A LOW-ENERGY RETROFIT STUDY OF AN OFF-GAS WELSH VILLAGE USING RENEWABLE ENERGY SIMULATION COMBINED WITH THE UK STANDARD ASSESSMENT PROCEDURE

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ABSTRACT

26 million homes¹ (Killip G., 2008) in the UK are traditional and ‘hard-to-treat’² dwellings that need urgent attention in order to meet the government’s carbon reduction targets. Most of these homes are situated in villages without mains gas. A computational methodology will be used to formulate energy retrofit and renewable energy technology (RET) solutions for a Welsh village. The UK Government’s widely used tool, Standard Assessment Procedure (SAP), is used for modelling baseline energy consumptions and energy efficiency measures for the dwellings. Due to shortfalls in SAP, the small power demand will be assessed in EnergyPlus in order to design power generating RETs. Furthermore, RETs such as solar photovoltaic (PV) and wind turbines will be modelled using software packages PV*Sol and RetScreen respectively.

The assessment highlights the limitations of the chosen computational simulation methods by formulating various feasible alternative energy solutions for the village.

INTRODUCTION

In the UK’s domestic building stock contributes 27% of the country’s CO₂ emissions through energy use (Killip, G., 2008). Hence reduction of energy demand and energy efficiency of this stock is vital for achieving the UK’s target of 80% CO₂ reductions by 2050(Climate Change Act, 2008). This can be modelled through computational tools for energy modelling of buildings.

Various computational tools are available in the market for energy modelling using either simple steady state or complex dynamic algorithms. Studies have used the dynamic simulation tool ESP-r to examine the effect of passive solar, PV and combined heat and power (CHP) systems on the heating and cooling needs of buildings (Clark and Strachan, 1994). For modelling zero energy design of homes, Wang et al. (2009) used EnergyPlus to model fenestration design and fabric improvements and TRNSYS to model renewable electricity and solar water heating for Cardiff weather conditions.

In the UK, SAP is the government’s approved methodology to check a dwelling’s compliance with building regulations and is based on steady-state algorithms that give the dwelling’s energy performance and CO₂ emissions. The capabilities of SAP and EnergyPlus however are limited for designing RETs for dwellings. Hence specific renewable energy simulation tools have been used with SAP taking a case study approach for formulating energy retrofit solutions for a village in Wales. One study conducted by Murphy et al. (2010) showed a comparison of simulations in SAP and TRNSYS in modelling different solar energy systems.

A significant proportion of the UK’s domestic building stock consists of pre-1930s, solid wall, hard-to-treat constructions. A part of this stock lies in Wales in economically deprived regions facing the problem of fuel poverty.

Many villages in the region are not supplied mains gas and rely on other carbon-intensive fossil fuel sources such as Liquefied Petroleum Gas (LPG), oil, and grid electricity in order to meet their heating demand. Due to high levels of fuel poverty determined by a survey³ of one such village, it is imperative to devise energy efficiency measures for these homes and incorporate suitable renewable energy strategies that could make the village self-sufficient, or less dependent on existing sources, in terms of energy. The paper aims at identifying a range of potential energy retrofit solutions for the village through computational modelling and thereby highlighting the limitations of the chosen computational methods in the combination with SAP.

SIMULATION TOOLS USED

The following sections, will briefly introduce the software tools used in the analysis.

¹ Based on year 2007 statistics
² ‘Hard-to treat’ homes are those that cannot be treated with traditional and cost-effective measures such as loft and cavity wall insulation in order to deliver affordable warmth.
³ Surveys conducted by Building Research Establishment in 2011 to assess fuel poverty and applicable energy efficiency and renewable energy technologies in a village
1. SAP 2009 is the UK Government's Standard Assessment Procedure for Energy Rating of Dwellings. It was adopted by government as part of the UK national methodology for calculation of the energy performance of dwellings. It is used to demonstrate compliance with the Building Regulations 2010 - Part L (England and Wales), Section 6 (Scotland) and Part F (Northern Ireland) - and to provide energy ratings for dwellings.

2. EnergyPlus (v.6.0.0) owned by the United States Department of Energy, is a building energy simulation program for modelling of heating, cooling, lighting, ventilation, and other energy flows. It is used in this study to model the electricity demand for cooking, lighting and appliances as this cannot be achieved with SAP2009.

3. PV*Sol Pro is a dynamic simulation programme for the modelling of photovoltaic system performance.

4. RETScreen Clean Energy Project Analysis Software (Version 4) is a tool used to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of renewable-energy and energy-efficient technologies including technologies of solar photovoltaic (PV), combined heat and power (CHP), wind turbines and heat pumps.

METHODOLOGY

The methodology used is based on the 'energy hierarchy'. The concept was conceived as part of the Local Government Position Statement on Energy in 1998 and advocated by the Carbon Trust (Carbon Trust, 2006) It states that organisations and individuals should pursue energy issues in the following order of priority:

1. Reduce the need for energy
   Calculate heating and electricity needs and see if they can be reduced.

2. Use energy more efficiently
   Treat energy efficiency measures as a priority before considering a switch to renewable energy.

3. Use renewable energy
   Renewable energy technologies are more affordable when they are incorporated after conducting energy efficiency measures

4. Any continuing use of fossil fuels should be clean and efficient.
   Often renewable energy technologies do not meet the reduced energy demand completely leaving some dependency on fossil fuels. Any continued use of fossil fuels should then be made clean and efficient.

In order to assess the energy demand of the village, a thorough technical assessment was carried out that included site surveys and desktop modelling of various house types and their energy consumption using relevant software tools. The detailed methodology used is as follows:

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Solid wall</th>
<th>Cavity wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall U values</td>
<td>2.4 W/m²K Typical brick or stone walls</td>
<td>0.3 W/m²K Assumes insulated cavity wall</td>
</tr>
<tr>
<td>Roof U values</td>
<td>0.29 W/m²K Assumes ~150mm mineral wool loft insulation</td>
<td>0.29 W/m²K Assumes ~150mm mineral wool loft insulation</td>
</tr>
<tr>
<td>Floor U values</td>
<td>0.68 W/m²K Un-insulated solid floor</td>
<td>0.68 W/m²K Un-insulated solid floor</td>
</tr>
<tr>
<td>Window &amp; Door U values</td>
<td>2.2 W/m²K Typical of pre 2006 double glazing</td>
<td>2.2 W/m²K Typical of pre 2006 double glazing</td>
</tr>
</tbody>
</table>

Figure 1 Map of the village
i. Typical solid wall end terrace
ii. Typical solid wall mid terrace
iii. Typical cavity wall detached

Detailed energy analysis of the house-types was carried out using SAP 2009 to obtain baseline energy consumption for space heating and hot water. Additional modelling in EnergyPlus was done to obtain the electricity demand for cooking, lighting and appliances.

The U-value of the building fabric is an important factor that SAP considers in energy analysis. Suitable U-values are assumed for the houses as per their age of construction (Table 1).

c. Various energy efficiency measures and renewable energy technologies for heating that can be deployed to the stock were then modelled in SAP to obtain respective energy savings. Depending on the age of construction, SAP has a generic database of heating systems with built-in efficiencies in accordance with the buildings regulations of that specific period. Hence all the impact of the measures considered in relation to the building regulations at the time of construction.

The measures considered were:

1. Switching to a higher efficiency boiler.
   Existing oil and gas boiler efficiencies are assumed as 66% and 69% respectively. Higher efficiency boilers at assumed at 90% for both oil and gas.

2. Solid wall insulation. The U-values have been reduced from 2.4 W/m²K to 0.3 W/m²K, in line with Energy Saving Trust best practice recommendations for refurbishment (EST, 2007)

3. Switching to an air source heat pump (ASHP) of CoP 1.87

4. Switching to a biomass boiler (efficiency 63%)

5. Installing a solar thermal system for space heating and hot water. Although solar thermal systems can cater to space heating and hot water they require a well designed seasonal storage capable of handling peak demand in winter (Pinel, P., 2011). Hence to avoid complexities, only hot water demand is catered for by solar thermal in this study.

6. Switching to ground source heat pump (GSHP) (only applicable for detached dwellings) CoP 2.4

7. Solar photovoltaic and wind were modelled in PV*Sol and RetScreen respectively to meet the electricity demand for cooking, lighting and appliances of the house types.

### SIMULATION RESULTS AND DISCUSSION

#### Energy efficiency measures

The baseline energy consumption\(^4\) was calculated assuming four different fuel types: - oil, bottled LPG, electricity and coal as the fuel types varied across households and could not be generalised against typology.

#### Solid Wall dwellings

Regardless of the fuel type, the highest savings in energy consumption for a typical solid wall end terrace could be achieved by installing an ASHP (Figure 2). This result can be attributed to the higher efficiency of heat pumps against boilers using fossil fuel. Irrespective of the fuel used, boiler efficiencies are in the range of 66-69%, whereas the efficiency of ASHP is 187% (CoP= 1.87). If the fuel type of the household is coal, 69% savings in energy can be achieved, reducing the demand from 366 kWh/m² to 113 kWh/m² (Table 2). Switching to a higher efficiency boiler and insulating the solid walls would achieve an energy saving of 32% and approximately 44% irrespective for the fuel type. Switching to biomass would not achieve significant energy savings to the household. In the case of electricity, the switch to biomass would actually consume more energy. Switching to solar thermal would meet a part of the hot water demand of the household and not space heating, hence the energy savings due to switching to solar thermal would also be insignificant (approximately 4-5%).

![Figure 2 Annual energy savings (%) for typical solid wall end terrace for various energy efficiency measures](image)

The result of typical solid wall mid terrace is similar to that of end-terrace. However, since a mid terrace is has fewer exposed walls, the baseline energy demand for the mid-terrace is lower than end-terrace (Table 3).

\(^4\) Energy consumption is expressed as Kilo-Watt-Hours per metre square floor area (kWh/m²) for dwellings rather than Tonnes of Oil Equivalent (TOE). 1 TOE= 11,630 kWh

### Table 2

<table>
<thead>
<tr>
<th>Energy Demand (kWh/m²)</th>
<th>Baseline</th>
<th>Higher Efficiency Boiler</th>
<th>Solid Wall Insulation</th>
<th>ASHP</th>
<th>Biomass</th>
<th>Solar Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>331</td>
<td>227</td>
<td>197</td>
<td>113</td>
<td>282</td>
<td>215</td>
</tr>
<tr>
<td>LPG</td>
<td>332</td>
<td>225</td>
<td>196</td>
<td>113</td>
<td>281</td>
<td>212</td>
</tr>
<tr>
<td>Electricity</td>
<td>253</td>
<td>0</td>
<td>131</td>
<td>113</td>
<td>129</td>
<td>66</td>
</tr>
<tr>
<td>Coal</td>
<td>366</td>
<td>0</td>
<td>201</td>
<td>113</td>
<td>146</td>
<td>102</td>
</tr>
</tbody>
</table>

### Table 1

<table>
<thead>
<tr>
<th>Hypothetical Typology</th>
<th>Baseline</th>
<th>Higher Efficiency Boiler</th>
<th>Solid Wall Insulation</th>
<th>ASHP</th>
<th>Biomass</th>
<th>Solar Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical cavity wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid wall end terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid wall mid terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typical solid wall end terrace in square floor area (kWh/m²)</th>
<th>Baseline</th>
<th>Higher Efficiency Boiler</th>
<th>Solid Wall Insulation</th>
<th>ASHP</th>
<th>Biomass</th>
<th>Solar Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>331</td>
<td>227</td>
<td>197</td>
<td>113</td>
<td>282</td>
<td>215</td>
</tr>
<tr>
<td>LPG</td>
<td>332</td>
<td>225</td>
<td>196</td>
<td>113</td>
<td>281</td>
<td>212</td>
</tr>
<tr>
<td>Electricity</td>
<td>253</td>
<td>0</td>
<td>131</td>
<td>113</td>
<td>129</td>
<td>66</td>
</tr>
<tr>
<td>Coal</td>
<td>366</td>
<td>0</td>
<td>201</td>
<td>113</td>
<td>146</td>
<td>102</td>
</tr>
</tbody>
</table>
Also, solid wall insulation achieves a 7-9% lower saving approximately than the end-terrace, reducing the energy demand from 277 kWh/m² to 182 kWh/m² for a coal heated household (Figure 3).

However installing an ASHP or higher efficiency boiler would result in savings similar to that achieved by the end terrace. Switching to biomass would increase the energy saving for mid-terrace compared to the end-terrace.

Hence switching to higher efficiency boilers, solid wall insulation and installing air source heat pumps are the most appropriate energy efficiency measures for solid wall dwellings.

Furthermore, a study on heat pumps installed on 'hard-to-treat' homes in the UK (Pither & Doyle, 2005) revealed that heat pumps work more effectively in insulated homes further increasing the energy savings compared to a non-insulated dwelling. The SAP results for solid wall dwellings clearly show that a combined approach of wall insulation and installation of air source heat pumps should be considered to maximise energy savings.

**Effect on carbon dioxide saving**

Energy consumption of the existing housing stock accounts for 27% of the total CO₂ emissions of the UK (Killip, G., 2008). Hence, while considering energy savings measures it is also important to consider their contribution towards CO₂ savings in order to meet the government’s carbon reduction targets. SAP 2009 was used to calculate the CO₂ emissions of various energy saving measures suggested for typical solid wall mid-terrace house (Table 4, Figure 4).

Irrespective of the baseline fuel type, switching to biomass boilers achieves 74-83% CO₂ savings. However, in terms of energy savings, biomass boilers prove to be inefficient achieving only 2-12% energy savings. Improving the efficiency by processing or drying the wood fuel would achieve higher carbon and energy saving. Processing or drying wood fuel is a mechanical process that consumes energy which would add to the CO₂ emissions. However, in this study only operational energy consumption is considered, and the carbon emissions quoted exclude the emissions from fuel production and delivery processes.

**Table 4**

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Baseline</th>
<th>Higher Efficiency Boiler</th>
<th>Solid Wall Insulation</th>
<th>ASHP</th>
<th>Biomass</th>
<th>Solar Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>73</td>
<td>53</td>
<td>45</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td>52</td>
<td>45</td>
<td>45</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>6</td>
<td>45</td>
<td>45</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>84</td>
<td>58</td>
<td>45</td>
<td>16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3 Annual energy savings (%) for typical solid wall mid terrace for various energy efficiency measures**

**Figure 4 Annual CO₂ savings (%) for Solid wall 2-bed mid terrace for various energy efficiency measures**

Heat pumps run on electricity hence account for significant carbon emissions if electricity is generated through fossil fuels. Yet it achieves an environmental benefit by achieving 28-52% CO₂ savings against the base line fuel type considered. Overall wall insulation and switching to higher efficiency boilers achieves a good balance between both energy and CO₂ savings.

**Cavity Wall dwelling**

3 English wood pellets have a calorific value range from 4.7-5 kWh/kg and moisture content of 5-10% of total weight. A higher calorific value and lower moisture content increases the efficiency of wood pellet stoves (Hansen, M., 2009).
The detached dwellings constructed recently are mainly ‘brick and block’ cavity wall construction. The dwellings have a fair amount of front and back garden that would ideally suit the laying of pipe work required for a GSHP. Hence an option for GSHP has been modelled for cavity wall dwellings only. Additional solid wall insulation is considered excessively costly for the relative additional benefit it would offer to these dwellings, since the cavity spaces have already been insulated to nearly an equivalent U value. Hence further external or internal wall insulation as a measure was not considered for these dwellings.

**Table 5**

Annual energy consumption (kWh/m²) of typical cavity wall detached for baseline against various energy efficiency measures

<table>
<thead>
<tr>
<th>Energy Demand (kWh/m²)</th>
<th>Baseline</th>
<th>Higher efficiency Boiler</th>
<th>ASHP</th>
<th>Biomass</th>
<th>Solar Thermal</th>
<th>GSHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>165</td>
<td>113</td>
<td>58</td>
<td>157</td>
<td>156</td>
<td>47</td>
</tr>
<tr>
<td>LPG</td>
<td>158</td>
<td>113</td>
<td>58</td>
<td>157</td>
<td>150</td>
<td>47</td>
</tr>
<tr>
<td>Electricity</td>
<td>110</td>
<td>0</td>
<td>58</td>
<td>157</td>
<td>104</td>
<td>47</td>
</tr>
<tr>
<td>Coal</td>
<td>176</td>
<td>0</td>
<td>58</td>
<td>157</td>
<td>168</td>
<td>47</td>
</tr>
</tbody>
</table>

**Figure 5** Annual energy savings (%) for typical cavity wall detached for various energy efficiency measures

For cavity wall dwellings, both air-source and ground source heat pumps achieved the highest energy savings amongst the measures considered (Table 5, Figure 5). If the property is suitable for GSHP it can achieve a saving of 71-73% when the fuel type is oil, LPG or Coal. However when run on electricity the savings reduced to 57%.

**Renewable Energy Technologies**

The energy efficiency measures discussed above achieve savings in space heating consumption only. As stated earlier, SAP does not calculate the electricity consumption of lighting, cooking and appliances. Modelling in EnergyPlus gave an annual electricity demand of 3400 kWh/household. The internal gains for this modelling were assumed to be 6 W/m² for lighting and appliances.

**Solar PV**

**Ideal scenario**

A monocrystalline panel (235 Wp) with 14.3% efficiency was modelled in PV sol for a due south orientation to achieve maximum power output. The solar irradiation data was taken from a nearby regional data set was assumed as 990 kWh/m². The tilt angle of the roof was assumed 30° according to the house types. A standard high efficiency inverter assumed at 95% was also used. It was found that a single panel with a due south orientation was generating 201 kWh/yr. The size of the panel is 1652mm * 994mm occupying 1.64 m² of roof area. Hence the approximate roof area required to supply 100% of the electricity demand (3400 kWh) would be 28m² (17 panels).

**Realistic scenario**

Power outputs from a solar PV array are highly dependent on its orientation and tilt and will be very sensitive to any amount of shading – much more so than solar thermal panels. Most systems operate within 90% of full capacity if orientated within 45 degrees of South. However, the majority of houses in the village are not orientated within this range. Roof orientations instead lie generally within the range from 45° due south (i.e. S-E & S-W) to 90° due south (i.e. E-W). In addition, the roof area of dwellings cannot accommodate such a large PV array of 28m². Hence, an array of 8 panels (1.88KW) is selected that occupy a roof area of 13.1 m². It is assumed that this would fit on any of the roofs within the village, while some dwellings may have space for a larger array. The modelling is repeated for different orientations.

The annual energy generated for different orientation is assumed at 95% was also used. The annual energy generated for different orientation was modelled using the combined efficiency of the PV panel and inverter (Table 6). The maximum annual energy produced from the assumed PV panel was 1614 kWh/yr from a south facing roof, dropping to 1255 kWh/yr for an east facing roof. As discussed earlier, the average electricity demand for a dwelling (i.e. from cooking and appliances) is 3400 kWh/yr, suggesting that the

**Table 6**

Variation in PV system output with orientation

<table>
<thead>
<tr>
<th>Orientation/ Tilt angle: 30°</th>
<th>Annual energy from system (kWh/yr)</th>
<th>System efficiency %</th>
<th>% efficiency compared to South facing panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1613.5</td>
<td>10.6</td>
<td>100</td>
</tr>
<tr>
<td>SSW</td>
<td>1598.3</td>
<td>10.6</td>
<td>99.1</td>
</tr>
<tr>
<td>SSE</td>
<td>1579.4</td>
<td>10.6</td>
<td>97.9</td>
</tr>
<tr>
<td>SW</td>
<td>1532.5</td>
<td>10.5</td>
<td>95.0</td>
</tr>
<tr>
<td>SE</td>
<td>1500.4</td>
<td>10.6</td>
<td>93.0</td>
</tr>
<tr>
<td>WS</td>
<td>1425.5</td>
<td>10.4</td>
<td>88.3</td>
</tr>
<tr>
<td>SE</td>
<td>1386.6</td>
<td>10.4</td>
<td>85.9</td>
</tr>
<tr>
<td>W</td>
<td>1287.2</td>
<td>10.2</td>
<td>79.8</td>
</tr>
<tr>
<td>E</td>
<td>1254.6</td>
<td>10.2</td>
<td>77.8</td>
</tr>
</tbody>
</table>
PV panel could supply approximately a 30%-50% of the electricity demand.

Wind

Onshore wind is seen to be the most advanced of all renewable technologies, the cheapest to install with fast payback times typically between 5 and 10 years in the region of the case study and therefore the most likely to bring about widespread renewable energy supply. However, in the short term, it is more likely that rural locations, away from buildings and other structures and with wind speeds above 6m/s at the height of the turbine rotor would be more justifiable from a payback and carbon lifecycle point of view. So rather than small scale turbines mounted on the roofs of individual dwellings, it will be preferable to look at larger scale community schemes where a number of households would benefit from a wind turbine placed in a windy, obstruction free zone, potentially farmland.

The UK Government Department for Energy and Climate Change Wind Speed Database (DECC, 2011) gives the average annual wind speed taken at different heights above ground on site for the village as follows:

- Wind speed at 10m hub-height – 5.6m/s
- Wind speed at 25m hub-height – 6.3 m/s
- Wind speed at 45m hub-height – 6.8 m/s

Table 7
Annual energy output of various wind turbines and their details

<table>
<thead>
<tr>
<th>Example system</th>
<th>WT-1</th>
<th>WT-2</th>
<th>WT-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power of system</td>
<td>55kW</td>
<td>100kW</td>
<td>225kW</td>
</tr>
<tr>
<td>Hub height (m)</td>
<td>24m</td>
<td>37m</td>
<td>30m</td>
</tr>
<tr>
<td>Anticipated wind speed at hub height (m/s)</td>
<td>6.0</td>
<td>6.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Rotor diameter (m)</td>
<td>19.2</td>
<td>24m</td>
<td>29m</td>
</tr>
<tr>
<td>Average annual output (kWh)</td>
<td>168,900</td>
<td>260,000</td>
<td>441,000</td>
</tr>
<tr>
<td>Number of dwellings non-heating load served (@ 3400 kWh/dwelling/yr)</td>
<td>50</td>
<td>76</td>
<td>130</td>
</tr>
</tbody>
</table>

Hence, three wind turbines of capacities ranging from 55kW to 225kW are modelled using RetScreen software tool to derive their annual outputs (Table 7). The village has 120 houses. Hence the most suitable options for wind turbines would be:

- 3 x 55kW turbines. Dwellings served = 150
- 2 x 100kW turbines. Dwellings served = 152
- 1 x 225kW turbines. Dwellings served = 130

LIMITATIONS OF THE TOOLS

SAP is a tool to check compliance of the domestic stock with building regulations of the UK. Hence, the tool gives an estimated energy consumption of space heating, hot water, lighting, ventilation, pumps and fans according to the building area and fabric U-value with a standard house occupancy level of 2.7. The tool does not consider variation in occupancy, usage of appliances etc. regarded as ‘non-regulated’ load in the UK. Hence EnergyPlus was used to calculate the ‘non-regulated’ load (cooking, lighting and appliances).

SAP calculates the energy consumption according to various fuel types:- coal, oil, LPG, electricity, biomass and heat pumps. Even though the tool considers the fuel type of biomass and heat pumps, it only assumes a certain efficiency of the system, but does not quantify the system. For example, the annual energy consumption of a cavity wall dwelling on biomass boiler or an ASHP would be 157 kWh/m² and 58 kWh/m² respectively but the size of the boiler or heat pump delivering this energy is unknown. Hence, SAP is not the right tool for system sizing of boilers and heat pumps. The output of the tool is limited to energy consumption and CO₂ savings. The size of the biomass or heat pump system would have implications on the space required for the system and is an important factor to be considered when doing any financial assessment of the technologies.

SAP also uses only one climatic data that is of the East Pennines region in UK. The climate in the UK varies drastically from Northern Scotland to Cornwall. Since SAP is a compliance tool to comparatively check energy performance of UK homes, the climatic data is assumed constant. EnergyPlus calculations however are sensitive to climatic data and use its own weather files. Consequently, EnergyPlus is a more refined tool than SAP for detailed modelling of energy consumption.

SAP also has restricted capabilities for modelling power generating technologies like solar PV and wind turbines. Hence the software tool is not intelligent to simulate hybrid systems for example combined PV and heat pump systems.

RetScreen is a more refined design and financial assessment tool for renewable energy technologies. For this paper, the use of the tool has been restricted to designing of wind turbine systems. However, it is anticipated that the tool will be further explored for...
sizing of systems like biomass boilers and heat pumps.

PV*Sol is a tool solely for the design of stand alone or grid connected photovoltaic systems. The study has not undertaken a detailed assessment of the roofs for PV panels, but has provided an estimated annual generation for an array that could be accommodated on the roofs, assumed 100% un-shaded, as per their orientation. A detailed roof-by-roof assessment that can be conducted in PV*Sol has not been included in the scope of the study due to the complexity of different roof orientations in the village.

The design of renewable energy technology is resource dependent. For example, the solar radiation and wind speeds of the site influence the design of solar PV and wind turbines respectively. All simulation programs mentioned in this study rely on climatic data from different sources. For example, PVsol relies on Meteonorm weather data. A thorough on-site assessment of wind speeds and solar radiation available needs to be conducted through monitoring to inform the simulation program so that a realistic output is generated.

Results of simulation tool are indicative and need to be validated against real-time monitoring data.

**SUMMARY**

Potential energy efficiency and renewable solutions for houses off the mains-gas network have been formulated in this study using different tools. SAP was used for energy modelling as it is widely used in the UK for energy assessments of houses. However SAP is limited in designing integrated renewable energy solutions, for which stand alone tools, PVsol and RetScreen, were used to design photovoltaic and wind turbine systems respectively. While SAP is an energy modelling tool, RetScreen and PVsol are stand alone tools for renewable energy system design not concerned with energy performance of dwellings. Hence there is a huge potential for developing tools that can be incorporated with SAP for the UK that simulates RETs and their impact on the energy performance of dwellings.

**CONCLUSIONS**

Using SAP 2009, it has been found out that solid wall insulation is a first measure in the energy hierarchy that can contribute to considerable energy savings of 30-40% and even higher for all solid wall dwellings.

Switching to a higher efficiency boiler where the efficiency of an existing oil or gas boiler is increased by 24% and 21% respectively can also lead to considerable energy savings of around 30-34% for both solid wall and cavity wall dwellings.

Air source heat pump as a low-carbon technology contributes to a much higher energy saving of 65-70% for all typologies. The energy savings are further increased to 70-75% if air source is switched to ground source. However GSHPs cannot be installed for all houses especially terraced housing with small gardens and in this study are only suitable for cavity walled detached dwellings in application in this study. A package of two options, wall insulation and installation of heat pump, can amount to a combined higher energy saving.

Solar thermal technologies only offer 5% energy savings since they contribute to domestic hot water only and are not considered for space heating. The space heating demand of a house is much more than the domestic hot water demand; and the energy savings calculated are towards space heating plus hot water. Studies (EST, 2006) indicate a typical solar thermal hot water system can provide 40-50% of the annual hot water demand of UK households.

It was also found that biomass boilers do not contribute effectively towards energy saving due to their low efficiency. In households using electricity for heating; biomass boilers on the contrary consume more energy for space heating than electricity for both solid wall and cavity wall dwellings. Only if the household uses coal as the baseline fuel for space heating, changing the fuel source to biomass would achieve an energy saving of around 12%. The energy saving potential of biomass boilers can be increased by increasing their efficiency.

While considering energy saving measures it is also important to assess their impact on CO₂ emissions. Biomass boilers are inefficient in terms of energy savings but have a much higher impact on the environment due to high savings in CO₂ emissions.

Measures such as wall insulation, switching to higher efficiency boilers prove to be efficient in both energy and CO₂ savings.

Photovoltaic panels and Wind turbines are both power generating technologies that could meet only the small power demand of the house. Since the space heating demand of the household is much more than the power demand for cooking, lighting and appliances, these technologies need to be carefully considered for implementation in terms of capital cost, payback period and return on investment.

Finally, SAP is UK government’s methodology to assess the energy performance of dwellings. However the tool has restricted features to simulate renewable energy technologies that today need to be integrated with new and existing dwellings to meet the carbon reduction targets. Hence further revisions of the SAP methodology would support improvements in this area.

**FURTHER RESEARCH**

The study highlights the huge potential in developing computational tools that incorporate SAP and
simulate building integrated renewable energy technologies for the UK. Since SAP is the UK government’s tool for building regulation compliance of dwellings it is intended to be a simplistic method that cannot be replaced with complex dynamic energy modelling tools. However, the market is turning towards renewable energy technology integration with dwellings that makes it imperative to revise SAP methodology. Recent studies have suggested that variances can exist between SAP methodology and dynamic simulation methods (Murphy et al., 2010). Further research will focus on incorporating algorithms in the existing SAP methodology that would enable it with mature renewable energy technology simulation capabilities.

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