Department of Mechanical Engineering

Comparison between PHPP and SAP

& Elaboration of monitored data for two dwellings with different insulation levels

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ABSTRACT

Within this thesis framework of investigating the gap between PHPP and SAP results in terms of energy use and the appropriateness of using SAP for an ultra low-energy dwelling, a set of objectives has been set. Factors which are considered to make this gap wider, such as internal heat gains, effective air change rate, internal temperature, detailed input and climate, have been investigated with regard to their impact on energy requirement especially for space heating. The main question that is attempted to be answered is not only if SAP predicted performance is closer to reality, but also why actual performance fails to meet expected consumption as resulted from SAP and PHPP.

In order to answer these questions, we consider two houses –a Passive House and a Code level 4 dwelling– as our case study and we attempt to investigate calculations or assumptions that differentiate PHPP and SAP through their own results. More specifically, having focused our attention on space heating, hot water and CO_2 emissions, we explore the impact of internal heat gains, internal temperature, effective air change rate, detailed orientation and climate in PHPP. Subsequently, we compare the predicted results from the two methodologies to energy bills. Additionally, a second comparison has been realised; this time between energy bill and monitored data.

Finally, having demonstrated the influence of the for-mentioned factors which differentiate one methodology to the other, we conclude that two main reasons for the mismatch between real and predicted performance are technical faults, which make input data in these methodologies diverge, and human factors that affect assumptions made in PHPP and SAP; from non-standard occupancy to occupants personal preference for indoor conditions. Ultimately, we find out that although both methodologies underestimate energy use compared to actual energy consumption, PHPP is closer to reality. As far as the appropriateness of SAP for Passive Houses is concerned, this thesis concludes that a more detailed methodology than SAP is required for such houses assessment, especially if Passive House standard is to be introduced as a new standard for EU countries.

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INTRODUCTION

Nowadays, there is a remarkably growing concern on sustainable building as well as on energy efficiency of buildings. Apart from integrated renewable technologies, the focus has been extended to energy efficiency and carbon dioxide (CO_2) emissions not only in a national level but also internationally. In fact, in developed countries such as European Union and in USA buildings energy consumption accounts for 20–40% of total energy use (Perez-Lombard, Ortiz, & Pout, 2008). Building sector could contribute significantly in the attempt to cut down carbon dioxide emissions globally or to meet CO_2 reduction targets in national level.

UK government approach for assessing energy efficiency in terms of both CO_2 emissions and fuel costs is Standard Assessment Procedure (SAP). More recently, Code for Sustainable Homes (‘CSH’) has been introduced as the national standard for assessing new homes from a more general environmental aspect in order to better promote and achieve “Zero Carbon Home” and sustainable building in general. It has a six-star rating scheme and nine categories of interest, one of which is Energy and CO_2 emissions. It is in this area where CSH makes use of SAP outputs (Department for Communities and Local Government, 2010). Within the scope of this thesis, we will focus only on energy use and CO_2 emissions and therefore only on SAP calculations and not on CSH as a whole.

Additionally, a standard originated from Germany and recently promoted in UK as well, the ‘Passive House’ standard, promotes buildings with extremely low energy demand. One could argue that its standards could be considered as criteria for energy efficiency. However, they follow considerably different paths in calculating energy consumption. Although it has its roots in Germany, this standard has been supported by EU through CEPHEUS (abbreviation for Cost Efficient Passive Houses as EUropean Standards) project which tested 14 building units (more than 200 houses) in Germany, Sweden, Austria, Switzerland and France (Feist, Peper, & Görg, CEPHEUS - Final technical Report, 2001). However, the fact that there was not any UK dwelling tested makes the investigation of a Passive House in UK interesting.

Moreover, taking into consideration EU intention for promoting Passive House as a standard for all EU countries from 2015 (Reason & Clarke, 2008) it becomes apparent that there may be a need to incorporate PHPP into SAP or vice-versa.

Therefore, in that sense it is critical not only to have a deep understanding of their differences and principles but also which one tends to calculate energy use closer to reality especially for ultra low-energy dwelling, such as Passive Houses.

LITERATURE SURVEY

A literature survey has always been essential in order to comprehend what has been done, investigated in this field and is the first step on which one stands to go one step further. With regard to the two methodologies investigated in this thesis (PHPP and SAP), there have been made several comparisons in different levels.

The main point highlighted in comparisons reviewed has been the different internal gains PHPP and SAP consider which result in higher space heating demand (Tuohy & Langdon, Benchmarking Scottish standards: Passive House and CarbonLite Standards: A comparison of space heating energy demand using SAP, SBEM, and PHPP methodologies, 2009). Others have attempted an investigation of certain assumptions these methodologies make, such as internal gains, ventilation, frame factor having as start-point the roots of each methodology. The conclusion has been that SAP may not always be appropriate for ultra-low energy dwellings such as Passive Houses (Reason & Clarke, 2008). In addition, studies have also been carried out concerning MVHR and natural ventilation in a Passive House, which concluded that MVHR helps minimising CO_2 emissions for space heating (AECB, 2009) as long as it is properly installed, has a good electrical efficiency and infiltration levels are low. Moreover, older studies have reached the conclusion that half of the BREDEM –the ancestor of SAP– prediction uncertainty could be due to physical factors and the rest to occupant behaviour (Dickson, Dunster, Lafferty, & Shorrock, 1996).
Considering these as a start point and having as guideline the manual for PHPP and SAP2005 documentation, this thesis will try to cover a few more points missing in this large-scale comparison which are considered to be of great importance and make the two methodologies so different in some cases.

Moreover, it is of great importance to mention certain outputs from CEPHEUS project which was mentioned earlier. Comparing PHPP calculation results for space heating to measured -normalised- space heat consumption, it has been shown that in some cases they are approximately the same, while for other cases they diverge. Some reasons for the latter are the fact that people may not be familiar with building service sytems or the “habituation phase of occupants" (Feist, Peper, & Görg, CEPHEUS - Final technical Report, 2001) (Schnieders, 2003). Despite the fact that these reasons occur basically during the first heating season, they could be influencing factors in general.

Furthermore, as far as CO_2 emissions are concerned, Zero Carbon Hub scheme for new dwellings after 2016 proposes 10 and 11 kg CO_2/m^2 per year for detached and semi-detached or terraced houses respectively (Zero Carbon Hub, 2010). Taking into account this suggestion, it would be interesting to compare SAP and PHPP results. At this point, it should be underlined, as well, that Carbon Compliance suggests target levels for carbon emissions based on fabric performance and on "performance of low/zero carbon heat and power technologies on or in the dwelling" (Zero Carbon Hub, 2010).

OBJECTIVES

The main scope of this thesis is to investigate the appropriateness of SAP for ultra-low energy dwellings such as Passive Houses. In addition to the Passive House, a Code Level 4 dwelling is investigated as well.

Within this framework, the first objective is to explore factors that have a major impact in the PHPP and SAP results which in some cases are significantly different in terms of energy use and CO_2 emissions. Prior to this, a study of the main dissimilarities in their calculations is essential.

However, a comparison only between the two methodologies would be of no use if there is no connection to the real world. Hence, with regard to energy consumption, a question that needs to be answered is whether PHPP or SAP predicts energy use closer to reality.

Additionally, it would be attempted to answer why actual energy use fails to meet the expected consumption from different standards such as Passive House standards and SAP. In fact, making use of monitored data for these dwellings gives us a better insight of issues than may affect electricity consumption in the end.

METHODOLOGY

First of all, it is essential to present the methodology followed in this thesis in order to achieve the objectives mentioned.

Firstly, after applying the methodologies of Passive House Planning Package and Standard Assessment Method to two different dwellings -to a Passive House and to a Code Level 4 dwelling- a direct comparison between the results of the methodologies for each house is performed. It should be underlined that the intention is not compare the two dwellings themselves but to compare the two methodologies.

Subsequently, we compare that predicted performance to actual energy consumption data as given in energy bill to find out how well these methodologies respond to reality.

In addition, having completed an elaboration of monitored data of these houses, a comparison between monitored data and bill is attempted as well. However, as it will be shown later, this comparison has to be indirect due to the fact that monitoring period is not the same as the billing period.

Additionally, it should be underlined that the elaboration of monitored data contributes and plays a significant role in a comparison between the predicted results and monitored consumption. In fact, it helps us investigate why reality fails to meet predicted performance.

BASIC PRINCIPLES OF THE TWO ASSESMENT METHODS

As mentioned in the introduction, two assessment methods have been used: Government's Standard Assessment Procedure for Energy Rating of Dwellings ('SAP 2005') and Passive House Planning Package 2007 ('PHPP2007'). The following sections of these chapter attempt to highlight the basic only principles of the two methods through their standards and a first approach of direct comparison between their calculation procedures.

PASSIVE HOUSE PLANNING PACKAGE 2007

The Passive House Planning Package is the official design tool for 'Passivhaus' standards of the independent organization 'Passive House Institute' founded by Dr Wolfgang Feist in Germany and the ideology has been expanding around the world and especially in EU as mentioned in the Introduction.

Generally, it should be mentioned that the Passive House approach is to have a building with little heating requirement so that space heating demand can be met by ventilation system, avoiding the use of a common heating system. In fact, the absence of the latter and its fuel is supposed to make a Passive House more economic (Tuohy & Langdon, Benchmarking Scottish standards: Passive House and CarbonLite Standards: A comparison of space heating energy demand using SAP, SBEM, and PHPP methodologies, 2009). The concept is to lower down energy demand before trying to implement integrated renewable technologies, like prevention before cure.

The basic principles of the 'passivhaus' standards is the high significance of the construction and the air-tightness with ultimate goal the minimisation of energy requirement, comfortable indoor conditions and the excellent energy performance. It should be underlined that the pre mentioned principles are only a part of the set of objectives that consists the ideology of the standards. Below, Table 1 shows the construction standards –targets– that a dwelling must satisfy in order to be certified as 'Passive House'.

Table 1: Passive house criteria and standards

	Criterion
U-value (heat transfer coefficient) of opaque constrictions	$U_{opaque} \leq 0.15$ W/m^{2}K
U-value (heat transfer coefficient) of windows only	$U_{windows} \leq 0.8$ W/m^{2}K
U-value (heat transfer coefficient) of windows after installation	$U_{windows,install} \leq 0.85$ W/m^{2}K
Air permeability	***$n_{50} \leq 0.6$ ac/h***
Specific Heating Demand and Specific Heating Load	***$Q_{heat} \leq 15$ kWh/m^2 per year or $P_{heat} \leq 10$ W/m^2 per year***
Specific Cooling Demand	***$Q_{cooling} \leq 15$ kWh/m^2 per year***
Specific Primary Energy Demand	***$Q_{primary} \leq 120$ kWh/m^2 per year***
MVHR	Ventilation efficiency≥75% and acoustics of plants ≤ 25dB
Frequency of overheating (temperature>25^{o}C)	≤10%

The Passive House Planning Package 2007 (we will refer to it as ‘PHPP’) consists of 30 spreadsheets where one should put all the necessary data so that the calculations could be performed. Among the inputs are the treated floor area, the orientation and type of windows (both glazing and frames), detailed construction of the walls, the floor and the roof with the thermal conductivity and the thickness of each material, rather detailed data for the ventilation system including length and insulation of the ductwork, the heat distribution and Domestic Hot Water system, as well as data for boilers and electricity. It needs to be underlined that PHPP requires detailed inputs for every aspect.

STANDARD ASSESSMENT PROCEDURE FOR ENERGY RATING OF DWELLINGS

This method which is more well-known since it has been adopted by UK government to assess dwellings energy performance (BRE, 2009) and complies with the European Directive on the Energy Performance of Buildings (Reason & Clarke, 2008) (Ogle). Standard Assessment Procedure (the term 'SAP' will be used henceforth), now part of Part L of the Building Regulations and Code for Sustainable Homes, relies on energy costs and savings of a house and CO_2 emissions in order to determine its efficiency. It takes into account aspects such as space heating and domestic hot water (DHW) demand and lighting.

As mentioned in the Introduction, this thesis scope, which concerns only energy use and carbon dioxide emissions, indicates that only SAP calculations are required; not a complete assessment according to CSH. In our case, we have used SAP 2005 edition, revision 3, and especially for the dwelling for which we have only rough plans and data for the construction Reduced SAP ('RdSAP'); on the other hand, for the house for which we have considerable amount of details SAP 2005 has been used.

DIFFERENCES BETWEEN THE TWO METHODS

As it will be illustrated in following chapters, there are considerable differences between the two methods (SAP/RdSAP and PHPP) resulting in different results. At this point, these differences need to be introduced and explained to a certain extent, whereas in following chapters the results of these methods will be presented in terms of figures and will be further investigated.

A first difference one would easily observe is the lack of local climate data input in SAP, while in PHPP not only there are four different regions for Great Britain but also one could input more localized data for a region, as long as the required elements in 'Climate Data' spreadsheet are filled. In fact, SAP uses Sheffield (East Pennines) climate for its assessment. More specifically, space heating demand in PHPP is based on heating degree hours per year or per month –annual and monthly method respectively– for each region, while SAP2005 uses annual method (Reason & Clarke, 2008).

Secondly, although both of them include internal gains from lighting and appliances, SAP considers remarkably higher gains. The default internal heat gains for PHPP are 2.1W/m^2, whereas according to the results for the for-mentioned dwellings using SAP, internal gains were 5.9 W/m^2. This dissimilarity derives from the assumption of less energy frugal, less energy efficient appliances in SAP (AECB, 2009) and loss of gains for evaporation (Reason & Clarke, 2008).

Furthermore, it should be underlined that in PHPP the required data for windows (including for glazing and framing) and shading are considerably more detailed. As far as the orientation of the windows is concerned, it needs to be mentioned, that in PHPP it is determined in degrees. Additionally, in PHPP it is required to fill details for the ground, the pipes and the distribution system.

Moreover, in SAP cooling does not include anything for space cooling. However, taking into account that it is only addressed for UK dwellings it is reasonable.

Another difference is that PHPP uses external dimensions whereas SAP assumes internal ones. However, for the Reduced SAP (‘RdSAP’) for existing dwellings, we can use external dimensions as well (Appendix S: Reduced Data SAP for existing dwellings, 2009).

It should be added, as well, that another element that differentiate SAP from PHPP method is the interior temperature. In PHPP, the default internal temperature to be maintained is 20^{o}C. In SAP the internal temperature is calculated and based on heating requirements, the heating system and living area of the dwelling. In fact, PHPP assumes that whole dwelling will have the same temperature while SAP assumes living area temperature will be higher from rest of the house (Reason & Clarke, 2008).

Additionally, as it will be presented later, treated floor area (‘TFA’) is not calculated in the exact same way. PHPP, based on German Floor Area Ordinance, does not account stairs with more than three steps or the 40% of basements and secondary rooms which are not determined as living space (Feist, Pfluger, Kaufmann, Schnieders, & Kah, 2007). SAP on the contrary does include stairs.

Finally, the two methodologies diverge with regard to CO_2 emissions calculation despite the fact that they both rely on the fuel used for the production of the energy. In PHPP, the data for the CO_2 emissions come from the DIN V 4701-10 and the software GEMIS 4.14 (Feist, Pfluger, Kaufmann, Schnieders, & Kah, 2007). More specifically the delivered energy is multiplied with a Primary Energy factor according to the energy carrier –for example electricity– and then, the product, which is the primary energy, is multiplied with a CO_2 emissions equivalent; in case of electricity, primary energy factor is 2.6 and CO_2 emissions equivalent are 0.68 kg/kWh. The difference is that in SAP these primary energy factors and

CO_2 emissions equivalent are different. In SAP 2005 it is 2.8 and 0.422kg/kWh for electricity respectively.

Summarising, essential points on which SAP and PHPP have different approaches as described above are the following:

- Climate data
- Internal heat gains
- Window details
- Shading
- Ground details
- Distribution system
- External/internal dimensions
- Internal temperature
- Treated floor area
- CO_2 emissions calculation

PHPP & SAP APPLIED FOR THE TWO DWELLINGS

For the purpose of this part of the thesis, both SAP and PHPP method has been applied for the two houses. It is worth noting that details for their construction, such as plans or geometry, need to be kept confidential; hence, only the results and the summary will be displayed here. PHPP and SAP excel sheets with some of the information that can be presented can be found in appendices at the end.

First of all, we will present each dwelling and, subsequently, the results of each methodology. The first house is a certified Passive House while the second is a Code level 4 dwelling. It should be mentioned that for the Passive House we have been provided with all the details, while for the Code 4 House we only have rough information about the construction.

Figure 1: Image taken from Google maps (©2011 GeoEye)

Figure 2: Photograph of the neighbourhood (Image by Gavin Murphy)

THE PASSIVE HOUSE

Before attempting to present the results of the methods, it is essential to introduce the dwellings and their specifications. As far as the Passive House is concerned, it is a semi-detached dwelling in Dunoon, Scotland, timber construction with two storeys; the U-values are shown in Table 2. It is has a MVHR unit, solar thermal panels of $4.6m^2$, a 200l TFF 200 Tank for hot water and an air source heat pump for space heating. The windows are tripled glazed filled with argon and it has three skylights as well; two facing south and one facing north. Additionally, regarding the electricity tariff, it is on Domestic Standard.

Figure 3: Passive House – SouthWest facades (Image by Gavin Murphy)

Table 2: U-values for Passive House examined

U-value of walls	0.094 W/m^2K
U-value of roof	0.094 W/m^2K
U-value of floor	0.154 W/m^2K
U-value of glazing	0.80 W/m^2K

PHPP FOR THE PASSIVE HOUSE

The PHPP method for the Passive House has been based on specifications provided by the architect and it is in accordance with the figures in the summary presented in the database for the built Passive House of the Passive House Institute (Built Passive Houses; Scottish Passive House Centre (SPHC)).

Having input all the necessary data in PHPP, we verified that the house can be certified as it fulfils the heating load, the air permeability and the specific primary energy demand criteria. A summary for the PHPP results is given in the following table (Table 3). It has to be mentioned that it has been used the Design mode and monthly method as well as that the effective air change rate ambient is 0.078 ac/h.

Table 3: Summary PHPP results for the Passive House

PASSIVE HOUSE - PHPP		
Internal Temperature	20 ^{o}C	
Treated Floor Area	88.5 m^2	
Internal gains	2.1 W/m^2	
Space Heating Demand	20.9 kWh/m^2 per year	1849.7 kWh per year
Space Heating delivered energy	9.6 kWh/m^2 per year	849.6 kWh per year
Domestic Hot Water (delivered)	11.10 kWh/m^2 per year	982.35 kWh per year
Auxiliary	2.5 kWh/m^2 per year	221.5 kWh per year
Household Appliances (incl. lights)	13.50 kWh/m^2 per year	1194.75 kWh per year

As already mentioned, PHPP for this particular house showed that it fulfils the criteria in order to be a certified Passive House. It should be underlined that although it does not meet the target for 15kWh/m^2 per year for space heating demand, it does meet the criterion for the heating load of 10W/m^2 (see Table 1).

SAP for the Passive House

In addition to PHPP, SAP calculations –in an excel format– have been carried out for this dwelling, as well, using the detailed specifications we already had. It should be noted that in this case thermal bridges were considered to be zero and the effective air change rate was calculated 0.065ac/h according to SAP, as shown in Appendix D of this thesis.

Apart from the results shown in Table 4, we should mention that SAP calculations resulted in Energy Efficiency and Environmental Impact Rating of band 'B' with 85 and 89 points respectively. It may seem strange that such a house, which is considered to follow strict standards and be ultra low energy house, is in any band lower than band 'A'. However, part of the explanation lies in the fact that SAP relies on energy tariff for the energy efficiency assessment; in other words, if the house was in a different tariff, the result would have been better.

Table 4: Summary SAP results for the Passive House

PASSIVE HOUSE - SAP		
Internal Temperature	19.2 °C	
Treated Floor Area	105.28 m^2	
Internal gains	5.9 W/m^2	
Space Heating Demand	8.16 kWh/m^2 per year	859.6 kWh per year
Space Heating delivered energy	3.76 kWh/m^2 per year	395.4 kWh per year
Domestic Hot Water Demand	15.20 kWh/m^2 per year	1600.4 kWh per year
Auxiliary	3.68 kWh/m^2 per year	387.11 kWh per year
Lights	4.80 kWh/m^2 per year	505.1 kWh per year

THE CODE LEVEL 4 DWELLING

The second house is located in the same location and is similar to the first one with the difference that it has an additional room -a kitchen- facing East underneath a terrace and therefore it is a little larger. For space heating it uses storage heaters and direct acting electric heating, for heating water it has an immersion boiler and it is naturally ventilated. Unfortunately, we do not have detailed specifications for this case. However, it has been assumed to have walls and glazing with U-values of 0.15 and 1.5W/m^{2}K respectively. Moreover, it should be mentioned this dwelling is on 24-hour low cost heating tariff.

Figure 4: Code Level 4 House – East facade (Image by Gavin Murphy)

SAP FOR THE CODE LEVEL 4 DWELLING

As far as SAP the Code 4 dwelling is concerned, the same version of SAP in excel format has been used with the difference that due to the lack of detailed specifications Appendix S (Reduced SAP for Existing Dwellings) has been followed where appropriate.

In this case, the effective air change rate has been found to be 0.67ac/h according to SAP calculations considering natural ventilation with two intermittent fans. The SAP -RdSAP in fact- results showed rating band ‘C’ for both Energy Efficiency and Environmental Impact Rating (see Appendix C) which is in accordance with the certificate issued by the certifier. The only difference is that the score is slightly lower, by two units; however, this is reasonable and could have been expected since the specifications available were quite limited to achieve the exact result with the certifier.

Table 5: Summary SAP results for the Code Level 4 Dwelling

CODE 4 DWELLING - SAP		
Internal Temperature	18.2 °C	
Treated Floor Area	139.01 m^2	
Internal gains	5.9 W/m^2	
Space Heating Demand	35.55 kWh/m^2 per year	4941.94 kWh per year
Domestic Hot Water Demand	25.44 kWh/m^2 per year	3536.85 kWh per year
Lights	4.80 kWh/m^2 per year	667.0 kWh per year

PHPP FOR THE CODE LEVEL 4 DWELLING

Additionally, PHPP has been applied for this house despite the significantly limited specifications of the construction and the fact that PHPP is not designed for natural ventilated dwellings.

The effective air change rate ambient in this occasion has been set to 0.505ac/h on the grounds that 0.5ac/h is the recommended ventilation by CIBSE Guide B2 (2001) and that PHPP could not accept exactly 0.5. A summary of the results is available in the following table (Table 6).

Table 6: Summary PHPP results for the Code 4 Dwelling

CODE 4 DWELLING - PHPP		
Internal Temperature	20 °C	
Treated Floor Area	101.4 m^2	
Internal gains	2.1 W/m^2	
Space Heating Demand	67.2 kWh/m^2 per year	6814.08 kWh per year
Domestic Hot Water Demand	31.30 kWh/m^2 per year	3173.82 kWh per year
Household Appliances (incl. lights)	16.70 kWh/m^2 per year	1693.38 kWh per year

PHPP VS SAP

At this point, a comparison between outputs of the two methodologies for each dwelling needs to be carried out. As a first illustration, Figures 5 and 6 show differences between the two examined methodologies with regard to space and water heating. More analytically, Tables 7 and 8 which follow summarise the main points of the results shown previously. The results are discussed and examined closer in the sections following the mentioned figures and tables.

It should be reminded that in all cases in PHPP, the monthly method has been selected.In addition, before continuing to the tables, it is important to bear in minds that the Passive House has 4.6m^2 solar panels installed and a heat pump. That is why the delivered energy is different from the energy demand.

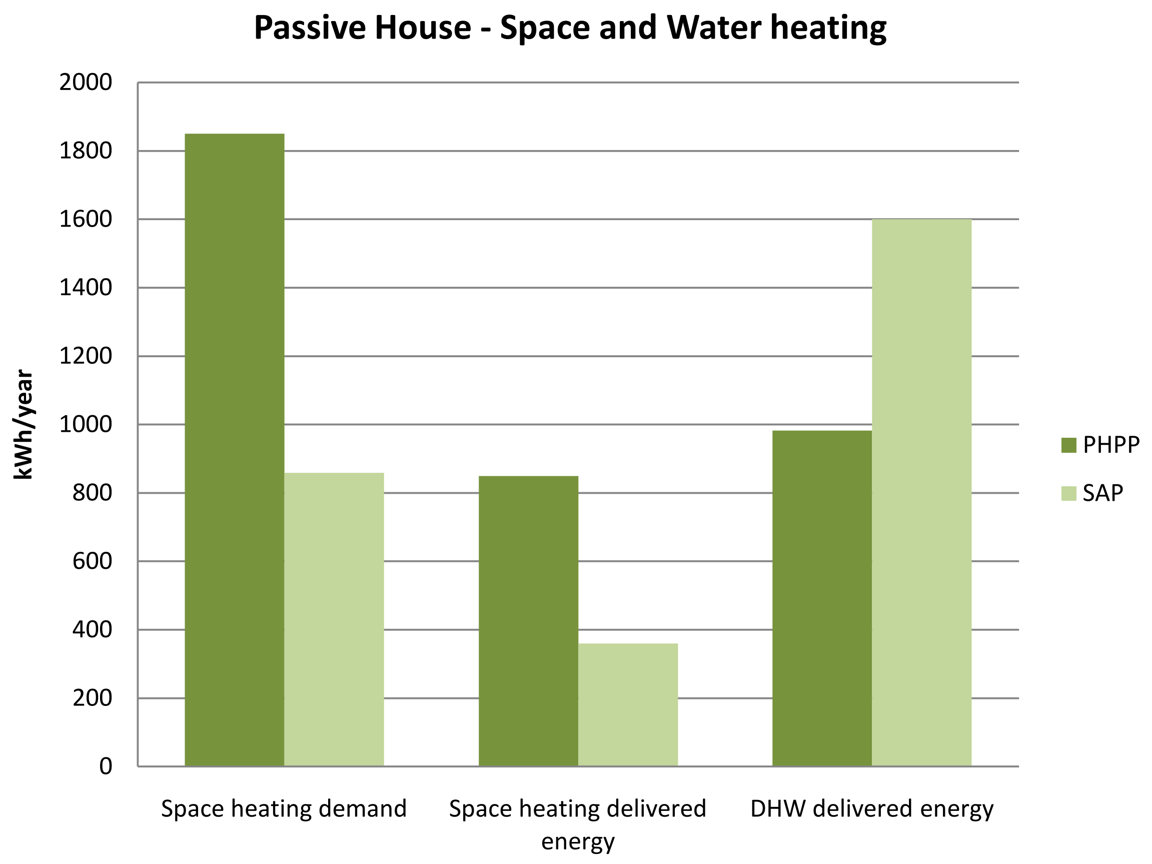


Figure 5: Space and Water heating comparison between SAP and PHPP for the Passive House

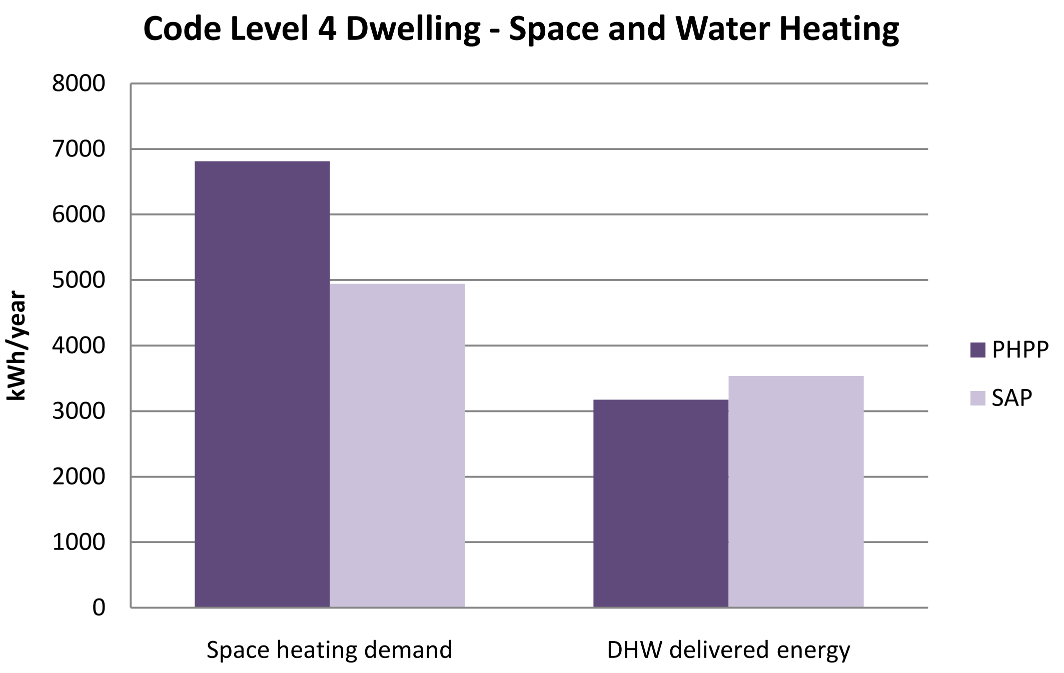


Figure 6: Space and Water heating comparison between SAP and PHPP for the Code Level 4 House

Table 7: Results overview for both methodologies

	Passive House - PHPP	**Passive House - SAP**	**CODE 4 - SAP**	**CODE 4 - PHPP**
Internal Temperature	20 ^oC	19.2 ^oC	18.2 ^oC	20 ^oC
Treated Floor Area	88.5 m^2	105.28 m^2	139.01 m^2	101.4 m^2
Internal gains	2.1 W/m^2	5.9 W/m^2	5.9 W/m^2	2.1 W/m^2
Effective air change rate	0.078 ac/h	0.065ac/h	0.67 ac/h	0.505 ac/h
Space Heating Demand	1849.7 kWh/year	859.6 kWh/year	4941.9 kWh/year	6814.1 kWh/year
DHW Demand	2148.8 kWh/year			3184.0 kWh/year
DHW energy delivered	982.4 kWh/year	1600.4 kWh/year	3536.9 kWh/year	3173.8 kWh/year
Lighting		505.1 kWh/year	667.0 kWh/year	
Household Appliances	1194.8 kWh/year			1693.4 kWh/year
Energy delivered for space heating	849.6 kWh/year	395.4 kWh/year	same as demand	same as demand

Table 8: Results for CO_2 emissions

	Passive House – PHPP		**Passive House – SAP**		**CODE 4 – SAP**		**CODE 4 – PHPP**	
	kg CO_2/m^2 per year	kg CO_2/year	kg CO_2/m^2 per year	kg CO_2/year	kg CO_2/m^2 per year	kg CO_2/year	kg CO_2/m^2 per year	kg CO_2/year
Space Heating	6.5	575.2	1.58	166.3	15.0	2085.1	45.7	4634.0
DHW	7.6	672.6	6.41	674.8	10.74	1493.0	21.3	2159.8

Space Heating

First of all, as far as space heating is concerned, Table 7 shows that, for the Passive House, PHPP concludes in higher demand by 115%, comparing to the SAP value for space heating. For the second dwelling the percentage drops to 38%. One would expect the main difference that affects this deviation to be the significantly higher internal heat gains of SAP; by considering 5.9W/m^2, whereas PHPP assumes only 2.1W/m^2, space heating will be clearly decreased. Other factors could be the different internal temperature or the air change rate. In an attempt to discover what may affect more the results, three factors have been altered in PHPP; the temperature, the internal heat gains (IHG) and the effective air change rate. The results are shown in Table 9. At this point, it is essential to mention that we have taken IHG as calculated from SAP in W/m^2, without converting them to W and then back to W/m^2 using PHPP TFA (in that case IHG would have been 7W/m^2), on the grounds that the intention was to highlight the difference in calculation procedures.

Table 9: Difference in space heating demand between the two methodologies by applying SAP values in PHPP

Changes to:	*No changes*	*IHG*	*Temperature*	*Effective air change rate*	*IHG + effective air change rate*	*IHG + temp + Effective air change rate*
Passive House						
SAP (kWh/year)	859.6					
PHPP(kWh/ year)	1849.7	513.3	1593.0	1770.0	442.5	318.6
Difference (kWh/year)	***990.1***	***-346.3***	***733.4***	***910.4***	***-417.1***	***-541.0***
Difference (%)	***115%***	***-40%***	***85%***	***106%***	***-49%***	***-63%***
Code Level 4 House						
SAP (kWh/year)	4941.9					
PHPP(kWh/ year)	6814.1	4400.8	5130.8	7990.3	5577.0	4056.0
Difference (kWh/year)	***1872.2***	***-541.1***	***188.9***	***3048.4***	***635.1***	***-885.9***
Difference (%)	***38%***	***-11%***	***4%***	***62%***	***13%***	***-18%***

It is important to clarify that the percentages shown in Table 9 and in Figure 7 refer to how much PHPP value for space heating demand differs from the corresponding value in SAP by using the same number for internal heat gains, temperature or effective air change rate; they indicate, in other words, the comparison gap. If, after applying a change, space heating demand was, for example, exactly the same then the percentage would be 0.

As expected, for the Code Level 4 House the change in internal gains resulted in a value significantly closer to SAP. The greater effect of the temperature, compared to Passive House case, is because it was changed by 1.8^{o}C while for the Passive House was altered only by 0.8^{o}C. We have to underline once again, that in Code Level 4 case there is a non-negligible uncertainty in the results on the grounds that the specifications were limited. In the case of Passive House, the results (Table 9) showed that although replacing internal heat gains gives a closer value of specific heat demand to the value calculated in SAP, it is still significantly different. In addition, it should be mentioned that increasing IHG leads to a significant rise in overheating frequency; it reached 26% for Passive House. In such cases further modifications have to be made from the designer.

Generally, whenever IHG have been altered to SAP value of 5.9W/m^2, space heating dropped dramatically. This is due to the fact that in PHPP internal gains come from all the appliances, occupants and evaporation (Reason & Clarke, 2008) and basically -along with the solar gains- are subtracted from the losses, while in SAP, losses from water heating system are actually translated into internal gains; in other words, an un-insulated water heating system would be beneficial for the space heating requirement. In fact, applying heat gains value from SAP meant almost a four-time decrease in space heating demand for Passive house, whereas for Code Level 4 dwelling only 1.5 time reduction. We should bear in mind that Passive House is not only a significantly more insulated construction but also remarkably more air-tight; it is more difficult for internal heat gains to escape comparing to Code level 4 house, where the effective air change is approximately 10 times higher, according to SAP.

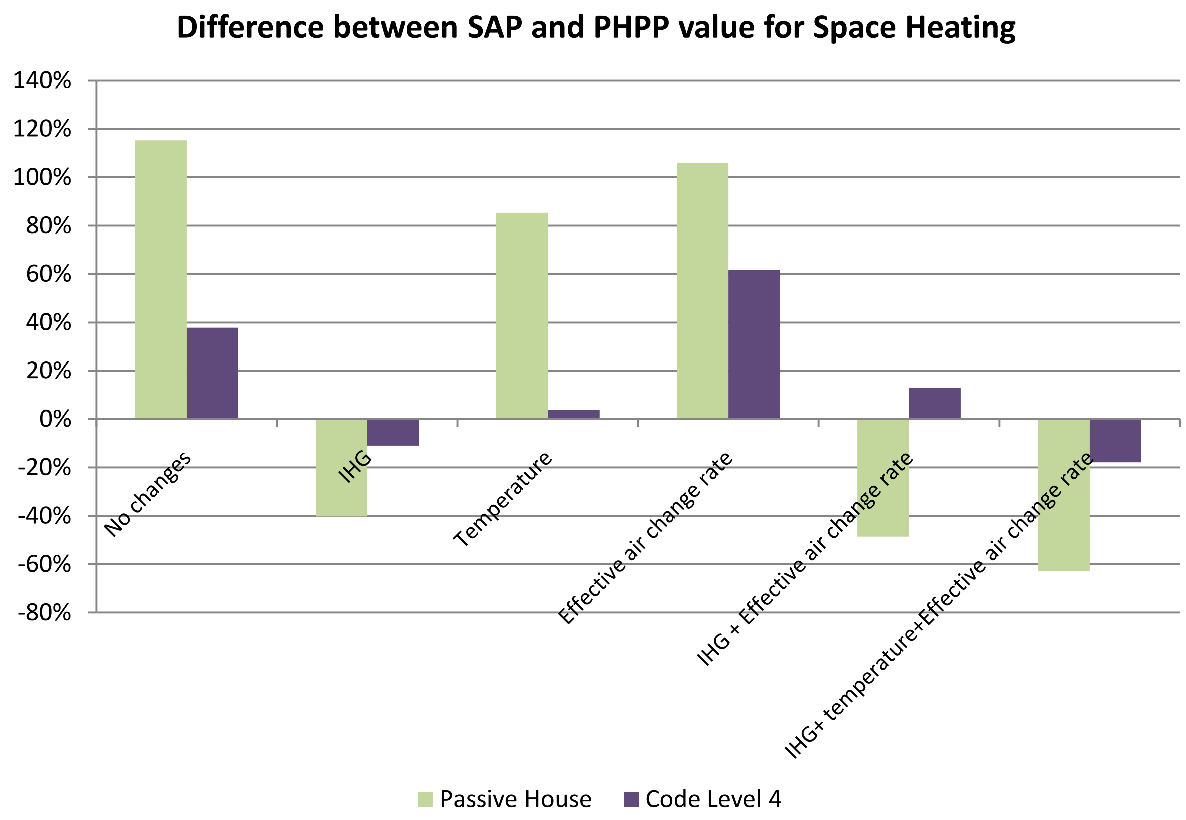


Figure 7: Difference (in %) in space heating demand between the two methodologies by applying SAP values in PHPP

However, it needs to be highlighted that SAP assumes the same climate data, that of Sheffield (Laughton, 2011) (Murphy, Kummert, Anderson, & Counsell, 2011), whereas in PHPP, which is location-specific, we have used Glasgow so far. In order to have a more accurate comparison, we applied new climate data so that the two methodologies would start from the same climate basis and made the previous modifications as well. The applied climate is East Pennines climate data which can be found in BRE's website (Building Research Establishment Ltd, 2011).

The following figures (Figure 9, 10, 11) and tables (Table 10, 11) illustrate the effect climate data had on space heating demand for the two dwellings.

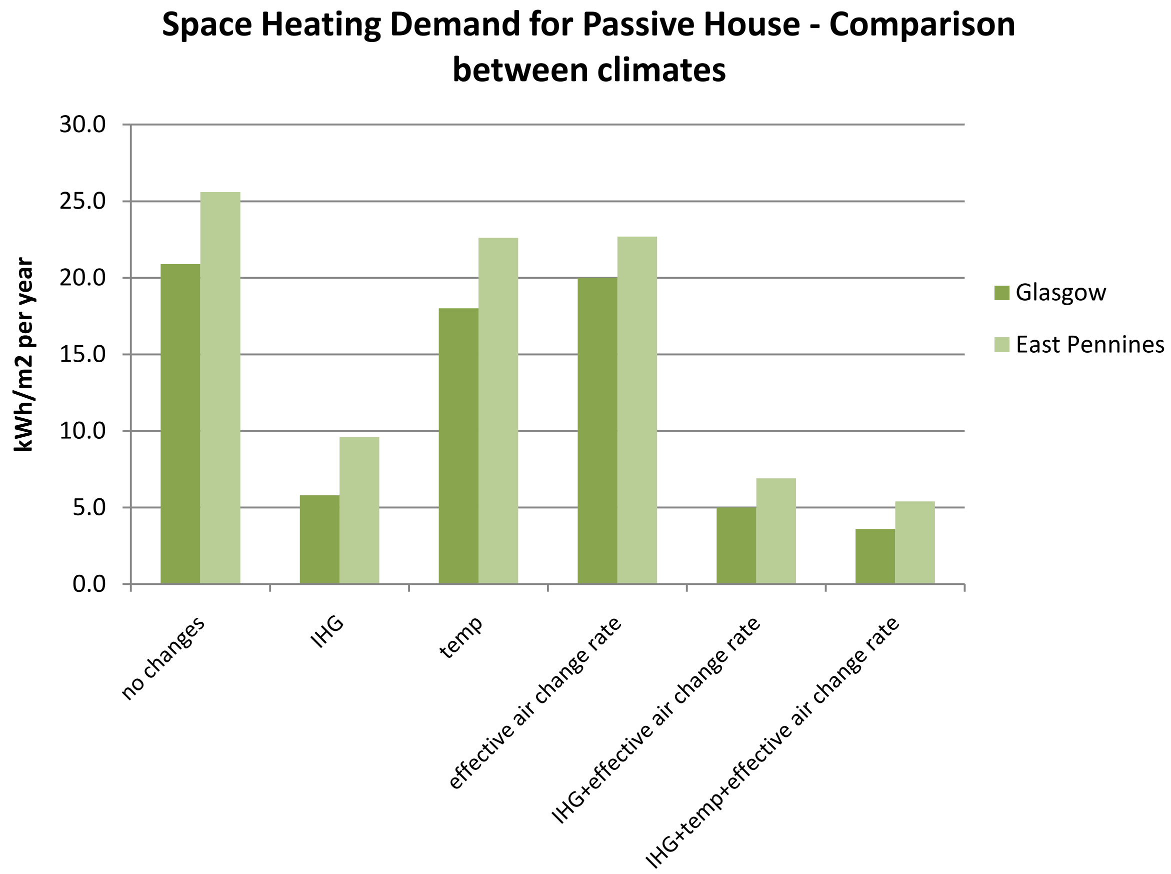


Figure 8: Different space heating demand for Passive house due to climate

Table 10: Space heating demand for Passive House using same climate as SAP

	Passive House	**PHPP**		**SAP**
	TFA (m^2):	88.5		105.28
	climate:	**Glasgow**	**East Pennines**	
Space Heating demand (kwh/m^2 per year)	no changes	20.9	25.6	8.16
	IHG	5.8	9.6	
	temp	18.0	22.6	
	effective air change rate	20.0	22.7	
	IHG+effective air change rate	5.0	6.9	
	IHG+temp+effective air change rate	3.6	5.4	

		PHPP		**SAP**	
	climate:	**Glasgow**	**East Pennines**		difference
Space Heating demand (kWh/year)	no changes	1849.7	2265.6	859.6	-163.6%
	IHG	513.3	849.6		1.2%
	temp	1593.0	2000.1		-132.7%
	effective air change rate	1770.0	2009.0		-133.7%
	IHG+effective air change rate	442.5	610.7		29.0%
	IHG+temp+effective air change rate	318.6	477.9		44.4%

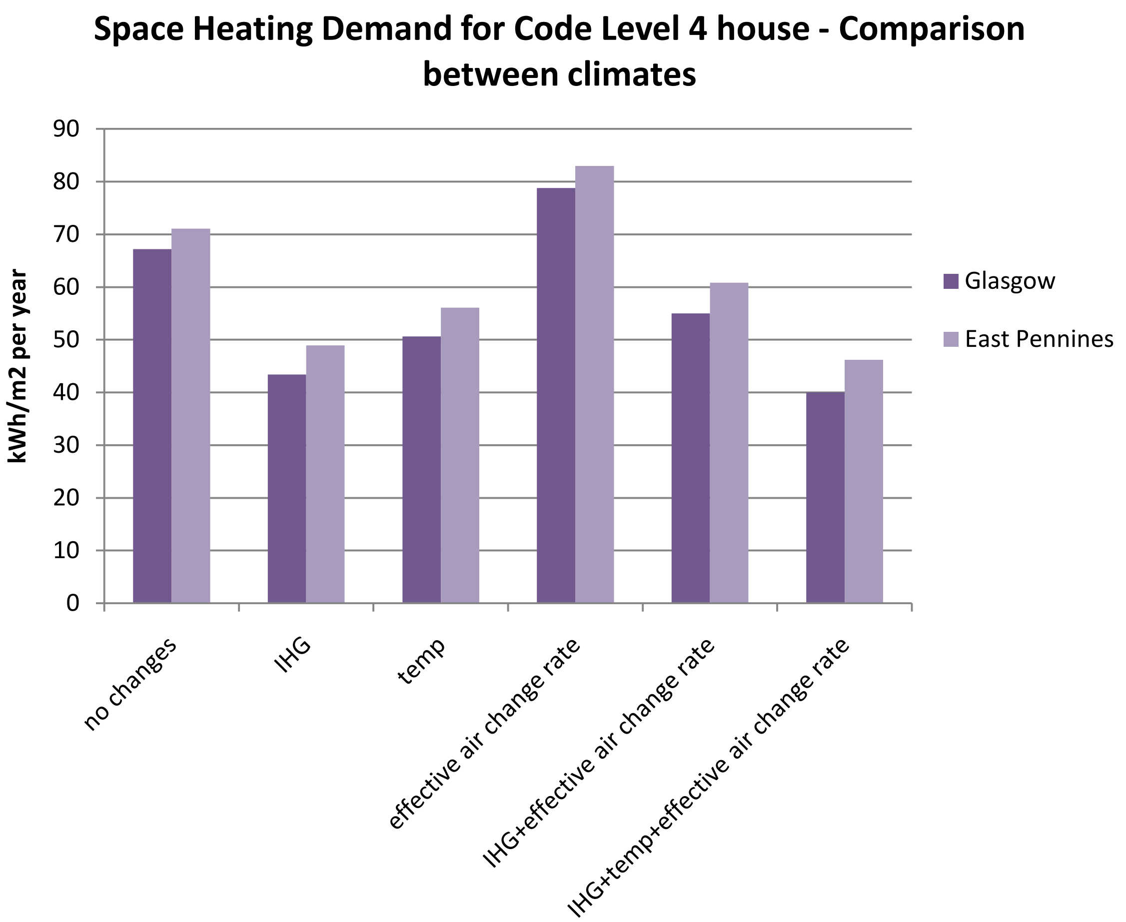
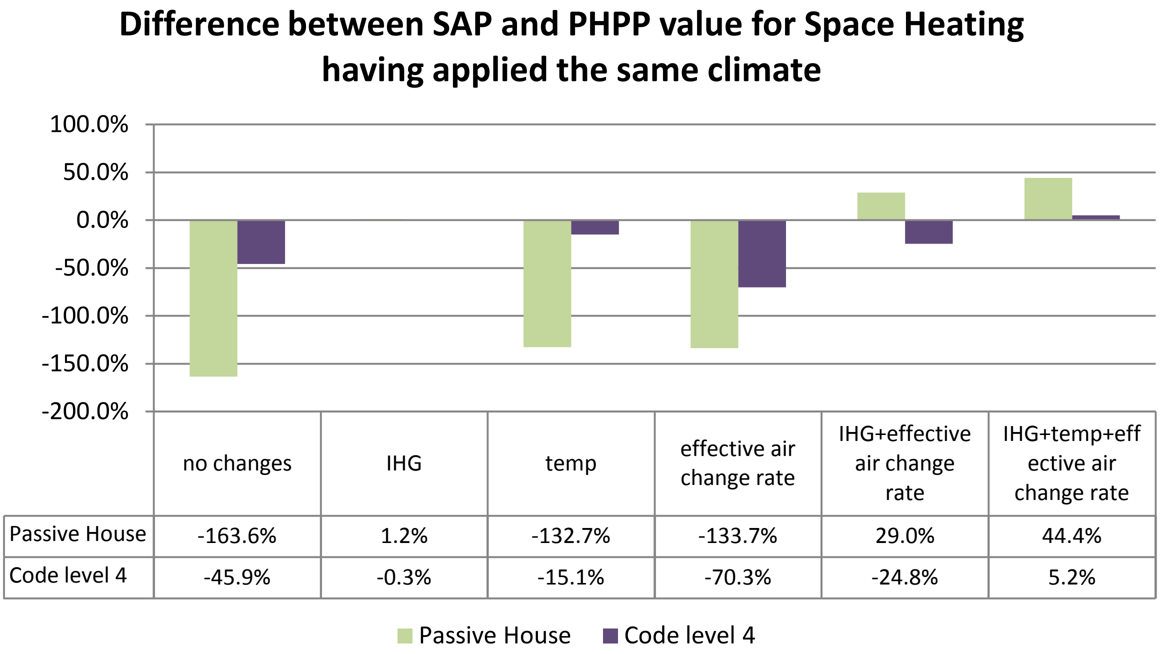


Figure 9: Different space heating demand for Code Level 4 house due to climate

Table 11: Space heating demand for Code Level 4 dwelling using same climate as SAP

	Code Level 4	**PHPP**		**SAP**
	TFA (m^2):	101.4		139.01
	climate:	**Glasgow**	**East Pennines**	
Space Heating demand (kwh/m^2 per year)	no changes	67.2	71.1	35.54
	IHG	43.4	48.9	
	temp	50.6	56.1	
	effective air change rate	78.8	83	
	IHG+effective air change rate	55.0	60.8	
	IHG+temp+effective air change rate	40.0	46.2	

		PHPP		**SAP**	
	climate:	**Glasgow**	**East Pennines**		difference
Space Heating demand (kwh/year)	no changes	6814.1	7209.5	4941.4	-45.9%
	IHG	4400.8	4958.5		-0.3%
	temp	5130.8	5688.5		-15.1%
	effective air change rate	7990.3	8416.2		-70.3%
	IHG+effective air change rate	5577.0	6165.1		-24.8%
	IHG+temp+effective air change rate	4056.0	4684.7		5.2%



	no changes	IHG	temp	effective air change rate	IHG+effective air change rate	IHG+temp+effective air change rate
Passive House	-163.6%	1.2%	-132.7%	-133.7%	29.0%	44.4%
Code level 4	-45.9%	-0.3%	-15.1%	-70.3%	-24.8%	5.2%

Figure 10: Difference in % between SAP and PHPP value for space heating demand on the same climate basis

The above results have shown certain interesting points. Firstly, it is clear that that localised climate plays an essential role in space heating, and therefore it needs to be taken into account by SAP as well. Additionally, it has been proved that climate and internal heat gains are the major factors that made SAP and PHPP results so different. By applying the same climate and internal gains to PHPP, the difference in space heating demand was only 1.2% and -0.3% for the Passive House and the Code level 4 dwelling, respectively (Table 10 and 11).

Furthermore, based on another difference between the two methodologies mentioned in the beginning, that of the detail input data for windows in PHPP, we investigated the impact of changing the windows orientation for the two dwellings (Figure 11). In fact, although we have changed the deviation from North by 5^{o}, the general orientation remained the same; in other words, South orientation remained South, North orientation remained North. This is because in SAP, there is only the possibility to determine orientation in such way, whereas in PHPP one has to input the exact deviation from North in degrees. It is obvious that detailed orientation is of great importance in PHPP. Additionally, comparing the two dwellings we can see that the effect is greater on Passive House; that is because of the higher quality of glazing and the air-tightness which affect solar gains.

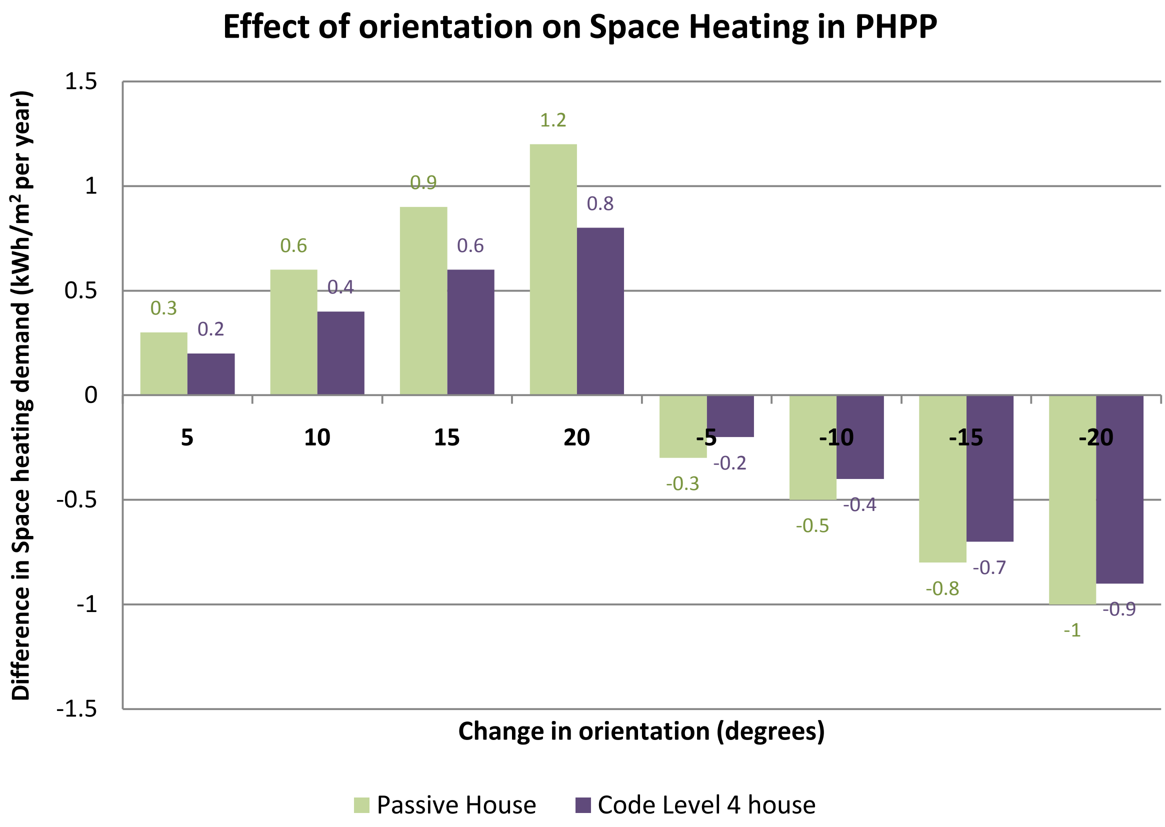


Figure 11: Effect of a change in degrees on Space Heating, while (general) orientation remained unchanged

Hence, it is crystal clear that for highly insulated dwelling, such as the Passive house we examine, the impact of internal gains on space heating demand, as well as the heating load itself, is greater based on the comparison between PHPP and SAP. Passive House seems to be more sensitive to changes and requires detailed data as PHPP is designed for; SAP more 'gross' methodology could be considered to bear a non-negligible uncertainty in its results especially because of standard values it uses including standard climate.

Domestic Hot Water

As shown in Table 7, PHPP predicts lower actual energy requirement (delivered) for the Passive House than SAP does. Although there are considerable differences in their approaches, the main reason for this seems to be the different solar contribution calculated by the two methodologies.

Taking a look at the spreadsheets would show us that the gains from solar thermal are 1167 kWh/year according to PHPP, while for SAP they only are 949 kWh/year; 18.7% less gains for SAP. More specifically, Table 7 revealed that for the Passive House according to PHPP solar panels contribution to DHW energy is 1166.4kWh/year, 13kWh/m^2 per year, or 54.3% of the DHW demand. Comparing to SAP, the actual energy needed (after having taken into consideration solar contribution) is 38.6% lower or, in other words, solar fraction was 44.8%.

It is worth mentioning at this point that although it seems more sensible PHPP to be closer to reality since it takes into account local climate data, a monitor data based study in Dublin – a UK similar climate– indicates that solar fraction should be around 40% (Ayompe, Duffy, Mc Keever, Conlon, & McCormack, 2011). One could argue therefore that PHPP could be considered optimistic as far as solar contribution is concerned.

Additionally, as described in SAP 2005, hot water usage is the addition of the product of 25litres/day per person with the number of occupants plus and additional 38litres/day. On the contrary, PHPP2007 does not consider any additional litres apart from the 25litres/day. Therefore, SAP would require more energy during a year for heating the necessary water. Moreover, another essential difference is that PHPP requires detailed input of plumbing apart from the separate ‘SolarDHW’ spreadsheet, while SAP pays attention on its standard loss factors related to cylinder size and insulation thickness.

It should be mentioned that we have focused on the Passive House, since there have been made certain assumptions for Code Level 4 DHW distribution system in PHPP which would lead to uncertain conclusions at this point. Such assumptions are the length of pipes, the width and insulation of the plumbing, which was taken identical to Passive House plumbing because of the lack of details.

CO_2 Emissions

Furthermore, taking into consideration the ratio of the delivered energy between the two methodologies, it is expected that CO_2 emission would follow the same trend. Hence, since SAP predicted less delivered energy for space heating, the emissions for that section are lower in SAP, as well. Similarly, according to PHPP, Passive House is responsible for lower emissions due to DHW.

As it has mentioned in the beginning, the two methodologies differ in CO_2 emissions calculation, although they both rely in the fuel used for the production of the energy. In PHPP, the data for the CO_2 emissions are based on DIN V 4701-10 and the software GEMIS 4.14. More specifically, the delivered energy is multiplied with a Primary Energy factor according to the energy carrier –for example the electricity– and then, the product, which is the primary energy, is multiplied with a CO_2 emissions equivalent; for electricity primary energy factor is 2.6 and CO_2 emissions equivalent are 0.68 kg/kWh. The difference is that in SAP these figures are different. In SAP 2005 it is 2.8 and 0.422 kg/kWh for electricity respectively. It should be noted that in SAP 2009, which is not used here, they have been revised.

This differentiation leads to significantly different results as shown in Table 8. It is only in the case of emissions for hot water for the Passive House where the two methodologies are approximately the same considering annual emissions per dwelling despite the fact the considerable difference in heating water energy. It is due to different CO_2 emissions equivalent as mentioned. Generally, one can observe that PHPP predicts higher CO_2 emissions than SAP for both dwelling; not only because of that factor but also because of the higher predicted energy.

We have not included intentionally the total emissions as calculated, on the grounds that SAP neglects the household appliances in this part; they only count for internal gains.

Furthermore, regarding Zero Carbon Hub carbon compliance suggestions for new dwellings after 2016, one may observe that using SAP for Passive House leads in a value of 8 kg CO_2/m^2 per year for DHW and space heating which is within the Zero Carbon Hub limits whereas PHPP concludes in 14.1 kg CO_2/m^2 per year; not too far from the suggestion (Zero Carbon Hub, 2010). However, this does not mean that PHPP results are not correct since they use different standard values, as mentioned previously.

COMPARISON WITH ENERGY BILLS (PART 1)

Having completed the comparison between the two methodologies itself, it would be useful to compare the results with energy bills, as well, in order to determine which one, SAP or PHPP, could predict better the annual running costs. Is SAP which aim is actually to conclude in these costs in order to assess energy efficiency of a dwelling? Or is it PHPP that predicts running costs closer to reality?

First of all, it is important to present the available data for this section. It is only for the Passive House that an energy bill was available to us. This bill, as shown below, regards the energy consumption from 18th of December 2010 to 8th of March 2011.

from:	18-Dec	*to:*	08-Mar
Electric usage	**2315**	units (kWh)	
Tariff: Domestic Standard			
	11.66	p/unit	
or	0.1166	£/unit	
	13.1544	£ is the Standing charge for 81 days at 0.162 p	
	283.08	£ (excl. VAT)	
	13.80	£ VAT 5%	
	296.88	**£** (incl.VAT)	

Figure 12: Energy bill for the Passive House

At this point, let us note the total annual consumption as it has been found in PHPP and SAP. Based on PHPP results, by adding energy delivered for space and water heating, auxiliary electricity and household appliances consumption, the annual consumption is 3248.2kWh/year or, in other words, 378.7£/year. SAP concludes in 2888.0kWh/year. However, it has to be highlighted that since we are using SAP2005 it considers 7.12p/kWh as fuel price for electricity on standard tariff; this means, that although SAP spreadsheet gives only 205.6£/year and despite its difference for space heating compared to PHPP, in fact, with current tariff it would be 336.7£/year. The truth is that SAP resulted in a lower amount (by 11%) because of the lower final space heating energy, as described previously, as well as because it does not include household appliances energy consumption in its running costs.

However, in order to compare these figures with the available bill, we follow the following rationale taking into account the fact that the requirement for space heating is not the same throughout the year. It should be noted that the procedure will be presented in table format later along with some modifications made that will be explained (Table 12).

First of all, we make use of monthly heat demand calculated in PHPP in 'Monthly Method' sheet (see orange columns and line in Table 12). For the 81 days of the billing period, the total kWh corresponding to space heating are 952.2; we take only the 13 days for December and 8 for March, 31 for January and 28 for February.

Subsequently, based on PHPP results for DHW delivered energy, auxiliary electricity and energy for appliances in kWh/m^2 per year, we convert them to kWh for this 81-day period and add them to space heating in order to get the total electricity consumption for this period.

The last step remaining is to multiply the result with 11.66p/kWh which is the tariff shown in the bill.

This procedure gives us a value of 1484.5kWh (as shown in Table 12) that should have been consumed during this period according to PHPP. One can observe that there is a great deviation from the actual consumption as shown in the bill.

As presented in Figure 12, the total units consumed were 2315, which means that 890kWh or 11.0kWh/day are missing. That is a significantly high number of missing electricity. At this point, it is essential to mention that during that period there were certain problems and issues identified and which could justify this additional electricity consumed. These issues are the following ones:

- Heat pump was not working during winter time (Tuohy & Murphy, Presentation for Fyne Homes, 2011)

  This information is responsible for two major issues. The first one is why in monitoring data we got regarding this dwelling the temperature is nothing but close to 20^{o}C, especially at the beginning of the monitoring, as it was supposed to be according to both PHPP and SAP. In addition, it can justify a large amount of the missing kWh of electricity since the occupants had electric heaters for space heating.

  More specifically, monitoring data showed that in March the temperature inside different rooms was quite low. Especially in living room, at the beginning of monitoring was 16.5^{o}C, and for the period from 19 March to 26 June the average was 18.5^{o}C, the maximum 22.2^{o}C and the minimum was 13^{o}C. As it will be shown in the

Monitoring Data chapter, outside temperature does not have a significant effect in such highly insulated houses. It is the not-working heat pump and consequently the ineffectiveness of the electric heaters used that the dwelling failed to reach the 20^{o}C.

Back to the missing energy, since we do not know exactly either the power of heaters used or the hours per day they were used, assumptions have to be made. Assuming that electric heaters running at low power -0.5kW for example- all day during that period we have:

$500W \times \left(81days \times \frac{0.024kh}{day}\right) = 972kWh$ (in other words 12kWh/day),

or running at 1.0kW: $1000W \times \left(81days \times \frac{0.024kh}{day}\right) = 1944kWh$ (24kWh/day)

or let us say heaters of 1.0kW running for 18 hours per day:

$1000W \times \left(81days \times \frac{0.016kh}{day}\right) = 1296kWh$ (or 16kWh/day).

Although the for-mentioned cases are only assumptions, the answer lies somewhere between them; yet we are not in a position to find it out.

- ❖ Additionally, according to the owners, MVHR has been used to maximum mode (100m^3/h) instead of standard mode (77m^3/h) as there was a misunderstanding of its appropriate use (Tuohy & Murphy, Presentation for Fyne Homes, 2011); it was thought that by operating at maximum the dwelling would be heated more easily, which in reality is not the case.

  Simulating this to PHPP resulted in an increase of effective air change rate to 0.141ac/h. Consequently, this leads to more energy required for space heating as the building becomes less air-tight.
- ❖ Moreover, it has been found that the installation of MVHR was not the one expected as the ductwork on the MVHR unit was missing a part of insulation and, as for the whole length of ducts insulation, that was only 19mm instead of the designed 140mm (Tuohy & Murphy, Presentation for Fyne Homes, 2011).
- ❖ Finally, another issue raised by the monitored data, which will be further discussed later in Monitoring Data section, is the wrong installation of solar thermal system to the tank. It seems that cold water has been brought in the tank instead of hot causing the tank temperature to decrease. Hence, more power is needed to maintain hot water in the tank.

  As it will be explained later in Monitored Data chapter, the power needed for this reason is approximately 2.5kW. Based on data from 19/03 to 26/03, we conclude that a mean value of 5.8kWh/day was used for heating water because of the erroneous installation. However, if we take into account that solar gains –as given in PHPP during the period of 81 days the bill refers to–are 22.7% of the gains for the 19/03-26/06 period, that additional energy for heating water could have been 7.1kWh/day (or 575kWh for the 81-day period) instead of 5.8kWh/day.

Hence, it is obvious that there is a mismatch between reality and the design in PHPP or SAP. Therefore, it was thought that some modifications should be made in PHPP to 'simulate' the reality. These changes are the modifications of inside temperature and of the insulation of ductwork (now input as 19mm), MVHR mode, as well as the elimination of heat pump. The results are shown in the following table (Table 12).

Table 12: Modifications to match reality and results

heat pump	no	no	no	no	Yes
insulation thickness	19mm	19mm	19mm	19mm	140m
MVHR mode	Max	Max	Max	Max	standard
temperature	17.2°C	18.0°C	20.0°C	16.5°C	20.0°C
Space Heating Energy Demand (kWh/m^2 per year)	14.0	16.8	24.4	11.8	20.9
Space Heating Energy Delivered (kWh/m^2 per year)	14.0	16.8	24.4	11.8	9.6

Monthly space heat demand according to PHPP

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total kWh for 81 days
280.1	230.1	165.9	55.4	5.1	0.3	0.0	0.0	0.2	42.8	177.8	283.6	717.6
317.7	263.9	202.0	80.3	11.3	1.0	0.1	0.0	1.2	70.9	214.0	321.2	820.3
411.9	348.9	294.6	156.0	45.7	9.7	2.2	1.2	17.4	156.2	304.9	415.4	1078.0
247.2	200.5	135.1	37.3	2.3	0.1	0.0	0.0	0.0	23.6	146.4	250.6	628.1
366.7	306.2	249.6	119.0	28.0	4.8	0.9	0.5	9.8	125.9	266.9	370.2	952.2

DHW delivered*	2.79	2.72	2.64	2.84	2.69	kWh/day
Household Appliances	3.27	3.27	3.27	3.27	3.27	kWh/day
auxiliary	0.61	0.61	0.61	0.61	0.61	kWh/day
for 81 days	540.09	534.20	528.31	544.02	532.24	kWh
total	***1257.67***	***1354.51***	***1606.31***	***1172.1***	***1484.5***	**kWh**

The temperatures selected in Table 12 (apart from the 20^{o}C) are indicative and are based on monitoring data; 16.5^{o}C was the average temperature in living room at the beginning of the monitoring, 17.2^{o}C was the average during the first month of monitoring and 18^{o}C was the average until the end of June.

Ultimately, out of the 890kWh missing (for the 81-day period), 575kWh could be due to the erroneous solar installation and 293kWh at least (derived from Table 12) because of the lack of 121mm insulation at MVHR, the non-operating heat pump, operating MCHR at maximum mode and assuming inside temperature would only reach 16.5^{o}C (see Table 13). However, it is important to underline that the latter –the inside temperature– has a major impact as it has been shown in Table 12 and unfortunately we do not have evidence of the temperature during the particular period the bill refers to. Although there is a considerable uncertainty in the for-mentioned justification, it is clear that PHPP is more close to reality than SAP, at least for the passive house.

In addition, the table in the following page (Table 13) summarises the above mentioned cases. It becomes apparent that the deviation of these cases from the real consumption shown in the bill varied from -26 to -9% (Table 13). This is due to the different internal temperature selected for which we do not have any evidence during the billing period. It is worth mentioning that although the last case of 20^{o}C is the one closest to energy bill, one should bear in mind that there are other factors that affect it such as an alteration in occupancy, unpredicted opening of windows for example.

Table 13: Justification of missing kWh

	kWh	kWh/day
BILL	2315	
PHPP	1425	
missing	***890***	11.0
no heat pump 19mm insulation 16.5°C MVHR-max mode	1131.7	14.0
erroneous solar installation*	575.1	7.1
	1706.8	21.1
variance from originally designed PHPP	*20%*	
variance from bill	***-26%***	

	kWh	kWh/day
BILL	2315	
PHPP	1425	
missing	***890***	11.0
no heat pump 19mm insulation 17.2°C MVHR-max mode	1211.9	15.0
erroneous solar installation*	575.1	7.1
	1787.0	22.1
variance from originally designed PHPP	*25%*	
variance from bill	***-23%***	

	kWh	kWh/day
BILL	2315	
PHPP	1425	
missing	***890***	11.0
no heat pump 19mm insulation 18.0°C MVHR-max mode	1302.7	16.1
erroneous solar installation*	575.1	7.1
	1877.8	23.2
variance from originally designed PHPP	*32%*	
variance from bill	***-19%***	

	kWh	kWh/day
BILL	2315	
PHPP	1425	
missing	***890***	11.0
no heat pump 19mm insulation 20.0°C MVHR-max mode	1539.3	19.0
erroneous solar installation*	575.1	7.1
	2114.4	26.1
variance from originally designed PHPP	*48%*	
variance from bill	***-9%***	

MONITORING DATA

As mentioned in the Introduction, apart from the comparison of the two methodologies themselves, monitored data have also been used to contribute to a better understanding of the dwellings' performance. The intention was to make use of these data in order to provide evidence for the performance expected from the methodologies.

First of all, It would be useful to present what have been measuring so far in the under examination dwellings. In both houses, temperature is measured in kitchen, bathroom, lounge and in the coldest room; relative humidity and CO_2 levels in the lounge; the current in Amps as total consumption of each dwelling; store temperature in the hot water tank, the temperature of cold water feed, and the hot water temperature leaving tank. In addition, for the Passive House, solar heated water temperature has been measuring. In the same dwelling, although sensors for the duct consumption and MVHR electric consumption were supposed to be installed as well, at the end this was not realised due to technical issues; interventions to cables insulation was needed and it there was not any permission for that. All monitoring equipment has been purchased from Eltek (Tuohy & Murphy, Presentation for Fyne Homes, 2011); the data have been downloaded and elaborated by Darca software and further analysed in Microsoft Excel.

DATA ELABORATION

PASSIVE HOUSE

STATISTICAL ANALYSIS

Firstly, correlations have been taken place in order to verify some relations and non-dependent factors. Correlations between electric meter, outside temperature, tank temperature, cold water feed, solar heated water temperature and hot water leaving tank have shown some interesting points (Table 14). The strong relationship between tank and hot water leaving tank temperature (correlation coefficient 91.3%) has been expected. However, the 62.8% correlation between cold water feed and solar heated water intake was considered unusual and needed further investigation. Based on graphical analysis of data later, we find that there must be something wrong with solar installation as it does not seem to contribute to hot water as supposed. In reality, what happens is that cold feed triggers the solar water flow since the sensor is at the bottom of the tank and as soon as the temperature difference is more than 6^{o}C than solar intake temperature (Tuohy & Murphy, Presentation for Fyne Homes, 2011), water from solar panels is brought in even if it is cold.

Table 14: Correlation between temperatures and electric meter

19/03-26/06	electric meter	outside temperature	Tank temperature	Cold water feed	solar heated water intake	hot water pipe leaving tank
electric meter	1					
outside temperature	0.019	1				
Tank temperature	-0.129	0.084	1			
Cold water feed	-0.206	0.303	0.186	1		
solar heated water intake	-0.086	0.448	0.286	**0.628**	1	
hot water pipe leaving tank	-0.039	0.137	0.913	0.008	0.268	1

Moreover, in such a highly insulated dwelling inside temperature and especially electric consumption is not expected to be strongly influenced by external conditions. This is verified by both Table 14, where the corresponding coefficient is 1.9%, and a correlation between lounge temperature and external temperature which gave a 0.48 coefficient for the same period.

Additionally, it has been performed a multiple regression among tank temperature and the mentioned parameters as well; however, the Coefficient of determination (R-square) was not satisfying (less than 0.9) and therefore it will not be presented.

Furthermore, the main concern, at least at the beginning, has been the quantification of space and water heating. Unfortunately, since sensors for the duct consumption and MVHR electric consumption have not finally been installed, the goal was not fulfilled. As for the energy consumed for hot water, although there have been attempts to quantify it, the result would not be representative on the grounds that solar contribution cannot be taken into consideration due to possible errors as mentioned previously and as shown below.

As far as the total electric consumption of the Passive House is concerned, it has been analysed in a weekly basis and is presented in the following graph (Figure 13) in terms of daily energy consumed. It is clearly shown that the consumption does not follow an expected trend which would show a gradual decrease as we move to summer. On the contrary, from the third week of May and later, it is considerable higher than it was in April. Taking into account that in June space heating demand is approximately zero as well as that solar gains are supposed to be higher (Figure 14), one could argue that this increase seems unusual.

The answer for this could be a combination of the followings: the amazingly low consumption during some weeks of April could be due to an absence of occupants (however note that the numbers shown in Figure 13 are only average values). In fact, until mid May, the owner of the house had been working. Then, occupants went on a one-week holiday after 14th of May and afterwards she was significantly more often at home (Tuohy & Murphy, Presentation for Fyne Homes, 2011). These issues, along with the solar installation issue, are reflected on energy consumption and in the irregular trend shown in Figure 13.

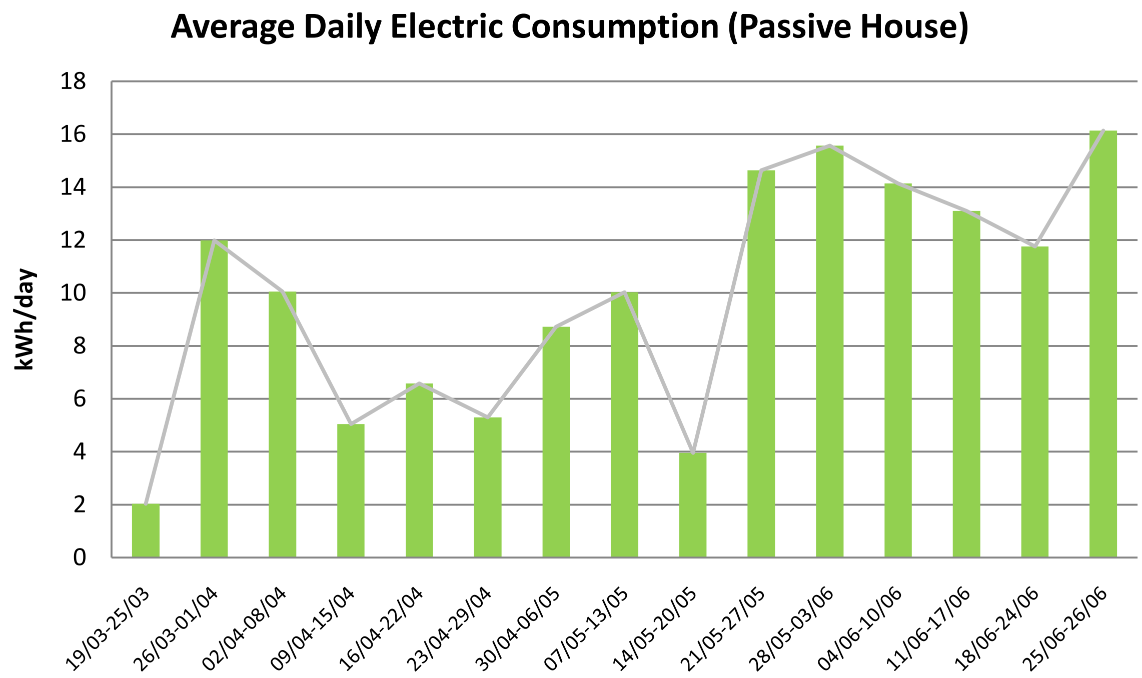


Figure 13: Average daily (total) electric consumption of Passive House on a weekly basis

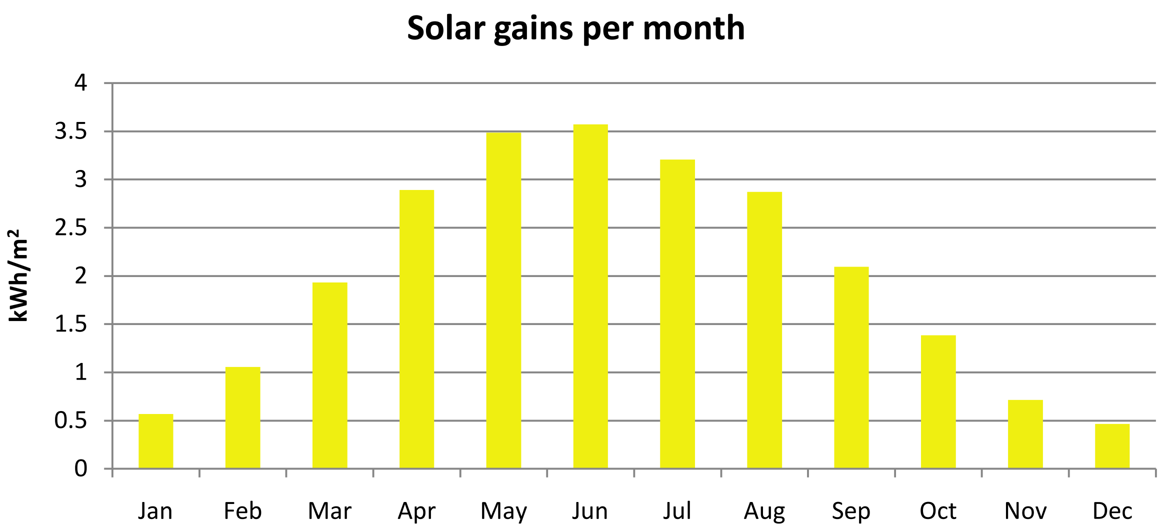


Figure 14: Solar gains (kWh/m^2) per month for the Passive House according to PHPP2007

GRAPHICAL METHOD

Generally, although the intention has been to come up with a 'non-manual/non-graphical' way to analyse the results, by using statistical methods to identify problems in the performance, at the end this has not been feasible due to the nature of monitoring data. By 'Graphical method' we mean visual observation to identify issues and relations by using Darca software. A sample of monitored data for Passive is shown in Figure 15.

Bearing in mind the findings from the statistical method, the relation between hot water leaving tank and tank temperature as well as between cold water feed and solar water intake is apparent in Figure 16, where the first two quantities follow approximately the same pattern. Observing cold water feed and hot water pipe leaving tank peaks and general pattern in the same sample (Figure 16), one could argue that it seems a relation between them as well.

This relation between cold water feed and hot water pipe leaving tank consists another evidence for a possible erroneous installation of solar system.

Moreover, as far as the additional energy because of that installation, which we have been referring to in previous chapters, is concerned, it could become more easily understood by observing Figure 17. It is obvious from the spikes of electric meter, store temperature of tank and hot water temperature leaving tank, which are circled, that approximately 10 Amps (that is 2500W, by multiplication of amps with 250V) are used for heating the water in tank. The same phenomenon is observed during the rest of the period. Therefore, one could say that a spike more than 10Amps could be for heating water. For this period the average energy for that purpose seems to have been 5.8kWh/day based on the data. That is how the additional energy of 5.8kWh/day for heating water mentioned in previous sections has been found.

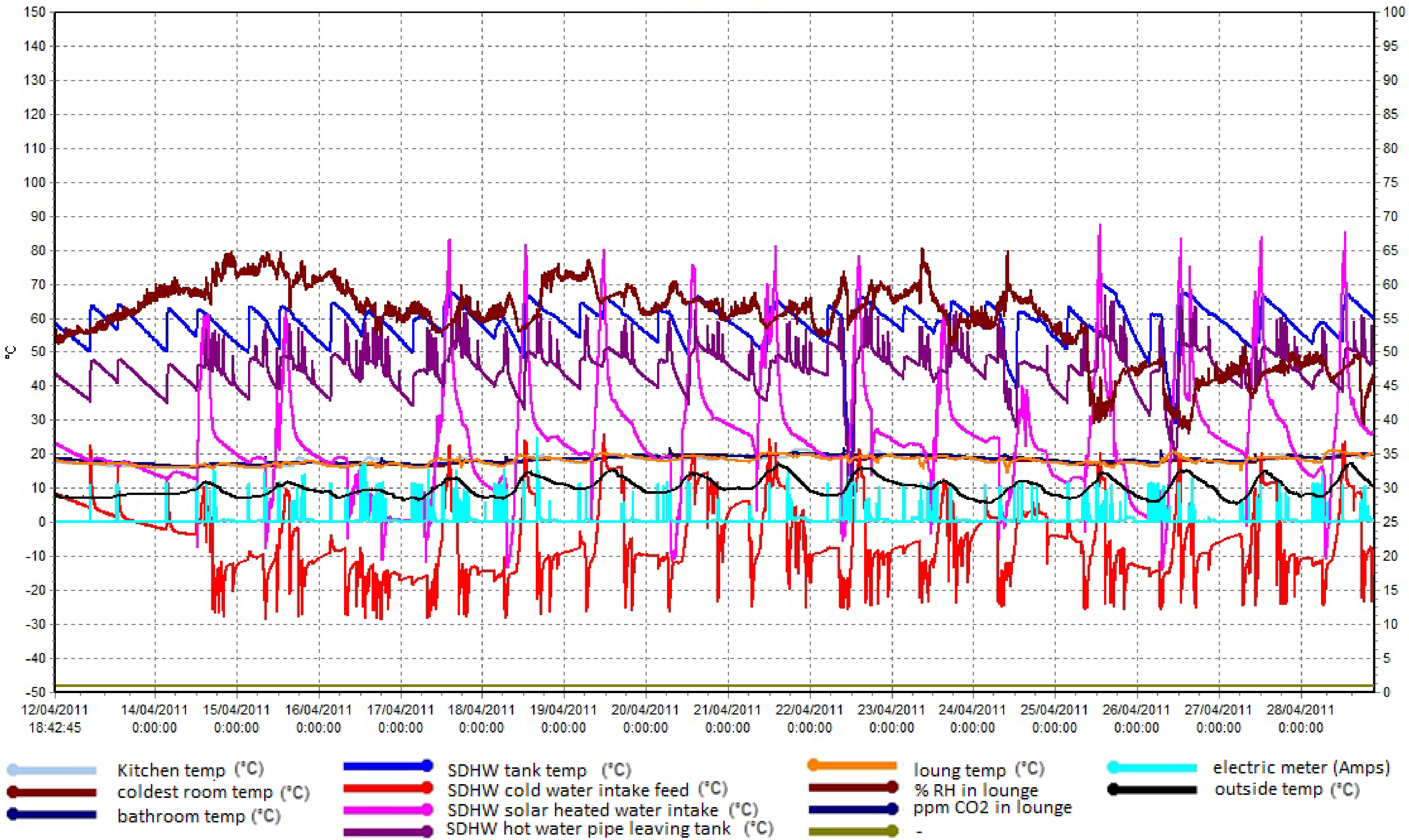


Figure 15: Sample of monitored data for Passive House

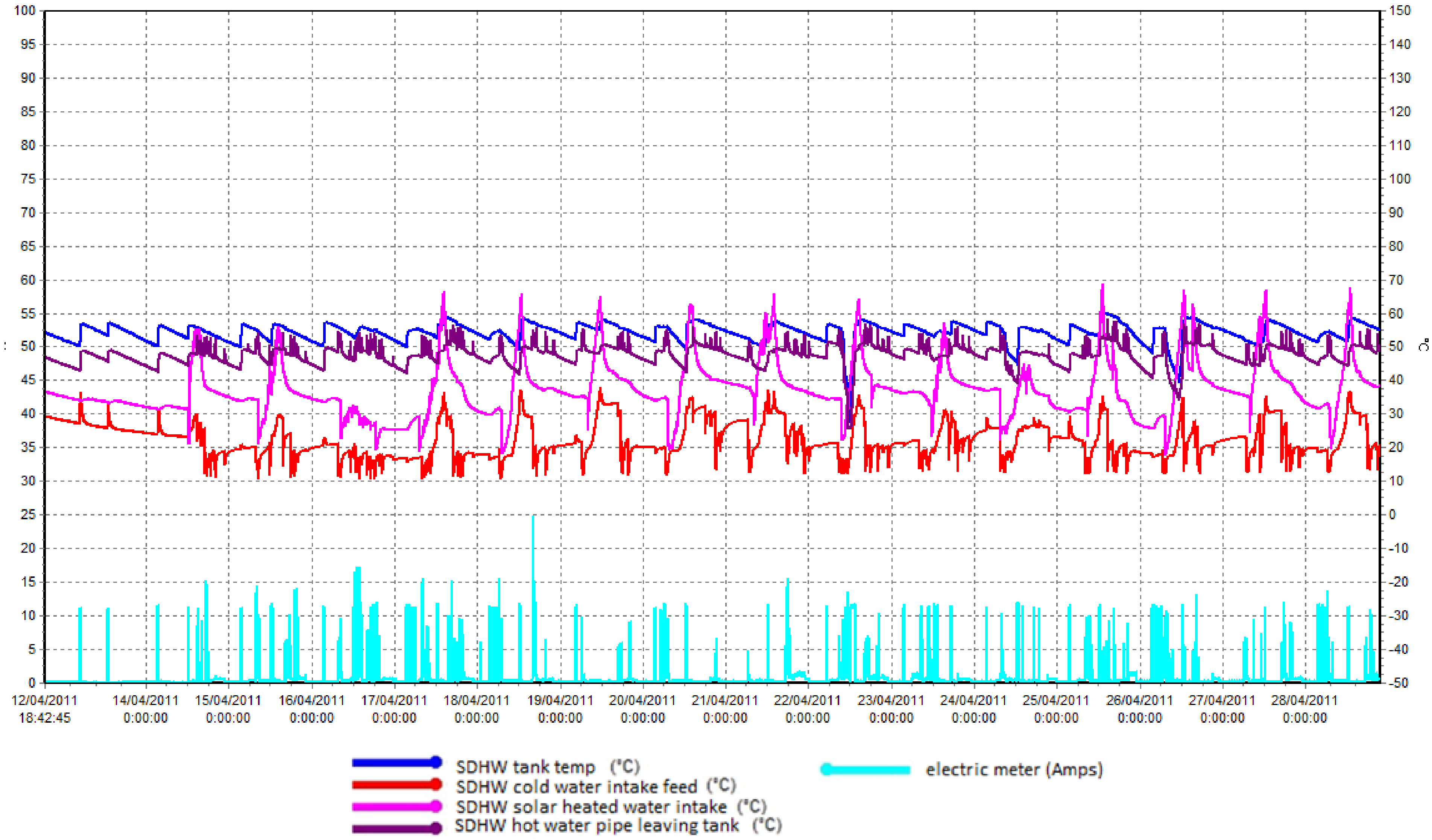


Figure 16: Sample of monitored data for tank in Passive house

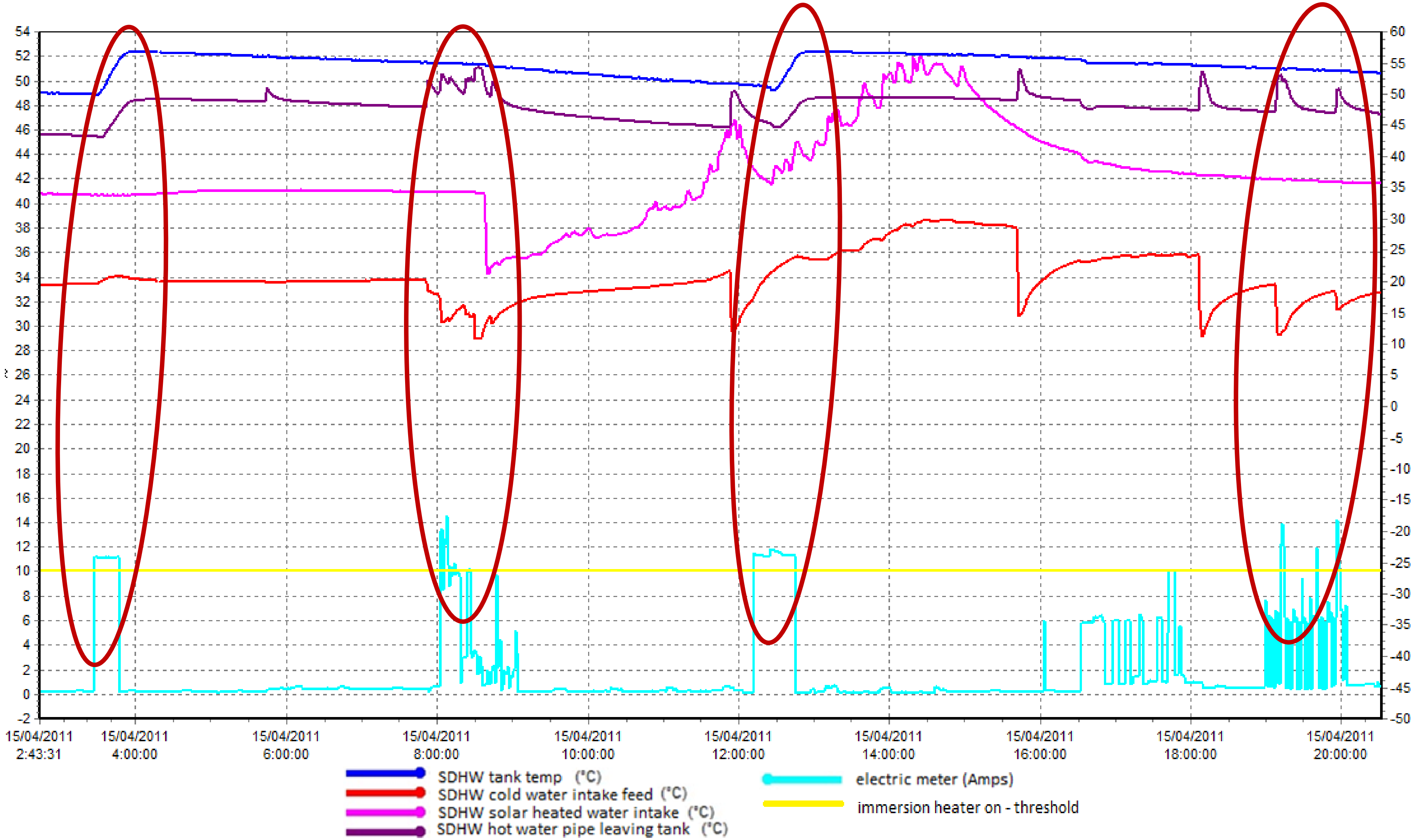


Figure 17: Relation between electric meter and tank

Code Level 4 Dwelling

As far as the Code Level 4 dwelling monitored data which have been analysed, the results are as follow. First of all, due to the fact that the channel for the hot water living tank had almost no signal during the period 19/03-26/06, a correlation among the electric meter and the tank temperatures has not been performed.

Moreover, an interesting point is that the average lounge temperature was 21.2^{o}C for the for-mentioned period, while PHPP and SAP assumed it would be 20 and 18.2^{o}C respectively. It should be mentioned that for 83.7% of the time the temperature in living room was more than 20^{o}C, and only 1.6% of the time it dropped lower than 19^{o}C.

Furthermore, it is worth mentioned, that considering that the cold water intake needs to be heated at tank temperature every minute, the data show us that 872.3kWh would have been used for heating DHW; in other words, 8.81kWh/day which is a value close to the one predicted by PHPP as shown below (Table 15). The error is only -1.8% if we consider the designed conditions or -1.2% if account 21.2^{o}C. As for SAP, it has predicted 25.44kWh/m2 per year or 9.69kWh/day (using TFA according to SAP).

Furthermore, according to electric meter, the total consumption for these period was 2134.9kWh, whereas PHPP using similar method as described earlier for the Passive House predicted 2803.1kWh; a difference of 31% (Table 15).

Table 15: Energy consumption for Code Level 4 house between 19/03 and 26/06

temperature	average in lounge	as designed	
	21.2	20.0	^{o}C
Space Heating Demand	**79.3**	**67.2**	**kWh/m^2 per year**

Monthly space heat demand according to PHPP

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total kWh 19/03-26/06
	1149.5	1040.7	1010.4	761.1	465.4	263.4	152.6	135.1	304.7	673.5	930.9	1152.0	1838.5
	1034.7	936.9	895.7	651.1	358.4	174.0	78.3	62.4	202.7	559.0	819.7	1037.1	1502.2

DHW delivered	8.67	8.70	kWh/day
Household Appliances	3.75	3.75	kWh/day
auxiliary	0.69	0.69	kWh/day
19/03-26/06	1298.14	1300.89	kWh
total	*3136.7*	*2803.1*	*kWh*
According to monitoring data:		2135	kWh
error:	47%	31%	

The above numbers could indicate the impact of human behaviour can have on electric consumption. The assumptions due to lack of detailed specifications, a possible absence or the radical drop in electric consumption at the beginning of April (Figure 18) are not enough to justify the deviation in energy consumption shown previously. However, we should mention that a gradual decrease in energy use is expected as we move to summer since requirement for heating reduces. In contrast with Passive House (Figure 13), the mean daily electricity consumption in Code level 4 house (Figure 18) decreases gradually from mid-March to late June.

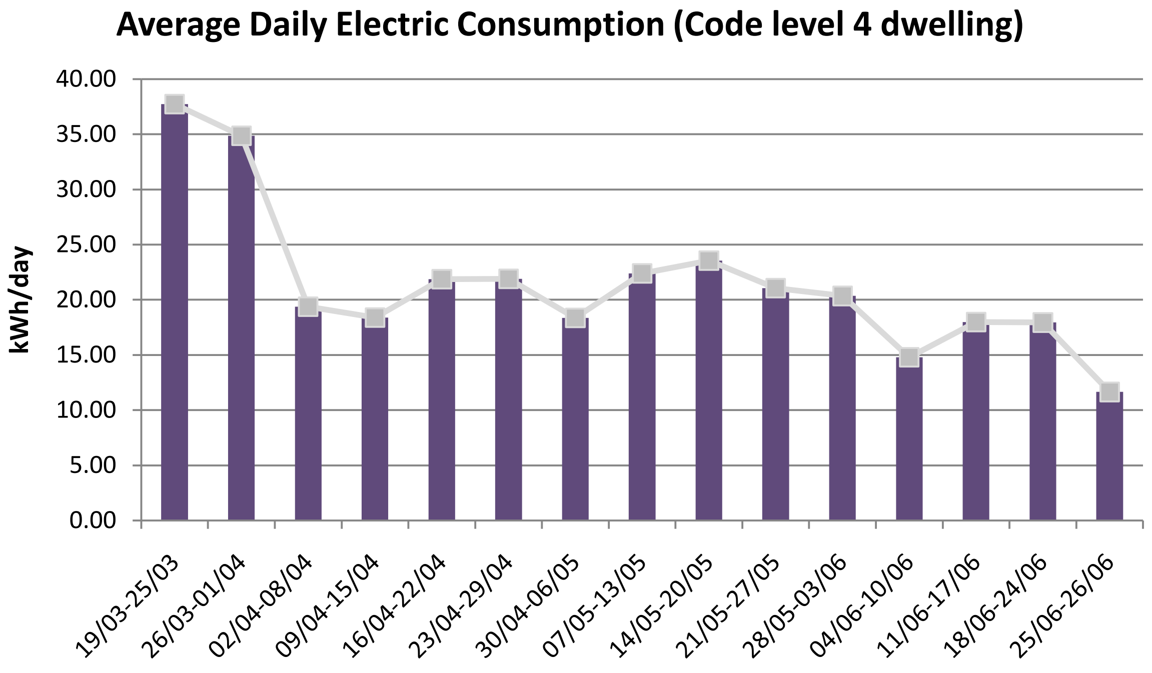


Figure 18: Average daily (total) electric consumption of Code Level 4 house on a weekly basis

Back, to the missing kWh and human factor, one thing that we should highlight for this Code Level 4 dwelling is that we have considered natural ventilation and an effective change of 0.50ac/h. However, it is hard to maintain 0.505ac/h by naturally ventilate a dwelling. Consequently, this must have an impact on space heating requirement, apart from occupants' health.

In an attempt to investigate the above, we focused on CO_2 concentration inside the house. It has been found that CO_2 concentration is remarkably high (Table 16). In fact, 54.7% of the monitoring period the concentration was more than 1000ppm –this upper limit has been based on CIBSE recommendation for a medium quality of indoor air (Dwyer, 2011). This means occupants do not open windows regularly or enough time. Therefore, it can be considered that air change rate is less than 0.505ac/h and consequently, there is need for less energy to heat the building. Hence, that lower figure for energy consumption of monitored data comparing to PHPP can be justified.

Table 16: CO_2 concentration

	Code Level 4	Passive House
Average concentration	1060.1 ppm	594.3 ppm
Maximum concentration	2231 ppm	1384 ppm
Minimum concentration	422 ppm	401 ppm
More than 900ppm	65.6%	3.4%
More than 1000ppm	54.7%	1.7%

COMPARISON WITH ELECTRIC BILLS (PART 2)

Finally, with regard to energy bills and the monitored data of Passive House, the situation is as follows. From the monitored period 19/03-26/06 that has been examined, according to the electric meter, the total consumption was 1020.7kWh.

Similarly to the methodology used in the previous comparison to energy bills (COMPARISON WITH ELECTRIC BILLS – Table 12), one could say that the expected energy consumption should have been 704.8kWh for this period assuming internal temperature 18^{o}C, 19mm of insulation and MVHR running at max mode. However, taking into consideration the 5.8kWh/day due to erroneous solar installation corrected for the winter period as described in Comparison with electric bills (Part 1) section, the total electric consumption should have been 1279.0kWh; in other words, a deviation of -25.3% which can be due to the last assumption, due the temperature assumption or because of human impact on energy.

DISCUSSION OF RESULTS

Summarising the for-mentioned results, it is clear that there are significant differences between the two methodologies examined. Some due to different principles, some due to the different scale of details required, and some due to different standard values they take into account.

The results has been divided into two categories; based on direct comparison between the two methodologies in terms of space heating, DHW and CO_2 emissions, and based on comparison with actual data, reality.

PHPP vs SAP

Space Heating

Based on the presented investigation, SAP expects a dwelling to require less energy for space heating mainly because it takes into account significantly higher *internal heat gains*. In fact, whenever IHG were modified there was a radical drop in heating demand. The reasons these gains are higher have been outlined earlier.

Moreover, a second factor that has a major impact on space heating has been proved to be climate. By applying the same *climate and internal gains* as in SAP at the same time, PHPP gave the same value for space heating demand as SAP.

Additionally, it has been shown that *internal heat gains and effective air change rate* not only they influence space heating energy but also in case of a very air-tight building, such as the Passive House examined, it reduces space heating demand dramatically; on the contrary, with regard to a less air-tight house, such as the Code Level 4 dwelling, although those two factors decrease space heating demand, as well, they bring it significantly closer to SAP value.

Furthermore, as far as the detailed inputs are concerned, it has been showed that it is not only local climate data that PHPP allows one to select which differentiate the two methodologies. Shading, plumbing or duct details influence the result as well. However, a factor that both SAP and PHPP consider in a different scale is the *orientation of windows*. As it has been illustrated, the effect of the detailed input of windows orientation in PHPP is greater in case of Passive House.

Domestic Hot Water

As far as the hot water is concerned, apart from the different daily volume of water that they consider, the two methodologies consider *different solar contribution* as well. The latter has been proved by a direct comparison of the results of SAP and PHPP. From this comparison, it derived that PHPP considers higher solar contribution than SAP and based on third part's monitored data for Dublin we could characterise PHPP as optimistic in this particular section. However, despite Dublin has only a slightly different climate and since our data did not allow us to verify this, we have to be sceptical with this. Further investigation of more monitored houses with solar panels should take place.

On the other hand, in case of the second dwelling which did not have any solar panels, the comparison with monitored data indicated that *PHPP predicted approximately the same energy use for heating water as actual data* for Code Level 4 dwelling.

CO_2 Emissions

Regarding to CO_2 emissions, the real concern is not that they use *different primary energy factors*; it has to do with the *omission of household appliances* use –in terms of CO_2 emissions– by SAP, apart from the dissimilar energy demand.

The gap between the two methodologies is not so wide for the ultra low-energy house as it is for the Code 4 House. Therefore, this can be considered as a optimistic evidence that the two methodologies could find a golden mean, at least for new-built low-energy dwellings. However, there are two points of interest that need to be considered. Firstly, should appliances carbon emissions be included or space and water heating carbon emissions are sufficient? The second issue is that, no matter the answer to the previously posed question, same emissions should be applied in the two methodologies.

Hence, one could argue that Passive House is more sensitive to certain negligible for SAP, but significant to PHPP, changes. Moreover, although SAP relies on annual running costs to rate a dwelling, it seems that it is not so close to reality as PHPP is, at least for space heating demand of an ultra low-energy house.

PHPP vs Actual Data

An additional interesting point risen from the investigation is that there are several reasons that predicted energy use diverges from reality; from *technical issues* to *human behaviour*. These can be a non-working appliance, imprecise application of designed details, misuse or misunderstanding of systems and appliances, or even a non-standard human occupancy with remarkable fluctuations. Especially for Passive Houses, designing construction details is not enough; their application is of outmost importance having an impact on moisture or air-tightness and consequently on energy consumption.

As far as comparison between predicted energy use and electricity bill is concerned, it has shown a significant deviation. That is due to the mentioned problems and issues in the Passive House we examine. In order to 'simulate' reality in PHPP we made certain modifications. We concluded in figures that deviation from reality –from the energy consumption according to bill– between was from -26 to -9%. Such diversions are because of the lack of evidence of interior temperature during the billing period (note that monitoring data began after the bill had been issued) or of human factors such as frequency of windows opening or occupants personal preference for indoor temperature, as in case of Code level 4 House.

Generally, it should be mentioned that in annual basis, SAP concluded in less energy consumption than PHPP and consequently lower running costs and considerably less close to reality.

Furthermore, the elaboration of monitored data has illustrated and provided evidence for several issues as well. Concerning the Passive House data, it has been shown that there was something wrong with the installation of solar water feed; cold water feed triggers solar water flow and brings water from solar panels even if it is cold. In fact, this issue has been identified by three different methods: by correlation, by 'graphic-visual' method of data and by comparing weekly average consumption. In addition, the latter has revealed an alteration in occupancy, which has been confirmed by the occupants.

Human factor has played a significant role in Code Level 4 dwelling as well. Data elaboration showed that the average interior temperature was 1.2 and 2^{o}C higher than PHPP and SAP considered temperature, respectively. It should be underlined one more time that in case of this dwelling, significant details for PHPP were missing and assumptions needed to be made such as the length or the insulation. The most interesting issue for this dwelling has been that based on carbon dioxide concentration data monitored in living room it seems that occupants do not open as much the windows so that the 0.505ac/h could be achieved. Consequently, this has lead to lower energy for space heating.

CONCLUSION

Arriving at the end of this study and having summarised the results, we should highlight the main findings as well as the answers to the critical questions posed at the beginning of the thesis.

First of all, it has been proved that major factors that influence PHPP and make the gap between PHPP and SAP wider are the following:

- Internal gains
- Climate data and internal gains
- Effective air change rate and internal gains
- Detailed input – particularly orientation of windows
- Solar contribution

Secondly, as far as the reasons for which actual energy use fails to meet the predicted consumption from SAP and PHPP methodology are concerned, one could conclude that they have different roots as outlined below:

- Technical errors
  - Construction not as designed
  - Non working appliances
  - Erroneous installation of systems

- Human factors
  - Misuse or misunderstanding of systems/appliances principles
  - Non-standard occupancy, absence
  - Personal preference for interior temperature
  - Frequency and duration of windows opening

Moreover, according to results illustrated earlier, although PHPP seems to underestimate actual energy consumption, it predicts running costs closer to reality comparing to SAP which relies on these costs to assess buildings energy efficiency. As for the carbon dioxide emissions, the main factor that makes the two methodologies diverge is the predicted energy consumption; same CO_2 equivalent factors could be easily be adopted by the two methodologies.

Ultimately and more significantly, is Passive House standard to be a new standard for EU countries, government's approach for energy assessment of buildings needs to be reconsidered; details that SAP overlooks and disregards are essential when it comes to a Passive House.

FURTHER WORK

The theme of this thesis is generally broad and further analysis is required in different levels. Firstly, in order to conclude to more safe results there is need to analyse monitored data from more Passive Houses in UK –as wells as from dwellings with different level of insulation– and apply the methodology to them. Monitored data from dwellings with solar thermal installation would be beneficial as well in order to conclude whether SAP or PHPP is more accurate.

A next significant step could be a calculation for uncertainty taking into account all the mentioned factors which make predicted energy differ from actual.

Furthermore, as far as Passive House standard is concerned, a topic for study could be a method to set levels-targets for CO_2 emissions of Passive House either based on annual energy use only or on lifetime emissions.

Finally, as mentioned in the beginning, it would be useful to modify PHPP so that it could accommodate or integrate SAP rating.

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APPENDICES

APPENDIX A – PHPP FOR PASSIVE HOUSE

Passive House Verification

Building:	Bethania, Typ D (Plot 15)	
Location and Climate:	Northern Europe	GB-Glasgow
Street:	Bullwood Road	
Postcode/City:	PA23 7QL, Dunoon, Argyll	
Country:	Scotland	
Building Type:	End-terraced	
Home Owner(s) / Client(s):	Fyne Initiatives Ltd	
Street:		
Postcode/City:		
Architect:	*EIRINI MOUTZURI*	
Street:		
Postcode/City:		
Mechanical System:		
Street:		
Postcode/City:		

No Standard Climate

Year of Construction:	2009				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	446.7	m^3	Internal Heat Gains:	2.1	W/m²
Number of Occupants:	2.5				

Calculation Electricity / Internal Heat Gains

Building Type: Residential

Internal Heat Gains

Utilisation Pattern: Dwelling

Type of Values Used: Standard

Planned Number of Occupants: 3 — Design

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area: 88.5 m^2

	Applied:	Monthly Method	PH Certificate:		Fulfilled?
Specific Space Heat Demand:	21	$kWh/(m^2a)$	15 $kWh/(m^2a)$		No
Pressurization Test Result:	0.2	h^{-1}	0.6 h^{-1}		Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	95	$kWh/(m^2a)$	120 $kWh/(m^2a)$		Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	57	$kWh/(m^2a)$			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	$kWh/(m^2a)$			
Heating Load:	10	W/m^2			
Frequency of Overheating:	3	%	over	25 °C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$	15 $kWh/(m^2a)$		
Cooling Load:	8	W/m^2			

Verification: Monthly Method

Specific Space Heat Demand, Annual Method	20.9
Specific Space Heat Demand, Monthly Method	20.9

Passive House Planning

VENTILATION DATA

Building: Bethania, Typ D (Plot 15)

Treated Floor Area A_{TFA}	m²	89	(Areas worksheet)
Room Height h	m	2.5	(Annual Heat Demand worksheet)
Room Ventilation Volume (A_{TFA}*h) = V_V	m³	221	(Annual Heat Demand worksheet)

Ventilation System Design - Standard Operation

Occupancy	m²/P	35					
Number of Occupants	P	2.5					
Supply Air per Person	m³/(P*h)	30					
Supply Air Requirement	m³/h	75					
Extract Air Rooms		Kitchen	Bathroom	Shower	WC		
Quantity		1	1	0	1		
Extract Air Requirement per Room	m³/h	40	40	20	20		
Total Extract Air Requirement	m³/h	100					
Design Air Flow Rate (Maximum)	m³/h	100					

Average Air Change Rate Calculation

Type of Operation	Daily Operation Duration h/d	Factors Referenced to Maximum	Air Flow Rate m³/h	Air Change Rate 1/h
Maximum		1.00	100	0.45
Standard	24.0	0.77	77	0.35
Basic	0.0	0.54	54	0.24
Minimum		0.40	40	0.18
x Residential Building	Average value	0.77	Average Air Flow Rate (m³/h): 77	Average Air Change Rate (1/h): 0.35

Infiltration Air Change Rate according to EN 13790

Wind Protection Coefficients According to EN 13790		
Coefficient e for Screening Class	Several Sides Exposed	One Side Exposed
No Screening	0.10	0.03
Moderate Screening	0.07	0.02
High Screening	0.04	0.01
Coefficient f	15	20

		for Annual Demand:	for Heat Load:		
Wind Protection Coefficient, e		0.07	0.18		
Wind Protection Coefficient, f		15	15	Net Air Volume for Press. Test V_{n50}	Air Permeability q_{50}
Air Change Rate at Press. Test n_{50}	1/h	0.20	0.20	317 m³	0.21 m³/(hm²)

Type of Ventilation System

		Please Check	for Annual Demand:	for Heat Load:
Balanced PH Ventilation				
Pure Extract Air				
Excess Extract Air		1/h	0.00	0.00
Infiltration Air Change Rate $n_{V,Res}$		1/h	0.020	0.050

ve Heat Recovery Efficiency of the Ventilation System with Heat Recovery

Central unit within the thermal envelope.

Central unit outside of the thermal envelope.

Efficiency of Heat Recovery	η_{HR}		0.92	thermos 200 DC - Paul
Transmittance Ambient Air Duct	Ψ	W/(mK)	0.189	Calculation see Secondary Calculation
Length Ambient Air Duct		m	6	
Transmittance Exhaust Air Duct	Ψ	W/(mK)	0.189	Calculation see Secondary Calculation
Length Exhaust Air Duct		m	6.5	Room Temperature (°C): 20
Temperature of Mechanical Services Room		°C		Av. Ambient Temp. Heating P. (°C): 7.6
(Enter only if the central unit is outside of the thermal envelope.)				Av. Ground Temp (°C): 11.2

ve Heat Recovery Efficiency $\eta_{HR,eff}$ **83.3%**

ve Heat Recovery Efficiency Subsoil Heat Exchanger

SHX Efficiency	η^*_{SHX}	0%
Heat Recovery Efficiency SHX	η_{SHX}	0%

RTIFIED HEAT RECOVERY UNITS

Heat Recovery Unit	Heat Recovery Efficiency %	Electric Efficiency Wh/m³
- User defined -		
RegaVent	70%	0.63
Compact unit as selected in Compact work	kg/a	
Reco-Boxx COMFORT - AEREX	85%	0.35
Comfoair 500 - StorkAir	88%	0.42
aeronom WS 250 - MAICO	85%	0.35
thermos 200 DC - Paul	92%	0.36
atmos 175 DC - Paul	88%	0.30
multi 100 DC - Paul	79%	0.36
multi 150 DC - Paul	79%	0.36
climos 100 DC - Paul	82%	0.41
climos 150 DC - Paul	82%	0.41
campus 500 DC - Paul	83%	0.28
INNOAIR 255 DC - Sachsenland Bauelemente	88%	0.30
Recovery Deluxe 250P - Schrag	83%	0.29
TSL 150 G / DC - Schmeißer	84%	0.31
Comfoair flat 150 - Zehnder	82%	0.41
WRA 400 PHZ - Ned Air	77%	0.39

Secondary Calculation:
Ψ-value Supply or Ambient Air Duct

Nominal Width	125	mm
Insul. Thickness:	140	mm
Reflective? Please mark with an "x"!		
x	Yes	
	No	
Thermal Conductivity	0.04	W/(mK)
Nominal Air Flow Rate	77	m³/h
Δϑ	12	K
Interior Duct Diameter	0.125	m
Interior Diameter	0.125	m
Exterior Diameter	0.405	m
α-Interior	9.10	W/(m²K)
α-Surface	2.31	W/(m²K)
Ψ-value	0.189	W/(mK)
Surface Temperature Difference	1.447	K

Secondary Calculation:
Ψ-value Extract or Exhaust Air Duct

Nominal Width	125	mm
Insul. Thickness:	140	mm
Reflective? Please mark with an "x"!		
x	Yes	
	No	
Thermal Conductivity	0.04	W/(mK)
Nominal Air Flow Rate	77	m³/h
Δϑ	12	K
Interior Duct Diameter	0.12500	m
Exterior Duct Diameter	0.12500	m
Exterior Diameter	0.40500	m
α-Interior	9.10	W/(m²K)
α-Surface	2.31	W/(m²K)
Ψ-value	0.189	W/(mK)
Surface Temperature Difference	1.447	K

Passive House Planning

SPECIFIC ANNUAL HEAT DEMAND MONTHLY METHOD

(This page displays the sums of the monthly method over the heating period)

Climate: GB-Glasgow — Interior Temperature: 20 °C
Building: Bethania, Typ D (Plot 15) — Building Type/Use: End-terraced
Location: Northern Europe — Treated Floor Area A_{TFA}: 88.5 m²
Spec. Capacity: 80 Wh/(m²K) (Enter in "Summer" worksheet.)

	Building Element	Temperature Zone	Area m²	U-Value W/(m²K)		Month. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area
1.	Exterior Wall - Ambient	A			*	1.00	*	86	=	971	
2.	Exterior Wall - Ground	B			*	1.00	*		=		
3.	Roof/Ceiling - Ambient	A			*	1.00	*	86	=	743	
4.	Floor Slab	B			*	1.00	*	64	=	617	
5.		A			*	1.00	*		=		
6.		A			*	1.00	*		=		
7.	Wall to porch	X			*	0.50	*	86	=	17	
8.	Windows	A			*	1.00	*	86	=	1890	
9.	Exterior Door	A			*	1.00	*	86	=	230	
10.	Exterior TB (length/m)	A			*	1.00	*		=		
11.	Perimeter TB (length/m)	P			*	1.00	*		=		
12.	Ground TB (length/m)	B			*	1.00	*		=		

ransmission Heat Losses Q_T — Total 4468 kWh/a — 50.5 kWh/(m²a)

Effective Air Volume V_{RAX}: A_{TFA} 89 m² * Clear Room Height 2.50 m = 221 m³

	$n_{V,system}$ 1/h		η_{*SHX}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h
lective Air Change Rate Ambient $n_{V,e}$	0.348	*(1-	0%	)*(1-	0.83	)+	0.020	=	0.078
lective Air Change Rate Ground $n_{V,g}$	0.348	*	0%	*(1-	0.83	)		=	0.000

	V_{RAX} m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
entilation Losses Ambient Q_V	221	*	0.078	*	0.33	*	86	=	489	5.5
entilation Losses Ground $Q_{V,e}$	221	*	0.000	*	0.33	*	64	=	0	0.0

entilation Heat Losses Q_V — Total 489 kWh/a — 5.5 kWh/(m²a)

otal Heat Losses Q_L: (Q_T 4468 kWh/a + Q_V 489 kWh/a) * Reduction Factor Night/Weekend Saving 1.0 = 4957 kWh/a — 56.0 kWh/(m²a)

	Orientation of the Area	Reduction Factor See Windows worksheet		g-Value (perp. radiation)		Area m²		Global Radiation kWh/(m²a)		kWh/a
1.	North	0.46	*	0.45	*	0.8	*	510	=	81
2.	East	0.44	*	0.51	*	8.6	*	669	=	1291
3.	South	0.27	*	0.47	*	4.4	*	899	=	510
4.	West	0.18	*	0.51	*	6.4	*	447	=	264
5.	Horizontal	0.40	*	0.00	*	0.0	*	872	=	0
6.	Sum Opaque Areas									0

Available Solar Heat Gains Q_S — Total 2145 kWh/a — 24.2 kWh/(m²a)

Internal Heat Gains Q_I: 0.024 kh/d * Length Heat. Period 365 d/a * Spec. Power q_I 2.1 W/m² * A_{TFA} 88.5 m² = 1629 kWh/a — 18.4 kWh/(m²a)

Free Heat Q_F: Q_S + Q_I = 3774 kWh/a — 42.6 kWh/(m²a)

Ratio Free Heat to Losses: Q_F / Q_L = 0.76

Utilisation Factor Heat Gains η_G = 82%

Heat Gains Q_G: η_G * Q_F = 3108 kWh/a — 35.1 kWh/(m²a)

Annual Heat Demand Q_H: Q_L - Q_G = 1848 kWh/a — **21** kWh/(m²a)

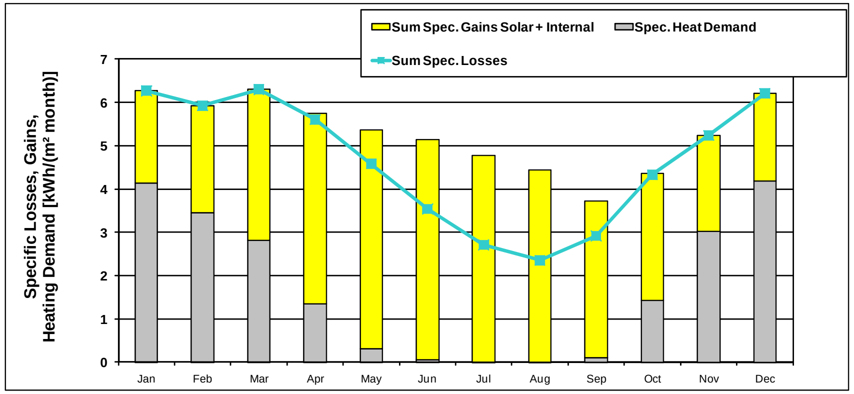
Limiting Value: 15 kWh/(m²a) — Requirement met? (Yes/No): **No**

PASSIVE HOUSE PLANNING

SPECIFIC ANNUAL HEAT DEMAND MONTHLY METHOD

Climate: GB-Glasgow — Interior Temperature: 20 °C
Building: Bethania, Typ D (Plot 15) — Building Type/Use: End-terraced
Location: Northern Europe — Treated Floor Area A_{TFA}: 89 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - E	9.7	9.2	9.7	8.6	6.9	5.3	3.9	3.4	4.3	6.7	8.2	9.7	86	kKh
Heating Degree Hours - G	6.5	6.1	6.7	6.2	5.8	4.9	4.6	3.7	4.1	4.6	5.1	5.9	64	kKh
Losses - Exterior	493	466	493	437	350	266	196	173	219	339	415	493	4340	kWh
Losses - Ground	62	59	65	59	56	48	44	35	40	45	49	57	617	kWh
Sum Spec. Losses	6.3	5.9	6.3	5.6	4.6	3.5	2.7	2.4	2.9	4.3	5.2	6.2	56.0	kWh/m²
Solar Gains - North	1	2	5	9	14	15	14	10	6	3	1	1	81	kWh
Solar Gains - East	29	56	101	158	184	196	168	154	107	75	37	25	1291	kWh
Solar Gains - South	15	27	45	60	68	64	61	57	48	33	19	13	510	kWh
Solar Gains - West	5	9	20	29	43	40	40	33	25	11	6	3	264	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Internal Heat Gains	138	125	138	134	138	134	138	138	134	138	134	138	1629	kWh
Sum Spec. Gains Solar +	2.1	2.5	3.5	4.4	5.0	5.1	4.8	4.4	3.6	2.9	2.2	2.0	42.6	kWh/m²
Utilisation Factor	100%	100%	100%	97%	85%	69%	57%	53%	78%	99%	100%	100%	82%	
Annual Heat Demand	367	306	250	119	28	5	1	0	10	126	267	370	1848	kWh
Spec. Heat Demand	**4.1**	**3.5**	**2.8**	**1.3**	**0.3**	**0.1**	**0.0**	**0.0**	**0.1**	**1.4**	**3.0**	**4.2**	**20.9**	kWh/m²



Annual Heat Demand: Comparison

EN 13790 Monthly Method	**1848**	**kWh/a**	**20.9**	**kWh/(m²a) Reference to habitable area**
PHPP, Heating Period Method	**1846**	**kWh/a**	**20.9**	**kWh/(m²a) Reference to habitable area**

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total	Heating Period Method
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	205
Ambient Temp.	6.90	6.30	6.90	8.00	10.70	12.70	14.79	15.40	14.00	11.00	8.60	6.90	10.2	7.6
North Radiation	5.0	9.0	19.0	28.0	44.0	48.0	47.0	34.0	21.0	13.0	6.0	4.0	278	116
East Radiation	9.0	20.0	41.0	71.0	89.0	98.0	83.0	73.0	45.0	29.0	12.0	7.0	577	223
South Radiation	30.0	49.0	74.0	91.0	92.0	87.0	82.0	80.0	74.0	58.0	36.0	27.0	780	342
West Radiation	12.0	21.0	44.0	62.0	85.0	78.0	77.0	67.0	53.0	27.0	15.0	8.0	549	124
Hori. Radiation	13.0	28.0	61.0	103.0	140.0	145.0	134.0	109.0	71.0	40.0	18.0	10.0	872	240
Tsky	-3.60	-4.60	-3.30	-2.73	0.10	2.80	5.40	6.30	5.00	2.00	-1.10	-3.30	0.3	
Ground Temp	11.31	10.90	10.94	11.43	12.23	13.13	13.88	15.09	14.25	13.77	12.97	12.07	12.7	11.8

Passive House Planning

SPECIFIC SPACE HEATING LOAD

Building:	Bethania, Typ D (Plot 15)	Building Type/Use:	End-terraced
Location:	Northern Europe	Treated Floor Area A_{TFA}:	88.5 m²
		Interior Temperature:	20
		Climate (HL):	GB-Glasgow

	Design Temperature		Radiation: North	East	South	West	Horizontal	
Weather Condition 1:	0.4	°C	15	20	30	20	25	W/m²
Weather Condition 2:	5.0	°C	5	5	5	5	5	W/m²
Ground Design Temp.	10.2	°C						

	Building Element	Temperature Zone	Area	U-Value	Factor	TempDiff 1		TempDiff 2		P_T 1		P_T 2
			m²	W/(m²K)	Always 1 (except "X")	K		K		W		W
1.	Exterior Wall - Ambie	A		0.094	* 1.00	* 19.6	or	15.0	=	222	or	170
2.	Exterior Wall - Groun	B			* 1.00	* 9.8	or	9.8	=		or	
3.	Roof/Ceiling - Ambien	A		0.094	* 1.00	* 19.6	or	15.0	=	170	or	130
4.	Floor Slab	B		0.154	* 1.00	* 9.8	or	9.8	=	94	or	94
5.		A			* 1.00	* 19.6	or	15.0	=		or	
6.		A			* 1.00	* 19.6	or	15.0	=		or	
7.	Wall to porch	X		0.094	* 0.50	* 19.6	or	15.0	=	4	or	3
8.	Windows	A		1.093	* 1.00	* 19.6	or	15.0	=	432	or	331
9.	Exterior Door	A		1.160	* 1.00	* 19.6	or	15.0	=	53	or	40
10.	Exterior TB (length/m)	A			* 1.00	* 19.6	or	15.0	=		or	
11.	Perimeter TB (length/m)	P			* 1.00	* 9.8	or	9.8	=		or	
12.	Ground TB (length/m)	B			* 1.00	* 9.8	or	9.8	=		or	
13.	House/DU Partition Wall	I		0.094	* 1.00	* 0.0	or	0.0	=	0	or	0

Transmission Heat Losses P_T

Total	=	974	or	768

Ventilation System:

	A_{TFA}		Clear Room Height		
	m²		m		m³
Effective Air Volume, V_V	88.5	*	2.50	=	221

					η_{SHX} 1		η_{SHX} 2
Efficiency of Heat Recovery of the Heat Exchanger	η_{HR} 83%	Heat Recovery Efficiency SHX	0%	Efficiency SHX	0%	or	0%

	$n_{V,Res}$ (Heating Load)		$n_{V,system}$		Φ_{HR}		Φ_{HR}				
	1/h		1/h						1/h		1/h
Energetically Effective Air Exchange n_V	0.050	+	0.348	*(1-	0.83	or	0.83	) =	0.108	or	0.108

Ventilation Heating Load P_V

V_L		n_L		n_L		c_{Air}		TempDiff 1		TempDiff 2		P_V 1		P_V 2
m³		1/h		1/h		Wh/(m³K)		K		K		W		W
221.3	*	0.108	or	0.108	*	0.33	*	19.6	or	15.0	=	155	or	118

Total Heating Load P_L

		P_L 1		P_L 2
		W		W
$P_T + P_V$	=	1129	or	886

	Orientation the Area	Area		g-Value (perp. radiation)		Reduction Factor (see Windows worksheet)		Radiation 1		Radiation 2		P_S 1		P_S 2
		m²						W/m²		W/m²		W		W
1.	North	0.8	*	0.5	*	0.5	*	16	or	5	=	2	or	1
2.	East	8.6	*	0.5	*	0.4	*	23	or	5	=	45	or	10
3.	South	4.4	*	0.5	*	0.3	*	32	or	5	=	18	or	3
4.	West	6.4	*	0.5	*	0.2	*	17	or	5	=	10	or	3
5.	Horizontal	0.0	*	0.0	*	0.4	*	25	or	5	=	0	or	0

Solar Heat Gain, P_S

Total	=	76	or	16

Internal Heat Gains P_I

Spec. Power		A_{TFA}		P_I 1		P_I 2
W/m²		m²		W		W
1.6	*	89	=	142	or	142

Heat Gains P_G

		P_G 1		P_G 2
		W		W
$P_S + P_I$	=	218	or	158
$P_L - P_G$	=	911	or	728

Heating Load P_H

= **911** W

Specific Heating Load P_H / A_{TFA}

= **10.3** W/m²

Passive House Planning

HEAT DISTRIBUTION AND DHW SYSTEM

Building:	Bethania, Typ D (Plot 15)	
Location:	Northern Europe	
Interior Temperature:	20	°C
Building Type/Use:	End-terraced	
Treated Floor Area A_{TFA}:	89	m²
Occupancy:	2.5	Pers
Number of Residences:	1	
Annual Heat Demand $q_{Heating}$:	1848	kWh/a
Length of Heating Period:	205	d
Average Heat Load P_{ave}:	0.4	kW
Marginal Utilisability of Additional Heat Gains:	94%	

			Parts: Warm Region 1	Cold Region 2	Cold Region 3	Total		
Space Heat Distribution								
Length of Distribution Pipes	L_H	*(Project)*					m	
Heat Loss Coefficient per m Pipe	Ψ	*(Project)*					W/(mK)	
Temperature of the Room Through Which the Pipe	ϑ_X	*Mechanical Room*	20				°C	
Design Flow Temperature	ϑ_{dist}	*Flow, Design Value*					°C	
Design System Heat Load	$P_{heating}$	*(exist./calc.)*					kW	
Flow Temperature Control (check)								
Design Return Temperature	ϑ_R	$=0.714*(\vartheta_{dist}-20)+20$					°C	
Annual Heat Emission per m of Plumbing	q^*_{HL}	$=\Psi\ (\vartheta_m-\vartheta_X)\ t_{Heating}*0.0$				Total 1,2,3	kWh/(m·a)	
Possible Utilization Factor of Released Heat	η_G						-	
Annual Losses	Q_{HL}	$= L_H \cdot q^*_{HL} \cdot (1-\eta_G)$	0	0	0	0	kWh/a	
Specif. Losses	q_{HL}	$= \Sigma Q_{HL} / A_{TFA}$					kWh/(m²a)	0.0
Utilisation Factor of Space Heat Distribution	$h_{a,HL}$	$= q_H / (q_H + q_{HL})$				100%	-	

			Total		
DHW: Standard Useful Heat					
DHW Consumption per Person and Day (60 °C)	V_{DHW}	*(Project or Average Value 25 Litres/P/d)*	25.0	Litre/Person/d	
Average Cold Water Temperature of the Supply	ϑ_{DW}	*Temperature of Drinking Water (10°)*	10.0	°C	
DHW Non-Electric Wash and Dish		*(Electricity worksheet)*	180	kWh/a	
Useful Heat - DHW	Q_{DHW}		1503	kWh/a	
Specif. Useful Heat - DHW	q_{DHW}	$= Q_{DHW} / A_{TFA}$		kWh/(m²a)	17.0

			Warm Region	Cold Region		Total		
DHW Distribution and Storage								
Length of Circulation Pipes (Flow + Return)	L_{HS}	*(Project)*	0.0				m	
Heat Loss Coefficient per m Pipe	Ψ	*(Project)*	0.163				W/m/K	
Temperature of the Room Through Which the Pipe	ϑ_X	*Mechanical Room*	20				°C	
Design Flow Temperature	ϑ_{dist}	*Flow, Design Value*	60.0				°C	
Daily circulation period of operation.	td_{Circ}	*(Project)*	0.0				h/d	
Design Return Temperature	ϑ_R	$=0.875*(\vartheta_{dist}-20)+20$	55				°C	
Circulation period of operation per year	t_{Circ}	$= 365\ td_{Circ}$	0				h/a	
Annual Heat Released per m of Pipe	q^*_Z	$=\Psi\ (\vartheta_m-\vartheta_X)\ t_{Circ}$	0.0				kWh/m/a	
Possible Utilization Factor of Released Heat	η_{GDHW}	$=t_{heating}/365d * \eta_G$	52.4%				-	
Annual Heat Loss from Circulation Lines	Q_Z	$= L_{HS} \cdot q^*_Z \cdot (1-\eta_{GDHW})$	0			0	kWh/a	
Total Length of Individual Pipes	L_U	*(Project)*	27.00				m	
Exterior Pipe Diameter	d_{U_Pipe}	*(Project)*	0.018				m	
Heat Loss Per Tap Opening	$q_{Individual}$	$=(c_{pH2O}V_{H2O}+c_{pMat}V_{Mat})(\vartheta_{dist}-\vartheta$	0.2461				kWh/tap opening	
Occupancy Coefficient	n_{Tap}	$= n_{Pers} . 3 . 365 / n_{LU}$	2738				Tap openings per year	
Annual Heat Loss	q_U	$= n_{Tap} \cdot q_{Individual}$	673.6				kWh/a	
Possible Utilization Factor of Released Heat	η_{G_U}	$=t_{heating}/8760*\eta_G$	52.4%				-	
Annual Heat Loss of Individual Pipes	Q_U	$= q_U \cdot (1-\eta_{G\_U})$	320.4			320	kWh/a	
						Total 1,2,3		
Average Heat Released From Storage	P_S		78.0				W	
Possible Utilization Factor of Released Heat	η_{G_S}	$=t_{heating}/8760*\eta_G$	52.4%					
Annual Heat Losses from Storage	Q_S	$= P_S \cdot 8.760\ kh \cdot (1-\eta_{G\_S})$	325.1			325	kWh/a	
						Total 1,2,3		
Total Heat Losses of the DHW System	Q_{WL}	$= Q_Z+Q_U+Q_S$				646	kWh/a	
Specif. Losses of the DHW System	q_{WL}	$= Q_{WL} / A_{TFA}$					kWh/(m²a)	7.3
Utilisation Factor DHW Distrib and Storage	$\eta_{a,WL}$	$= q_{DHW} / (q_{DHW} + q_{WV})$				70.0%	-	
Total Heat Demand of DHW system	Q_{gDHW}	$= Q_{DHW}+Q_{WL}$				2149	kWh/a	
Total Spec. Heat Demand of DHW System	q_{gDHW}	$= Q_{gDHW} / A_{TFA}$					kWh/(m²a)	24.3

Passive House Planning

HOT WATER PROVIDED BY SOLAR

Building:	Bethania, Typ D (Plot 15)	Building Type/Use:	End-terraced
Location:	Northern Europe	Treated Floor Area A_{TFA}:	88.5 m²

Solar Fraction with DHW Demand including Washing and Dish-Washing

Heat Demand DHW	q_{gDHW}	2149	kWh/a	from DHW+Distribution worksheet
Latitude:		55.9	°	from Climate Data worksheet
Selection of collector from list (see below):		5	Selection:	M08
Solar Collector Area		4.55	m²	
Deviation from North		163	°	
Angle of Inclination from the Horizontal		45	°	
Height of the Collector Field			m	
Height of Horizon	h_{Hori}		m	
Horizontal Distance	a_{Hori}		m	
Additional Reduction Factor Shading	r_{other}	100%	%	
Occupancy		2.5	Persons	
Specific Collector Area		1.8	m²/Pers	

Estimated Solar Fraction of DHW Production	**54%**			
Solar Contribution to Useful Heat	**1167**	kWh/a	**13**	kWh/(m²a)

Secondary Calculation of Storage Losses

Selection of DHW storage from list (see below):	1	Selection:	TFF 200
Total Storage Volume	180	litre	
Volume Standby Part (above)	54	litre	
Volume Solar Part (below)	126	litre	
Specific Heat Losses Storage (total)	2.6	W/K	
Typical Temperature DHW	60	°C	
Room Temperature	20	°C	
Storage Heat Losses (Standby Part Only)	78	W	
Total Storage Heat Losses	104	W	

Passive House Planning

PRIMARY ENERGY VALUE

Building:	Bethania, Typ D (Plot 15)	Building Type/Use:	End-terraced
Location:	Northern Europe	Treated Floor Area A_{TFA}:	89 m²
		Space Heat Demand incl. Distribution	21 kWh/(m²a)
		Useful Cooling Demand:	0 kWh/(m²a)

			Final Energy	Primary Energy	Emissions CO_2-Equivalent
			kWh/(m²a)	kWh/(m²a)	kg/(m²a)
Electricity Demand (without Heat Pump)				PE Value	CO_2-Emissions Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		*(Project)*	10%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	100%	2.6	680
Direct Electric Heating	$Q_{H,de}$		2.1	5.4	1.4
DHW Production, Direct Electric (without Wash&Dish)	$Q_{DHW,de}$	*(DHW+Distribution, SolarDHW)*	9.7	25.2	6.6
Electric Postheating DHW Wash&Dish		*(Electricity, SolarDHW)*	1.4	3.6	1.0
Electricity Demand Household Appliances	Q_{EHH}	*(Electricity worksheet)*	13.5	35.1	9.2
Electricity Demand - Auxiliary Electricity			2.5	6.4	1.7
Total Electricity Demand (without Heat Pump)			29.1	75.7	19.8
Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		*(Project)*	90%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	2.6	680
Energy Carrier - Supplementary Heating			Electricity	2.7	680
Annual Coefficient of Performance - Heat Pump		*Separate Calculation*	2.50		
Total System Performance Ratio of Heat Generator		*Separate Calculation*	0.40		
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}		7.5	19.5	5.1
Non-Electric Demand, DHW Wash&Dish		*(Electricity worksheet)*	0.0	0.0	0.0
Total Electricity Demand Heat Pump			7.5	19.5	5.1
Compact Heat Pump Unit				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	2.6	680
Energy Carrier - Supplementary Heating			Electricity	2.7	680
COP Heat Pump Heating		*(Compact worksheet)*	0.0		
COP Heat Pump DHW		*(Compact worksheet)*	0.0		
Performance Ratio of Heat Generator (Verification)		*(Compact worksheet)*			
Performance Ratio of Heat Generator (Planning)		*(Compact worksheet)*			
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}	*(Compact worksheet)*	0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish			0.0	0.0	0.0
Total Compact Unit		*(Compact worksheet)*	0.0	0.0	0.0
Boiler				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	1.1	250
Boiler Type		*(Boiler worksheet)*			
Utilisation Factor Heat Generator		*(Boiler worksheet)*	0%		
Annual Energy Demand (without DHW Wash&Dish)		*(Boiler worksheet)*	0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish		*(Electricity worksheet)*	0.0	0.0	0.0
Total Heating Oil/Gas/Wood			0.0	0.0	0.0
District Heat				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	0.7	-70
Heat Source		*(District Heat worksheet)*			
Utilisation Factor Heat Generator		*(District Heat worksheet)*	0%		
Heat Demand District Heat (without DHW Wash&Dish)		*(District Heat worksheet)*	0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish		*(Electricity worksheet)*	0.0	0.0	0.0
Total District Heat			0.0	0.0	0.0
Other				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	1.5	55
Heat Source		*(Project)*	Gel Fire		
Utilisation Factor Heat Generator		*(Project)*	100%		
Annual Energy Demand, Space Heating			0.0	0.0	0.0
Annual Energy Demand, DHW (without DHW Wash&Dish)			0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish		*(Electricity worksheet)*	0.0	0.0	0.0
Non-Electric Demand Cooking/Drying (Gas)		*(Blatt Strom)*	0.0	0.0	0.0
Total - Other			0.0	0.0	0.0
Cooling with Electric Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
				kWh/kWh	g/kWh
Covered Fraction of Cooling Demand		*(Project)*	100%	2.6	680
Heat Source			Electricity		
Annual Cooling COP					
Energy Demand Space Cooling			0.0	0.0	0.0
Heating, Cooling, DHW, Auxiliary and Household Electricity			36.6	95.2	24.9

Total PE Value	95.2	kWh/(m²a)		
Total Emissions CO_2-Equivalent	24.9	kg/(m²a)		(Yes/No)
Primary Energy Requirement	120	kWh/(m²a)		Yes

	Final Energy	Primary Energy	Emissions
Heating, DHW, Auxiliary Electricity (No Household Applications)	21.7	56.5	14.8

Specific PE Demand - Mechanical System	56.5	kWh/(m²a)
Total Emissions CO_2-Equivalent	14.8	kg/(m²a)

APPENDIX B – PHPP FOR CODE LEVEL 4 HOUSE

Passive House Verification

Photo or Drawing

Building:	Bethania, Type E (Plot 08)	
Location and Climate:	Northern Europe	GB-Glasgow
Street:	Bullwood Road	
Postcode/City:	Dunoon, Argyll	
Country:	Scotland	
Building Type:	End-terraced	
Home Owner(s) / Client(s):	Fyne Initiatives Ltd	
Street:		
Postcode/City:		
Architect:	*EIRINI MOUTZOURI*	
Street:		
Postcode/City:		
Mechanical System:		
Street:		
Postcode/City:		

No Standard Climate

Year of Construction:	2009			
Number of Dwelling Units:	1	Interior Temperature:	20.0	°C
Enclosed Volume V_e:	446.7 m³	Internal Heat Gains:	2.1	W/m²
Number of Occupants:	4.0			

Calculation Electricity / Internal Heat Gains

Building Type: Residential

Internal Heat Gains

Utilisation Pattern: Dwelling

Type of Values Used: Standard

Planned Number of Occupants: 4 Design

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area: 101.4 m²

	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	67	kWh/(m²a)	15 kWh/(m²a)	No
Pressurization Test Result:		h⁻¹	0.6 h⁻¹	
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	300	kWh/(m²a)	120 kWh/(m²a)	No
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	250	kWh/(m²a)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	kWh/(m²a)		
Heating Load:	22	W/m²		
Frequency of Overheating:	1	%	over 25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m²a)	15 kWh/(m²a)	
Cooling Load:	8	W/m²		

Verification: Monthly Method

Specific Space Heat Demand, Annual Method	58.2
Specific Space Heat Demand, Monthly Method	67.2

Passive House Planning

SPECIFIC ANNUAL HEAT DEMAND MONTHLY METHOD

(This page displays the sums of the monthly method over the heating period)

Climate: GB-Glasgow — Interior Temperature: 20 °C
Building: Bethania, Type E (Plot 08) — Building Type/Use: End-terraced
Location: Northern Europe — Treated Floor Area A_{TFA}: 101.4 m²
Spec. Capacity: 80 Wh/(m²K) (Enter in "Summer" worksheet.)

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Month. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area
1.	Exterior Wall - Ambient	A		*	0.150	*	1.00	*	86	=	1396	
2.	Exterior Wall - Ground	B		*		*	1.00	*		=		
3.	Roof/Ceiling - Ambient	A		*	0.150	*	1.00	*	86	=	1410	
4.	Floor Slab	B		*	0.154	*	1.00	*	68	=	752	
5.		A		*		*	1.00	*		=		
6.		A		*		*	1.00	*		=		
7.	Wall to kitchen	X		*	0.150	*	0.50	*	86	=	104	
8.	Windows	A		*	1.547	*	1.00	*	86	=	3433	
9.	Exterior Door	A		*	1.160	*	1.00	*	86	=	230	
10.	Exterior TB (length/m)	A		*		*	1.00	*		=		
11.	Perimeter TB (length/m)	P		*		*	1.00	*		=		
12.	Ground TB (length/m)	B		*		*	1.00	*		=		

ransmission Heat Losses Q_T — Total 7324 kWh/a — 72.2 kWh/(m²a)

Effective Air Volume V_{RAX}: A_{TFA} 101 m² * Clear Room Height 2.50 m = 254 m³

	$n_{V,system}$ 1/h		η^*_{SHX}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h
ective Air Change Rate Ambient $n_{V,e}$	0.005	*(1-	0%	)*(1-	0.00	)+	0.500	=	0.505
ective Air Change Rate Ground $n_{V,g}$	0.005	*	0%	*(1-	0.00	)		=	0.000

	V_{RAX} m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
entilation Losses Ambient Q_V	254	*	0.505	*	0.33	*	86	=	3624	35.7
entilation Losses Ground $Q_{V,e}$	254	*	0.000	*	0.33	*	68	=	0	0.0

entilation Heat Losses Q_V — Total 3624 kWh/a — 35.7 kWh/(m²a)

otal Heat Losses Q_L: (Q_T 7324 kWh/a + Q_V 3624 kWh/a) * Reduction Factor Night/Weekend Saving 1.0 = 10948 kWh/a — 108.0 kWh/(m²a)

	Orientation of the Area	Reduction Factor See Windows worksheet		g-Value (perp. radiation)		Area m²		Global Radiation kWh/(m²a)		kWh/a
1.	North	0.22	*	0.51	*	2.2	*	298	=	76
2.	East	0.42	*	0.51	*	12.9	*	500	=	1401
3.	South	0.40	*	0.00	*	0.0	*	780	=	0
4.	West	0.32	*	0.51	*	10.7	*	620	=	1093
5.	Horizontal	0.40	*	0.00	*	0.0	*	872	=	0
6.	Sum Opaque Areas									0

Available Solar Heat Gains Q_S — Total 2570 kWh/a — 25.3 kWh/(m²a)

Internal Heat Gains Q_I: kh/d 0.024 * Length Heat. Period 365 d/a * Spec. Power q_I 2.1 W/m² * A_{TFA} 101.4 m² = 1865 kWh/a — 18.4 kWh/(m²a)

Free Heat Q_F: $Q_S + Q_I$ = 4435 kWh/a — 43.7 kWh/(m²a)

Ratio Free Heat to Losses: Q_F / Q_L = 0.41

Utilisation Factor Heat Gains η_G = 93%

Heat Gains Q_G: $\eta_G * Q_F$ = 4138 kWh/a — 40.8 kWh/(m²a)

Annual Heat Demand Q_H: $Q_L - Q_G$ = 6810 kWh/a — 67 kWh/(m²a)

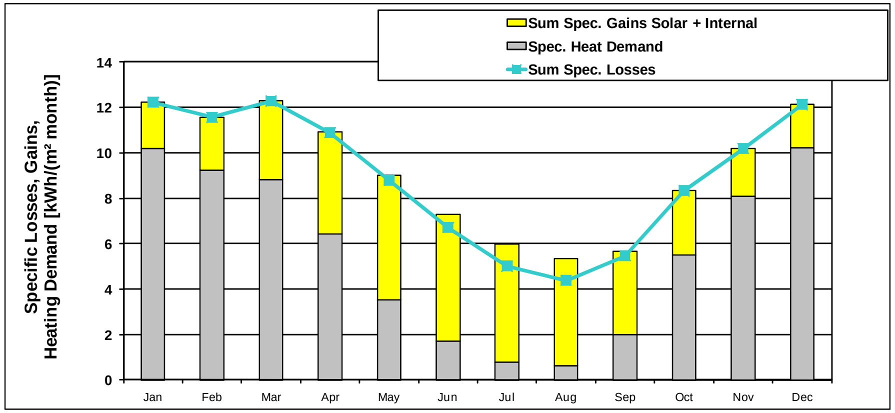
Limiting Value: 15 kWh/(m²a) — **Requirement met?** (Yes/No): No

PASSIVE HOUSE PLANNING

SPECIFIC ANNUAL HEAT DEMAND MONTHLY METHOD

Climate: GB-Glasgow — Interior Temperature: 20 °C
Building: Bethania, Type E (Plot 08) — Building Type/Use: End-terraced
Location: Northern Europe — Treated Floor Area A_{TFA}: 101 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - E	9.7	9.2	9.7	8.6	6.9	5.3	3.9	3.4	4.3	6.7	8.2	9.7	86	kKh
Heating Degree Hours - G	7.4	7.1	7.8	7.0	6.3	5.0	4.3	3.4	3.7	4.4	5.2	6.5	68	kKh
Losses - Exterior	1158	1094	1158	1027	822	625	461	407	513	796	976	1158	10196	kWh
Losses - Ground	81	78	86	77	69	56	47	38	41	49	58	71	752	kWh
Sum Spec. Losses	12.2	11.6	12.3	10.9	8.8	6.7	5.0	4.4	5.5	8.3	10.2	12.1	108.0	kWh/m²
Solar Gains - North	1	2	5	8	12	12	13	9	6	3	2	1	76	kWh
Solar Gains - East	17	42	94	171	225	253	214	182	105	65	23	12	1401	kWh
Solar Gains - South	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - West	29	49	92	125	159	145	143	128	107	60	35	21	1093	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Internal Heat Gains	158	143	158	153	158	153	158	158	153	158	153	158	1865	kWh
Sum Spec. Gains Solar +	2.0	2.3	3.4	4.5	5.5	5.6	5.2	4.7	3.7	2.8	2.1	1.9	43.7	kWh/m²
Utilisation Factor	100%	100%	100%	99%	96%	90%	81%	80%	95%	100%	100%	100%	93%	
Annual Heat Demand	1035	937	896	651	358	174	78	62	203	559	820	1037	6810	kWh
Spec. Heat Demand	**10.2**	**9.2**	**8.8**	**6.4**	**3.5**	**1.7**	**0.8**	**0.6**	**2.0**	**5.5**	**8.1**	**10.2**	**67.2**	kWh/m²



Annual Heat Demand: Comparison

EN 13790 Monthly Method	**6810**	**kWh/a**	**67.2**	**kWh/(m²a) Reference to habitable area**
PHPP, Heating Period Method	**5899**	**kWh/a**	**58.2**	**kWh/(m²a) Reference to habitable area**

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total	Heating Period Method
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	205
Ambient Temp.	6.90	6.30	6.90	8.00	10.70	12.70	14.79	15.40	14.00	11.00	8.60	6.90	10.2	7.6
North Radiation	5.0	9.0	19.0	28.0	44.0	48.0	47.0	34.0	21.0	13.0	6.0	4.0	278	80
East Radiation	9.0	20.0	41.0	71.0	89.0	98.0	83.0	73.0	45.0	29.0	12.0	7.0	577	131
South Radiation	30.0	49.0	74.0	91.0	92.0	87.0	82.0	80.0	74.0	58.0	36.0	27.0	780	335
West Radiation	12.0	21.0	44.0	62.0	85.0	78.0	77.0	67.0	53.0	27.0	15.0	8.0	549	210
Hori. Radiation	13.0	28.0	61.0	103.0	140.0	145.0	134.0	109.0	71.0	40.0	18.0	10.0	872	240
Tsky	-3.60	-4.60	-3.30	-2.73	0.10	2.80	5.40	6.30	5.00	2.00	-1.10	-3.30	0.3	
Ground Temp	10.07	9.40	9.47	10.26	11.55	13.00	14.22	15.42	14.82	14.03	12.74	11.29	12.2	10.9

Passive House Planning

SPECIFIC SPACE HEATING LOAD

Building:	Bethania, Type E (Plot 08)	Building Type/Use:	End-terraced
Location:	Northern Europe	Treated Floor Area A_{TFA}:	101.4 m²
		Interior Temperature:	20
		Climate (HL):	GB-Glasgow

	Design Temperature		Radiation:	North	East	South	West	Horizontal	
Weather Condition 1:	0.4	°C		15	20	30	20	25	W/m²
Weather Condition 2:	5.0	°C		5	5	5	5	5	W/m²
Ground Design Temp.	10.2	°C							

	Building Element	Temperature Zone	Area		U-Value		Factor Always 1 (except "X")		TempDiff 1		TempDiff 2		P_T 1		P_T 2
			m²		W/(m²K)				K		K		W		W
1.	Exterior Wall - Ambie	A		*	0.150	*	1.00	*	19.6	or	15.0	=	319	or	244
2.	Exterior Wall - Groun	B		*		*	1.00	*	9.8	or	9.8	=		or	
3.	Roof/Ceiling - Ambien	A		*	0.150	*	1.00	*	19.6	or	15.0	=	322	or	246
4.	Floor Slab	B		*	0.154	*	1.00	*	9.8	or	9.8	=	108	or	108
5.		A		*		*	1.00	*	19.6	or	15.0	=		or	
6.		A		*		*	1.00	*	19.6	or	15.0	=		or	
7.	Wall to kitchen	X		*	0.150	*	0.50	*	19.6	or	15.0	=	24	or	18
8.	Windows	A		*	1.547	*	1.00	*	19.6	or	15.0	=	784	or	600
9.	Exterior Door	A		*	1.160	*	1.00	*	19.6	or	15.0	=	53	or	40
10.	Exterior TB (length/m)	A		*		*	1.00	*	19.6	or	15.0	=		or	
11.	Perimeter TB (length/m)	P		*		*	1.00	*	9.8	or	9.8	=		or	
12.	Ground TB (length/m)	B		*		*	1.00	*	9.8	or	9.8	=		or	
13.	House/DU Partition Wall	I		*	0.150	*	1.00	*	0.0	or	0.0	=	0	or	0

Transmission Heat Losses P_T

Total = 1610 or 1257

Ventilation System:

	A_{TFA}		Clear Room Height		
	m²		m		m³
Effective Air Volume, V_V	101.4	*	2.50	=	254

Efficiency of Heat Recovery of the Heat Exchanger η_{HR} 0%

Heat Recovery Efficiency SHX 0%

Efficiency SHX: η_{SHX} 1: 0% or η_{SHX} 2: 0%

	$n_{V,Res}$ (Heating Load)		$n_{V,system}$		Φ_{HR}		Φ_{HR}				
	1/h		1/h						1/h		1/h
Energetically Effective Air Exchange n_v	0.500	+	0.005	*(1-	0.00	or	0.00	) =	0.505	or	0.505

Ventilation Heating Load P_V

V_L		n_L		n_L		c_{Air}		TempDiff 1		TempDiff 2		P_V 1		P_V 2
m³		1/h		1/h		Wh/(m³K)		K		K		W		W
253.5	*	0.505	or	0.505	*	0.33	*	19.6	or	15.0	=	**828**	or	**634**

Total Heating Load P_L

		P_L 1		P_L 2
		W		W
$P_T + P_V$	=	**2438**	or	**1891**

	Orientation the Area	Area		g-Value (perp. radiation)		Reduction Factor (see Windows worksheet)		Radiation 1		Radiation 2		P_S 1		P_S 2
		m²						W/m²		W/m²		W		W
1.	North	2.2	*	0.5	*	0.2	*	15	or	5	=	4	or	1
2.	East	12.9	*	0.5	*	0.4	*	18	or	5	=	50	or	14
3.	South	0.0	*	0.0	*	0.4	*	30	or	5	=	0	or	0
4.	West	10.7	*	0.5	*	0.3	*	22	or	5	=	39	or	9
5.	Horizontal	0.0	*	0.0	*	0.4	*	25	or	5	=	0	or	0

Solar Heat Gain, P_S

Total = **94** or **24**

Internal Heat Gains P_I

Spec. Power		A_{TFA}		P_I 1		P_I 2
W/m²		m²		W		W
1.6	*	101	=	**162**	or	**162**

Heat Gains P_G

		P_G 1		P_G 2
		W		W
$P_S + P_I$	=	**256**	or	**186**
$P_L - P_G$	=	**2181**	or	**1704**

Heating Load P_H = **2181** W

Specific Heating Load P_H / A_{TFA} = **21.5** W/m²

Passive House Planning

HEAT DISTRIBUTION AND DHW SYSTEM

Building:	Bethania, Type E (Plot 08)	
Location:	Northern Europe	
Interior Temperature:	20	°C
Building Type/Use:	End-terraced	
Treated Floor Area A_{TFA}:	101	m²
Occupancy:	4.0	Pers
Number of Residences:	1	
Annual Heat Demand $q_{Heating}$:	6810	kWh/a
Length of Heating Period:	205	d
Average Heat Load P_{ave}:	1.4	kW
Marginal Utilisability of Additional Heat Gains:	100%	

			Parts: Warm Region 1	Cold Region 2	Cold Region 3	Total	Unit	
Space Heat Distribution								
Length of Distribution Pipes	L_H	*(Project)*					m	
Heat Loss Coefficient per m Pipe	Ψ	*(Project)*					W/(mK)	
Temperature of the Room Through Which the Pipe	ϑ_X	*Mechanical Room*	20				°C	
Design Flow Temperature	ϑ_{dist}	*Flow, Design Value*					°C	
Design System Heat Load	$P_{heating}$	*(exist./calc.)*					kW	
Flow Temperature Control (check)								
Design Return Temperature	ϑ_R	$=0.714*(\vartheta_{dist}-20)+20$					°C	
Annual Heat Emission per m of Plumbing	q^*_{HL}	$= \Psi\ (\vartheta_m-\vartheta_X)\ t_{Heating}*0.0$				Total 1,2,3	kWh/(m·a)	
Possible Utilization Factor of Released Heat	η_G						-	
Annual Losses	Q_{HL}	$= L_H \cdot q^*_{HL} \cdot (1-\eta_G)$	0	0	0	0	kWh/a	
Specif. Losses	q_{HL}	$= \Sigma Q_{HL} / A_{TFA}$					kWh/(m²a)	0.0
Utilisation Factor of Space Heat Distribution	$h_{a,HL}$	$= q_H / (q_H + q_{HL})$				100%	-	

			Total	Unit	
DHW: Standard Useful Heat					
DHW Consumption per Person and Day (60 °C)	V_{DHW}	*(Project or Average Value 25 Litres/P/d)*	25.0	Litre/Person/d	
Average Cold Water Temperature of the Supply	ϑ_{DW}	*Temperature of Drinking Water (10°)*	10.0	°C	
DHW Non-Electric Wash and Dish		*(Electricity worksheet)*	288	kWh/a	
Useful Heat - DHW	Q_{DHW}		2405	kWh/a	
Specif. Useful Heat - DHW	q_{DHW}	$= Q_{DHW} / A_{TFA}$		kWh/(m²a)	23.7

DHW Distribution and Storage			Warm Region	Cold Region	Total	Unit	
Length of Circulation Pipes (Flow + Return)	L_{HS}	*(Project)*	0.0			m	
Heat Loss Coefficient per m Pipe	Ψ	*(Project)*	0.163			W/m/K	
Temperature of the Room Through Which the Pipe	ϑ_X	*Mechanical Room*	20			°C	
Design Flow Temperature	ϑ_{dist}	*Flow, Design Value*	60.0			°C	
Daily circulation period of operation.	td_{Circ}	*(Project)*	0.0			h/d	
Design Return Temperature	ϑ_R	$=0.875*(\vartheta_{dist}-20)+20$	55			°C	
Circulation period of operation per year	t_{Circ}	$= 365\ td_{Circ}$	0			h/a	
Annual Heat Released per m of Pipe	q^*_Z	$= \Psi\ (\vartheta_m-\vartheta_X)\ t_{Circ}$	0.0			kWh/m/a	
Possible Utilization Factor of Released Heat	η_{GDHW}	$=t_{heating}/365d * \eta_G$	55.9%			-	
Annual Heat Loss from Circulation Lines	Q_Z	$= L_{HS} \cdot q^*_Z \cdot (1-\eta_{GDHW})$	0		0	kWh/a	
Total Length of Individual Pipes	L_U	*(Project)*	27.00			m	
Exterior Pipe Diameter	d_{U_Pipe}	*(Project)*	0.018			m	
Heat Loss Per Tap Opening	$q_{Individual}$	$=(c_{pH2O}V_{H2O}+c_{pMat}V_{Mat})(\vartheta_{dist}-\vartheta$	0.2461			kWh/tap opening	
Occupancy Coefficient	n_{Tap}	$= n_{Pers} \cdot 3 \cdot 365 / n_{LU}$	4380			Tap openings per year	
Annual Heat Loss	q_U	$= n_{Tap} \cdot q_{Individual}$	1077.7			kWh/a	
Possible Utilization Factor of Released Heat	η_{G_U}	$=t_{heating}/8760*\eta_G$	55.9%			-	
Annual Heat Loss of Individual Pipes	Q_U	$= q_U \cdot (1-\eta_{G\_U})$	475.7		476	kWh/a	
					Total 1,2,3		
Average Heat Released From Storage	P_S		78.0			W	
Possible Utilization Factor of Released Heat	η_{G_S}	$=t_{heating}/8760*\eta_G$	55.9%				
Annual Heat Losses from Storage	Q_S	$= P_S \cdot 8.760\ kh \cdot (1-\eta_{G\_S})$	301.6		302	kWh/a	
					Total 1,2,3		
Total Heat Losses of the DHW System	Q_{WL}	$= Q_Z+Q_U+Q_S$			777	kWh/a	
Specif. Losses of the DHW System	q_{WL}	$= Q_{WL} / A_{TFA}$				kWh/(m²a)	7.7
Utilisation Factor DHW Distrib and Storage	$\eta_{a,WL}$	$= q_{DHW} / (q_{DHW} + q_{WV})$			75.6%	-	
Total Heat Demand of DHW system	Q_{gDHW}	$= Q_{DHW}+Q_{WL}$			3183	kWh/a	
Total Spec. Heat Demand of DHW System	q_{gDHW}	$= Q_{gDHW} / A_{TFA}$				kWh/(m²a)	31.4

Passive House Planning

PRIMARY ENERGY VALUE

Building:	Bethania, Type E (Plot 08)	Building Type/Use:	End-terraced
Location:	Northern Europe	Treated Floor Area A_{TFA}:	101 m²
		Space Heat Demand incl. Distribution	67 kWh/(m²a)
		Useful Cooling Demand:	0 kWh/(m²a)

			Final Energy kWh/(m²a)	Primary Energy kWh/(m²a)	Emissions CO_2-Equivalent kg/(m²a)
Electricity Demand (without Heat Pump)				PE Value	CO_2-Emissions Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		(Project)	100%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	100%	2.6	680
Direct Electric Heating	$Q_{H,de}$		67.2	174.6	45.7
DHW Production, Direct Electric (without Wash&Dish)	$Q_{DHW,de}$	(DHW+Distribution, SolarDHW)	28.5	74.2	19.4
Electric Postheating DHW Wash&Dish		(Electricity, SolarDHW)	2.8	7.4	1.9
Electricity Demand Household Appliances	Q_{EHH}	(Electricity worksheet)	16.7	43.4	11.3
Electricity Demand - Auxiliary Electricity			0.3	0.8	0.2
Total Electricity Demand (without Heat Pump)			115.5	300.4	78.6
Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		(Project)	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	0%	2.6	680
Energy Carrier - Supplementary Heating			Electricity	2.7	680
Annual Coefficient of Performance - Heat Pump		Separate Calculation	2.50		
Total System Performance Ratio of Heat Generator		Separate Calculation	0.40		
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}		0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish		(Electricity worksheet)	0.0	0.0	0.0
Total Electricity Demand Heat Pump			0.0	0.0	0.0
Compact Heat Pump Unit				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		(Project)	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	0%	2.6	680
Energy Carrier - Supplementary Heating			Electricity	2.7	680
COP Heat Pump Heating		(Compact worksheet)	0.0		
COP Heat Pump DHW		(Compact worksheet)	0.0		
Performance Ratio of Heat Generator (Verification)		(Compact worksheet)			
Performance Ratio of Heat Generator (Planning)		(Compact worksheet)			
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}	(Compact worksheet)	0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish			0.0	0.0	0.0
Total Compact Unit		(Compact worksheet)	0.0	0.0	0.0
Boiler				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		(Project)	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	0%	2.6	2600
Boiler Type		(Boiler worksheet)			
Utilisation Factor Heat Generator		(Boiler worksheet)	0%		
Annual Energy Demand (without DHW Wash&Dish)		(Boiler worksheet)	0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish		(Electricity worksheet)	0.0	0.0	0.0
Total Heating Oil/Gas/Wood			0.0	0.0	0.0
District Heat				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		(Project)	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	0%	0.7	-70
Heat Source		(District Heat worksheet)			
Utilisation Factor Heat Generator		(District Heat worksheet)	0%		
Heat Demand District Heat (without DHW Wash&Dish)		(District Heat worksheet)	0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish		(Electricity worksheet)	0.0	0.0	0.0
Total District Heat			0.0	0.0	0.0
Other				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand		(Project)	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	0%	1.5	55
Heat Source		(Project)	Gel Fire		
Utilisation Factor Heat Generator		(Project)	100%		
Annual Energy Demand, Space Heating			0.0	0.0	0.0
Annual Energy Demand, DHW (without DHW Wash&Dish)			0.0	0.0	0.0
Non-Electric Demand, DHW Wash&Dish		(Electricity worksheet)	0.0	0.0	0.0
Non-Electric Demand Cooking/Drying (Gas)		(Blatt Strom)	0.0	0.0	0.0
Total - Other			0.0	0.0	0.0
Cooling with Electric Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
				kWh/kWh	g/kWh
Covered Fraction of Cooling Demand		(Project)	100%	2.6	680
Heat Source			Electricity		
Annual Cooling COP					
Energy Demand Space Cooling			0.0	0.0	0.0

Heating, Cooling, DHW, Auxiliary and Household Electricity		115.5	300.4		78.6
Total PE Value	300.4	kWh/(m²a)			
Total Emissions CO_2-Equivalent	78.6	kg/(m²a)			(Yes/No)
Primary Energy Requirement		120	kWh/(m²a)		No

Heating, DHW, Auxiliary Electricity (No Household Applications)		96.0	249.6	65.3
Specific PE Demand - Mechanical System	249.6	kWh/(m²a)		
Total Emissions CO_2-Equivalent	65.3	kg/(m²a)		

APPENDIX C – SAP (RDSAP) FOR CODE LEVEL 4 HOUSE

1. Overall dwelling dimensions:

		area(m2)	h (m)	vol (m3)
1	Ground floor	76.66	2.60	199.30
2	First floor	62.36	2.55	159.01
5	Total floor area	139.01		
6	Total volume			358.31

2. Ventilation rate:

				m3/h		
7	Chimneys	0.00	40.00	0.00		
8	Open flues	0.00	20.00	0.00		
9	Intermit fan /pass vents	2.00	10.00	20.00		
9a	flueless gas fires	0.00	40.00	0.00		
						ac/h
10	Inf ch/f/f			20.00	div(6)	0.06
	Fabric infiltration: if no permeability number avail (else skip to 19)					
11	Storeys	2.00				
12	Inf storeys					0.10
13	Struct inf (0.25 steel/timber, 0.35 masonry)					0.25
14	Floor inf (susp wooden 0.2 unsealed, 0.1 sealed)					0.10
15	Draught lobby (no 0.05, yes 0)					0.05
16	Percent wiondows /doors ds (100 new build)				22.10	
17	Window inf					0.21
18	Inf rate calc					0.76
		y/n	Q50			
19	Permeability known (pressure test or design)	n	10.00			0.76
20	sheltered sides (2 for unknown location)			3		
21	shelter factor			0.775		
22	adjusted inf for shelter					0.590253
				y/n		
23	whole house MVHR			n		na
23a	whole house balanced MV			n		na
23b	whole house extract or +ve from outside			n		na
24	nat vent or +ve vent from loft			y		0.674199
25	Effective air change rate					0.674199

3. Heat loss parameters and heat losses:

	element		area	Uvalue	AU W/K	
26	Doors		1.85	2	3.7	
27	windows type1		23.63	1.5	33.43868	1/((1/U)+.04)
27a	windows type 2		0.00		0	1/((1/U)+.04)
27b	rooflights		0.00		0	1/((1/U)+.04)
28	ground floor		76.66	0.15	11.499	
29	walls type 1 (ex glz,dr)		89.79	0.15	13.4685	
29a	walls type 2(ex glz,dr)				0	
30	roof type 1 (ex rooflight)		76.66	0.15	11.499	
30a	roof type 2(ex rooflight)				0	
31	other - exposed 1st floor				0	
32	total area (m2)		268.59			
33	fabric heat loss (ex thbr)				73.60518	
34	thermal bridges	Y=	0.08		21.4872	
35	total fabric losses				95.09238	
36	vent heat loss				79.71974	
37	heat los sco-efficient (W/K)				174.8121	
38	heat loss parameter HLP W/m2K				1.257531	

	4. Water heating energy requirements:			
	Occupancy (tfa)			4.13
				kWh/year
39	Energy content of hot water used (tfa)			2561
		y/n		
40	Distribution losses (tfa) inst pou?	n		452
		y/n		
	Combi system	n		
	Storage losses	y/n		
	manufacturers data available?	n		
41	manufacturers kWh/day			
41a	Temp factor Table 2b			
42	Energy lost from storage			0
	If no manufacturers data			
43	Cylinder volume (litres)		180	
44	Storage loss factor Table 2 (kWh/l/day)		0.0152	
44a	Volume factor Table 2a		0.87358	
44b	Temp factor Table 2b		0.6	
45	Energy lost from storage			523.4354
46	Storage losses			523.4354
	Solar hot water (appendix H)			
H11	dedicated solar storage volume (litres)		n	
		y/n		
47	dedicated solar storage?	n	Storage loss	523.4354
48	primary circuit losses Table 3			0
49	combi loss Table 3a			0
50	Solar DHW input (appendix H)			0
51	Output from water heater Kwh/year			3537
52	Heat gains from water heating kWh/year			1420.709
	(assumes cylinder inside dwelling)			

	5. Internal gains:		
53	Lights appliances cooking and metabolic Table 5		755.6704
	lighting consumption /m2 (EB)	L1	9.3
	% LEL		100
	correction factor C1=1-0.5*NLE/N	L2	0.5
	light transmittance (6b)		0.8
	frame factor (6c)		0.7
	light access factor (6d)		0.83
	glazing ratio GL	L5	0.05807
	correction factor C2 dep on GL><.095	L3,L4	1.03181
	annual lighting energy used EL kWh/yr	L6	666.969
	Reduction in lighting energy for LEL	L7	666.969
53a	Reduction in gains due to LEL (Appendix L)	L8	100.0453
53b	Additional gains Table 5a		0
54	Water heating		162.1813
55	Total internal gains		817.8064

6. Solar gains:

		access Tab 6d	area m2	flux Tab 6a		G_L Tab 6b.	FF Tab 6c	Gains W
56	North	0.77		29	0.9	0.76	0.7	0
57	Northeast	0.77		34	0.9	0.76	0.7	0
58	East	1	12.93	48	0.9	0.76	0.7	297.1624
59	Southeast	0.77		64	0.9	0.76	0.7	0
60	South	0.77		72	0.9	0.76	0.7	0
61	Southwest	0.77		64	0.9	0.76	0.7	0
62	West	1	10.69	48	0.9	0.76	0.7	245.6819
63	Northwest	0.77		34	0.9	0.76	0.7	0
64	Rooflights	0.77		75	0.9	0.76	0.7	0
65	Total solar gains							542.8443

66	Total gains W	1360.651	
67	Gain to Loss ratio (GLR) Gains / Heat Loss Co-eff (K)	7.783503	
68	Utilisation factor Table 7.	0.900995	Autocalc
69	Useful gains W	1225.939	
	7. Mean internal temperature:		
	Heating type (table 4a, 4d)	2	
	Control (table 4e)	3	
	Responsiveness (table 4a, 4d)	0.75	
	HLP = 1.257531	C	
70	Mean internal temp of living area Table 8	19.31371	Autocalc
71	Temp adjustment from Table 4e	0	
72	Adjustment for gains	0.451934	
73	Adjusted living temp C	19.76564	
74	Temp difference between zones Table 9	1.839018	Autocalc
75	Living area fraction (0 to 1)	0.15	
76	Rest of house fraction	0.85	
77	Mean internal temperature	18.20248	
	8. Defree days:		
78	Temp rise from gains	7.012896	
79	Base temp (Mean int - Temp rise from gains = heat temp)	11.18958	
80	Degree days Table 10.	1177.916	
	9. Space heating required:		
81	Space heating required (useful) kWh/year	4941.936	
	9a. Energy requirement (individual heating systems):		
	Space heating		
82	Fraction from secondary	0.1	
83	Efficiency for main system (%) (SEDBUK plus adjustments)	100	
84	Efficiency of secondary	100	
85	Space heat fuel (main) kWh/year	4447.742	
85a	Space heat fuel (secondary) kWh/yr	494.1936	
	Water heating		
86	Efficiency of water heater	100	
86a	Energy required for water heating kWh/year	3536.85	
	Electricity for pumps and fans	kWh/yr	
87a	central heating pumps Table 4f	0	
87b	boiler with fan assisted flue Table 4f	0	
87c	warm air heating fans Table 4f	0	
87d	mech vent (balanced, extract or +ve from outside Table 4f	0	
87e	keep hot for combi boiler Table 4f	0	
87f	pump for solar water heating Table 4f	0	
87	Total electricity for above equipment kWh/year	0	

	10a Costs (individual heating systems):	Fuel (kWh/year)	Fuel price (Table 12)	Fuel cost (£/year)
88	**Space heating - main system**	4447.742	4.09	181.9127
89	**Space heating - secondary**	494.1936	4.09	20.21252
	Water heating (electric off-peak)			
90	On-peak fraction (Table 13, or Appendix F for electric CPSUs)			
90a	Off-peak fraction			
			Fuel price	
91	**On-peak cost**	0		0
91a	**Off-peak cost**	0		0
91b	**Water heating cost (other fuel)**	3536.85	4.09	144.6572
92	**Pump and fan energy cost**	0		0
93	**Energy for lighting (calculated in Appendix L)**	666.9688	4.09	27.27902
94	**Additional standing charges (Table 12)**			51
	Renewable and energy-saving technologies (Appendices M, N and Q)			
95	Energy produced or saved, kWh/year			
95a	Cost of energy produced or saved, £/year			0
96	Energy consumed by the technology, kWh/year			
96a	Cost of energy consumed, £/year			0
97	**Total energy cost**			425.0614

	11a SAP rating (individual heating systems):		
98	Energy cost deflator (SAP 2005)	0.91	
99	Energy cost factor (ECF)	1.939034	
100	**SAP rating (Table 14)**	73	**C**

	12a DCER (individual heating systems):	Energy kWh/year	Emm Fact CO2/kWh	Emm CO2/year
101	Space heating from main	4447.742	0.422	1876.95
102	Space heating from secondary	494.1936	0.422	208.55
103	Energy for water heating	3536.85	0.422	1492.55
107	Space and water heating			3578.05
108	Electicity for pumps and fans	0	0.422	0.00
109	Energy for lighting (Appendix L)	666.969	0.422	281.46
110	Energy produced or saved in dwelling	0		0.00
111	Energy consumed by above technology	0		0.00
112	Total CO2 kg/year			3859.51
113	Dwelling CO2 Emission Rate (DER) kg/m2.year			27.8
	Carbon factor			21.0
	EI			72
	rating			C

APPENDIX D – SAP FOR PASSIVE HOUSE

1. Overall dwelling dimensions:

		area(m2)	h (m)	vol (m3)
1	Ground floor	52.64	2.60	136.86
2	First floor	52.64	2.80	147.39
5	Total floor area	105.28		
6	Total volume			284.26

2. Ventilation rate:

				m3/h			
7	Chimneys	0.00	40.00	0.00			
8	Open flues	0.00	20.00	0.00			
9	Intermit fan /pass vents	0.00	10.00	0.00			
9a	flueless gas fires	0.00	40.00	0.00			
						ac/h	
10	Inf ch/f/f			0.00	div(6)	0.00	
	Fabric infiltration: if no permeability number avail (else skip to 19)						
11	Storeys	2.00					
12	Inf storeys					0.10	
13	Struct inf (0.25 steel/timber, 0.35 masonry)					0.25	
14	Floor inf (susp wooden 0.2 unsealed, 0.1 sealed)					0.10	
15	Draught lobby (no 0.05, yes 0)					0.05	
16	Percent wiondows /doors ds (100 new build)				14.88		
17	Window inf					0.22	
18	Inf rate calc					0.72	
		y/n	Q50				
19	Permeability known (pressure test or design)	y	0.40			0.02	
20	sheltered sides (2 for unknown location)			2			
21	shelter factor			0.85			
22	adjusted inf for shelter					0.017	
	Calculate effective air change rate for the applicable case:						
22a	If balanced whole house	mechanical ventilation air throughput (in ach, see 2.6				**0.483**	
22b	If balanced with heat recovery		fficiency in % allow ing for in-use facto			**90**	
				y/n			
23	whole house MVHR			y		0.0653	
23a	whole house balanced MV			n		na	
23b	whole house extract or +ve from outside			n		na	
24	nat vent or +ve vent from loft			n		na	
25	Effective air change rate					0.0653	

3. Heat loss parameters and heat losses:

	element		area	Uvalue	AU W/K	
26	Doors		1.85	1.4	2.59	
27	windows type1		13.20	1.1	13.908046	1/((1/U)+.04)
27a	windows type 2				0	1/((1/U)+.04)
27b	rooflights		2.95	1.4	3.9109848	1/((1/U)+.04)
28	ground floor		52.64	0.15	7.896	
29	walls type 1 (ex glz,dr)		100.60	0.095	9.557	
29a	walls type 2(ex glz,dr)				0	
30	roof type 1 (ex rooflight)		76.66	0.094	7.20604	
30a	roof type 2(ex rooflight)				0	
31	other - exposed 1st floor				0	
32	total area (m2)		247.9			
33	fabric heat loss (ex thbr)				45.068071	
34	thermal bridges	Y=	0		0	
35	total fabric losses				45.068071	
36	vent heat loss				6.1254325	
37	heat los sco-efficient (W/K)				51.193503	
38	heat loss parameter HLP W/m2K				0.4862605	

	4. Water heating energy requirements:			
	Occupancy (tfa)			3.26
				kWh/year
39	Energy content of hot water used (tfa)			2167
		y/n		
40	Distribution losses (tfa) inst pou?	n		382
		y/n		
	Combi system	y		
	Storage losses	y/n		
	manufacturers data available?	n		
41	manufacturers kWh/day			
41a	Temp factor Table 2b		1.08	
42	Energy lost from storage			0
	If no manufacturers data			
43	Cylinder volume (litres)		180	
44	Storage loss factor Table 2 (kWh/l/day)		0.0152	
44a	Volume factor Table 2a		0.87358	
44b	Temp factor Table 2b		1.08	
45	Energy lost from storage			942.18379
46	Storage losses			0
	Solar hot water (appendix H)			
H1	Aperture area of solar collector, m²		4.6	
H2	Zero-loss collector efficiency, h0, from test certificate or Table H1		0.75	
H3	Collector heat loss coefficient, a1, from test certificate or Table H1		6	
H4	Collector performance ratio a1/h0		8	
H5	Annual solar radiation per m² from Table H2		1023	
H6	Overshading factor from Table H3		1	
H7	Solar energy available		3529.35	
H8	Solar-to-load ratio		1.384133	
H9	Utilisation factor		0.514451	
H10	Collector performance factor		0.6364	
H11	dedicated solar storage volume Vs (litres)		0	
H12	If combined cylinder, total volume of cylinder, litres		180	
H13	Effective solar volume, Veff		54	
H14	Daily hot water demand, Vd, (litres) from Table 1		131.7	
H15	Volume ratio Veff/Vd		0.410023	
H16	Solar storage volume factor f (Veff/Vd)		0.821691	
H17	Solar input Qs		949.4614	
		y/n		
47	dedicated solar storage?	y	Storage loss	0
48	primary circuit losses Table 3			0
49	combi loss Table 3a			0
50	Solar DHW input (appendix H)			949.4614
51	Output from water heater Kwh/year			1600
52	Heat gains from water heating kWh/year			847.82979
	(assumes cylinder inside dwelling)			
	5. Internal gains:			
53	Lights appliances cooking and metabolic Table 5			600.44755
	lighting consumption /m2 (EB)		L1	9.3
	% LEL			100
	correction factor C1=1-0.5*NLE/N		L2	0.5
	light transmittance (6b)			0.7
	frame factor (6c)			0.7
	light access factor (6d)			0.83
	glazing ratio GL		L5	0.0580697
	correction factor C2 dep on GL><.095		L3,L4	1.0318102
	annual lighting energy used EL kWh/yr		L6	505.12476
	Reduction in lighting energy for LEL		L7	505.12476
53a	Reduction in gains due to LEL (Appendix L)		L8	75.768714
53b	Additional gains Table 5a			0
54	Water heating			96.784223
55	Total internal gains			621.46306

6. Solar gains:

	access	area	flux		G_L	FF	Gains
	Tab 6d	m2	Tab 6a		Tab 6b.	Tab 6c	W
56 North	0.77		29	0.9	0.51	0.7	0
57 Northeast	0.77		34	0.9	0.51	0.7	0
58 East	1	6.60	48	0.9	0.51	0.7	101.7878
59 Southeast	0.77		64	0.9	0.51	0.7	0
60 South	0.77		72	0.9	0.51	0.7	0
61 Southwest	0.77		64	0.9	0.51	0.7	0
62 West	0.3	6.6	48	0.9	0.51	0.7	30.53635
63 Northwest	0.77		34	0.9	0.51	0.7	0
64 Rooflights	0.77	2.95	75	0.9	0.45	0.6	41.39809
65 Total solar gains							173.7223

66 Total gains W	795.18534	
67 Gain to Loss ratio (GLR) Gains / Heat Loss Co-eff (K)	15.532935	
68 Utilisation factor Table 7.	0.6861462	Autocalc
69 Useful gains W	545.61341	

7. Mean internal temperature:

Heating type (table 4a, 4d)		1	
Control (table 4e)		2	
Responsiveness (table 4a, 4d)		1	
HLP =	0.48626	C	
70 Mean internal temp of living area Table 8		18.907156	Autocalc
71 Temp adjustment from Table 4e		0	
72 Adjustment for gains		1.3315728	
73 Adjusted living temp C		20.238729	
74 Temp difference between zones Table 9		1.3014957	Autocalc
75 Living area fraction (0 to 1)		0.20	
76 Rest of house fraction		0.8	
77 Mean internal temperature		19.197532	

8. Defree days:

78 Temp rise from gains	10.657864
79 Base temp (Mean int - Temp rise from gains = heat temp)	8.5396681
80 Degree days Table 10.	699.6015

9. Space heating required:

81 Space heating required (useful) kWh/year	859.56125

9a. Energy requirement (individual heating systems):

Space heating	
82 Fraction from secondary	0.1
83 Efficiency for main system (%) (SEDBUK plus adjustments)	250
84 Efficiency of secondary	100
85 Space heat fuel (main) kWh/year	309.44205
85a Space heat fuel (secondary) kWh/yr	85.956125
Water heating	
86 Efficiency of water heater	100
86a Energy required for water heating kWh/year	1600.4026
Electricity for pumps and fans	kWh/yr
87a central heating pumps Table 4f	75
87b boiler with fan assisted flue Table 4f	0
87c warm air heating fans Table 4f	0
87d mech vent (balanced, extract or +ve from outside Table 4f	312.11
87e keep hot for combi boiler Table 4f	0
87f pump for solar water heating Table 4f	0
87 Total electricity for above equipment kWh/year	387.11309

10a Costs (individual heating systems):

		Fuel (kWh/year)	Fuel price (Table 12)	Fuel cost (£/year)
88	**Space heating - main system**	309.44205	7.12	22.03227
89	**Space heating - secondary**	85.956125	7.12	6.120076
	Water heating (electric off-peak)			
90	On-peak fraction (Table 13, or Appendix F for electric CPSUs)			
90a	Off-peak fraction	1		
			Fuel price	
91	**On-peak cost**	0	7.12	0
91a	**Off-peak cost**	1600.4026		0
91b	**Water heating cost (other fuel)**	1600.4026	7.12	113.9487
92	**Pump and fan energy cost**	387.11309	7.12	27.56245
93	**Energy for lighting (calculated in Appendix L)**	505.12465	7.12	35.96488
94	**Additional standing charges (Table 12)**			
	Renewable and energy-saving technologies (Appendices M, N and Q)			
95	Energy produced or saved, kWh/year			
95a	Cost of energy produced or saved, £/year			0
96	Energy consumed by the technology, kWh/year			
96a	Cost of energy consumed, £/year			0
97	**Total energy cost**			205.6283

11a SAP rating (individual heating systems):

98	Energy cost deflator (SAP 2005)	0.91	
99	Energy cost factor (ECF)	1.045527	
100	**SAP rating (Table 14)**	85	**B**

12a DCER (individual heating systems):

		Energy kWh/year	Emm Fact CO2/kWh	Emm CO2/year
101	Space heating from main	309.442	0.422	130.58
102	Space heating from secondary	85.95612	0.422	36.27
103	Energy for water heating	1600.403	**0.422**	675.37
107	Space and water heating			842.23
108	Electicity for pumps and fans	387.1131	0.422	163.36
109	Energy for lighting (Appendix L)	505.1248	0.422	213.16
110	Energy produced or saved in dwelling	0		0.00
111	Energy consumed by above technology	0		0.00
112	Total CO2 kg/year			1218.75
113	Dwelling CO2 Emission Rate (DER) kg/m2.year			11.6
	Carbon factor			8.1
	EI			89
	rating			**B**