2$, areas of apartments varying from circa 80-220 m$^2$.

Rolf Disch achieved his aim of building energy-surplus houses, whether looked at as primary energy (solar surplus = 36 kWh/m$^2$) or as delivered energy (solar surplus = 13.3 kWh/m$^2$; 36 kWh/m$^2$ divided by the primary factor of 2.7). Double-checking, (13.3 surplus + 29 demand) kWh/m$^2$ = 42.3 kWh/m$^2$ x 137 m$^2$ = 5.795 kWh, divided by 49 m$^2$ PV = 118.3 kWh/m$^2$, which suggests the 120.6 kWh/m$^2$ PV yield based on the estimate for the whole project was 2% optimistic relative to the monitored group. Even if we apply a “what if?” scenario of ground source heat pumps with a modest COP of 3.5 in lieu of the district CHP system, there is a surplus of electricity: 21 kWh/m$^2$ divided by 3.5 = 6 kWh/m$^2$, deducted from 13.3 leaves 7.3 kWh/m$^2$ electrical surplus, multiplied by 2.7 factor = 19.7 kWh/m$^2$ primary annual surplus from the PV-generated electricity.

It is also noteworthy that while all multi-unit case studies visited apart from in Freiburg used heat pumps to meet residual thermal loads, with PV supplying the power, the two examples cited from Detail Green 02/09* use wood pellet boilers.

SolaR2 in Munich gives what appear to be a remarkably low annual primary energy estimate for heating and hot water - 5 kWh/m$^2$ to be added to 44 5 kWh/m$^2$ for electricity. We are also told that 40% of heat is supplied by the solar thermal array and 60% by wood pellets. This returns us to the question of what is a reasonable weighting factor for delivered to primary energy and what is the efficiency of the wood pellet boiler? Larger boilers of circa 50 kW should have an efficiency of 94.5%. If we apply the Minergie-P weighting factor of 0.5, this implies a total thermal demand of 17.64 kWh/m$^2$ (5 kWh/m$^2$ divided by 0.5; divided by 0.945; divided by 0.6), just above the PassivHaus limit.

The other aspect of this analysis is that the PV roofs validate the CHP system in Vauban. Without the generation from roofs, there would be too much waste heat from the CHP for such an energy-efficient development. To be commercially viable, Germany’s Feed In Tariff (FIT) is an essential ingredient, but there is much more to it than that - income from FIT over 20 years at a profit of 42 Euros/kWh [15] effectively allows the householder to pay off a mortgage for the roof in the region of 40-50k Euros. The purchase cost of the dwellings varied between 2,700-3,300 Euros/m$^2$, depending on the individual fittings etc.
Another project in Vauban given a ‘walk-by’ on this tour was the pioneering ‘Wohnen und Arbeiten’ (Living and Working) 1999 co-housing project by Michael Gies [16] - www.passivhaus-vauban.de also provides a fair bit of information (in English) on this early PassivHaus project under various sub-headings. The two new ‘Kleehauser’ zero-energy blocks by the same architect bear out the consistently pragmatic approach adopted by this practice. Here the website states that the project is “approaching zero-energy standard (see www.zero-haus.de)”, noting that Zerohaus is a certification scheme for zero emission buildings dating from 2005. In practice, as it is understood that Vauban’s district CHP is still partly reliant on natural gas, it is not presently possible for any of its housing to conform to this certification - paradoxically not even Disch’s Energy-Surplus-House©.

The architects kindly supplied performance data for the two Kleehauser blocks - the smaller 9-dwelling, timber-clad one of 1,413 m² denoted A and the larger one 16-dwelling, Corten-gabled one of 2,095 m² (north of A) denoted B. The primary energy consumption per unit area in each case is virtually identical: respectively 37.0 and 36.7 kWh/m². Since respective A and B average floor areas for each dwelling are 157 m² and 131 m², average primary energy consumption per dwelling vary somewhat - A: 5,809 kWh and B: 4,808 kWh.

There is other more detailed data for block B. The U-values for walls, insulated with 25 cm mineral wool insulation is given as 0.17 W/m²K; the roof 0.11, with 34 cm insulation; the glazing 0.6, windows with frames 0.98 and the average for the window façade 1.7. There is also 60 m² of polycrystalline PV, or a relatively low area of 3.75 m² per household. In this regard, one should bear in mind that Vauban also has renewable electricity from its district CHP and, by the same token, no electrical demand for heat pumps. The array has an estimated peak output of 7.03 kW, and annual primary yield of circa 24,000 kWh. What this signifies in terms of delivered energy is again dependent on the weighting factor adopted. The 2.7 weighting used in the monitoring for Solarsiedlung am Schlierberg is lower than the PassivHaus grid value by 0.27, presumably accounting for embodied energy of the PV and/or Vauban’s CHP. The 2.7 factor gives a predicted delivered output of 8,889 kWh or 148 kWh/m², which seems optimistic. If 2.97 were used, it brings the prediction down to 135 kWh/m², still on the high side - especially when compared with the data for Solarsiedlung am Schlierberg. There is also 56.4 m² of flat-plate thermal collector, or 3.5 m² per flat. This is a typical area for continental Europe designed to contribute a significant part of the annual hot water load.

Fig. 10 View of south façade of Kleehauser block B
2005 Rislerstr refurbishment of 1961 housing by Resettlement Society of Freiburg

External guided access by Innovation Academy (Fig. 11)

This was the only Freiburg housing refurbishment project visited outside Vauban that included some key performance data: 87% reduction of space heating loads from 292 kWh/m² to 39 kWh/m² - i.e. not as low as PassivHaus standard - with 25 m² flat-plate collectors on each block contributing to hot water and larger arrays of PV. The retrofit included new windows, with overall U-value of 0.8 W/m²K, 20 cm of external insulation and 26 cm of roof insulation; and MHRV located in roof-spaces. Heating is by normal radiators and the fuel in this case is natural gas. The cost of this refurbishment came to some 1,100 Euros/m², roughly half of which was for energy upgrading other than the PV. Rents were raised from 4.04 to 5.44 Euros/m² in order to help fund the improvement, and occupants were not decanted during works.

Concluding comments

Over the city, Freiburg has some 10 MWp of installed PV, but still only has 3.2% of its electricity generated renewably, some by wind turbines on nearby hills; and excluding hydro-electric power generated in the wider region, which is likely to be significant. In Switzerland almost two thirds of electricity generation is hydro. But if Freiburg still has renewable energy ‘mountains’ to climb, and Switzerland also, with its Minergie-P-ECO projects only dating back three or four years, where are we? On the face of it, as indicated in the introduction, although we have less solar energy in the UK, this is compensated by warmer winters - at least in terms of heating demand. Our ‘mountains’ lie with lack of cultural and economic will to drive down electricity demand, while driving up thermal efficiency; this coupled with the lack of political will to provide the incentives to pump-prime a more enlightened cultural and economic agenda - a circular ‘catch 22’ that needs to be transformed into a sustainable eco-cycle by substituting ‘presence’ for ‘lack’. Quite apart from economics of PV itself, our smaller housing areas would make PV areas of circa 50 m² on roofs per dwelling harder to achieve. On the other hand, a minimum of 12 m² PV is a reasonable goal together with thermal collectors of 1 m²/person and a passive solar design policy. Then if we adopted the same insulation and glazing standards as PassivHaus or Minergie-P, the balance of our thermal loads would be correspondingly lower, and less electricity would be required to fund similar high-COP heat pumps to the ones commonly used in continental Europe.

This approach also answers the question embedded in the title. There can be a Passive solar PassivHaus paradigm for Scotland in a zero-carbon quest. All new-build projects described above are ‘passive solar’, with ample southerly fenestration, adequate thermal capacity and efficient shading control. They also are all PassivHaus or the harmonised Swiss equivalent, Minergie-P. Moreover, they all go beyond this in terms of building integrated renewable energy (BIRE), often with bespoke design flair.

This means that PassivHausUK approach with BIRE could, in theory if not so easily in practice, meet all planned CO₂ reduction targets. Overheating becomes less of a problem the further north you get within the UK and solar supply falls off less rapidly than heat demand [17]. Thus the first barrier to surmount for us is to significantly upgrade our specifications, as well as our construction methods and standards [18]. This includes revising attitudes to overall thickness of the external envelope. In the days of stone, 60 cm was normal, and that order of expectation of thickness, certainly no less than 45 cm, needs to become normal again for modern energy-efficient construction. Such barriers are more a matter of determined effort than lack of financial means, or lack of knowledge. In this regard, the specific attributes of using MHRV need care. Smart variable control is one issue, as is operation of manual overrides - this could include zoning such that bedrooms might opt out overnight, reverting to window control. Noise transmission is another concern and accessibility for maintenance, filter-changing in particular, yet another. Moreover, other methods of controlling ventilation are not off the agenda, even if outside PassivHaus certification. That was the lesson from Peter Dransfeld. The one from Rolf Disch is that his Energy-Surplus-House© did not just happen. Neither did a shift to advanced prefabricated methods in Switzerland. Rather, persistent individual champions manifested all such results, thereafter followed systematically by the hard effort of the many.
REFERENCES


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