MONITORING PLAN:
HEATING AND VENTILATION SYSTEM: COMBI 185
SOLCER HOUSE

Abstract

This paper develops a monitoring plan for analysing the impact of users into the combined ventilation and heating system in "Solcer House". Primarily, a detailed view of the performance of the building and the combine system performance is given. And then, the overall plan strategy and techniques for monitoring the user impacts with the combined system are discussed. Factors such as the occupancy levels, user routines and actions have been taken in account within the monitor strategies. Besides, the main environmental factors which have a direct relation with the combined system. Finally, the methods to analyse the data and estimate the contribution of occupants to the performance gap between "as design" and the actual values post occupancy.

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1. Introduction:

The purpose of this paper is to design a monitoring plan to investigate users influence in the performance of the combined ventilation, water and space heating system in "Solcer House". This building was design with the of being *the* first of many affordable energy positive dwellings designed by The Welsh School of Architecture. That is why the monitoring of the performance of the components of this construction are of highly importance in the search of an efficient sustainable architecture that can meets the UK 2050 Carbon targets[1].

Therefore, the performance of the combined system has a great significance because as the typical consumption energy for this purpose is very significant. Currently, the average percentage of energy demand in a European household for water and space heating is 78.9% (Figure 1), reaching up to 81% in United Kingdom (Figure 2). That is why the reduction of energy consumption for these purposes is essential.

Generally, there is extended simulations of the performance of buildings at design stage where energy values are shown very low meet and systems like the one study on this paper reveals high level of efficiency. Indeed, operating test are often carried out with satisfactory results too. However, post-occupancy monitoring shows frequently that "design standards have been exceed by a factor of 30% or more" (Edwards & Naboni, 2013). Then, external factors may be playing an essential role on this "underperformance" of systems, as Edwards & Naboni (2013) stated "Buildings are constantly in flux as their use, occupancy, environmental systems and other factors change over the time".

For those reasons, the understanding of the impact of external factors, in particular of users, on the combined system (COMBI 185) will contribute to understand thus minimise the performance gap.

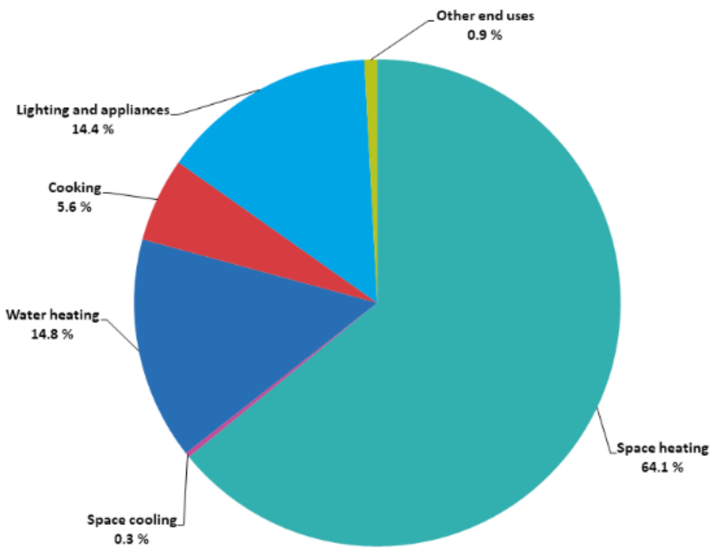

Figure 1. Final Energy consumption in the residential sector by use, EU-28. (Eurostat. , 2017)

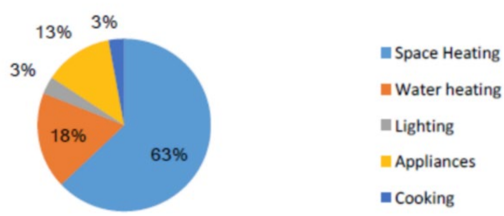

Figure 2. Usage by Percentage of Household Energy in UK Dwellings Using CHM Data (Knight, 2019)

2. Overall performance of the dwelling:

The main components of this two-storey construction are: high insulated fabric to lower the energy demand, a PV array for supplying energy, an electrical battery to storage it and a combined system with a triple function. It provides hot water storage, fresh air and space heating. All together makes of this dwelling of 100 m2 for 2 adults and 2 children a low demand and energy positive building.

[1] UK 2050 Carbon Targets: Reduction of 100% carbon emissions from the levels of the year 1990.

The fabric is made of SIP[2] panels, insulated render and low emissivity double glazed aluminium cladded timber reaching values very similar to those of Passivhaus standards as it is shown in table 1. Also, integrated in the fabric are a TSC[3] system and $34m^2$ of Photovoltaic panels with 4.3KWP (LCRI , 2015). The former pre-heats the fresh air, using solar energy, up to 10-14° C in a sunny winter day (Jenkins, 2020) prior to be force to the MHRV[4] system by a fan. The latter, the PV array supplies part of the required energy, and even exports more energy to the grid than the one taken from it in a ratio of 1.75 (LCRI , 2015) through the year. Ultimately, This is bolstered by the combined system, COMBI 185 (which is explained in the next section) to meet comfort recommended values by CIBSE[5] , while the demand of energy is reduced.

Element	Solcer House*	Passivhaus Benchmarks *1
Walls	0.13	0.15
Glazing	1.21	0.85
Ground Floor	0.13	0.15
Roof	0.14	0.15
Air tightness	$2.6m^3/hm^2$ < 3 (Current best practice, (CIBSE, 2000)	0.6ACH

Table 1.U-Values and Air tightness -Solcer House and Passivhaus Benchmark.* (Coma, 2015) *1 (Latif, 2020)

Overall, the combination of all these features provide "Solcer house" with an autonomy of 70% (LCRI , 2015).

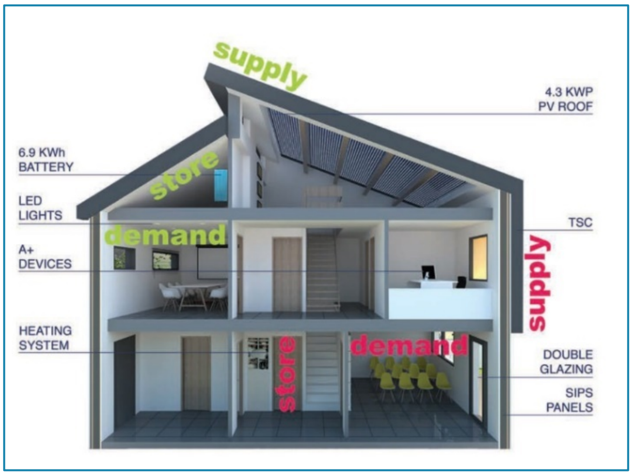

Figure 3. House Features. Performance Diagram. (LCRI , 2015)

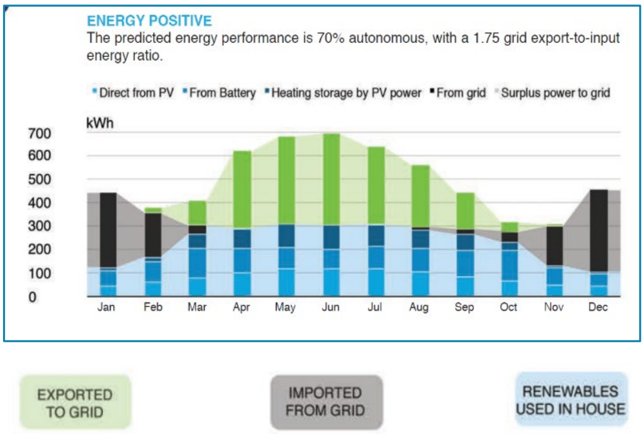

Figure 4. Energy Positive Diagram. (LCRI , 2015)

3. Combi 185

This feature supplies hot water, fresh air and space heating as stated previously. For that, it comes with three main elements: Heat exchanger, thermal water storage and an air heat pump which works together as shown in Figure 5. Additionally, it includes supply and extract fans, filters and all a control panel.

The heat exchanger increases the fresh air temperature coming from the TSC up to the desired temperatures by the user, supported if it is necessary by the heat pump. In order to achieve it, this unit is made of parallel metal plates (Figure 6) which transfer the heat from the exhausted air to the fresh air, as both fluids are push through the sheets. This counter flow heater exchange has a tested efficiency of 95% (Genvex, 2012). However, efficiency of the system may vary depending on environmental factors or the use that occupant make of it.

[2] SIP Panels = Structural Insulated Panels
[3] TSC = Thermal solar collector
[4] MHRV = Mechanical heating recovery ventilation

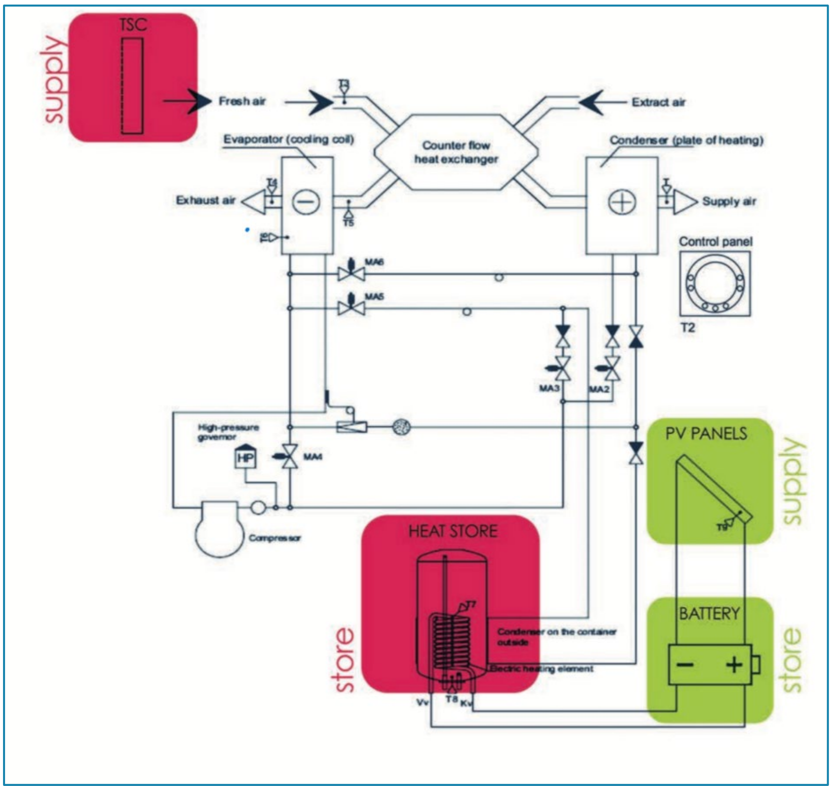

Figure 5. COMBI 185 Operation Diagram (LCRI , 2015)

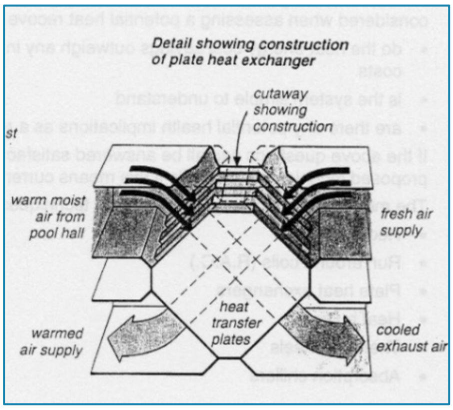

Figure 6. Heater Exchanger (McMullan, 2012)

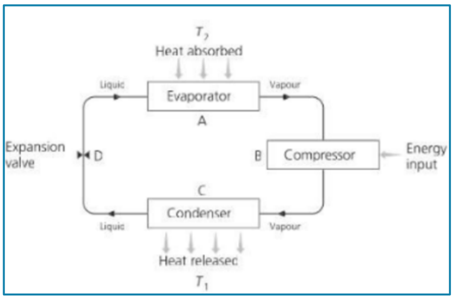

Figure 8. Heat Pump Cycle. (McMullan, 2012)

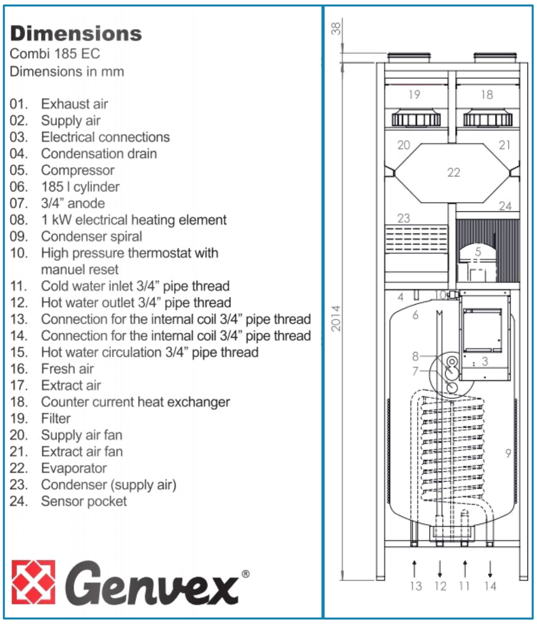

Figure 7. COMBI 185. Cross Section showing water tank. (Genvex, 2012)

On the other hand, the DHW6 is supply from a hot water cylinder (figure 7) with a capacity for 185 l. The water is kept between 52 ºC and 65ºC, ideally at 60ºC (HM Government, 2013) , by the heat pump, which prioritize this against the space heating. its heating time is 9 h from 15 ºC to 55 ºC. Obviously, the performance and energy consumption depends on the supply water inlet temperature but mostly on the user's usage of water, which can make vary the energy input greatly. Also, it is contemplated to connect the water tank with the Photovoltaic in the future, which would alter highly the manner that energy is consume and might impact in the quantity. Therefore, it could be also, an important variable to introduce in the monitoring plan, in the case this would happen before the measure tools were set up in place.

The other main element is the heat pump which works by "extracting heat from a low temperature source and upgrades it to a higher temperature" (McMullan, 2012)For that, it utilise electricity from the PV array, the battery & the grid in this order of preference. The performance of this element is of high importance as it is the main consumer of fuel, apart from appliances and lighting. That is why it is very relevant it's high efficiency as "it produces more usable energy than it consumes" (McMullan, 2012), it is measured by the COP7 which is the ratio between the energy output and the energy input and it can vary between 2 and 5, so at least it duplicates the energy input. In the present case, it uses the remained heat on the exhausted air, after the heat exchanger, as a low temperature source to heat the fluid in the coil in the evaporator (figure 8) prior to be boosted with electrical energy at the compressor. Then it is force to two condensing coils; "one wrapped around DHW tank and the other in the supply air flow" (LCRI , 2015) thus it heats the water storage and assist the heat exchanger with upgrading the air temperature.

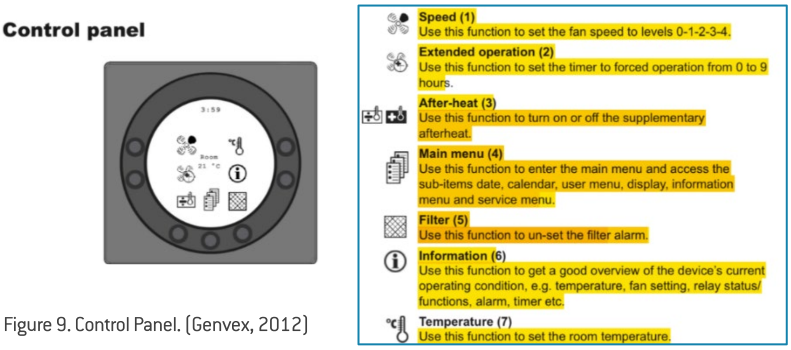

Figure 9. Control Panel. (Genvex, 2012)

Finally, the COMBI 185 has a control panel where the occupants can choose freely the temperature of the air supply, the ventilation rate and even they can decide if the heat pump contributes to the increase the temperature of the air or not (figure 9). Therefore, the most direct connection between users and the system, as it shows in the monitoring plan in strategy.

4. Monitoring Strategy:

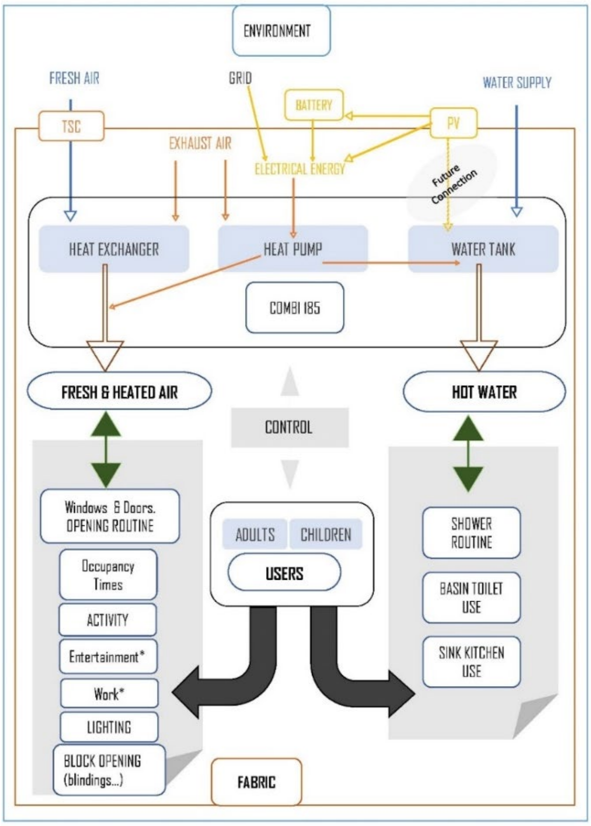

Figure 10. Elements influencing on COMBI 185. Diagram

Table 1 Elements of practice

Element	Description
Technologies	Tangible physical environment that makes up the world in which we live
Engagements	Social significance of participating in a practice: norms; aspirations; attachments; motivations; ideas; symbolic meanings
Know-how and embodied habits	Practical understanding gathered through experience, which is (usually unwittingly) embodied into everyday habitual life
Institutionalized knowledge and explicit rules	Sourced from those ('experts') who know more than you: less intuitive, explicitly spoken information; cultural myths; recommendations for using technologies

Figure 11. Levels of user's knowledge related to technologies. (Foulds, et al., 2013)

4.1. Overview:

This monitoring plan aims to find , understand and quantify the impact of the users in the combined system performance, especially since "Solcer house represents a lifestyle change" (Green & Forster, 2017) as it has features that distinct it from a traditional house, thus "One of the most significant challenges will involve introducing tenants to a new way of thinking" (Green & Forster, 2017). In order to be able to understand and quantify the impact made by the users, all elements and factors involved have been taking in account as in the diagram shown in Figure 10.

Primarily, the monitoring plan strategy intend to establish the percentage of energy consumption that varies because of the user's actions. Then, it is expected to be able to link particular changes in the consumption to specific routines, actions or level of knowledge of the system by users (See figure 11). Furthermore, the ratio between the input and output of electrical energy in the heat pump will be measured and related with specific changes introduced by the users to see how those can affected to the self-efficiency of the system. For that, special consideration is given to peak energy loads due to occupancy changes, and charge and discharge times of water storage. tank.

With that purpose, the key indicators of the main elements (Heat exchanger, heat pump and thermal storage tank) of COMBI 185 are to be monitored as well as the main user actions which can affect the fresh heated air input or the hot water consumption. Besides all elements which are able to modify heat loads such as outdoors weather or fabric. (Figure 10).

4.2. Key indicators

To simplify the analysis, parameters have been divided into two categories those related to the fresh and heat air supply and the ones involved in the hot water supply, but always taking in account that the heat pump is involved in both proccess, so the electrical fuel use by this element is suplying heat to both proccesses.

Aditionally, as shown in the tables 2 ande 3, parameters have been group by categories (Colours) for a better understanding of the monitoring plan:

1. Temperature and Relative Humidity - Orange
2. Air flow and its characteristics - Blue
3. Energy - Yellow
4. User Actions regarding Openings and occupation rates - Green
5. Other user actions / activities – Purple

FRESH & HEATED AIR SUPPLY – COMBI 185		
KEY INDICATOR		KNOWLEDGE PROVISION
T_A	Air Temperature	• Performance of COMBI 185 • Users perception manipulation of control panel • Difference of temperature through the system to associate to the different inputs of energy
RH	Relative Humidity	• RH before and after Combined system • elements modifying it. User perception
R	Solar radiation	• Solar direct radiation outdoors vs indoors light sensor to determine blockage of openings and impact in temperature changes indoors.
AQ	Air Quality	• Levels of pollution in fresh air and exhausted air • Quantification of pollution created by users
F_A	Air Flow	• Ventilation rates • Users manipulation of Control panel: Air flow
S_A	Air Speed	• Measure of changes when windows and doors are opened
E	Electricity	• Combi 185 Consumption (peak loads and mayor changes)
H	Heat	• Heat generated by the heat pump for Hot water • Heat generated by the pump for Heated air • Heat generated by occupants • Heat generated by appliances and lighting
U	U-Value	• Check against specifications • Quantification of its impact on the system
P	Air Tightness	• Check against specifications • Quantification of its impact on the system
O	Opening Time	• Opening of windows: When the windows are open and for how long time.
S_O	Size of Opening	• To calculate flow of air passing through opening
LP	Occupational rates (Number & Location)	• To compare against changes in system such us peak loads
H_a	After heat Force	• Users manipulation of control panel and impact in Temperature & energy.
F_T	Fan speed / Force Time	• Users manipulation of control panel and impact in Ventilation rates & Energy
T	Day/hour	• Activity Time to link actions to energy changes
D	Duration	• Activity Duration to link actions to energy changes

Table 2. KEY INDICATORS FOR FRESH AND HEATED AIR SUPPLY BY COMBI 185

DOMESTIC HOT WATER SUPPLY – COMBI 185		
KEY INDICATOR		KNOWLEDGE PROVISION
T_w	Water Temperature	• Performance of COMBI 185 • Legionella free
F	Water Flow	• Quantify hot water supply by the system • Occupants use of cold and hot water routines
E	Electricity	• Input of electricity on Combi 185, especially peak loads and link to user routines and changes • Quantify other sources of consumption for comparison
H	Heat	• Heat generated by the heat pump to work out efficiency of the pump • Quantify heat from the pump used for the water

Table 3. KEY INDICATORS FOR HOT WATER SUPPLY BY COMBI 185

Furthermore,it has been consider that some of these parameter, those do not show in "Red" in the table above, which in case that cost must be cut down or occupants do not feel at ease with them , the data can be taken from existing monitoring plans or specifications as they are not essential in the mater of concern (Users and COMBI system). Therefore, specifications or previous monitor plan data could be use for U- values and Airtightness (See References). Also air quality, air spped or size of opening are part of the analysis because they add further information regarding the impact of opening windows or the quantity of pollution originated indoors and the system must extract. Hoever, without them the plan would still provinding enough that regarding the energetic impact of user actions into the COMBI system.

4.3. Equipment and techniques:

In order to monitor the key indicators explained above, the specific equipment detailed in the table 4 below will be employed; and complemented by existing data and specific questionnaires to the occupants.

For all key indicators, but those specifically indicated in the table 4 and 5, a longitudinal study is to be carried out with the aim of find robust patterns and trends which shows clear relations between action and effect, and consistent measures. Therefore, the frequency of the recordings will be kept the same across all the installed equipment to keep steady results and send automatically to a data logger. Measures will be taken each one minute, because although there is more regular parameters such as temperature or RH which, there are certain users actions such as wash the dishes, shower or open an external door that can be done within minutes.

On the other hand, looking for representative data the periods have been chosen according to weather conditions, mostly changes in outdoors temperature (See Figure 12); and users lifestyle alterations such as holidays. Then December, January, April, July, August and October are the adequate months to embody the different seasons (heating and no-heating) but also Christmas and Summer holidays as well as working months. Specially January, when people spends longer times at home due to weather conditions and just after a holiday. Nevertheless, being aware of the high disturbance could cause a monitoring every now and then, the plan might be readjusted in an agreement with occupants and limited only to 2 summer months and 2 winter ones.

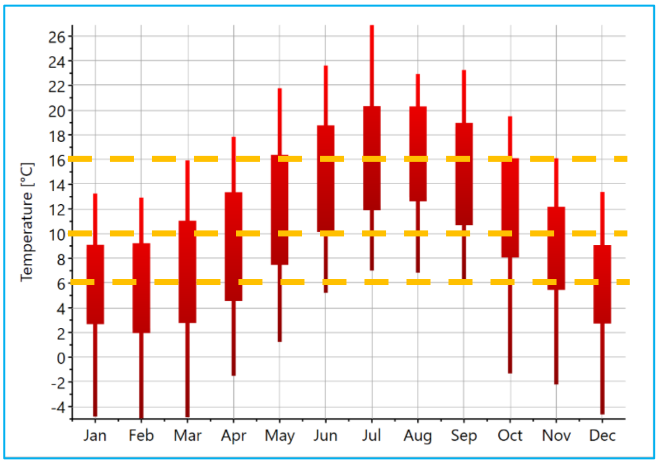

Figure 12. Temperatures at St. Athan Station (closest to Solcer House) (Meteonorm, 2018)

FRESH & HEATED AIR SUPPLY – COMBI 185 (Frequency = 1 minute)					
KEY INDICATOR		Measurement tool	Unit	Nº of Items	Comments / Outcomes
T_A	Air Temperature	Temperature and RH meter	ºC	12+1	• Control Panel. Monitoring of indoors temperatures set up by users. • 1sensor outside and indoors located as per section 4.4 • ΔT and %RH through system • Duration of period since user set up Temperature and rooms reach that value
RH	Relative Humidity		%	12	
R	Solar radiation	Pyranometer & indoors Light Sensor	W/m^2	1/ 6	• Quantification of solar radiation outdoors • Quantification light come in from windows
E	Electricity	Light on/off sensor	KWh	10	• One for each artificial light. • Quantify 1 per room, subject to change on-site
H	Heat	Heat meter	KWh	2	• Both in Combi System to quantify heat used for Fresh air and for water. • Heat input from appliances and lighting, see below specifications use.
H_a	After heat Force	Control Panel History	On/ off-	-	• Existing Control panel history recorded. Users control of heat pump input in heated air
S_A	Air Speed	Anemometer	m/s	8	• Located near or in windows subject to window opening time • Detection of speed air alterations due to user actions
F_A	Air Flow	Mass flow meter/ Volumetric Flow meter	Kg/ s – m^3/s	5	• Located in Fresh air supply vents and Combi system to study ventilation rates • For Air flow due to Windows/ Doors see O S_O
F_T	Fan speed /Force Time	Control Panel History	Level 1-4/ 0-9 h	-	• Existing control panel recording tools. • User set up fan speed and duration
AQ	Air Quality	Air quality meter	µg / m^3	5	• 1 outdoors • 1 Supply air • 3 Exhausted air located in extract vents
U	U-Value	Heat flux + 2 thermometers	W/m^{2}K	1+2	• One Time Test • Subject of using existing data
P	Air Tightness	Blower Door Test	m^3/hm^2	1	
O	Opening Time	Window and door sensors	hh:mm:ss	8	• Records when a door or window is open to plot it against changes in temperature, RH or Air quality
S_O	Size of Opening	Distance sensor	cm	8	• A distance sensor will be set up in each window or door in such a way, the distanced record to the direct opposite wall will be a particular one for each angle of opening and through equations and the air speed data air flow through Windows and door will be worked out.
LP	Occupational rates	Motion Sensor	-	11	• Occupancy rates to plot against temperatures and energy consumption • Location of users within the home – stablished range of activities – human heat input -
T	Day/hour	Smart watch	Date	4	• Human heat Input - quantification • When and for how long • Sleeping time
D	Duration	Smart watch	Calories (hh:mm:ss)	4	

Table 4. Key indicators- Measurement Tools- Fresh Heated Air

DOMESTIC HOT WATER SUPPLY – COMBI 185					
KEY INDICATOR		Measurement tool	Unit	Nº of Items	Comments
T_w	Water Temperature	Water thermometer	ºC		
F	Water Flow	Mass flow meter/ Volumetric Flow meter	Kg/ s – m^3/s		
E	Electricity	Electric meter	KWh		
H	Heat	Heat Meter	KWh		

Table 5. Key indicators- Measurement Tools – Hot Water

In order to find out secondary data, as it was commented earlier, the control panel history will be included in the plan. Then, direct inputs of users can be assessed against temperatures and ventilation rates in the rooms and outside, but also, occupants' perceptions can comment regarding the system can be check against the data. In order to gather that kind of information questionnaires related to how to use the system and perceptions about its performance against users' comfort will be given to occupants. However, the validity of this information is constrained because of the limited number of users and will have to be supported by other quantifiable parameters. Also, to have a full data package, specifications from appliances and lighting will be fundamental to quantify their input in the house heat balance.

4.4. Equipment location

It is essential the correct location of equipment for obtaining relevant data, thus specific positions are shown in the following diagrams.

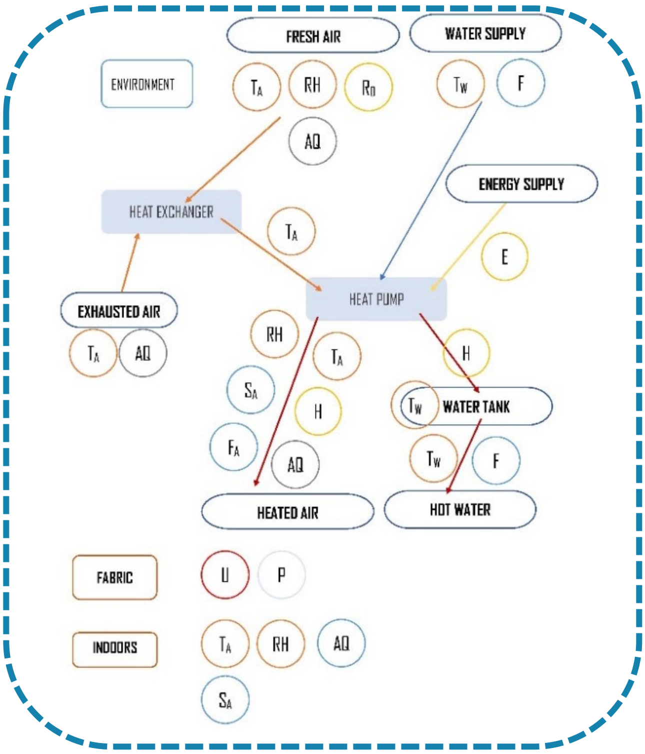

Figure 12. Characteristic indicators of each element involved and location. Equipment location related to outdoors environment and COMBI 185.

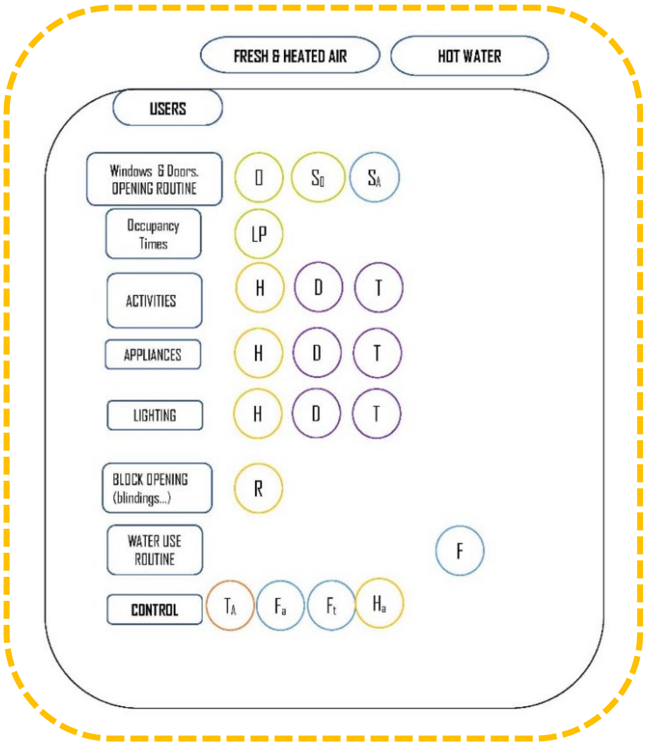

Figure 13. Characteristic indicators of user's actions (See locations in floor plans together with indoors parameters.

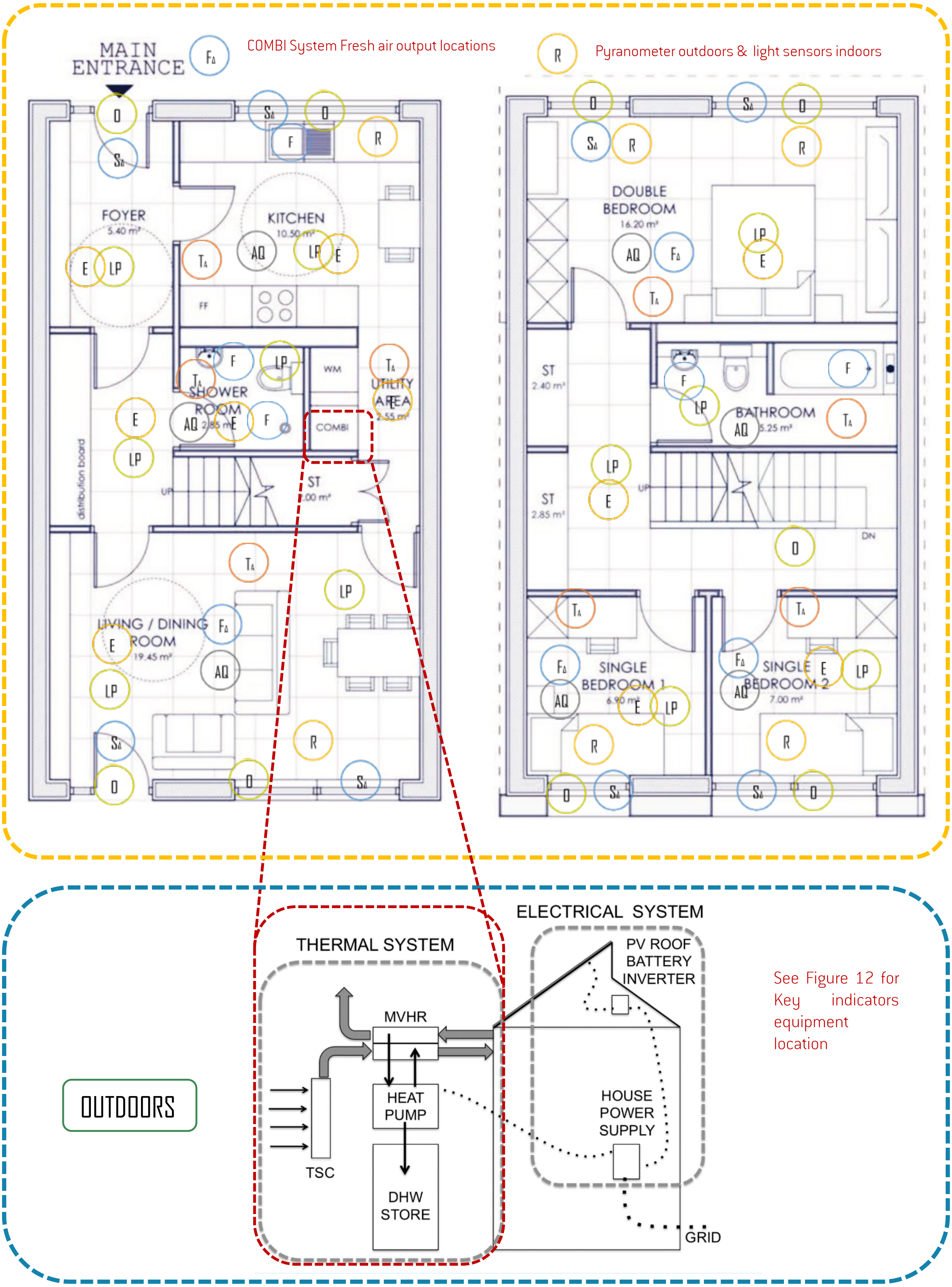

Figure 14. Indoors location of Key indicators Equipment

5. Data Collection Analysis :

$$COP_{H} = \frac{\text{Heat energy output}}{\text{Pump energy input}} = \frac{T_1}{T_1 - T_2}$$

where

T_1 = absolute temperature of heat output (K)

T_2 = absolute temperature of heat source (K).

Figure 15. Heat Pump. Efficiency Coefficient. (McMullan, 2012)

Once data collection is completed, it will be grouped to simplify the analysis, so averages will be created by hour, by daytime and night-time and then group by weeks and months of every parameter. Furthermore, some data must be included in relevant equations to generate, ultimately, the data needed, this is the case when analysing the Fresh heated air process. Essentially, the steady state heat balance equation will be used to analyse the heat input of each factor as in the figure 16 and then be able to make assumptions of actions and effects. In addition, the COP factor (Figure 15) of the combined system will be also calculated for the different relevant periods.

HEAT BALANCE EQUATION

$Q_f + Q_v + Q_V + Q_s + Q_h + Q_o + Q_i = 0$

Q_f = Fabric heat Q_v =Infiltration heat

Q_V = Ventilation heat Q_s = Solar heat

Q_o = Occupants heat Q_i= Incidental Heat

Q = Heating Load -

Fabric heat transfer

$Qf = \Sigma UA (To - Ti)$

A = Element Area To-Ti= ΔTemperature

U = Thermal Transmittance Value

Air exchange infiltration

$Q_v = n_v V/3 (To - Ti)$

V = Room Volume To-Ti= ΔTemperature

n = Average infiltration Rate

Air exchange Ventilation

$Q_V = n_V V/3 (To - Ti)$

V = Room Volume To-Ti= ΔTemperature

n_V = Average ventilation Rate

Solar gains

$Qsi = \Sigma I_{\phi} giAi$

I= Irradiance g=g-value

A = glazing Area

Qv – Qo – Qi are the main variables subjected to user actions and affecting the heat input from the combined system

Figure 16. Essential equation to analysis relevant data

Subsequently, data will be compared as in the following table in relevant periods that can varied once data is analysed. The main times of interest are: Day time and Night-time(Daily) and making a difference between Workdays and weekends and Holidays; monthly averages and seasonal averages. Also, peak loads will be analysed and compared separately.

	Comparisons
1	Total Energy Consumption (to heat air) VS COMBI System energy Consumption(total. Heated air + Hot water) VS AS Design Values
2	COMBI System energy Consumption (to heat air) Vs Occupation Rates
3	Combi SYSTEM Energy Consumption (to heat air) VS Duration of Activities (Work/ Cleaning/Entertainment)

4	Combi SYSTEM Energy Consumption (to heat air) VS Users Heat and electrical appliance or lighting related to the specific activities
5	Combi SYSTEM Energy Consumption (to heat air) VS Opening Windows and doors
6	Opening Windows & Doors VS Temperatures
7	Combi SYSTEM Energy Consumption (to heat air) VS Modifications in control panel by users rather than Temperature
8	Ventilation Supply and Exhaust rates VS "As Design" VS User Manipulation of control panel
9	Combi SYSTEM Energy Consumption (to Heat water) VS Manufacturing Specifications VS Water Consumption. Group by Activity and duration
10	COMBI SYSTEM COP Efficiency VS Manufacturing specifications Vs All Activity changes (those involving water included)
11	ΔT (Heat exchanger) VS Supply air Temperature
12	Temperatures set up by users VS Actual Temperatures in rooms VS CIBSE Recommendations
13	Water consumptions VS Assumed averages in CIBSE and the building (HM Government, 2013)
14	Evaluation of Occupant perception against performance of the system

6. Results Purposes

The main goal of this monitoring plan is to assist to diminishing the performance gap between the "as design" energy consumption values of the combined system and the post-occupancy values through the understanding of the users influences. Subsequently, changes in user style of life will eventually be proposed as well as COMBI 185 design might be able to be rethought to adapt them to users' routines. Additionally, and as other publications such as Zero Carbon Hub (2014) already proposed Soft landings plan might be created in based to more consolidated and accurate data. Furthermore, this data could be extrapolated to other combined systems to adapt them to the users.

Ultimately, the analysis of the data is expected to point out towards measures to cut down energy consumption through the alteration of user actions but also the adaptation of high efficiency equipment such as COMBI 185 to people

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Final Assignment Submission Declaration

Essay Title: Monitoring Plan: Heating and Ventilation System: COMBI 185. Solcer House.

Module: Investigation of the Building Environment

Before submitting your essay, please complete the following checklist, fill in the number of words in your assignment, and then sign the declaration at the bottom of the page:

Checklist:

- ✓ ☐ I have taken into account guidance provided by the assignment brief and by the module tutor.
- ✓ ☐ I have acknowledged and documented all sources from which I have borrowed ideas and information
- ✓ ☐ I have ensured that any computer software used in the preparation of this work is appropriately licensed.
- ✓ ☐ I have proofread my essay.
- ✓ ☐ I have used a font of at least Arial 11 and left a reasonable margin space around the work.
- ✓ ☐ Number of words: 2597 not including the abstract, contents list, tables, figures, reference list

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This assignment is my own work, and does not involve either plagiarism or collusion

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Student id: 1948781 Course: ENVIRONMENTAL DESIGN OF BUILDINGS 2DL

Date:1 1/03/2020

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