607: Sustainable Housing Development: Design Towards Zero Energy For Space Heating

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Abstract
The aim of this paper is to evaluate and compare the architectural and environmental design strategies in terms of layout and orientation, internal space planning, building fabric and energy consumption plan of three carefully selected housing projects in the UK. These case studies are: Hockerton Housing Project (1998), BedZED (2002) and Kingspan Lighthouse (2007). The first two schemes are selected because both are designed with the aim to achieve zero space heating targets and the third one is selected as it has achieved level 6 of the latest Code for Sustainable Homes. Comparative analyses of actual or predicted measurements of energy consumption for the three case studies will be carried out, based on data collected from various sources. Best design strategies for achieving zero energy consumption for space heating are discussed as the result of this comparative analysis.

Keywords: Housing, Zero Energy, Space Heating

1. Introduction

Climate change is a serious and long-term challenge caused by human activities. Greenhouse gases from human activities trap the sun's radiation near ground level, thus increasing the mean surface temperature of the planet. CO2 contributed at around 77 per cent of the UK's total emissions of greenhouse gases in 1990 or 161.5 MtC [9]. Under the Kyoto Protocol, the UK's domestic goal is to reduce CO2 emission by 20 per cent by 2010 below the 1990 levels and 60 per cent by about 2050. However, CO2 emissions only fell by about 5.6 per cent to 152.5 MtC between 1990 and 2004. In 2005, the projection of UK's CO2 emissions for 2010 was about 10.6 per cent below the 1990 levels. This means that further efforts are required in order to achieve the UK's domestic goal to reduce CO2 emissions [9].

The domestic sector is responsible for about 27 per cent of CO2 emissions on an end user basis. This comes from the energy consumption by a wide range of different appliances in the home, with over half of the energy consumption being used for space heating and around one-fifth for water heating [4]. Demographic change in the UK where increased population coupled with a decrease in household's size has inflated the energy use in the domestic sector [5]. A 23 per cent increase in energy consumption is likely to happen by 2050 [3] if nothing is done to reduce households' energy consumption. Therefore, it is crucial to analyse the various strategies that can be adopted in housing design towards achieving zero energy consumption for space heating.

1.1 Selection of case studies

Stern (2006) noted that the most cost effective way to ensure good energy performance of a building is implementing various strategies at its design phase [24]. The German [26] and UK [23] Passivhaus Design Concepts which emphasize reducing energy demand for a home has led to the selection of two case studies: the Hockerton Housing Project (HHP) in Southwell and BedZED in Sutton. HHP is designed with the aims to eliminate the need for space heating and as to be as autonomous as possible in terms of provision of utilities, including water. The BedZED housing project is designed with the aim to eliminate the conventional central heating system. Since the 1st May 2008 The Code for Sustainable Homes [6, 7] has become a mandatory standard for all new homes built in the UK. The Lighthouse project in Watford which has been independently assessed at the post construction stage, has achieved a rating of 6 out of 6 stars according to the criteria used in the Code for Sustainable Homes and is therefore selected as the third case study. (see *Table 1*).

Table 1: Background of Three Case Studies

	Hockerton Housing Project , Southwell [10]	BedZED, Sutton, Surrey [1]	Lighthouse, Watford [18]
Completed	1998	2002	2007
Latitude	53°05' N	51°23' N	51°42' N
Designer	Prof Brenda and Dr. Robert Vale	Bill Dunster (Architect), Glyn Carter (BioRegional Development Group) and Arup (Engineer)	Sheppard Robson (Architect), Kingspan Off-Site and Arup (Engineer)
Site Area	2.43 ha (homes + facilities) and 4.05 ha small holding (food & animals)	1.7 ha	N/A
Developer	Self-build Co-operative	The Peabody Trust	Kingspan Off-Site
Description	5 homes of self-suffience housing development in food, water and energy	Compact mixed-use urban development - 82 homes (all with balcony and private garden), 271 habitable rooms and over 2500m² of space for offices, studios, shops and community facilities.	1 out of 6 houses developed at BRE to test on the innovative design, MMC, Technologies and Smart Building System
House Type	1-storey 3 bedroom houses	2 & 3-storey, 1- & 2- bedrooms flats and 1, 2, 3, 4 bedroom houses	2 1/2-storey 2/3 bedroom houses

1.2 PassivHaus Design Concept and the Code for Sustainable Homes

The key underlying principles of the PassivHaus design concept are simply to reduce the energy demand and meet the remaining energy requirements as efficiently and cleanly as possible [24]. For Europe (40 to 60 N°), a dwelling is considered as passive if the energy used for its space heating and cooling is less than 15 kWh/m^{2}y of treated floor area while the total primary energy use for all appliances, domestic hot water and space heating and cooling is less than 120 kWh/m^{2}y. The Code for Sustainable Homes aims to rate the sustainability of the 'whole home' as a complete package. The Code measures the sustainability of a home against nine design categories: Energy and CO2 emission; Water; Materials; Surface Water Run-off; Waste; Pollution; Health and Wellbeing; Management; and Ecology. The Mandatory minimum performance standards are set for four issues that are identified to impact on the environment. These issues include environmental impacts of materials, management of surface water run-off from development, storage of non recyclable waste and recyclable household waste and construction site waste management. Two other issues with increasing mandatory minimum standards are dwellings emission rate (Level 6 is equal to 'Zero Carbon' home) and indoor water use (Level 5 and 6 is with 80 litres/person/day of potable water consumption). Apart from these minimum requirements the Code is completely flexible allowing developers to be free to choose how many standards they intend to implement to obtain 'credit' under the Code in order to achieve a higher sustainability rating.

Hence, one can argue that a home that achieves Level 6 of the Code for Sustainable Homes doesn't necessarily have a better energy performance than a home which complies with the passivehaus standard. For instance, the Lighthouse has achieved Level 6 of the Code for Sustainable Homes; however the target for its energy consumption for space heating is 19 kWh/m^{2}y. As mentioned earlier, the domestic sector is responsible for about 27 per cent of CO2 emissions on an end user basis where over half of the energy consumption is being used for space heating. Therefore, there is an urgent need to increase the Code mandatory minimum standard for dwellings emission rate.

2. Methodology

2.1 Structure of the Paper

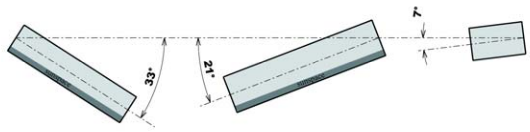
This paper is divided into three parts. The first part compares the three case study projects in terms of their architectural design strategies, layout and orientation, internal space planning, and building fabric. The second part examines their environmental design strategies to improve their performance according to the UK passivhaus design and to the criteria in the Code for Sustainable Homes. This is presented in a comparative table assessing each case study according to the nine criteria spelled under the Code for Sustainable Homes. The final section evaluates the energy consumption (measured data/ designed data) of the three selected case studies. These are presented along the energy demands estimates in a range of domestic building types as determined in the building regulations of 2006 and provide some reference data [8]. The best design strategies for achieving zero energy consumption for space heating are discussed as the result of this comparative analysis.

2.2 Data Collection and Analysis

The design approaches and strategies for the three case studies were collected through literature review and site visits. The HHP's energy consumption and house temperature for the year 2007 were obtained from Hockerton Housing Project Trading Limited [see references 10 to 16]. For the BedZED project, the energy consumption for space heating as well as the results of the questionnaire survey conducted with the local residents, focusing on energy consumption for the year 2007, was obtained from the Bio Regional Development Group [see references 1, 2 and 25]. The details, Code Star Rating Certificate and final certificate for the Lighthouse project were obtained from Lighthouse website and Potton Limited [see references 17 to 22]. However, data for the actual energy consumption of Kingspans Lighthouse was not available due to the fact that so far there is still no occupancy on the Lighthouse scheme, therefore the designed data for energy consumption rather than actual energy consumption for Lighthouse was used in this study. For comparative analysis, the energy consumption data gathered was converted in kWh/m²y.

3. Architectural Design Strategies

The analysis focuses only on the underlying principles such as U-values for the building fabric including walls, roof, floors and windows; as well as orientation, internal planning and ventilation system that may help in reducing energy consumption for space heating.



(a) HHP (b) BedZED (c) Lighthouse

Fig. 1 Diagrams of Orientation

3.1 Layout and orientation (see *Fig. 1*)

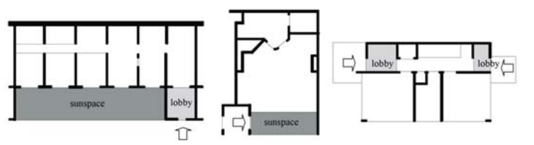
The HHP and BedZED dwelling units are arranged in a terrace in order to optimize the construction costs and minimize heat loss. The whole HHP dwelling block is oriented to face approximately 30° West of South, whereas in BedZED all dwellings are facing 20° East of South. Both schemes are oriented in order to take advantage of passive solar gain as the main source of energy for space heating. Both HHP and BedZED were carefully positioned to prevent overshadowing from plants and adjacent buildings. In HHP, the building block (each house = 6m Depth x 19m Width) is oriented so that maximum sun penetration is allowed in winter and a minimal is allowed in the summer. In BedZED, the extensive use of north roof light ensures a high level of daylight in the spaces. Lighthouse is a free standing building with East-West orientation. Due to its orientation, external shading devices are designed to prevent overheating of the house during the summer months.

3.2 Internal space planning (see *Fig. 2 & 3*)
HHP has a conservatory on the south that acts as a passive solar heat gain collector. The conservatory buffers the front wall and the porch reduces heat loss from the main entry or exit point. All interior rooms take advantage of the conservatory solar heat gain. In summer, the houses are ventilated through a large opening light in each bay. In winter, air is extracted from the bathroom, kitchen & utility, then passes through a heat exchanger to warm incoming fresh air. The conservatory acts also as a drying space in the winter.

BedZED has a typical 3 bedrooms maisonette layout where the kitchen, living and dining are located at the ground floor and bedroom at first floor, 1 bedroom flat located at the second floor. The entrance at the ground floor is through the sunspace, while entrance at the second floor is through the terrace lobby. Unheated doubled glazed sunspaces act as passive solar heat gain collector and form an integral part of each dwelling. In summer the outer windows can be opened to create open air verandas, and internal balcony provides summer shading. Ground floor levels of northern blocks are stepped up by 1200mm reducing over shading of ground floor windows. The draft report on energy statistics (unpublished) for BedZED included the results of a survey carried out in 2007 (71 households took part). The survey revealed that 71 per cent of households with sunspaces do have curtains or blinds up, of which only 2 households cited temperature control as the main reason for using curtains whereas 90 per cent of those using curtains or blinds in the outer sunspace glazing and 73 per cent in the inner cited privacy as their main reason. In view of the privacy problem, the hybrid layout of combining dwellings that are facing south and workspaces that are facing north in order to reduce energy consumption needs further investigation.

For Lighthouse, the bedrooms are placed at the ground floor and the living, dining and kitchen are placed at the upper level in order to reduce energy consumption for artificial lighting. Glazing is 5 to10 per cent less than those in the traditional home in order to reduce heat loss. Strategies to reduce energy consumption for space heating include the introduction of an entrance lobby located at the front and back to reduce heat loss. In addition, the utility room was designed to provide a dedicated drying area as an alternative to the tumble dryer. The ceiling's thermal mass allows the storage of heat during the day and its release back to the spaces during the night.

3.3 Building Fabric
Both HHP and BedZED adopted heavy construction on roofs, walls and floors. High mass concrete acts as a heat store resulting in a very stable temperature throughout the year. In HHP, the building fabric is principally concrete; the roof and slabs are of 300mm reinforced concrete and the back wall of 450mm concrete. The internal walls are at 3.2m intervals and are constructed of 200mm concrete blocks. In addition, the entire structure has an external surround of 300mm of expanded polystyrene. As soil temperature will only drop to 5 to 6 °C at worst, the maximum temperature difference will be around 12 to13 °C. Therefore earth-covering further reduces the heat loss from the building fabric. For BedZED, a 300mm 'overcoat' of super-insulation is used for the roofs, walls and floors. The insulation is placed outside the building structure to avoid thermal bridging. High thermal performance and air-tightness in Lighthouse is achieved by adopting TEK building system.

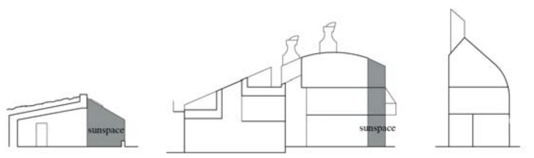


(a) HHP
- sunspace
- lobby (porch

(b) BedZED
- sunspace

(c) Lighthouse
- entry lobby

Fig. 2 Diagrams of Ground Floor Plans



(a) HHP
- sunspace

(b) BedZED
- sunspace

(c) Lighthouse
- entry lobby

Fig. 3 Diagrams of Cross Sections

4. Environmental Design Strategies
As mentioned earlier, the Code for Sustainable Homes aims to rate the sustainability of the 'whole home' as a complete package as opposed to passivhaus design concept that aims to reduce energy demand and meet the remaining energy requirement as efficiently and cleanly as possible. Therefore the nine categories as spelled in the Code were used to compare the three case studies as well as the passivhaus design concept.

Table 2 clearly demonstrates that if one is to measure the whole home as a complete package, there are many reasons why the UK passivhaus standard can be adopted in the future to improve the total environmental performance of a building. Although HHP does not fulfil all the UK passivhaus standards (window U-value higher than that of UK passivhaus standard), its total energy use over period of 1998 to 2002 is only one third (37 kWh/m²y) of the target outlined in the German Passivhaus Standard (max. of 120 kWh/m²y). This suggests that the architectural and environmental design strategies are equally important factors that ensure the success of achieving low energy demand for a home.

Table 2: Passivhaus Design and 3 Case Studies

Code for Sustainable Homes			UK PassivHaus [23]	Case Studies in the UK: HHP [10-14]	BedZED [1]	Lighthouse [20]
1	Energy	Wall, U-value	< 0.15 W/m²K	0.11 W/m²K	0.10 W/m²K	0.11 W/m²K
		Roof, U-value	< 0.15 W/m²K	0.11 W/m²K	0.11 W/m²K	0.11 W/m²K
		Floor, U-value	< 0.15 W/m²K	0.11 W/m²K	0.10 W/m²K	0.11 W/m²K
		Window, U-value	< 0.80 W/m²K with solar heat gain coefficients around 50%	1.10 W/m²K (wood frame, triple-glazed, gas filled). Conservatory: doubled-glazed	1.20 W/m2K (wood frame, triple-glazed, gas filled). Conservatory: doubled-glazed	0.70 W/m2K (wood frame, triple-glazed, gas filled)
		Air permeability	< 1 m³/ h/m² @ 50 Pa	0.95-1.23 m³/h/m² (excl conservatory) at 50 Pa	2-3 m3/h/m2 at 50 Pa	1m3/h/m2 at 50 Pa
		Thermal bridging	N/A	N/A	N/A	4.5% of surface area
		Ventilation	Preheat fresh air above 5°C with > 80% heat recovery	70% heat recovery	70% heat recovery	90% heat recovery
		Fan power	N/A	N/A	N/A	0.92 W/ l/s
		Lighting	N/A	Low energy light	Low energy light	Low energy light
		Drying room	N/A	Yes, with fittings	No	Yes, with fittings
		Energy labelled	Low energy appliances	Low energy appliances	Low energy appliances	A++ white goods
		External Lights	N/A	No	No	On PAR sensors
		Storage	N/A	Covered bicycle	Covered bicycle	Cycle storage
		Other Facilities	N/A	Resource centre	Commercial & Other	Home office
	On-site renewable energy	Electricity	N/A	6 kW & 5 kW Wind turbines plus	Bio-fuel Combined Heat & Power (CHP)	Photovoltaics 4.7kW
		Hot water	N/A	Air to water heat pump + immersion	Community heating system - CHP	Solar hot water (4m2)(summer), Wood
		Space heating	Passive solar	Passive solar	Passive solar + CHP	Wood pellet boiler
		Ventilation	N/A	Mechnical heat exchangers (heat recovery)	Passive ventialtion system activated by the 'windcatcher' (heat recovery)	Passive ventialtion system activated by the 'windcatcher' (heat recovery)
		Elec for car	N/A	No	109 kW PV to charge 40 electric cars	No
2	Water	Shower	N/A	Water saving appliances	No power shower	Low water, 8 litres/ min and taps
		WC	N/A	Water saving WC	Dual flush, 5/ 3 litres	Dual flush, 4/ 2 litres
		Bath	N/A	Used minimally	Lower-volume sculpted bath	160 litre
		Goods	N/A	Energy-efficient appliances	Energy-efficient appliances	Water labelled A++ washing white goods
		Greywater recycling	N/A	Drinking water - filtered rain water recycling	Foul water (green water)	WC flushing
		Rainwater harvesting	N/A	Washing/ others	Flushing toielts & irrigation	Washing machine & irrigation
3	Materials	Wall	N/A	Concrete/ brick	Concrete/ brick	TEK Building System
		Roof	N/A	Concrete/ brick	Concrete/ brick	TEK Building System
		Cladding	N/A	Earth	Timber/ brick	Timber/ brick
		Paved surface	N/A	Loose agregate stone + chips	Porous block paving over gravel	Recycled/ sustainable sources
4	Surface water run-off	Water management	N/A	Lake/ water catchment	Ditch catchment	Bio-filtration - swales catchment
5	Waste	Construction	N/A	N/A	Recycled/ reclaimed materials, product with low embodies energy	Recycled/ reclaimed materials, product with low embodies energy
		Household	N/A	Compost bins & Reed-bed system	N/A	Bin compactment
6	Polution	GWP of insulants	N/A	N/A	Foul water - on site sewage treatment	Composting
7	Health and wellbeing	Daylight	N/A	N/A	N/A	N/A
		Sound Insulation	N/A	N/A	N/A	1.5% - 2% daylight
		Private space	N/A	Conservatory	Sunspace/ Terrace	Balcony
		Life-time home	N/A	Yes, 1 level	N/A	N/A
8	Manage-ment	Guide	N/A	Self-built (self	User guide	Home user guide
		Construction Impact	N/A	Min. visible	Brownfield	N/A
		Security	N/A	N/A	N/A	N/A
9	Ecology	Biodiversity	N/A	Wild life pond, lake, duck pond, vege growing area	A ditch designed as a water feature to attract wildlife	Native planting and creation of surface water
General Remarks			Total energy demand for space heating and cooling = < 15 kWh/m²y	Total energy demand for space heating and Domestic Water is 12 kWh/m²y	Total energy demand for space heating and Domestic Water is 48 kWh/m²y	Total energy demand for space heating is 19 kWh/m²/yr and Domestic Water is 29 kWh/m²y

Note: N/A - Not Available

5. Energy Consumptions: 3 Case Studies

Having reviewed the architectural and environmental design strategies, this part of the paper investigates the energy consumptions (targeted/ measured) of three case studies (see table 3). Energy demands in range of domestic buildings that comply with building regulation 2006 are also presented in the same table as reference data. Table 3 clearly shows that HHP has achieved the lowest total energy consumption (37 kWh/m^{2}y) as well as the lowest space heating cum domestic hot *w*ater consumption (12 kWh/m^{2}y) as compared with BedZED and Lighthouse. It uses less than 25 per cent of the total energy consumption as opposed to other domestic buildings which comply with the building regulation 2006.

In term of thermal performance, HHP's record shows that with passive solar heating, the average annual internal room temperature in the year 2007 was 22.2ºC. Additional space heating device is used occasionally (total of 5 hour per annum) during the month of December and January (*see table 4*). On the other hand, BedZED space heating is achieved mainly by solar gain and incidental gains resulting from occupation. Additional space heating is gained by having small finned tube radiators with water taken from the hot water tank in each unit. BedZED's survey on thermal performance was carried out in year 2007. The thermal performance of internal room is only rated by the occupant in the scale of 1 (too cold) to 7 (too hot). The survey revealed that there is problem of thermal comfort within the house during summer months (see table 5). This resulted from the excess heat from the hot water cylinder plus the radiator which are not locally controlled. Besides, it is possible that households do not use the windows and sunspace to cool the house as originally intended in the design. The results of the survey reveal the importance of the design of heating services in reducing the total energy consumption for heating by avoiding wastage in energy consumption for space heating during summer months.

Table 3: Energy Consumption

	Area	Energy Consumption, kWh/ m2y: Electricity				Heat		
	m²	Lighting	Other Appliances	Fan & Pump	Cooking/ catering	Domestic Hot Water	Space heating	Total
Energy Demand for Three selected Case Studies								
HHP* [10]	108.0	10		2	13	12		37
BedZED** [2]	75.0		34			48		82
Lighthouse ***[19]	93.0	4	20	6	9	29	19	87
Energy Demand in range of Domestic Buildings Compliant with Building Regulations 2006**** [8]								
Top floor flat	60.9	36		0	19	46	37	138
Mid Terrace	78.8	35		0	16	41	28	120
End Terrace	78.8	35		0	16	41	37	129
Semi-detached	88.8	34		0	15	38	39	126
Detached	104.0	35		0	13	36	43	127

Notes:

* Average total energy consumption per dwelling over period of 1998 to 2002

** The data for electricity consumption was based on average figures from 56 BedZED dwellings. This electricity consumption includes all delivered electricity such as electricity use for appliances, lighting and occasional electric heating. The data for heat consumption for space heating and hot water was based on average figures from 64 BedZED dwellings.

*** Design data for energy consumption

**** With assumption of no secondary heating is provided and that all of the space heating and hot water requirement is met by, where main heating system is with 86 per cent efficient, and the energy requirement figures provided do not include production, delivery and appliance conversion losses.

Table 4: HHP Thermal Performance, 2007

Month	Jan	Feb	Mac	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Temperature*, °C	19.4	20.5	21.6	21.5**	22.1	22.3	24.0	24.0	24.0	23.8	23.0	19.9***

Note:

* Temperature taken from 'house 2' in lounge at approximately 8:00 am (the coldest it get)
- normally warmest in everning with up to an additional 0.5 °C

** Limited data

*** Included 28 kWh space heating = approximately £3

Table 5: BedZED Thermal Performance, 2007

Scale	1 (too cold)	2	3	4 (just right)	5	6	7 (too hot)
Winter Months, %			20	44	20		
Summer Months, %				10		56	

Notes:
- 71 households (86.6 per cent of total households) taking part
- 30 per cent respondents do use electrical fan in average 1 to 2 months
- 42 per cent respondents do use electrical heater in average 1 to 2 months

As mentioned earlier, there are still no occupants in the Lighthouse project, therefore the energy consumption (table 3) is based on designed value and not actual measurements. Although Lighthouse achieved the Code for Sustainable Homes Level 6, its target for energy consumption for domestic hot water and space heating is at 29 kWh/m²y and 19 kWh/m²y respectively. The double volume space in the living area may result in more energy use for space heating as compared with HHP. It is likely to reckon that because of its architectural design that does not make use of passive solar gain more energy is required for space heating. Further research on improving its architectural design, such as incorporating passive solar gain, may help in reducing energy consumption for space heating.

Both Lighthouse and BedZED achieved a total primary energy consumption of 87 kWh/m²y and 82 kWh/m²y, which is below of 120 kWh/m²y (German PassivHaus criteria). However, energy consumption for space heating is targeted as 19 kWh/m²y in Lighthouse which is far higher than passivhaus standard (less than 15 kWh/m²y). In addition, this study highlights that by achieving the Code for Sustainable Homes Level 6 does not necessarily mean that the building is energy efficient. Further improvement particularly on its targets for energy use for space heating is vital.

Both HHP and BedZED have sunspace or conservatory facing south, with units arranged in a terrace to reduce heat loss with similar U-values for their building fabric and heat recovery ventilation system. Design principles that may result in a better thermal performance in HHP as opposed to BedZED are the enclosed entrance lobby or porch and the lower air permeability. In Lighthouse, an entrance lobby at the front and back is introduced to reduce heat loss at exit point, however the lobby orientation does not allow for passive solar gain and this is likely to be the reason why the targeted energy consumption is higher than that of HHP.

6. Guidelines and Best Design Strategies

As the result of this study, the following section put forward a number of guidelines and best design strategies for achieving zero energy consumption for space heating. Firstly, it is important to minimise heat loss through building envelope, hence dwellings should be designed with compact layout and grouped together to reduce its exposed surfaces, for instance the terrace form in HHP and BedZED schemes. Secondly, it is important to design entrances with enclosed lobbies (at front and/ or rear) to reduce potential heat loss at exit points. The enclosed entrance lobby concept is adopted in HHP and Lighthouse schemes. Thirdly, a high thermal performance and super insulation for the building fabric are vital. All three case studies have U-values of 0.11 W/m²K or less for their walls, roofs and floors and U-value of 1.20 W/m²K or less for their windows (wood frame, triple glazed, gas filled). For the sunspaces, double glazing is used. It is likely that one of the reasons' for the BedZED's lower energy performance compared to that of HHP is its higher air permeability. Hence, it is crucial to ensure that air permeability of the building envelope is with 1 m³/h/m² at 50 Pa less. Additionally, to further reduce heat loss, a mechanical ventilation system with at least a 70 per cent heat recovery system is needed.

Furthermore, to achieve good passive solar gain for space heating, the dwelling depth and orientation of the building / building block with the appropriate use of sunspace is crucial. The whole HHP dwelling block is oriented to face approximately 30° West of South, whereas in BedZED all dwellings are facing 20° East of South. Hence, the orientation of $\pm$30° east or west of south should be suitable. However, care should be taken when deciding about dwelling depth to ensure good winter sun penetration and summer sun protection. For instance, the internal room depth of HHP's is only 6m as compared with its south facing frontage of 19m. In addition, operable panels and shading devices are to be incorporated in the sunspaces to prevent over heating during summer months. Operable windows or ducting should also allow heat from the sunspace to be extracted and diverted from the internal spaces. Dwellings should also be carefully positioned to prevent overshadowing from plants and adjacent buildings. Sunspace can also be utilized as buffer zones to provide reduced temperature gradient between the inside and outside of homes. For example, HHP's sunspace provides a buffer zone to the front wall and the porch to reduce heat loss from main entry or exit point. Another advantage of the sunspace in winter is that it can be used as a laundry drying space during winter time, thus reduce energy use. In the in HHP dwelling, the use of high thermal mass materials allows the walls, floors and ceilings to act as a heat store and this has proven to be very successful in providing stable internal room temperature throughout the year. High mass materials can also prevent potential overheating caused by solar gain during summer months. Although the results of the BedZED thermal performance survey were not satisfactory particularly for summer months' period, it is reckoned that the problems may be caused by the design of its services and human factor.

For 400mm thick of soil, the temperature will only drop to 5-6ºC at worst; the maximum temperature difference will be around 12 to 13ºC. Therefore, the use of a garden terrace as buffer zone to provide reduced temperature gradient between the inside and outside of homes like in BedZED and HHP schemes is a pragmatic approach. The idea of space above ceiling as a heat store, where hot air captured during day time is released back into the space below during night time, may be adopted once this is proven to be effective. However, the success of this concept is yet to be tested in the Lighthouse project. Last but not least, it is important to ensure the provision of standby alternative heating devices for the occupants for contingency uses during severely cold winter weather conditions.

7. Future Research

The energy consumption for Lighthouse presented in this paper is based on designed values, thus detailed evaluation of the actual energy consumption is recommended in the future when the building is occupied and the data is available for analysis. Future research on methods for reducing energy consumption for water heating is recommended. The hot water system used in the HHP may act as one of the case studies in the study.

8. Conclusion

The architectural and environmental design strategies adopted in the three case studies have successfully contributed to achieving low energy consumption target. Although HHP was a self-build small scale housing development, with a clear aim to eliminate the need for space heating and to be as autonomous as possible, its energy performance is better than both the Lighthouse and the BedZED projects with a total energy consumption of 37 kWh/m²y or 12 kWh/m²y for domestic hot water and space heating. In order to operate a truly low energy home, the commitment of the occupiers is of a paramount importance. They need to be well-informed of how the systems work for their home, making optimum use of appliances and systems that reduce energy consumption and generate renewable and alternative forms of energy. In this respect, HHP is a very successful model.

A home that achieves Level 6 of the Code for Sustainable Homes doesn't necessarily achieve zero space heating standard or even UK Passivhaus Standard. Although, the Code rates the sustainability of the 'whole home' as a complete package, it does not lead to achieving the UK's domestic goal to reduce CO2 emissions. The best design strategies to achieve zero energy for space heating have been discussed in this paper. It is highly recommended to have mandatory standards in the Code for zero energy for space heating in dwellings to combat the challenge of UK's domestic goal to reduce CO2 emissions.

9. Acknowledgements

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10. References

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