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NEAR ZERO CARBON CARE HOME DESIGN IN THE UK

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Abstract

The global construction industry is in a transition period of reducing energy consumption and carbon emissions. The recast of the EU Energy Performance of Buildings Directive (EPBD) in 2010 will require Member States to achieve nearly zero-energy for all new buildings from the 1st of January 2021 and for all new buildings occupied and owned by public authorities to be nearly zero-energy from the 1st of January 2019[1].

Care homes have consistent high energy requirements 24 hours a day and 7 days a week. It is important to improve their energy efficiency to tackle the issues of overall fuel security and climate change, as well as to reduce their running cost in order to reduce the finance burden in an aging society. In addition, energy consumption patterns to operate care homes and their special thermal requirements present both opportunities and challenges to achieve successful near zero carbon care homes.

Reducing energy consumption in a building requires an integrative approach to balance all design aspects affecting energy performance, whilst ensuring a comfortable and healthy built environment for occupants. This paper aims to investigate the potential to deliver near zero carbon care homes design through a systems approach incorporating innovative technologies. The systems approach for low carbon care homes design is focussed on four steps: 1) reducing internal heat loads, 2 using passive design strategies), 3) applying efficient HVAC systems and 4) integrating renewable energy supply and storage systems into the building design. Building simulation is used to optimise the design in each step in order to achieve the most practical design solution.

In this study, a standard care home in the UK is used to provide the design information, and building simulation will be carried out within a local context and climate to evaluate the impact of different design strategies. Furthermore, the impact of each design strategy on thermal comfort, energy consumption and carbon emissions will be discussed.

1. INTRODUCTION

The global population is aging. By 2035, more than a third of the UK population will be over 60 [2]. There is an increasing demand to build more care homes. On the other hand, a proportion of existing care homes face closing down due to the cutback of funding. Money is tight for the majority of care homes. These care homes are generally occupied 24 hours 7 days a week, and older people have higher requirements for the comfort, which leads to potential higher energy cost and carbon emissions.

Zero carbon design strategies have been developed to respond to the zero carbon transition in the construction industry. Some pioneering care home projects have made effort to reduce their carbon emissions. However, a systems approach to maximize the efficiency is not normally fully considered. In order to reduce the financial stress of running a care home as well as to comply with national and international building regulations and legislations, it is important to investigate zero carbon solutions to accommodate an aging population.

The paper will review a systems approach and innovative technologies that have been applied to other projects, and then investigate the related benefits of the applications in care homes in the UK. A standard care home building will be established, and building simulation will be carried out with local context and climate to evaluate the impact of different design strategies. How the building simulation results can inform the design process will be presented. In addition, the impact of each design strategy on thermal comfort, energy consumption and carbon emissions will be discussed.

2. A SYSTEMS APPROACH TO NEAR ZERO CARBON DESIGN

A systems approach is a sustainable design method that integrates across site planning, architectural design and building engineering, and which can result in a zero carbon building development. This can provide lower running costs and contribute to reducing the demand on the energy supply infrastructure. A holistic systems approach consists of 1) reducing energy demand, 2) using passive strategies, 3) applying efficient HVAC systems and 4) integrating renewable energy supply and storage systems [3] (Fig.1). The four aspects of the systems approach are further discussed in the following sections.

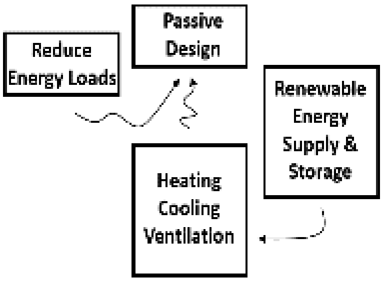

Figure 1: Four aspects of a systems approach [1]

2.1 Reducing energy demand

The first aspect is to reduce the energy demand by using energy efficient equipment and lighting systems to reduce the direct energy usage as well as the heat gains to the space. An energy consumption labelling scheme [4] has been developed to indicate the energy efficiency of appliances and lighting systems in terms of a set of energy efficiency classes from A+++ to G on the label. A+++ is the most energy efficient, G is the least efficient. Considering lighting energy, halogen lights, the compact fluorescent light (CFL) can save up to 75% energy usage compared to incandescent. In addition, light emitting diode (LED) lights can provide a further one third saving in energy.

2.2 Using passive strategies

The second aspect is to apply passive design strategies in relation to site planning, building form and building fabric, to utilize free energy (mainly solar and wind), and to reduce heat gain in the cooling season and heat loss in heating season. This aspect is important as these design elements tend to remain unchanged throughout the building's life time. Building fabric design should be the focus, as there is generally less flexibility associated with site planning and building form.

2.2.1 Multi-layer glazing

New glazing systems may be used, for example, the innovative TRIMO glazing which consists 4, 6 and 7-pane glazing has a low U value (ranging from 0.13-0.49 W/m^{2}K) to reduce the heat loss and a low G value (ranging from 10% to 35%) to reduce solar heat gain [5]. The application of this glazing can 1) reduce annual heating and cooling consumption, 2) reduce peak loads to decrease capacity of service systems and 3) improve thermal comfort due to better internal glazing surface temperature.

2.2.2 Structural Insulated Panels (SIPs)

SIPs are composite building panels, consisting of a layer of platunum insulation (expanded polystyrene) sandwiched between two layers of structure Oriented Strand Board (OSB). SIPs can be used as both wall panels and roof panels. When used wall panels applied with 100mm brickwork with 60 clear cavity, it can provide a U-valude of 0.13W/m^2/K. Other advantages of this system include fast build times, good air tightness, avoiding cold bridging as well as fast erection [6].

2.2.3 Transpired Solar Collector

A Transpired Solar Collector (TSC) is a solar thermal technology, which heats or preheats the ventilation air supply to buildings and can be intergraded into the building envelope [7]. There are two main types. The Unglazed Transpired Solar Collector (UTSC) is made of a layer of metal cladding with perforations, installed at several centimetres from a building wall, creating a cavity, allowing the preheat of ventilation air [8]. The external metal skin absorbs solar heat energy and heats up the boundary layer of air on its surface. External air (including the boundary layer of heated air) is drawn into the cavity via a fan through the perforations. In addition, the air in the cavity is further heated by the internal surface of the metal layer, and then directly distributed to the internal space through a mechanical ventilation system. The Glazed Transpire Solar Collector (GTSC) has a glazing cover enclosing air cavity over the perforated metal layer. Figure 2 shows the working principles of both types of TSC. Besides the reduction of heating load, TSC provides a buffer zone to reduce heat loss through external walls. In summer time when heating is unnessasry, the heated air in the cavity can be released through a by-pass valve or used to heat domestic hot water.

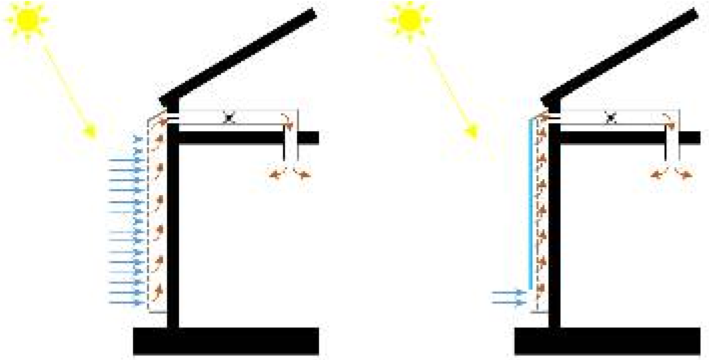

Figure 2: Transpired Solar Collector (left: UTSC, right: GTSC)

2.3 Applying efficient HVAC systems

The third aspect is to further reduce the energy demand through the application of efficient heating, cooling and ventilation service systems. Using an air system in care homes has its advantages. Firstly, furniture arrangement in a room can be more flexible due to the absence of radiators. Secondly, it avoids the risk cause by high radiator surface temperature. Mechanical ventilation and heat recovery (MVHR) systems work by extracting heat from the outgoing air to warm incoming air via an air to air heat exchanger within the MVHR unit. The heat recovery rate of modern MVHR systems can reach 85% [9].

2.4 Integrating renewable energy supply and storage systems

The last aspect is to integrate renewable energy systems in order to decarbonise the remaining energy requirements combined with batteries to provide local energy storage. The aim is to integrate the renewable energy systems into the building design as construction elements (eg. solar PV roof, Solar air collector (TSC) wall) rather than use a bolt-on approach.

2.4.1 Integrated PV systems

Monocrystalline silicon PV panels (Mono-Si), have a cell efficiency that can reach 20% while the module efficiency can reach 17%. It is important to integrate PV system into buildings as part of a building component rather than a bolt-on element, to reduce capital cost and improve the design aesthetics. Figure 3 shows PV panels are used as roof panels in Solcer Low Carbon Demonstration Centre [10].

Figure 3: Integrated PV roof panel (left: external view, right: internal view)

2.4.2 Battery systems

Introduction of battery electrical storage can optimise the balance of energy import and export from and to the grid. There are many battery technologies available, including Lead-Acid, NiCd, NiHM and Li-Ion. Currently, Li-Ion battery developed in 1990s is the most recent technology which has higher specific energy density (up to 190Wh/kg), longer life time (up to 2000 cycle time), lower self-discharge per month (less than 5%) and lower maintenance requirement [11]. When there is no energy generated by the PV system, the DC power stored in the battery system can be used to supply energy demands of the building. Once the battery system is depleted, electricity from the grid will be used to meet the demand.

3. RESEARCH METHODOLOGY

3.1 Building simulation

The above section has described the four aspects of a systems approach to near zero carbon design, based primarily on the practice experience of building design in Switzerland and the Solcer zero carbon near zero carbon demonstration building located in South Wales. Building energy modeling is used to investigate the performance of a care home design. This takes account of the complex dynamic thermal interactions between the external environment, building fabric, internal heat gains, HVAC systems and renewable energy systems and storages. HTB2 (Heat Transfer in Buildings version 2), a dynamic building energy model developed at the Welsh School of Architecture (Cardiff University), is used in this study. It has undergone extensive testing, validation, including the IEA Annex 1 [12], IEA task 12 [13] and the IEA BESTEST [14], and has been applied in many research and design projects [15]. Based on weather data, building construction and layout details, shading masks, building services, and occupation profiles for people, equipment and lighting, it can simulate hourly and annual energy consumption and internal thermal conditions. In this study, the building services is simplified by using an average efficiency and Coefficient of Performance (COP) for heating and cooling systems, and the energy generated by PV systems is calculated using an average PV efficiency.

3.2 Care homes

There are two main categories in dwellings for the elderly in the UK: 1) sheltered housing (retirement housing) which is usually in the form of bungalows or apartments, self-contained with communal areas, such as the lounge, laundry room and garden; 2) care homes which are staffed 24 hours a day and all meals are provided. This study focuses on the second categories. This study was conducted in three steps:

1. A typical design of care home in the UK was selected and located in Cardiff.
2. Modelling frameworks for current practice, as well as for near zero carbon design, were developed, including parameters for the building fabric, internal gains, HVAC systems and renewable energy and storage systems.
3. Building simulations for (i) current practice and (ii) near zero carbon design, were conducted using HTB2. The simulation results are compared and discussed, for monthly energy supply and annual energy demand. The analysis focuses on solar energy potential, as well as annual energy and CO_2 emissions.

4. BUILDING SIMULATION

This section presents the care home design, the simulation process and results for both the current practice and near zero carbon design cases.

4.1 Typical care home design

A typical care home design (total floor area 2030.5m^2) is selected with a floor to ceiling height 3.0m (Fig.4).

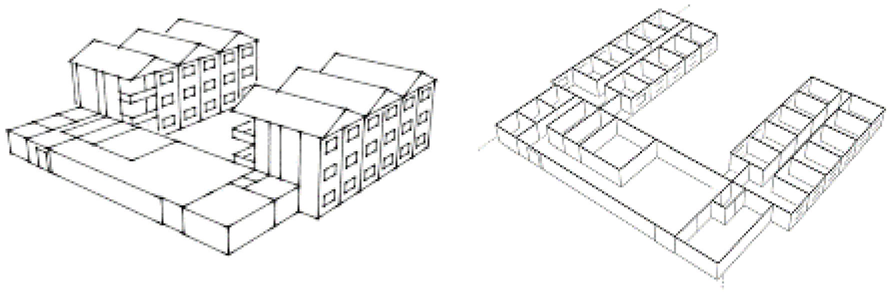

Figure 4: Typical care home design

4.2 Modelling frameworks

4.2.1 For current practice

The main input data for current practice are based on the threshold of the current building regulation. Various studies [16] have found that clients tend to comply to building regulation only. Data used in the simulation for the current practice is summarized in Table 1.

Table 1 Simulation input data for current practice

Internal gains (W/m^2)				Ventilation	Fabric energy efficiency U-value (W/m^2/K)	
Rooms	Occupant	Lighting	Plug load		External wall	0.30
Single rooms	3.5	9.4	2.0	10L/P/s	Roof	0.20
Corridor	0	7.0	0	10L/P/s	Ground floor	0.25
Reception	5.0	8.3	4.0	10L/P/s	Glazing	2.0
Office	4.8	15.9	7.0	10L/P/s		G=45%
Dinning/ lounge	22.1	6.9	2.0	10L/P/s	Systems	Gas boiler SEDBUK=88% 89.5% Operating 00:00 - 24:00
Kitchen	7.8	17.0	40.0	30L/P/s		
Treatment room	14.2	15.9	20.0	10L/P/s		

Notes:

a) The building is only used 7 days a week, 24 hours a day;

b) The internal gain profile and lighting and plug load are based on the SIA 2024 [17]. The occupant's load is based on the design.

c) The fabric energy efficiency U-value and systems, as well as the infiltration rate (at $10m^3/h/m^2$ @50pa) are based on British Building Regulation Part L A1.

According to CIBSE Guide A [18], studies have found that the thermal environments preferred by older people did not differ significantly from those preferred by younger ones due to their lower metabolism being compensated by a lower evaporative loss. The designed room temperature used in the simulation is 22 (winter) to 24°C (summer).

4.2.2 For near zero carbon design

Data used in the simulation for near zero carbon design is summarized in Table 2. Figure 5 shows the installation of PV and UTSC systems on the typical building.

Table 2 Simulation input data for near zero carbon design

Internal gains (W/m²)				Ventilation	Fabric energy efficiency U-value (W/m²/K)	
Rooms	Occupant	Lighting	Plug load		External wall	0.13
Single rooms	3.5	6.3	1.0	10L/P/s	Roof	0.13
Corridor	0	4.6	0	10L/P/s	Ground floor	0.10
Reception	5.0	5.6	1.5	10L/P/s	Glazing	0.35
Office	4.8	11.6	3.0	10L/P/s		G=0.15
Dinning/ lounge	22.1	4.6	1.0	10L/P/s	Systems	
Kitchen	7.8	12.5	30.0	30L/P/s	• UTSCs on the second and third floor of west facade of the apartment for the MVHR system in winter, 216 m² • Mono-Si Solar PV on the south facing roof and the flat roof, 480 m² at 17% efficiency • MVHR at 85% efficiency	
Treatment room	14.2	11.6	10.0	10L/P/s		
Notes: a) The internal gain profile and lighting and plug load are based on the SIA 2024. The occupant's load is based on the design. b) The fabric energy efficiency U-value and systems are based on near zero carbon design in practice. c) The infiltration rate for the near zero carbon design is 06ac/h@50Pa, based on Passivhaus standard.						

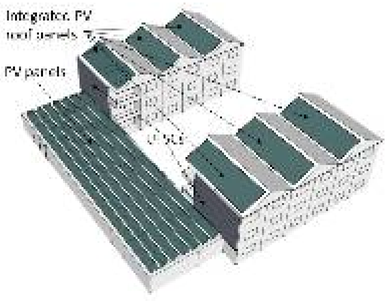

Figure 5: Near zero carbon care home design

5. RESULTS AND DISCUSSION

5.1 Energy performance of current practice

The simulation results of the energy performance of current practice are shown in Figure 6. The main heat loss was associated with ventilation (infiltration and mechanical ventilation system), with a total of 94.3kWh/m²/year. Heat loss from the fabric was predicted to be 52.71kWh/m²/year. The heat gains were solar gains at 19.1kWh/m²/year and internal gains (including occupant, lighting and equipment) at 87.7kWh/m²/year. Therefore, a net heat input of 53.7 kWh/m²/year from the heating system is required. In addition, a net cooling load of 19.1 kWh/m²/year is predicted. The total annual energy consumption for heating, cooling, lighting and equipment is 133.4kWh/m²/year.

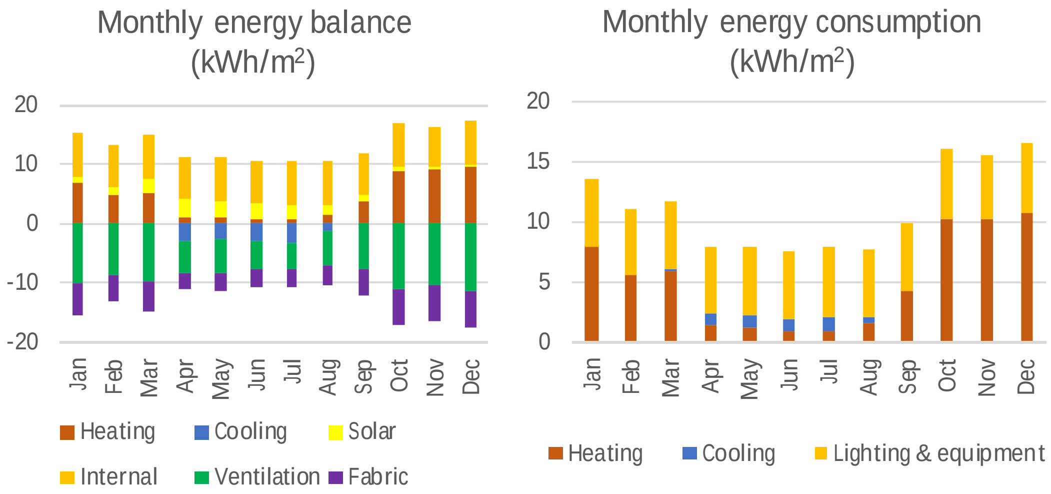

Figure 6: Energy performance of current practice

5.2 Energy performance of near zero carbon design

The simulation results predicting the energy performance of the application of each aspect of the systems approach are shown in Figure 7-10.

5.2.1 Aspect 1: Reduction of internal heat loads

Figure 7 accounts for a reduction in incidental gain by 25%, from 87.7kWh/m^2/year to 63.9kWh/m^2/year, due to the use of energy efficient lighting and equipment. However, the heat input from the heating system is increased from 53.7kWh/m^2/year to 67.7kWh/m^2/year to compensate the loss of heat gains from these systems, while the cooling load is decrease from 19.1kWh/m^2/year to 5.8kWh/m^2/year. The total annual energy consumption is reduced by 7.8%, to 122.9kWh/m^2/year.

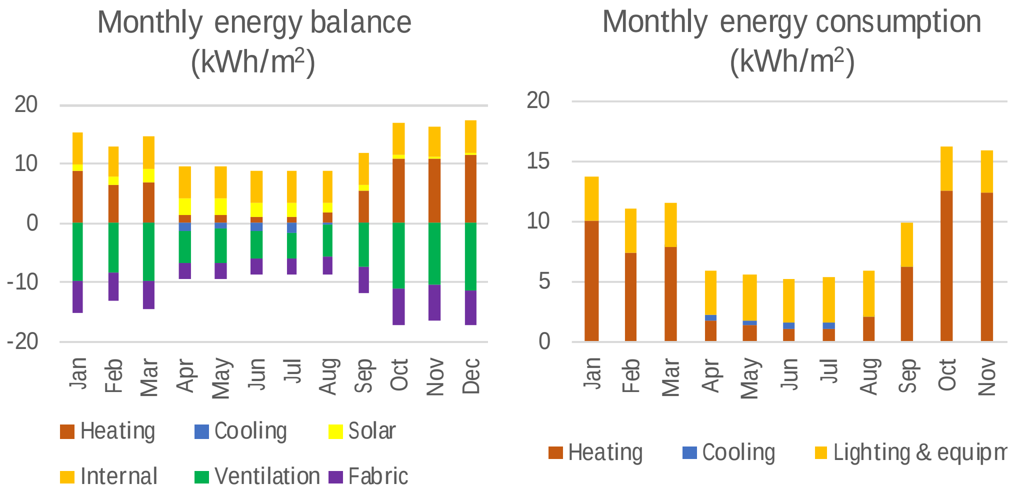

Figure 7: Energy performance of the reduction of internal heat loads

5.2.2 Aspect 2: Passive design with improved insulation and air tightness

Figure 8 accounts for a reduction in ventilation energy from 93.0kWh/m^2/year to 80.5kWh/m^2/year with the improvement of air tightness from a standard Building Regulation requirement to a Passivhaus standard. In addition, the heat loss through the fabric is reduced from 51.8kWh/m^2/year to 18.9kWh/m^2/year due to the improvement of u-values. The total annual energy consumption is reduced from 122.9kWh/m^2/year to 89.7kWh/m^2/year for heating, cooling, lighting and equipment.

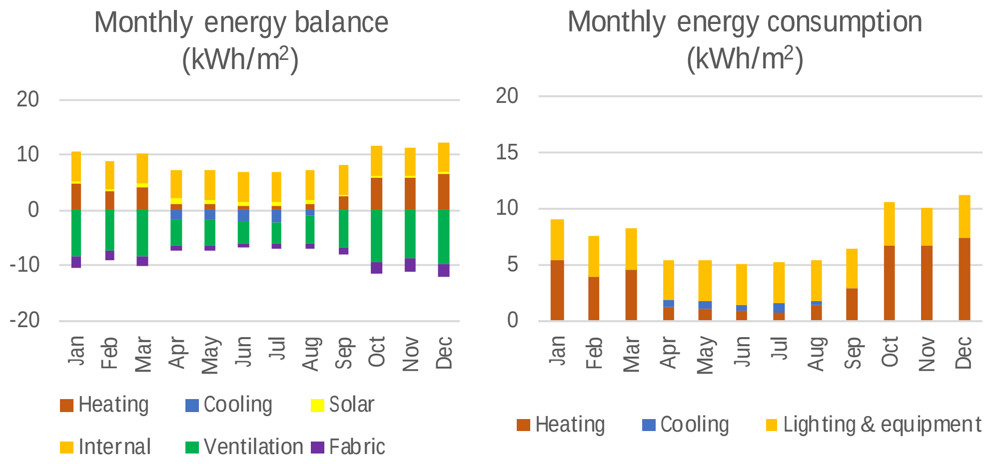

Figure 8: Energy performance of passive design

5.2.3 Aspect 3: Efficient HVAC systems with the application of UTSCs

Figure 9 accounts for a further reduction in ventilation energy from 80.5kWh/m2/year to 23.8kWh/m^2/year with the UTSCs and MVHR systems. The total annual energy consumption is significantly reduced from 89.7kWh/m^2/year to 58.4kWh/m^2/year for heating, cooling, lighting and equipment. The annual heating energy consumption is now 4.6Wh/m^2/year, and the cooling energy consumption is 9.9Wh/m^2/year.

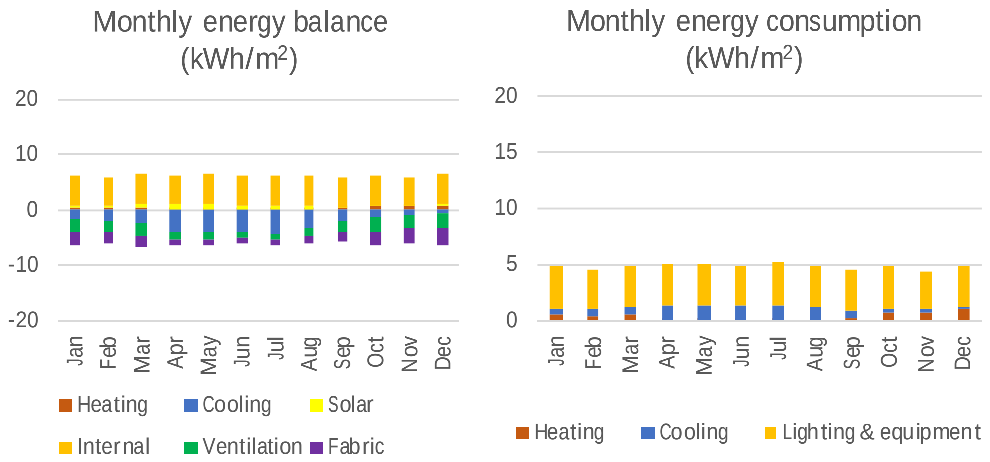

Figure 9: Energy performance of efficient HVAC systems

5.2.4 Aspect 4: Integrated renewable energy supply and storage systems

Sketchup with the virvil plugin, developed by the Welsh School of Architecture [19], has been used to predict the solar radiation falling on the designed PV systems. Figure 10 shows that around 1000kWh/m^2/year solar radiation is projected on the proposed surfaces (480m^2). Assuming a 17% PV panel efficiency, the total electricity generated by the proposed PV system was 45.6kWh/ m^2/year of total floor area (2030.5m^2). It is about one third of the energy consumption (133.4kWh/m^2/year) predicted for heating, cooling, lighting and equipment for the current practice building. However, it can supply 80% of the energy consumption for the near zero carbon design (54.8kWh/m^2/year). In summer months (from May to August), the electricity is sufficient to supply the energy consumption for heating, cooling, lighting and equipment, while energy from the grid is only required in winter months.

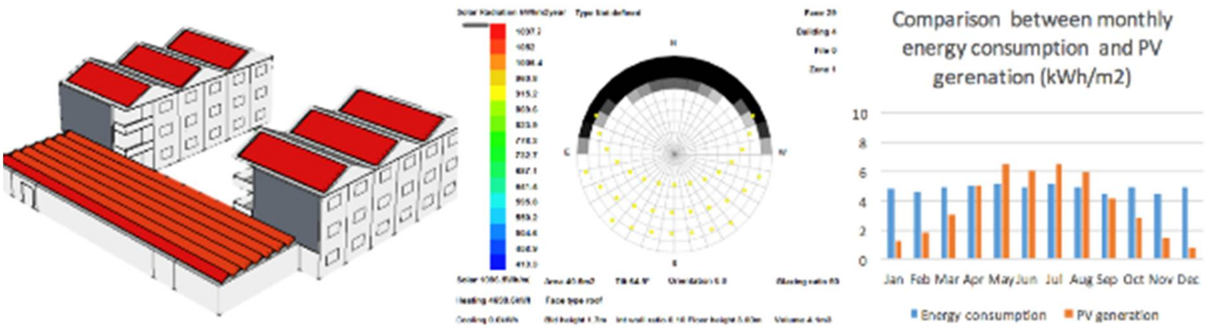

Figure 10: Energy performance of PV systems

5.3 Discussion

The overall simulation results (Figure 11) suggests that

- Reducing internal heat gain is the first step of the systems approach and it can provide 7.8% of energy saving.
- Passive design (improved insulation, reduced g-value and air tightness) has an impact on reducing energy consumption of heating, cooling, lighting and equipment by one third of the consumption compared to current practice.
- Energy efficient systems design (MVHR and UTSCs) is the most influential design aspect. With the proposed systems, the energy consumption for heating, cooling, lighting and equipment can be further reduced to 40% of current practice. In addition, the monthly energy consumption profile is evened out, which can reduce the peak capacity of the required HVAC systems.
- Renewable energy systems cannot offset all the energy consumption due to the high energy demand of care homes; however, it can provide 80% the overall energy consumption of heating, cooling, lighting and equipment.

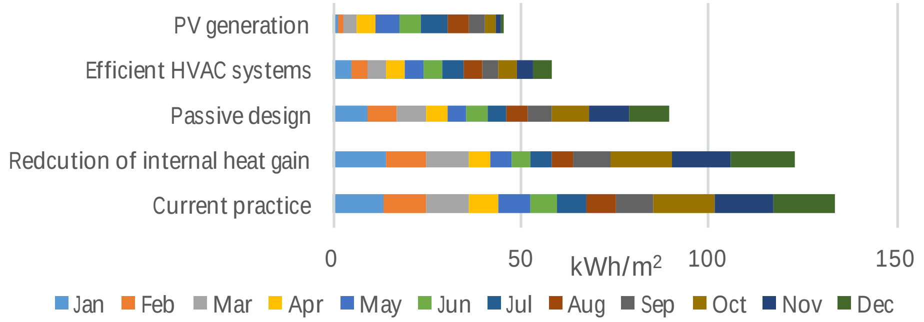

Figure 11: Comparison of annual energy supply with monthly breakdown of the application of each stage of the systems approach

Besides the benefit from energy saving, other benefits of the proposed design can be recognized, including:

1. Flexible room layout due to the absence of radiators.
2. Reduction of the risks of exposure to hot radiator surfaces. Although, care homes and hospitals are required to maintain all exposed heater surfaces at or below 43°C since temperatures above and around 43°C will begin to cause skin damage if the skin contact is of sufficient duration [20].
3. Improved ventilation to provide good indoor air quality.

6. CONCLUSION

The paper has discussed the concept of a systems approach, combining reduced energy demand, passive design, efficient HVAC systems, and the use of building integrated renewable energy systems and energy storage. This study has described a process of achieving a near zero carbon care home design through a systems approach and innovative technologies. The building energy simulations presented an analysis of the energy performance of a standard care home building in Cardiff in 5 conditions: 1) current practice, 2) with reduction of internal heat gains from lighting and equipment, 3) with passive design to improve building fabric, 4) with efficient HVAC systems (MVHR and UTSCs), 5) with solar PV systems. The simulation focuses on energy consumption of heating, cooling, lighting and equipment. It relates energy demand to the required energy supply, and to the potential for meeting this supply from renewable energy. The results indicate that the systems approach provides the potential for using solar energy to meet most of the energy supply needs. In addition, CO_2 emissions are reduced from 133971.7kg to 58657.4kg (carbon emission factor 0.4964kg/kWh). Supply the remaining energy requirement with energy from grid generated with renewable sources can the option to achieve the zero carbon target.

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