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IEE PassREg

PASSIVE HOUSE REGIONS WITH RENEWABLE ENERGY

Deliverable D5.4.1 "Common evaluation of the beacons implemented within PassREg"

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CONTENTS

1 INTRODUCTION

The Passive House concept is a widely recognised basis for the design of energy efficient buildings in many parts of Europe. The energy balance and Passive House Design tool PHPP, or Passive House Planning Package, has proved successful in practice. Numerous built examples across Europe acknowledge this and show the close correlation between monitored energy consumption and calculated energy demand. Furthermore, PHPP has also developed into a tool for the verification of EnerPHit projects which apply Passive House components in existing buildings.
The beacons of the European “PassREg” project demonstrate that the calculated energy demand with PHPP correspond to the energy consumption monitored in the realized buildings. Moreover, the buildings currently under construction were all calculated with PHPP and can thus provide accurate design data in terms of energy performance and comfort. All beacon information is publicly available on the database www.passivehouse-database.org. Cost estimations/real costs complete the follow-up of those buildings and show their successful implementation.

2 PARAMETERS

In order to evaluate the success of the beacon projects, all projects underwent a “follow-up” consisting of information on their energy performance, comfort and costs. The Passive House Institute developed templates for a success monitoring which could be used by the consortium partners to fill in, and thus, “monitor” project specific data during a specified time frame of at least one year. Within the framework of the PassREg project, two Italian beacons as well as the Bahnstadt Passive House district in Heidelberg, Germany were monitored for energy performance and the Italian projects were also examined for comfort.
So in general, first of all, the energy performance was followed up. This was done in the case of the Italian beacons, the German Bahnstadt district and the beacon project in Ergli, Latvia, via monitoring the energy consumption, see respective chapters in this report. In the case of the German Bahnstadt a success monitoring scheme was used as described in chapter 4 of this report.
The Ergli beacon project used the templates provided by the Passive House Institute, see Annex II.
Second, the comfort of all beacons was followed-up. In the case of beacons still in design or construction phase, the PHPP calculations were carried out by the project team and the Passive House Institute collected all the PHPPs. They state the standard comfort conditions and prove that the building was designed to meet those conditions, see exemplary PHPP screenshot in Annex III as well as the information on the Passive House database which features certified projects as well as projects calculated with PHPP. As specific values, which means values “per m²”, are displayed, all the projects can be compared with each other.
Third, all beacons were followed-up in terms of costs. If the beacons have not yet been built, cost estimates were provided. Otherwise, the real costs were stated. All information is publicly available including contact details on the Passive House database and the PassREg website.

3 DETAILED MONITORING OF TWO ITALIAN BEACONS

3.1 Botticelli project in Mascalucia, Sicily

3.1.1 Project description

The Botticelli building is a zero-energy, certified Passive House new build with strategic shading and cooling strategies as well as photovoltaic and other renewable energy systems. It is designed as zero-energy building and certified according to Passivhaus standard, respecting requirements in terms of thermal performance and air tightness. The reduction of energy need is accompanied by the local production of renewable energy by means of photovoltaic modules, a thermal solar system and an earth to air heat exchanger (EAHE) in the mechanical ventilation system. In particular, the EAHE provides pre-heating or pre-cooling to the air supplied by the ventilation system. The supply-air temperature can be further adjusted by means of a heat recovery unit and a heating / cooling coil before entering the indoor environment. A solar thermal system is integrated with a heat pump generator. The system is automatically regulated by a building automation system supported by Konnex (KNX) protocol. The dwelling also benefits from natural ventilation (cross ventilation) - especially for night cooling - enhanced by an internal patio and the optimal layout of window openings. The building is under monitoring for energy and comfort by the eERG reasearch group, www.eerg.it

Figure 1: Botticelli project in Mascalucia, Sicily, Italy. ID 2123 www.passivehouse-database.org

3.1.2 Energy efficiency and use of renewables

The Botticelli project is a Smart NZEB built in Passive House Standard in Sicily near Etna Vulcan at Mascalucia village, in Catania Province. It is a first example of Net Zero Energy Building (NZEB) adopting complete integrated design of Passivhaus Institut concept in the South Mediterranean climate. It is also the first Passive House in Sicily. The building is

designed as zero-energy building and it is certified according to Passive House Standard, respecting requirements in terms of thermal performances, airtightness, and comfort quality.
It was designed by Eng. *Carmelo Sapienza* of *Sapienza & Partners* technical firm, with the support of dynamic simulations and comfort optimization techniques provided by *eERG-PoliMI - the end-use Efficiency Research Group of Politecnico di Milano*. There are also some industrial partners of the project as *Rockwool, Siemens, PM Plastic Material* and *Herholdt Controls*.
In the Botticelli project, the reduction of energy need is accompanied by the local production of renewable energy by means of photovoltaic modules, a thermal solar system and a earth to air heat exchanger (EAHE) in the mechanical ventilation system. In particular, the EAHE provides pre-heating or pre-cooling to the air supplied by the ventilation system. The supply air temperature can be further adjusted by means of a heat recovery unit and a heating / cooling coil before entering the indoor environment. A solar thermal system is integrated with an air to water heat pump generator.
The system is automatically regulated by a building automation system supported by KNX protocol, an easy open standard protocol for building and home automation to achieve energy efficiency, living and climatic comfort and energy management.
The dwelling also benefits from natural ventilation (cross ventilation) when the outdoor air temperatures are lower than indoor ones in the cooling period - especially for night cooling - enhanced by an internal patio and the optimal layout of window openings.
A high thermal insulation of the envelope has been guaranteed adopting common and consolidated local building technologies. Here, the main thermal feature of the building envelope are given:

- External Wall thermal transmittance: 0.13 W/(m² K)
- Basement thermal transmittance: 0.23 W/(m² K)
- Roof thermal transmittance: 0.13 W/(m² K)
- Window frame thermal transmittance: 0.97 W/(m² K)
- Window glazing thermal transmittance: 0.7 W/(m² K)
- Window glazing solar factor (g-value): 54%

Glazing surfaces are also completed with automatically controlled external blinds for solar shading, when needed.
An envelope air tightness value n_{50} lower than 0.6 1/h was reached and verified with an airtightness test at a pressure of 50 Pa.

3.1.3 Results and analysis

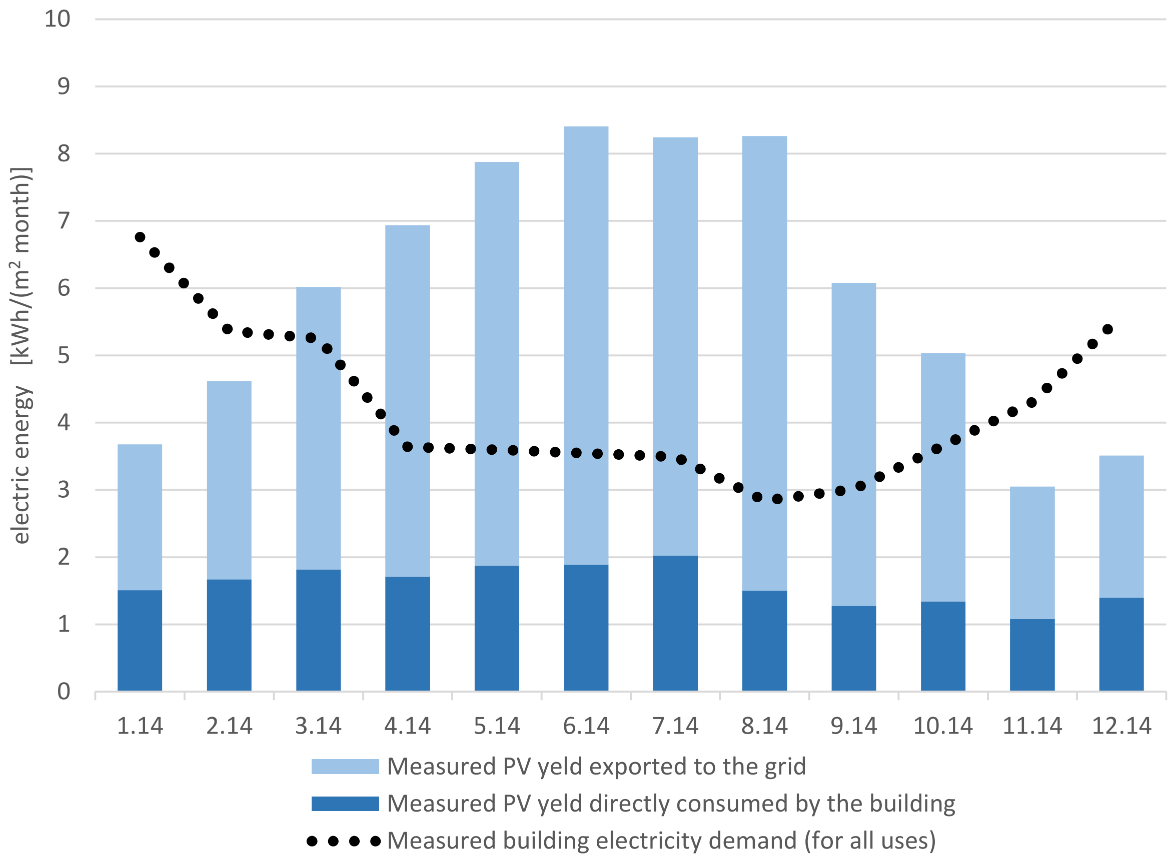


Figure 2: Botticelli project in Sicily - monthly total electric energy use of the building vs. total electric energy generated by the PV system, in the year 2014.

In the building all the energy uses are covered by electricity, for instance also thermal energy for heating and domestic hot water is produced by an electrical air-to-water heat pump. So all the delivered energy measured is electrical.
In the graph in Figure 2 we can see the total energy demand (dotted black line) measured for all uses which are globally requested in the building during the year 2014. Following a comprehensive approach, the whole energy demand here is considered, for instance also the energy demand for lighting of the outdoor spaces of the building or for the unconditioned service rooms. This allows to consider the energy demand as perceived actually by the building users.

The electrical energy demand can be directly compared to the measured energy production from the photovoltaic system (PV) integrated in the building roof. Part of the PV electricity production is directly consumed on-site in the building (dark-blue bars in Figure 2) and the other part is exported to the grid (light-blue bars).
The directly consumed PV yield is a bit higher in the summer period but it appears quite constant during the year. The total PV energy production increases during summer following the solar radiation available. The total electricity demand increases during the heating period due to different factor as a lower thermal energy production from the solar thermal system

integrated in the roof, the energy need for space heating and a greater need for the artificial lighting. However we can see that the coverage of the total energy demand appears good also during the winter months and in the greater part of the months during the whole year the renewable energy production from PV system is greater or much greater than the reduced and optimized energy demand.
The measured total electrical energy demand for all uses has been of 51.1 kWh/(m^2 a) referred to the building net conditioned area (*treated floor area*). While the measured electrical production from the installed PV has been of 71.7 kWh/(m^2 a) (referred to the same building net conditioned area), of this 19.1 kWh/(m^2a) has been directly consumed on-site for the building energy uses and 52.63 kWh/(m^2 a) has been exported to the grid.
Thanks to the energy efficiency measures according the Passive House Standard which are well adopted to the Mediterranean climate the energy needs have been very well reduced. So considering also the installed PV, the overall energy balance of the building is very interesting showing that the zero energy buildings features were reached, with very positive results both on a yearly as well as on a monthly basis, with a yearly net energy production.
The total energy demand of 51.1 kWh/(m^2 a) of electricity is composed by 19.1 kWh/(m^2 a) of energy produced by the on-site integrated PV system and directly consumed in the building and by the other 32 kWh/(m^2 a) imported by the grid, which, considering an average primary energy factor of 2.5, corresponds to a primary energy demand of 80 kWh/(m^2 a), for all energy uses.
This positive results in terms of energy performances bring also to guarantee very good indoor comfort conditions. In the following Figure 3 and Figure 4, we can see measured values of indoor temperature and relative humidity in the main building rooms, respectively for representative weeks in summer and winter seasons. In summer we can see that also in period with outdoor temperature higher than 30 °C (up to 36 °C) the building guarantee comfortable indoor temperatures.

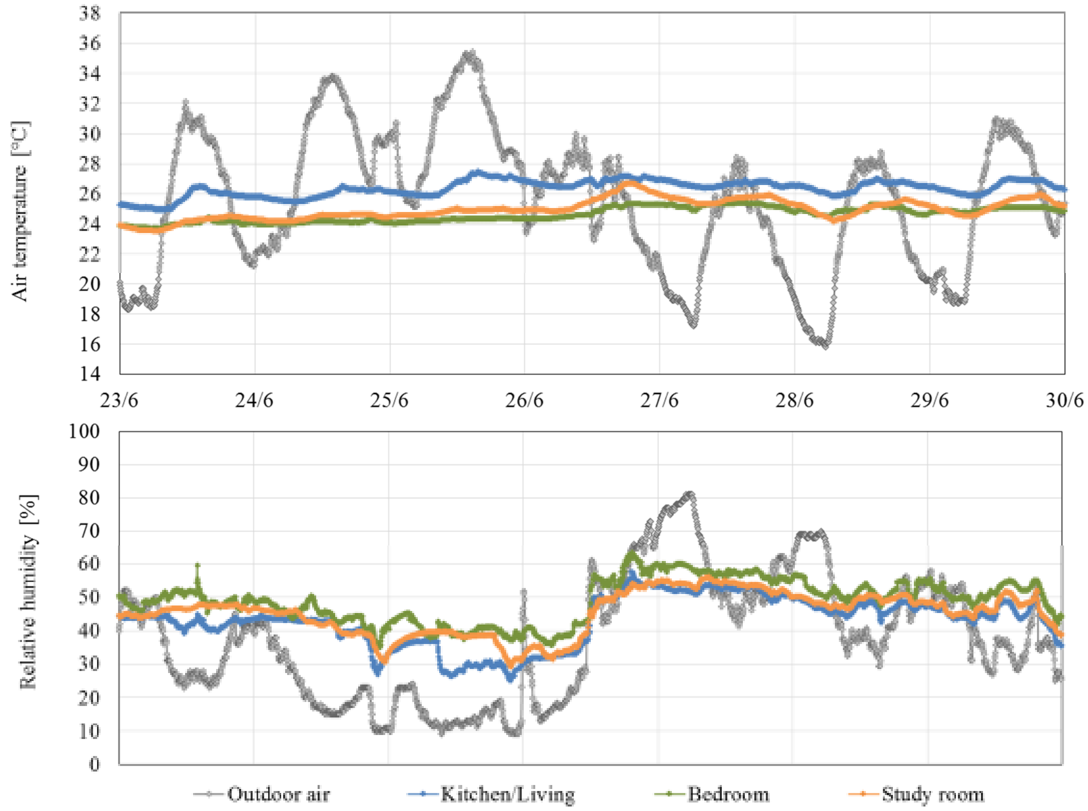


Figure 3: Botticelli project in Sicily - temperature and relative humidity values recorded in the kitchen, bedroom and study of the building in a warm week from 23rd to 30th of June 2014.

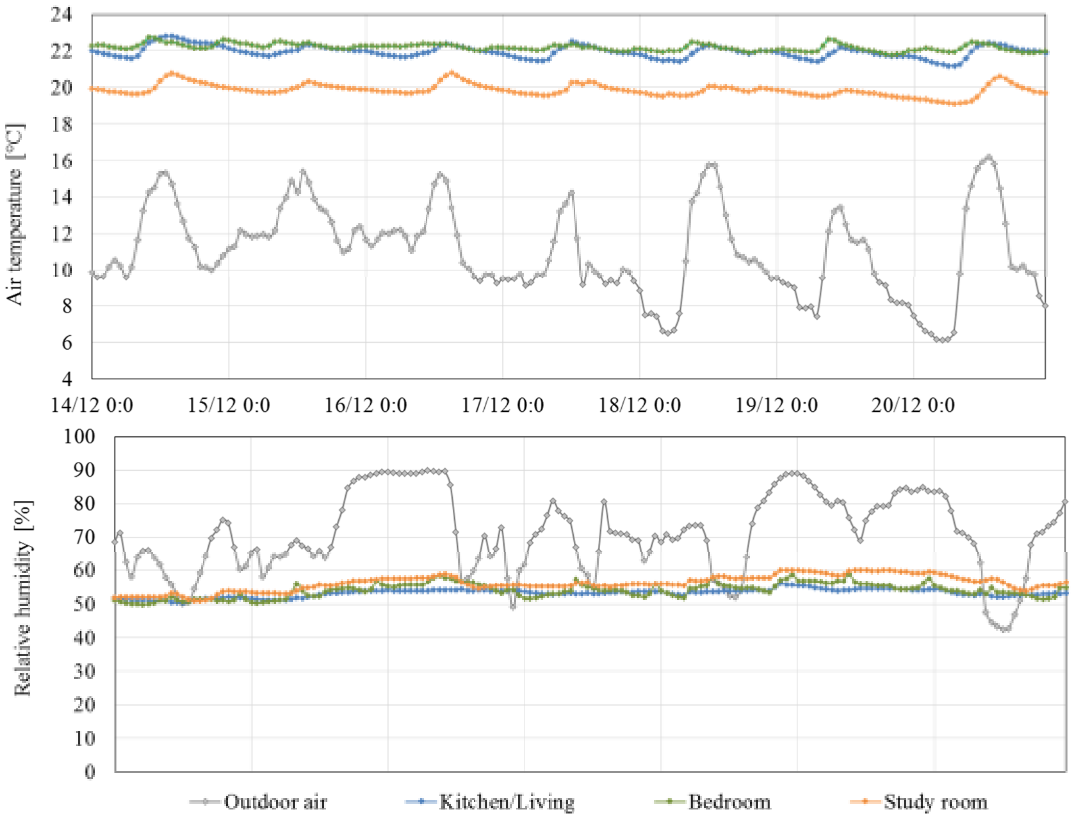


Figure 4: Botticelli project in Sicily - temperature and relative humidity values recorded in the kitchen, bedroom and study of the building in a cold week from 14th to 21st of December 2014.

3.2 LEAF House in the Marche region

3.2.1 Project description

The building is an apartments block with 6 dwellings, see Figure 5. It represents one of the very first examples of nZEB in Italy. Although not a certified passive house and not calculated with the PHPP, it shows technical features suitable with passive house strategies integrated with renewable energy systems, with high thermal insulation of envelope, solar thermal and photovoltaic systems, ground heat exchangers and heat pump. All the main suitable solutions for nZEBs are well adopted and integrated in this building and were calculated using dynamic building simulation. The project has been developed and managed by the Loccioni Group.

Figure 5: LEAF House (Loccioni Group) in the Marche region - Italy.

3.2.2 Energy efficiency and use of renewables

The LEAF house features a good thermal insulation level of the envelope. For instance the external walls have a thermal transmittance of 0.15 W/(m^{2}K), the windows considering glazed and frame areas have an average thermal transmittance of 1.1 W/(m^{2}K) and great care was taken to minimize thermal bridges with interesting details of thermal cut for balconies and good thermal insulation of rolling shutters boxes.

An earth to air heat exchanger pre-conditions renewal air for the installed mechanical ventilation system, which is demand-controlled basing on the installed sensors for indoor CO_2 concentration, air temperature and relative humidity and with switches related to windows opening.

Renewable solar systems are integrated in the building roof and façade and south-oriented. Particularly we can see a solar thermal system, with 7 collectors of 2.7 m^2 each (total surface of about 19 m^2), and a photovoltaic system, with a total surface of 150 m^2 with a total pick peak power of produced electrical energy of 20 kW$_p$.

A reversible geothermal heat pump with 3 vertical borehole heat exchangers (95 m depth each) and 2 heat storage tanks for heating and domestic hot water are installed. The system is

completed also with a back up gas condensing boiler. When water temperature in the installed borehole heat exchangers allow, also free cooling is possible, without using the reversible heat pump and saving the electrical energy for this.
The photovoltaic systems and the reversible heat pump can be managed to obtained optimal integration of electrical energy demand and production in situ.
A comprehensive building management system is installed for functions controls and performance monitoring.
Energy efficiency measures to reduce also energy uses for artificial lighting and electrical appliances are adopted, as solar tubes for daylighting, high energy efficiency light sources and electrical appliances, stand-by consumption cut off.

3.2.3 Results and analysis

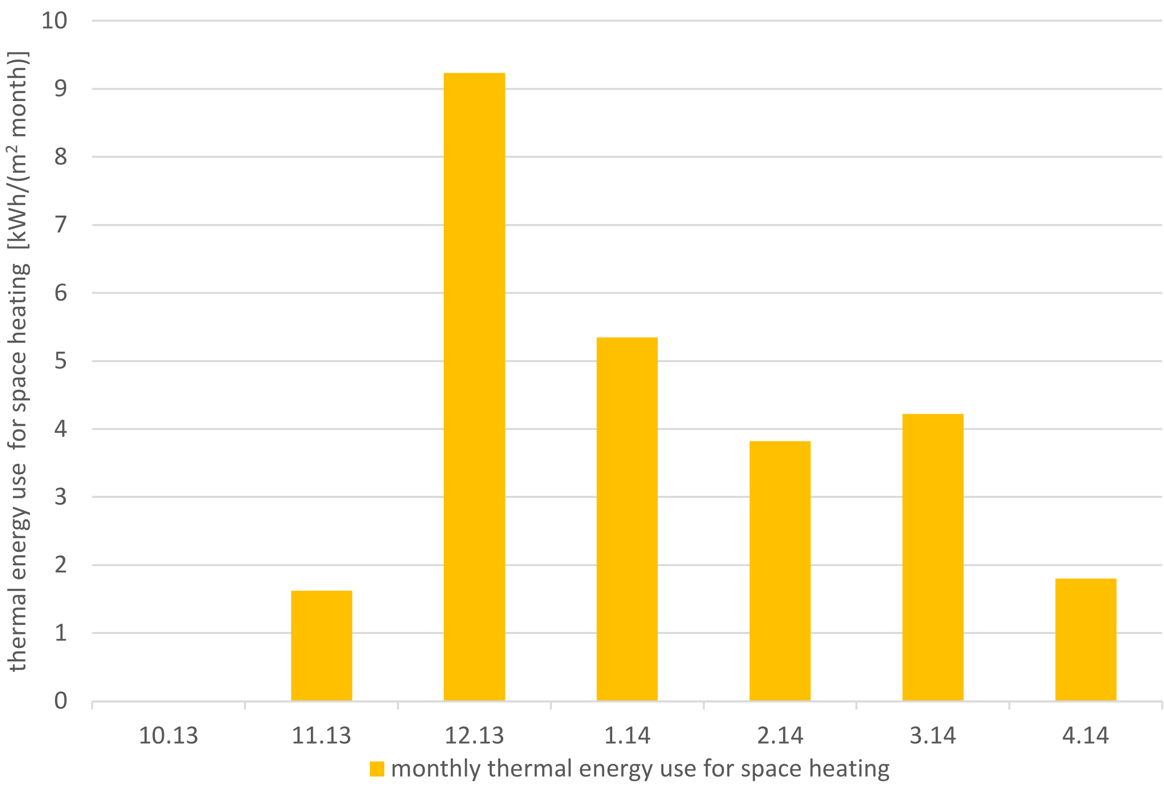


Figure 6: LEAF House in Marche - monthly thermal energy use for space heating, in year heating season 2013/2014.

Figure 6 shows the measured monthly energy use for space heating of all the apartments in the building during the heating season 2013-2014. The resulting yearly thermal energy use for space heating is equal to 26 kWh/(m^2 y) referred to the net conditioned area of the building. This results from the data measured directly in the services technical room, so it includes also the thermal losses due to pipes and distribution in the heating system.
This can represent an interesting result for an intermediate building case, which is not a certified Passive House, however, it successfully adopted many principles suggested by the Passive House strategy. Indeed this building represents one of the very first examples towards nZEB developed in Italy from 2010, showing also that solutions are robust in time. The

reduction of the energy needs and uses allows a more optimized use of the installed integrated renewable energy systems.

The building offers comfortable comfort condition during the overall year.

The following Figure 7 and Figure 8 show measured values of indoor temperature and relative humidity in the main rooms of two apartments, respectively for representative weeks in summer and winter seasons. The indoor conditions remain comfortable also during days when the outdoor temperatures reach high values in summer, and low ones in winter.

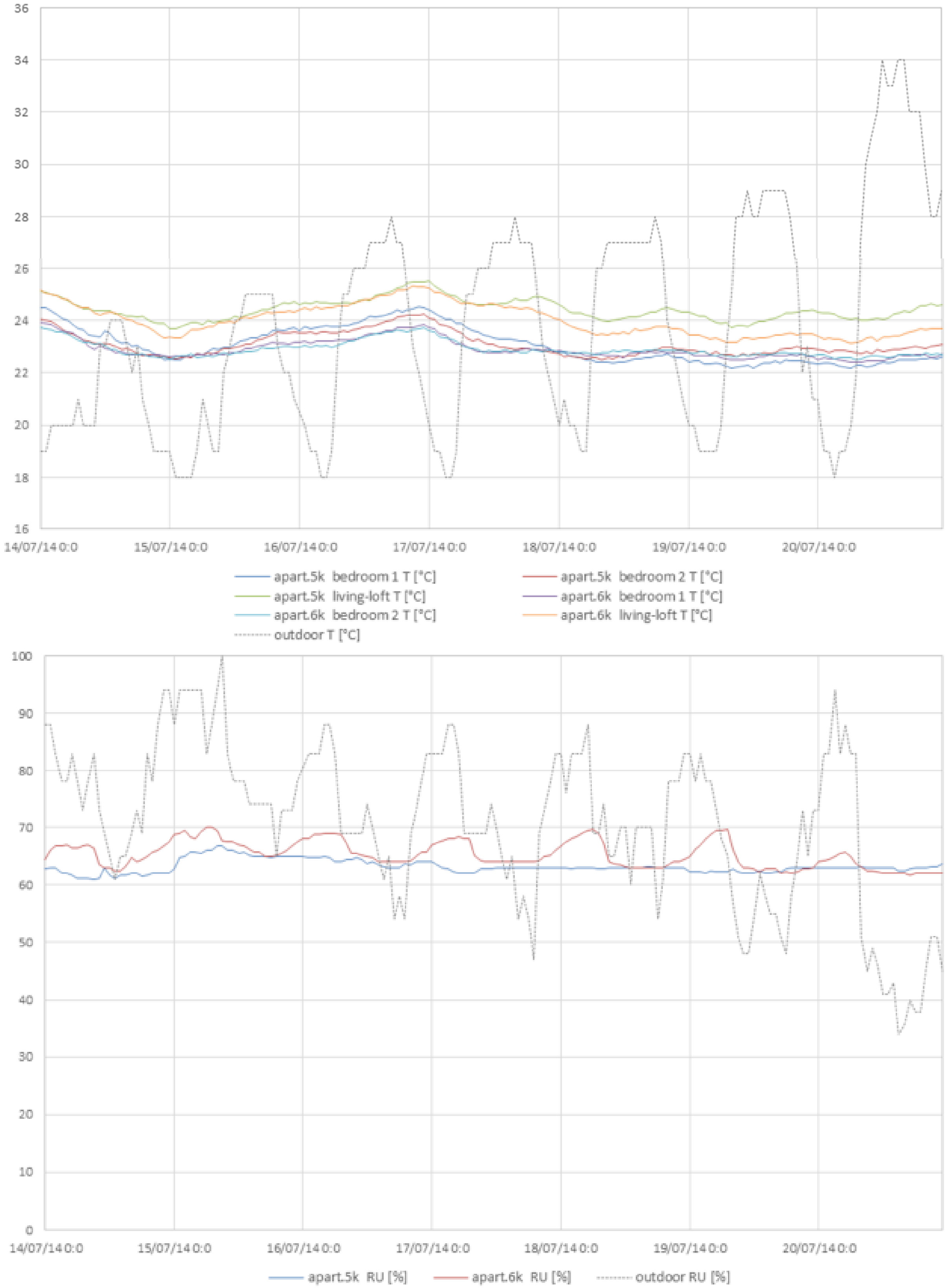


Figure 7: LEAF House in Marche - temperature and relative humidity values recorded in two apartments of the building in a warm week from 14th to 21ft of July 2014.

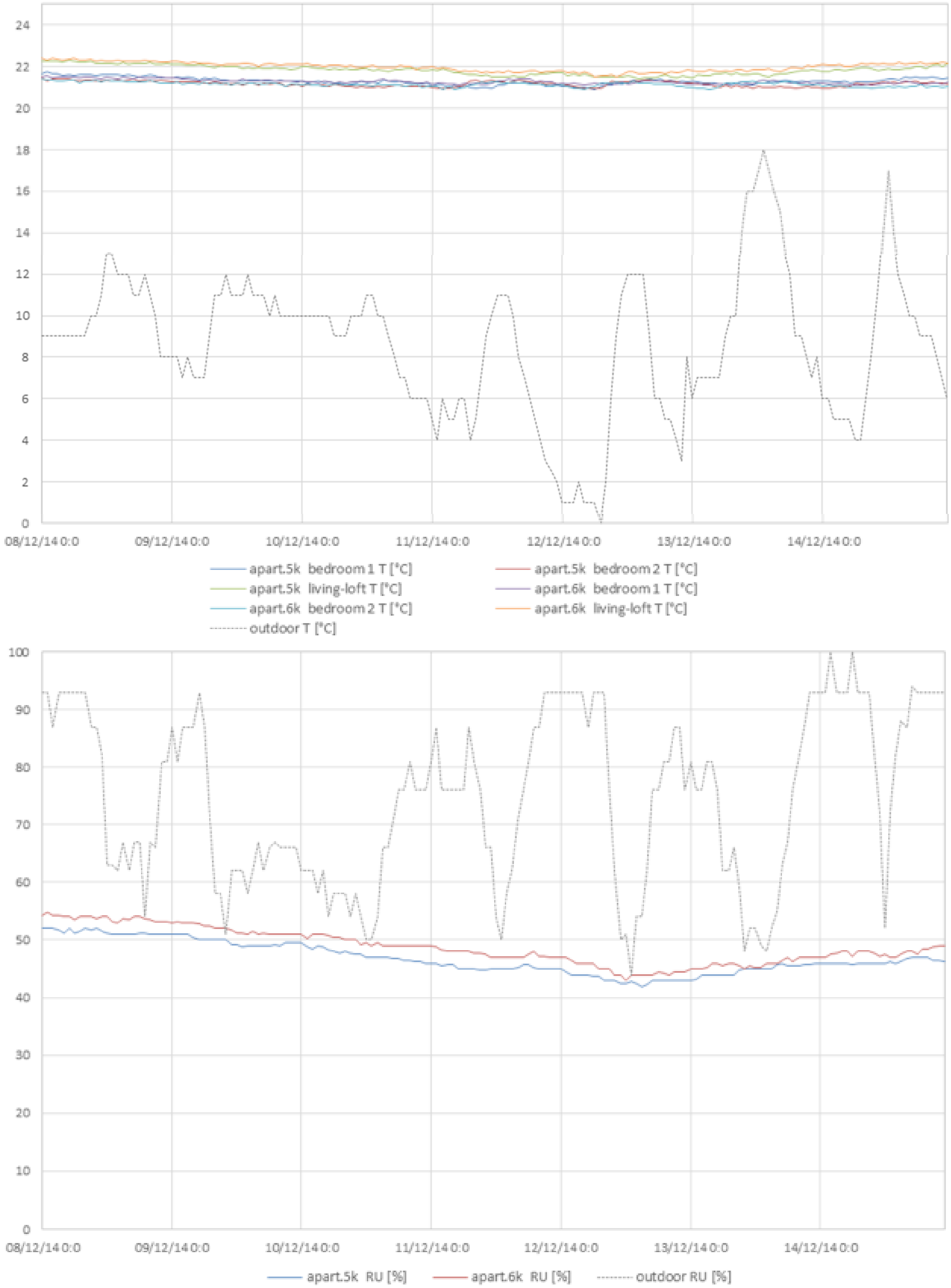


Figure 8: LEAF House in Marche - temperature and relative humidity values recorded in in two apartments of the building in a cold week from 8th to 15th of December 2014.

4 MONITORING OF BAHNSTADT HEIDELBERG, GERMANY

This chapter deals with the subject of how monitoring can be successfully carried out for the Bahnstadt district in Heidelberg, Germany, see Figure 9, which is currently the largest Passive House settlement within Europe. In this construction area, (due to lack of funding) it was not possible to carry out detailed measurements; however, monthly meter readings are available for the total heating consumption (heating, hot water and losses etc.) for entire development blocks and some larger buildings with over a hundred apartments each. For this reason, evaluation of the data will take place in the context of minimal monitoring where, with the aid of research findings from other projects, heating consumption will be calculated to a good approximation from these monthly values.

The Passive House Standard is mandatory in the whole district. Thus, a space heating demand of less than 15 kWh/(m²a) is one of the goals pursued already during the planning phase. For comparison, a recent study called „Energiekennwerte 2014") by techem on the space heating consumption in the year 2013 shows: Buildings supplied by a district heating system had on average 112 kWh/(m²a) energy consumption for space heating.

Figure 9: Aerial view of the Bahnstadt district where the buildings examined in this report are located (Picture: Kay Sommer / Copyright: City of Heidelberg)

Figure 10: View of some buildings in the Bahnstadt district (Pictures: PHI)

4.1 Energy consumption in the Bahnstadt Heidelberg

The Passive House development area Bahnstadt in Heidelberg consists of several large development blocks, each supplied by a central district heat connection. This means that only one central district heat connection exists for billing purposes for up to five large apartment blocks. The supplier has no access to any other sub-meters that may exist in individual buildings. These main heat meters at the transfer stations were previously read by the public utilities company "Stadtwerke Heidelberg" during on-site visits roughly every six months. Readings of these electronic heat meters will subsequently take place regularly via a data network connection. Monthly meter readings took place and were provided to the Passive House Institute for an initial overview of the overall functioning of the settlement.

The consumption data compiled in Table 1 were available from the development blocks. Here, the treated floor area constitutes the useable areas defined according to the PHPP (in case of dwelling units: living areas); when classifying the results, account must be taken of the fact that for the characteristic values according to the German minimum energy standard EnEV, the areas A_N for these buildings will be 28 % larger thus, the specific consumption values accordingly even lower:

Table 1: Overview of the type of buildings in the studied construction sites

Type	Number	Treated floor area	Number of dwelling units
Residential development	5	61 981m²	698
Student hostel	2	15 457 m²	564
Kindergarten	1	1 027 m²	-
Office use	1	9 694 m²	-
Laboratory building	1	21 346 m²	-

For evaluation to be meaningful, the buildings must have been fully occupied or utilised for at least one year, only then will it be possible to calculate a reliable annual consumption. So far, evaluable data of this scale is available from the development blocks with residential utilisation, the student hostels, and the kindergarten. These can be evaluated based on the existing data for the complete year 2014. However, this only applies to a limited extent for three development blocks, because these were only fully occupied one to three months later (January - Mach 2014). Exact details regarding the time of full occupancy are not available. It is not known whether the circumstances of full occupancy in these buildings led to over-consumption or under-consumption[1].

[1] If a dwelling unit in a building is not yet used, then the following two variants are possible:
(I) Increased consumption will result if heating already occurs at the housing level but internal heat sources (persons, electricity use) are not present. The activity relating to occupancy itself (such as open doors and windows) can also lead to considerable additional losses.
(II) Reduction of the consumption is also conceivable if no or reduced heating occurs before occupancy.

4.2 Minimal monitoring method for heating consumption

With the available monthly readings of the central heat meter, the consumptions for all heat uses are available as total values for each development block. These total values include the following consumption variables:

- Heating energy consumption
- Energy consumption for hot water
- Heat dissipation of distribution pipes (useable and non-useable)
- Transfer loss of the district heat station
- Storage losses of the hot water storage tank
- Miscellaneous, e.g. ramp heating for the entrance of the underground car park

The individual consumption variables cannot be differentiated out of the total values of the monthly consumptions, therefore an empirical method must be used which will at least enable a good estimate of this breakdown. In doing so, it should be kept in mind that the examined buildings do not have any solar heating panels and hot water generation in the residential buildings takes place completely via district heat.

In the main summer months the energy expenditure for all those applications which are not related to heating of the building can be determined from the monthly consumption values. In the process, it is assumed that unintentional and undesirable heating in summer does not take place. In Passive House buildings there is no distinct summer heating demand – on account of their long time constants even during "cold snaps" lasting several weeks, such buildings will still exhibit comfortable indoor temperatures without any heating at all. The month with the lowest summer consumption must not be used because some apartments may not be used in the summer due to long holiday periods. Since these are large buildings with many apartments, a slight concurrence of the holiday periods can be assumed.

The average consumption of the four summer months (June - September) is calculated and used as the consumption variable ‘**Expenditures without heating’** for each month; in a Passive House building in this climate, the heating demand in these months is definitively zero. If this average consumption value for the summer is now extrapolated to the whole year, this will result in the ‘annual expenditure without heating’. Figure 11 shows this consumption for the evaluation year inside the box with the green dotted line. For the sake of abbreviation, this will be referred to as the ‘**base consumption’**. In this development block, the average summer consumption value for Summer 2014 was 3.72 kWh/(m² month). All consumption values of the other months which are now above the green box are assessed as the "heating consumption".

In this simplest approach, the heat dissipated by the distribution pipes is assumed to be constant in the course of the year. The forward flow temperature of district heat is determined by the demand for year-round provision of hot water. Principally, the heat dissipated by the distribution pipes is influenced by the temperature difference between the surface of the pipework and the surrounding air (e.g. basement room, underground garage).

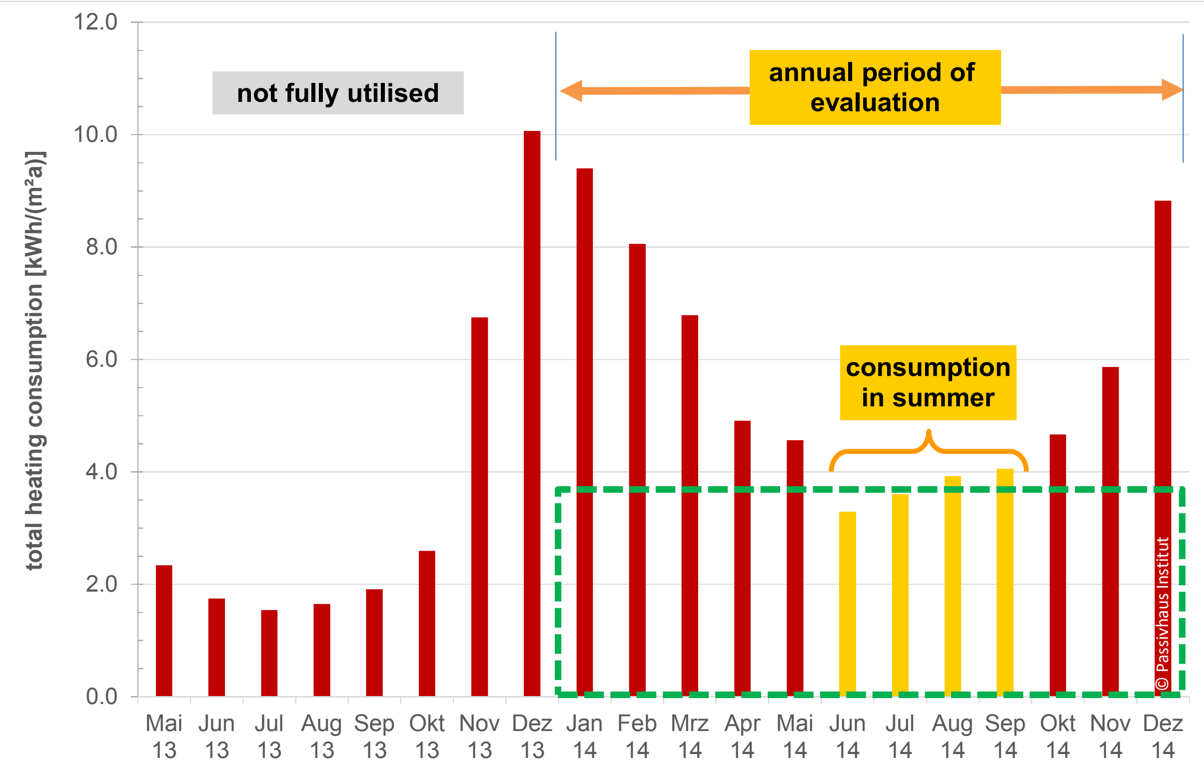


Figure 11: Monthly consumption values for district heat in an example development block in the Bahnstadt Heidelberg. The method for determining the heating energy consumption is explained in the text.

According to this method, the district heat consumption for the entire development block in the example shown in Figure 11 results as 23.3 kWh/(m²a) in a first approximation. The base consumption is 3.72 kWh/(m² month) x 12 months = 44.6 kWh/(m²a).
This type of calculation basically allows the calculation of the heating consumption value from the little measured data that is available. However, for different reasons, this first approximation leads to **overestimation of the heating consumption**:

- Hot water consumption in residential buildings is lower in summer than it is in winter. On account of the calculation of the base consumption in summer, the deduction for the winter is too low. In a building in Ludwigshafen, Germany, with 12 apartments, an analysis of the measured data from a detailed examination that was carried out there [Peper 2012a] shows that hot water consumption in winter is ca. 10 % higher than the average summer consumption. In a first approximation, overestimation of the heating consumption would be about **1 to 2 kWh/(m²a)**. In another project in Frankfurt with 19 apartments, the measured data showed an even stronger winter/summer increase (by 29 %). A more moderate approach with a winter/summer excessive increase of 10 % is used in the analysis carried out here.
- Heating of the underground car park entrances in some development blocks does not occur in summer and is therefore attributed to the heating consumption. An estimation of the consumption share for these development blocks with central underground car parks results in values of between **0.1 and 0.3 kWh/(m²a) for heating of the underground car park entrance ramps**.
- Undesirable heating may possibly be encountered (e.g. in the month May) due to unintentional operation. These expenditures are included in the calculated "Heating consumption". In the residential-use projects studied here, the heating consumptions

in May which are above the base consumption in summer are between 0.4 and 1.2 kWh/m²; **0.7 kWh/m²** on average.

- Heat dissipation from the distribution pipes in the ground and in the basement area - with largely constant forward flow temperature of the district heat - is determined by the type and quality of insulation and by the ambient temperature of the pipes. In winter the ambient temperatures are lower and therefore heat dissipation from heat distribution pipes increases. Through calculation of the "base heat" from the summer values, the increased dissipated heat in winter is completely attributed to the heating consumption. Estimation of the scale was performed for one of the development blocks. In doing so, a distinction was made between pipe lengths in the ground and in the basement, and the linear thermal transmittances of the different pipes were taken into account. The result is a difference of 1800 kWh/a between the summer approach and taking into account of the lower temperatures in winter, corresponding with about **2 kWh/(m²a)**. For simplification, this value is also used for the other development blocks.

Altogether, due to the first approximation ("base consumption method") the effects described here result in an overestimation of 1.4 to 2.5 kWh/(m²a) of the heating consumption **plus** the respective "unintentional" heating consumption for May. With the maximum value of 2.5 kWh/(m²a) and the project-specific heating consumption for May, the overestimation results as **2.9 to 3.7 kWh/(m²a)**. This consumption must be deducted in the second approximation that has now occurred in order to achieve a more realistic value for the district heat consumption for heating. A heating consumption (second approximation) of
23.3 kWh/(m²a) – 3.3 kWh/(m²a) = **20.0 kWh/(m²a)**
results for the development block Figure11. The major influences that lead to overestimation of the heating consumption in this method are thus taken into account. The values of the second approximation that are thus determined will subsequently be referred to as the "heating consumption" for the purpose of abbreviation again. The average measurement error here may be in the range ca. ±4 kWh/(m²a). The heating consumption in the useable area of over 80 000 m² that was measured here may be extremely small even with this (relatively large but in absolute terms extremely small) error margin. It is already apparent that the Passive House project with the Bahnstadt district in Heidelberg is extremely successful.

4.3 Evaluation of energy consumption with district heat

In accordance with the method described above, evaluation was first carried out for the available development blocks with residential utilisation. The average values of the same summer months (June - September) were always used for calculating the base consumption values (first approximation) – separately for each of the development blocks. For adjusting the district heat consumption for heating for the second approximation, the respective calculated values between 2.9 and 3.7 kWh/(m²a) were deducted and added to the "base consumption". This shifts the allocation of the consumption values but not their total amount.
In the study year 2014, the specific total district heat consumption values for the development blocks with residential use were between **46 and 68 kWh/(m²a)**. Allocation leads to base consumptions between 33.0 and 48.0 kWh/(m²a). The expenditure for heating is between **9.3**

and 24.2 kWh/(m²a); the average value based on area density is **14.9 kWh/(m²a)** for this. These consumption values are shown Figure 12 as a total value and as allocated values.
For the evaluation of the consumption data carried out here, account must be taken of the fact that the achievable accuracy is limited. This method uses simplifications and assumptions, which means that in this analysis, accuracies less than ± 3 kWh/(m²a) [Feist 2004], which are achievable with detailed measurements, are unacceptable.

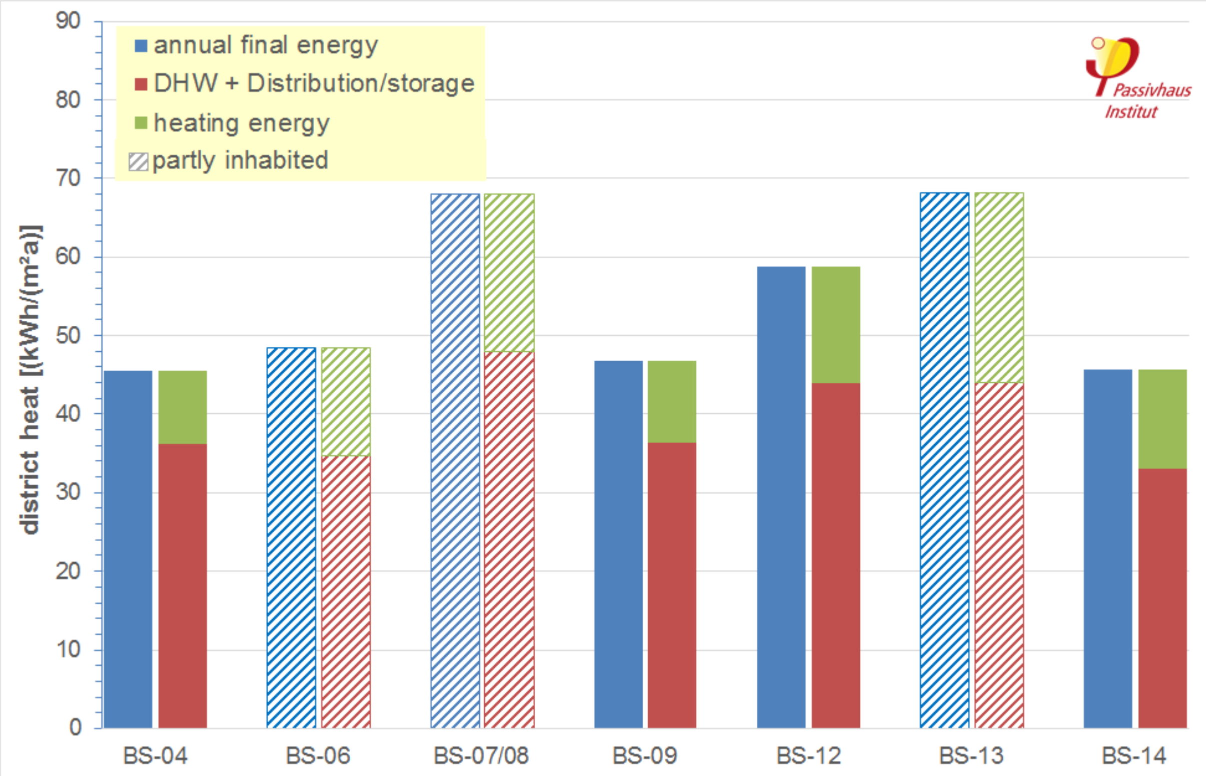


Figure 12: Annual consumption values for district heat for residential use (incl. student hostels) according to development blocks. Based on the method in Section 4.2, the total consumption (blue) is distributed across heating energy (green) and the remaining consumptions (red). The development blocks indicated with shading were only fully inhabited in 2014 after one to three months ("partly inhabited").[2]

It is clear that there is relatively large scattering of the consumption values between the development blocks. In particular it must be considered that three of the seven development blocks (shown hatched) were not fully inhabited during the complete one-year period of 2014. Based on the available data, these three development blocks were only inhabited one to three months later. As mentioned in the explanation in chapter 4.2, it is understandable that this can lead to an increase or reduction in the consumption values. Only the next study year can clarify this.
The scale of the distribution across heating and the remaining consumptions for the "base heat" for hot water provision, distribution and storage in the Bahnstadt is within the typical range compared with Passive House projects studied previously. In order to illustrate this, the data from a building with 19 apartments that was centrally supplied with heat and investigated in detail are shown in Figure 13. The heating energy, hot water consumption, distribution heat and other detailed variables were analysed in more detail in the related study [Peper/Grove-Smith/Feist 2009]. In this project, it was exemplarily demonstrated that the heating energy had

[2] The numbering of the development blocks are anonymized because of data protection

a 33 % share of the total supplied energy. The Bahnstadt objects presented here with shares between 20 and 36 % were thus within a realistic scale.
The potential for technical optimisation certainly also exists in this project, particularly with reference to storage and distribution losses. The two outliers with values above 60 kWh/(m²a) should be examined more closely in this respect and optimised if necessary.

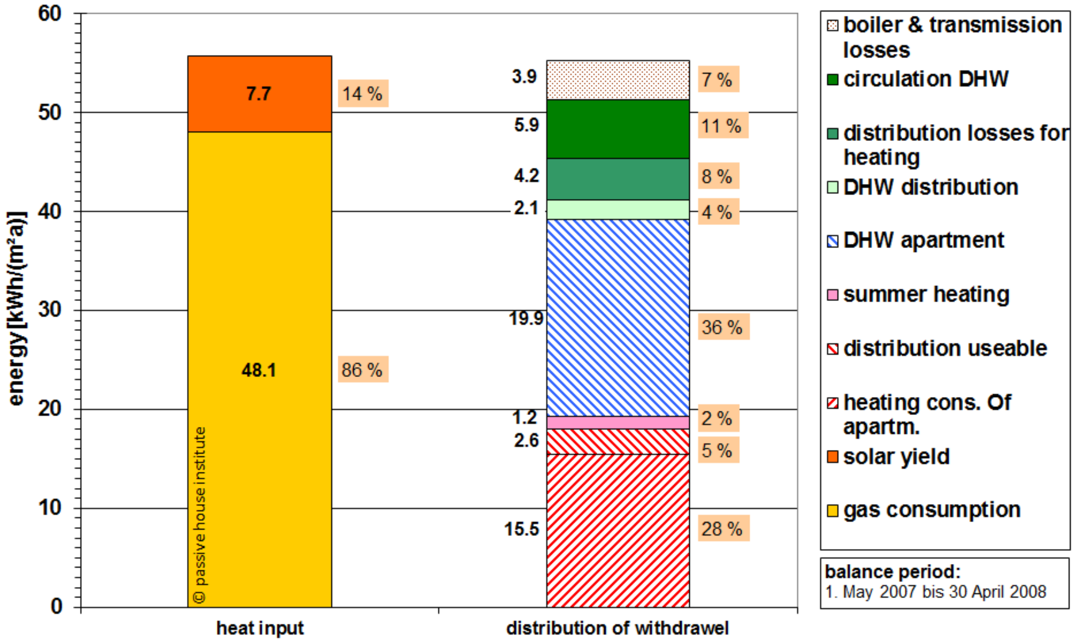


Figure 13: Energy balance of a Passive House with 19 apartments with centrally supplied heat, from the study [Peper/Grove-Smith/Feist 2009]. The heat supply and heat uses were broken down in metrological terms. Interestingly, the total amount for the year for this object was of the same scale as that for the Passive House buildings in the development blocks of the Bahnstadt Heidelberg project studied in this article.

4.4 Classification and evaluation of the results

For evaluation of the heating consumption values in particular, account must be taken of the fact that the consumption data depends significantly on the respective weather during the study period and the indoor temperature selected by the users. Thus it is unreasonable to expect that a building which has been balanced for 15.0 kWh/(m²a) during the planning should now give exactly this consumption value, for example. In addition, with the large number of apartments in a complex, it always comes down to the average consumption value as only this is conclusive. The actual weather conditions and actually set room temperatures should be taken into account for the actual consumption (see also [Peper 2012b]; these values cannot be known at the time of planning, therefore the planning team must use standardised design values). The measurement data are determined by these "boundary conditions" as well as by the characteristic values of the building.

Evaluation of the consumption data shows conclusively that extensive efforts by the City of Heidelberg to design a city district to a high standard of energy efficiency through provisions and quality assurance have proved successful. An extremely good result has been achieved here with heating consumption values of 14.9 kWh/(m²a) on average, for measurements mainly in the first year of operation and including hostels. The fact that this involved a very large number of apartments (over 1000) with a total studied living area of 75.000 m² is particularly impressive. With the great number of these buildings, it will be possible to show that widescale implementation of highly energy-efficient buildings with many different stakeholders is quite possible and can be done successfully.

The following illustration, Figure 14, shows the heating consumptions of the residential buildings and the area-weighted average value separately. In the next study year, slightly different results should be expected on account of different weather conditions, the complete year-round utilisation data which will become available, and the absence of first-year effects. It must be observed whether both higher consumption values (20 and 24 kWh/(m²a) respectively) change noticeably after full occupancy, for example. However, it can be stated that these consumption values will also remain at a low level and should not be assessed as problematic at all.

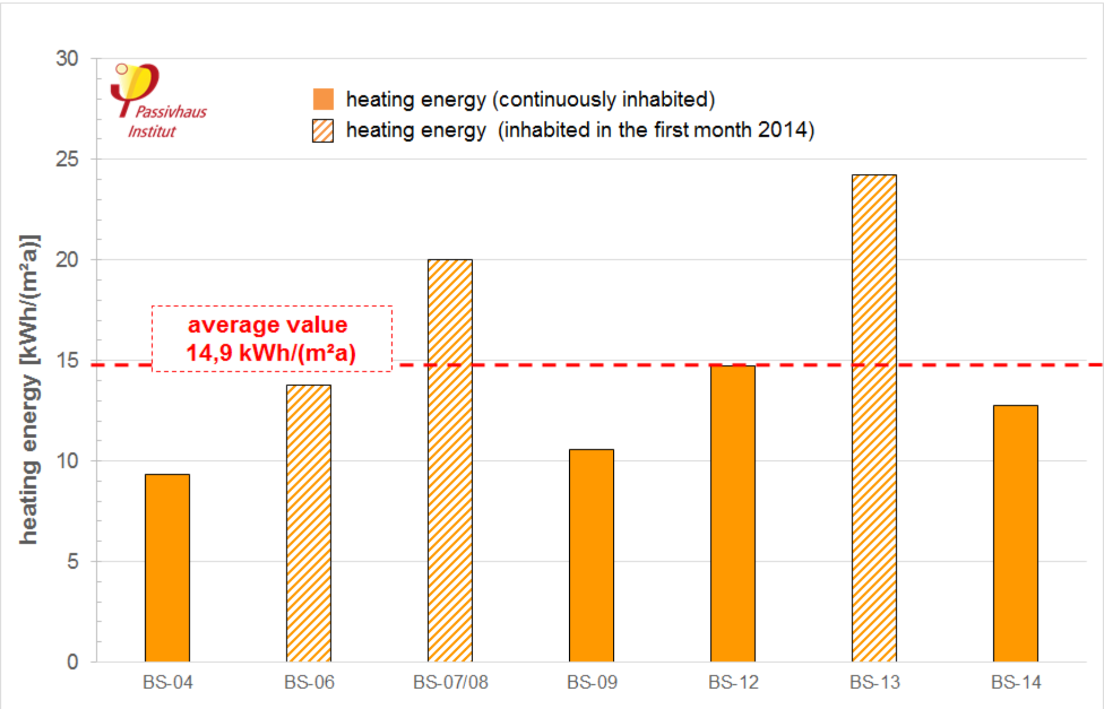


Figure 14: Annual heating consumption values for residential utilisation (incl. hostels) according to development blocks, from Figure 12.

4.5 Comparison of the heating consumption with PHPP planning data

The PHPP (Passive House Planning Package) was used for planning all buildings in the Bahnstadt district. This allows for energy-relevant optimisation of the building during the planning process. The PHPP was also used by the City of Heidelberg for quality assurance of the planning. Certification of the buildings by the Passive House Institute or an accredited

certifier only took place in a few individual cases, and none of the buildings in the development blocks that were studied here were certified.
Accurate and complete tracking of the changes made during the planning and particularly during the construction process are crucial for a realistic calculation.
Experience has shown that if this is done with the necessary level of accuracy, the PHPP (among other things) delivers a realistic heating demand in accordance with the boundary conditions applied, such as climate data, occupancy density, internal heat gains, indoor temperature etc. In the case of projects that were studied in more detail, the comparison between consumption data and the PHPP demand calculations often shows quite good correlations, see Figure 15. As the most important parameters for the comparison with the measurement, the climate data and the indoor temperature – as explained above – must be determined for this purpose in accordance with the actually existing boundary conditions, and used in the PHPP.

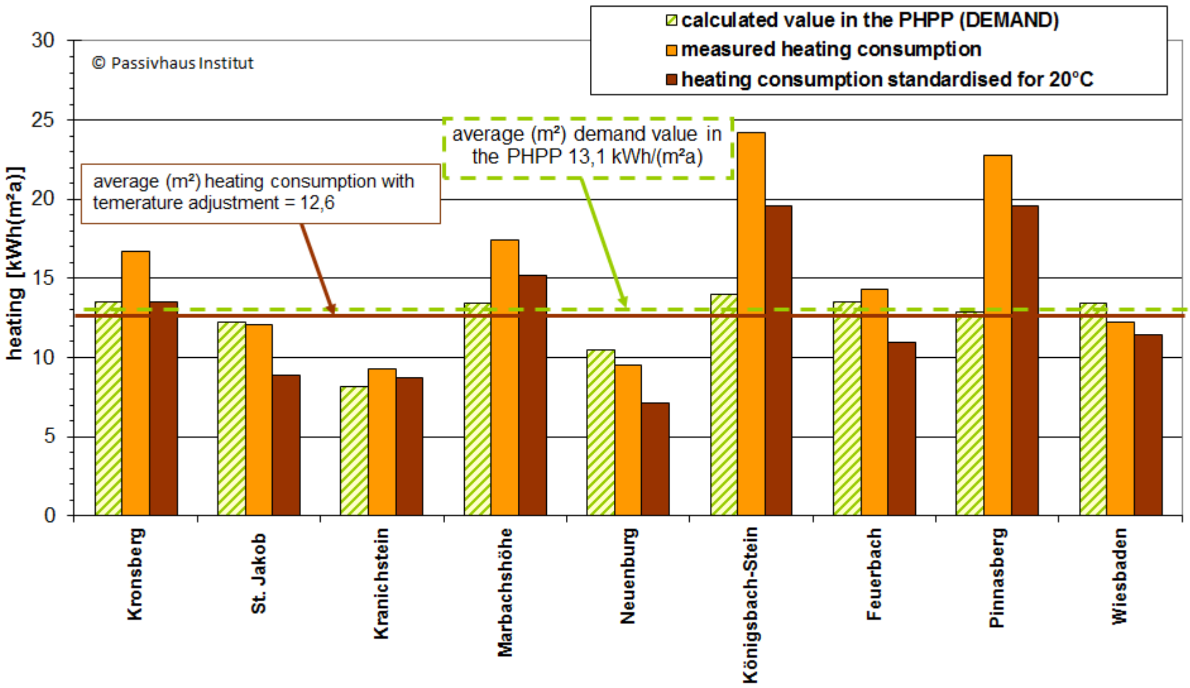


Figure 15: Measured heating consumption in comparison with the projected value of terraced, semi-detached and multiple-family houses built to the Passive House Standard. The calculated value in the PHPP was calculated for an indoor temperature of 20°C (from [Peper 2008])

4.5.1 Weather data

As a next step, the consumption data of the studied residential buildings in the Bahnstadt should be compared with the planning data in the PHPP. In this way it will be possible to check the data for plausibility and to identify any outliers. For the study in the Bahnstadt, the actual weather data for Heidelberg in the observation period 2014 was required. It was necessary to have at least the monthly outdoor temperature and the monthly total global radiation (horizontal). Data from a measuring station in Heidelberg-Kirchheim was used for the outdoor temperature (http://heidelberg-kirchheim-wetter.de). This was at a distance of ca. 2.5 km. The comparison with measurements from Ludwigshafen and Speyer (both in Germany) only showed slight variances. A source could not be found for obtaining the global radiation data for Heidelberg, therefore the radiation data for the location Ludwigshafen-Mundenheim was obtained from ZIMEN, the measuring network of the German State of Rheinland-Pfalz (www.luft-rlp.de). The outdoor air temperatures for Heidelberg exhibited minimal deviations from the location in Ludwigshafen-Mundenheim compared with the other alternative (Speyer). The weather data set that was thus prepared will subsequently be referred to as "Wetter Heidelberg" and "Wetter LU/HD".

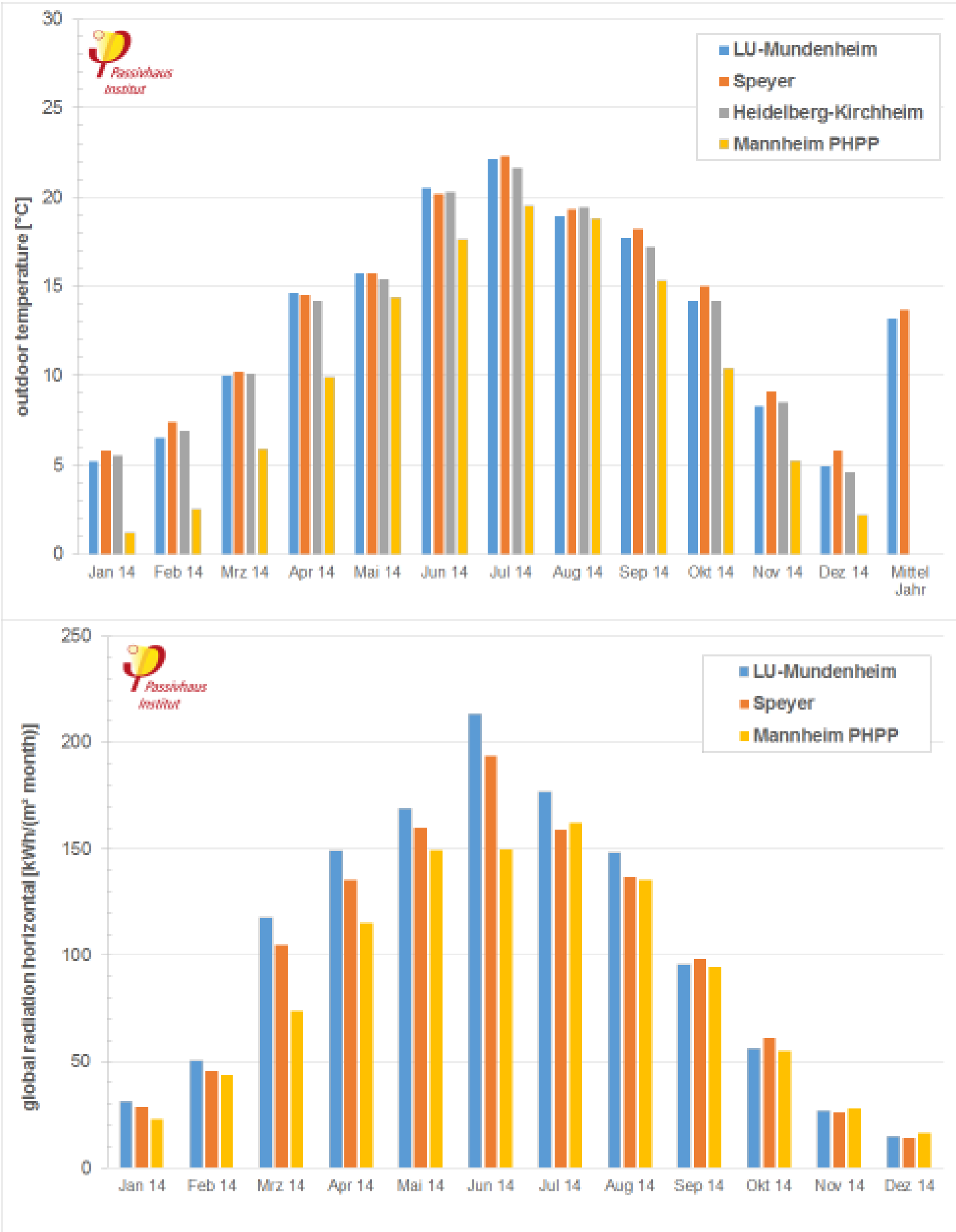


Figure 16: Comparison of the weather data sets for outdoor temperature and global radiation horizontal.

The comparison of the weather data for Heidelberg that was available for 2014 and the standard climate data set "Mannheim" in PHPP used during the planning shows clearly that the period 2014 was extremely mild: the winter months were significantly warmer than in the climate data set "Mannheim". Global radiation differed particularly during the summer months, which was not relevant here, see Figure 16.

4.5.2 Indoor temperatures

In the present minimal monitoring, measured indoor temperatures were not available for the 1260 dwelling units. This essential parameter for adjusting the PHPP calculation for planning can thus only be assumed on the basis of other monitored projects. In other measurements in residential-use Passive Houses, indoor temperatures of about 21.5 °C on average were measured in winter [Peper 2012b]. For this reason this indoor temperature has also been used here and was applied as a boundary condition in the PHPP.

4.5.3 Summarisation in the PHPP

The residential buildings and student hostels studied here in minimal monitoring were balanced in a total of 30 PHPP calculations. Since only one heat meter exists for each development block, the demand values for heating from the individual PHPP calculations of the development block must be summarised into a comparative, area-weighted value. The data for each student hostel is available in a separate PHPP calculation. For the development blocks with residential buildings there are between three and five, and in one case, ten PHPP calculations. Each of these PHPP calculations took place using the weather data set for HD/LU as a boundary condition, and in a second step, the indoor temperature was increased from 20 to 21.5°C. The resulting balance value calculated thus for a development block can now be compared with the consumption value from the previous section.
The PHPP calculations provided to the PHI could not be checked within the framework of this study. However, during the processing of the PHPP calculations, such as addition of the weather data set for 2014, a few points did come to light. Some of these have a noticeable effect on the heating demand and were therefore accommodated:

- Some PHPP calculations were set to the annual method instead of the **monthly method**. Both methods were allowed verification methods for the Passive House Standard at the time of planning. The more accurate monthly method has been used here exclusively. This results in an increase in the heating demand by up to 2.4 kWh/(m²a) in the studied buildings.
- Random tests of the PHPP calculations revealed a few questions in relation to the thermal building envelope in the basement area as well as to some thermal bridges. A detailed explanation could not be found within the timeframe of this report. This needs to be clarified at a later stage.
- In random tests, individual buildings in three development blocks were checked with reference to their **shading situations**. It turned out that within one development block, and in part between the blocks, shading had not been taken into account completely. For this reason, shading was updated for a sample development block. This led to an increase in the heating demand between 0.2 and 0.4 kWh/(m²a) (depending on the weather data set and indoor temperature). Since this is only a slight difference, this adjustment was not further taken into consideration.
- For this comparison, the two student hostels studied here were calculated uniformly using the consumption data with internal heat gains (IHG) of 2.1 W/m². The IHG in one of the PHPPs were changed for this. More detailed examination would be necessary in order to determine which values are more suitable for modern student hostels. On account of the room sizes typically used nowadays and the additional common areas, approximation of the values normally used for residential use seems realistic.

- In two buildings of a development block the IHG were set in project-specific calculations. Here also, these were changed to the standard values of 2.1 W/m².

Further tests and changes to the PHPP calculations did not take place. The changes that were made were taken into account in the values presented below. Figure 17 shows the heating consumption values, see chapter 4.4, with the summarised PHPP calculations for each development block. The results with the 2014 weather data set Heidelberg are shown for PHPP demand values. The heating demand value is depicted for 20 °C as well as for 21.5 °C.

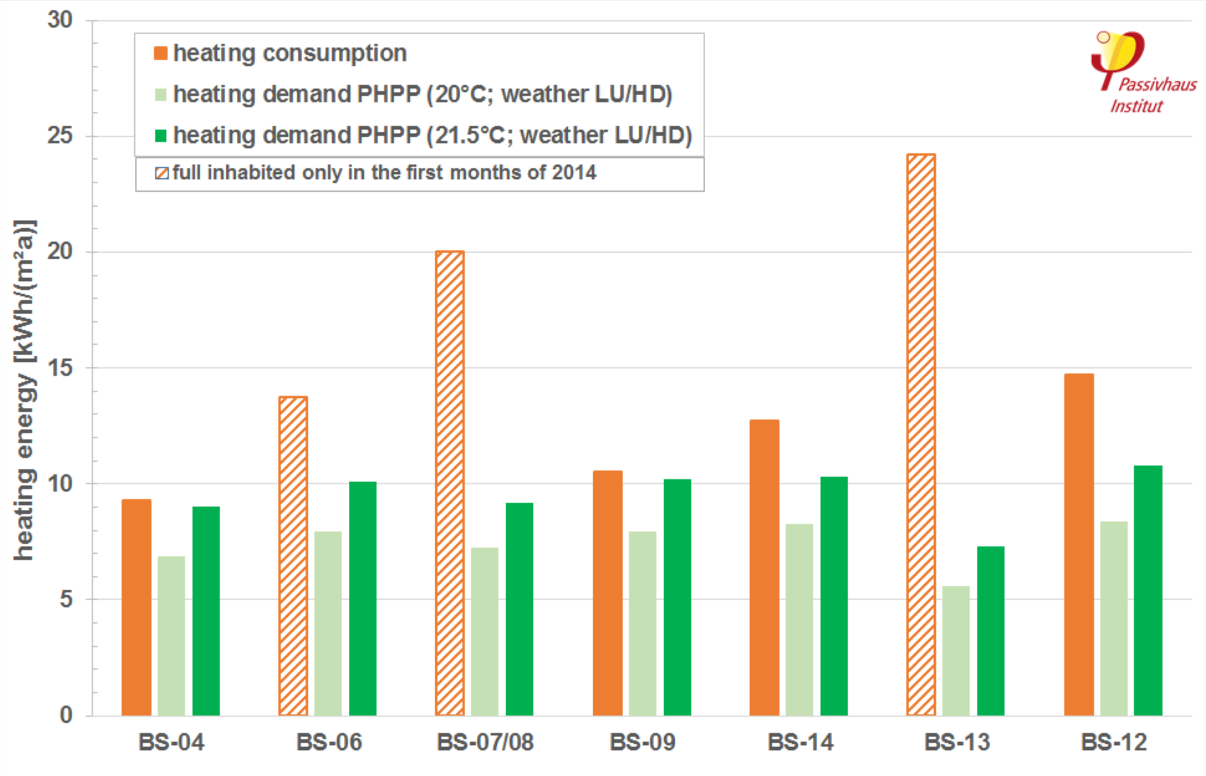


Figure 17: Comparison of the consumption data for heating and the PHPP demand values for the different weather/climate data sets and two indoor temperatures for the studied seven development blocks of the Bahnstadt district.

The consumption data can be most reasonably compared (orange and dark green bars) using the current boundary conditions described above (usual indoor temperature 21.5 °C and weather data for HD/LU) during the study period.

For five of the seven development blocks, there are excellent correlations with variations between 0.3 and 3.9 kWh/(m²a). This is excellent for a comparison of consumption measurements, particularly as this involves minimal monitoring with expected measurement deviation on the same scale. It can therefore be assumed that these PHPP calculations are reliable.

However, two of the studied projects (BS-07/08 and BS-13) show considerably larger differences between the measured consumption values and the PHPP calculations with the weather data set HD/LU at an indoor temperature of 21.5°C. These are also the development blocks with the highest measured consumption values.

There are significant deviations here, for which different reasons are conceivable:

- Three development blocks were fully occupied one to three months later, leading to an increase in consumption in the result for the year; because this occupancy took place in the cold period during the measurement period, this is the most likely reason.

- The PHPP calculations for these development blocks have not been prepared according to the actual situation of the buildings or the actual construction process has not been adequately tracked (this could be determined by means of random checking).
- Despite the large number of apartments, the average user behaviour of the occupants in these buildings differs greatly from the assumed usage (in itself, this is not likely, but can be tested by measuring thermal comfort).
- Settings which are not optimal or technical errors e.g. in building services or ventilation technology which lead to an increase in the consumption (e.g. bypass in the internal district heat distribution network, malfunctioning of thermostats).

There may be a mixture of different reasons; it would be pure speculation to make a decision about this at this point. One of the objectives of the present study was to find such projects so that more exact examinations can follow. With the present results, this is possible.
Figure 18 illustrates the results of the PHPP calculations for space heating using various weather/ climate data sets. The calculation results of the Mannheim climate data set (PHPP standard) also clearly point out the mildness of the study year 2014. Accordingly, higher consumption values can be expected in cooler years. But even if the climate data set Mannheim (long-term average from previous years) is used, low consumption values of just 16 to 18.5 kWh/(m²a) result in comparison.
Also, the influence of the respective higher indoor temperatures can be seen clearly for both climate or weather data sets: increases in the demand values for space heating of 15 % typically result for each Kelvin of indoor air temperature increase.

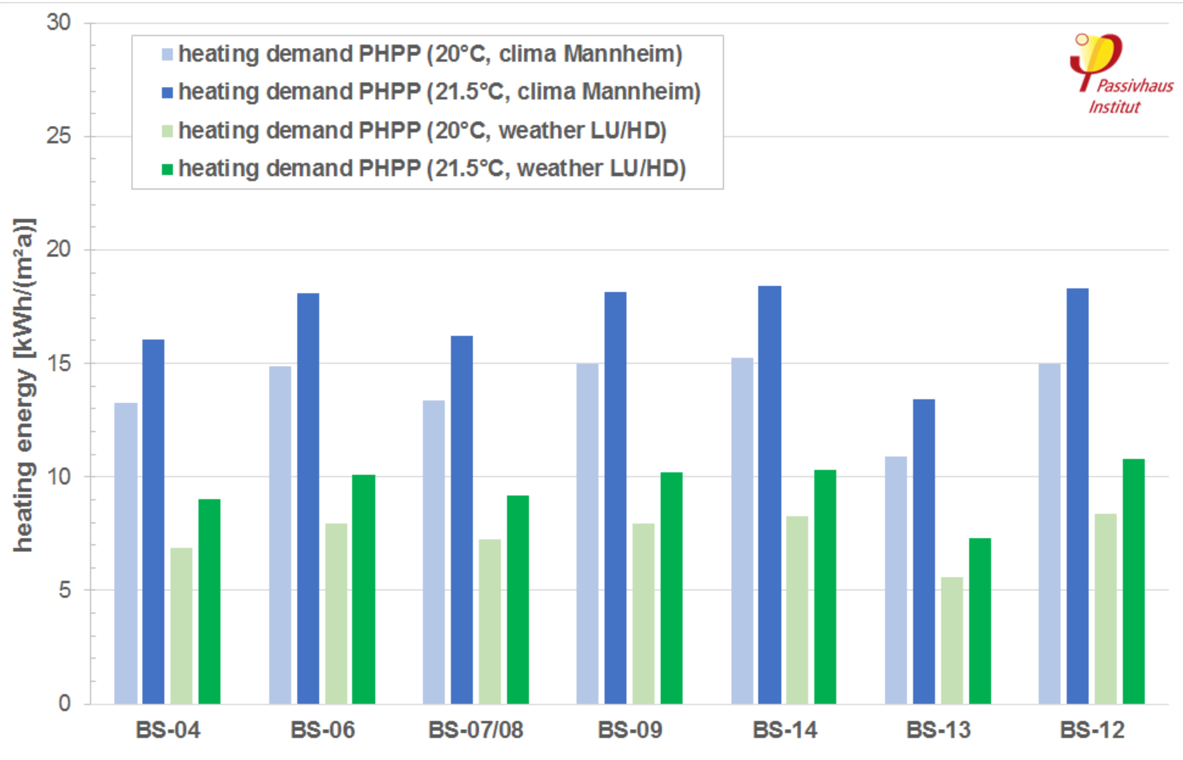


Figure 18: Comparison of the demand values for heating from the PHPP calculations for the different weather/climate data sets and indoor temperatures for the studied seven development blocks of the Bahnstadt district.

4.6 Bahnstadt monitoring conclusion

The following can be stated in conclusion: With a total useable area of more than 75 000 m², the buildings studied here consume only one third of the district heating of that of comparable existing buildings, with 55 kWh/(m²a) for heating, DHW distribution and storage losses together as an overall average. This is comparable with the results from a previous detailed study of two Passive House buildings with a district heating connection.

The district heating consumption for heating is around 15 kWh/(m²a) on average (±4). This is an excellent result for consumption in the first year of operation. According to various studies carried out in Switzerland, this first-year effect (e.g. caused by the drying process, commissioning of the building services) always leads to additional consumption which can be between 15 and 30 % of the regular consumption. Higher values were measured in the case of two development blocks that were first occupied during the measurement year; this was probably due to the influence of activities relating to moving in.

Comparison with the values in the PHPP planning (recalculated with the current weather data) gives an excellent correlation with measurement/calculation variances of less than ±4 kWh/(m²a), which remains within the limits of measurement accuracy; only the objects already mentioned above are beyond this mark.

In the first year of operation, the heating energy savings of about 87% envisaged for the present project through Passive House project planning was, in comparison to the measured mean value of 112 kWh/(m²a) by Techem company, already nearly achieved with 81% - including outliers.

5 FOLLOW-UP OF BEACONS

5.1 Introduction

Ideally at least one project per PassREg partner was monitored for energy consumption, comfort and costs, see Annex I, in order to provide best-practice examples. The matrix in Annex I gives an overview of all the projects, their status, ID number and their monitoring/follow-up results.

The Passive House Planning Package was used to assess the energy performance of those buildings still in planning/construction phase. The verification values can be found on the project database www.passivehouse-database.org, along with other information on involved parties, used materials and renewable integration. As PHPP uses boundary conditions based on international standards, achieving the values on the verification worksheet also means to keep within the limits of certain threshold values such as the frequency of overheating in summer or comfortable indoor temperatures in general. Thus, good comfort conditions can be expected and checked. The respective PHPP worksheets include assumptions in a transparent and comprehensive way and validation of PHPP using real buildings' monitoring data thus ensures that the reality can be matched as close as possible.

5.2 Energy consumption

Some projects like the residential Passive House apartment blocks of the Lodenareal in Innsbruck, Austria, underwent detailed monitoring already before the PassREg project. The outcomes of those monitorings including the monitoring report can be found on the PassREg website. Amongst others, one non-residential project, a supermarket in Hannover, Germany, displays impressive energy reductions: The Passive House design of the supermarket bases on the concept to use waste heat from cooling processes to heat the market in more than 90% of the year - But also using efficient cooling appliances e.g. close the refrigeration equipment with insulated glazing is required. The measured values show that heating required by the heat pump is only needed in a few times of the year: An electrical consumption of 5 kWh/(m^{2}a) is measured. Assuming an estimated seasonal performance factor (SPF) of approx. 2.5 it would result in 12.5 kWh/(m^{2}a). In total the market is 50% better than a standard supermarket in Germany. The monitoring shows a primary energy consumption of 240 kWh/(m^{2}a) or 4.3 kWh/(m^2 TDA d). Furthermore, research by the Passive House Institute reveals: If the operation is optimised, e.g. using less night setback during critical periods, no additional heating would be needed at all.
All PassREg beacons feature some kind of renewable energy sources. From PHPP Version 9 (2015) onwards it is possible to optimize the energy generation from renewables and display the annual generation on the verification worksheet, see Annex IV.
Within the framework of the PassREg project, the Ergli beacon, see also [IET_2015], was examined and is described in the following chapter 5.2.1 in more detail.

5.2.1 Evaluation of energy consumption in the vocational school student dormitory, Vidzeme region, Ergli, Latvia

The building in Ergli, Latvia is used as a students' hostel. This project has a treated floor area of 3521 m^2; it was originally built in 1972 and retrofitted in 2012 with Passive House components to the EnerPHit-Standard. Monthly meter readings from a central district heating meter and a total meter for electricity were available for evaluation of the energy consumption of this first large scale EnerPHit renovation in Latvia. According to information provided by the project team, these readings have been taken from the energy invoices.
The energy for space heating and for hot water generation in winter is supplied via the district heating network. Hot water generation in summer takes place using direct electricity. In the two transitional months (April and October) hot water generation takes place partly via district heating and partly via direct electricity. District heating is switched off completely in the summer months from May till September inclusively. In order to be able to meet the electricity demand, PV modules can be installed on the roof at a later point in time.
Due to the coupled energy supply for space heating and hot water generation, consumption cannot be accurately assigned to these two areas of consumption. For this reason, an attempt can be made to obtain an estimate of the heating energy consumption from the data using simplifications.

Procedure:

- The district heating consumptions for the five winter months with full hot water generation are added together ("FW_S1").

- The consumption values for district heating for the two months in which hot water is produced partly using direct electricity are also added ("FW_S2").
- For the electricity consumptions, the share for monthly water heating („WW_el“) is estimated from the difference between the winter consumption (without electrical hot water generation) and the consumption in the summer months with full electrical hot water generation (without the two holiday months). For this, it is assumed for simplification that the remaining electricity consumption is equally distributed over the entire year.
- Hot water generation using district heating will be inferred for the other months from the electrical expenditure for heating water. In order to take into account the higher losses for conversion of district heating supply compared with direct electrical supply, and the usually higher hot water consumption in winter, the final energy for electrical hot water generation is increased by 20 % as an overall amount. For simplification, this value ("WW") is used as the final energy expenditure for hot water generation using district heating.
- From the district heating consumptions including hot water generation (FW_S1), 5 x WW is deducted for the five months November to March. This will give an estimate of the heating energy consumption for the 5 winter months.
- For the transitional months April and October, it is assumed that electrical hot water generation was operated for half of the month respectively. Other information regarding this is not available. In these months, the 50 % reduced expenditure for WW is now subtracted twice from the FW_S2. This gives an estimate for the heating energy consumption for both these months.
- The heating energy for the entire year results from the sum of the estimates for the five winter months and for the two transitional months.

The following procedure is used for determining the electricity consumption without electrical hot water generation:

- in the winter months without electrical hot water generation, the entire electricity consumption is taken into account
- in the summer months with electrical hot water generation, the figure WW_el as determined above is subtracted from the electricity consumption
- in the months with partial electrical hot water generation, 50 % of the monthly sum WW is deducted from the consumption and
- in the two holiday months, the same share (58%) as in the three months with fully electrical hot water generation is deducted from the total monthly electricity consumption.

This annual electricity consumption without electrical hot water generation is subtracted from the total electricity consumption, giving the expenditure for electrical hot water generation. For this, the expenditure for hot water generation WW for the five months and the 50 % share of the two transitional months are added together. This results in the total energy consumption for hot water generation.

In this building, a total of 55.6 MWh district heat (equates to 15.8 kWh/(m²a)) and 40.6 MWh electricity (equates to 11.5 kWh/(m²a)) were used during the annual period 2014. This total electricity consumption includes all applications (building services including ventilation and hot water provision in summer, lighting, household appliances, communications equipment/PCs and cooking).

If evaluation of the data takes place as described above, then

a **heating energy consumption** of **11.7 kWh/(m²a),**
a **remaining electricity consumption** of **8.6 kWh/(m²a) and**
an **energy consumption for hot water generation** of **7.1 kWh/(m²a)**

will result for this building.

The remarkably low expenditure for hot water generation is plausible because the central sanitary installations in the basement (wash basins and showers) were not refurbished and are of a comparatively low standard. According to information provided by the local project team, only an extremely low hot water consumption altogether is possible with this. The electricity consumption values also indicate that the installations are economical.

Altogether, all consumptions can be assessed as very low. In particular, because the building in Latvia is located in a comparatively cold region, the heating energy consumption shows an extremely low consumption value.

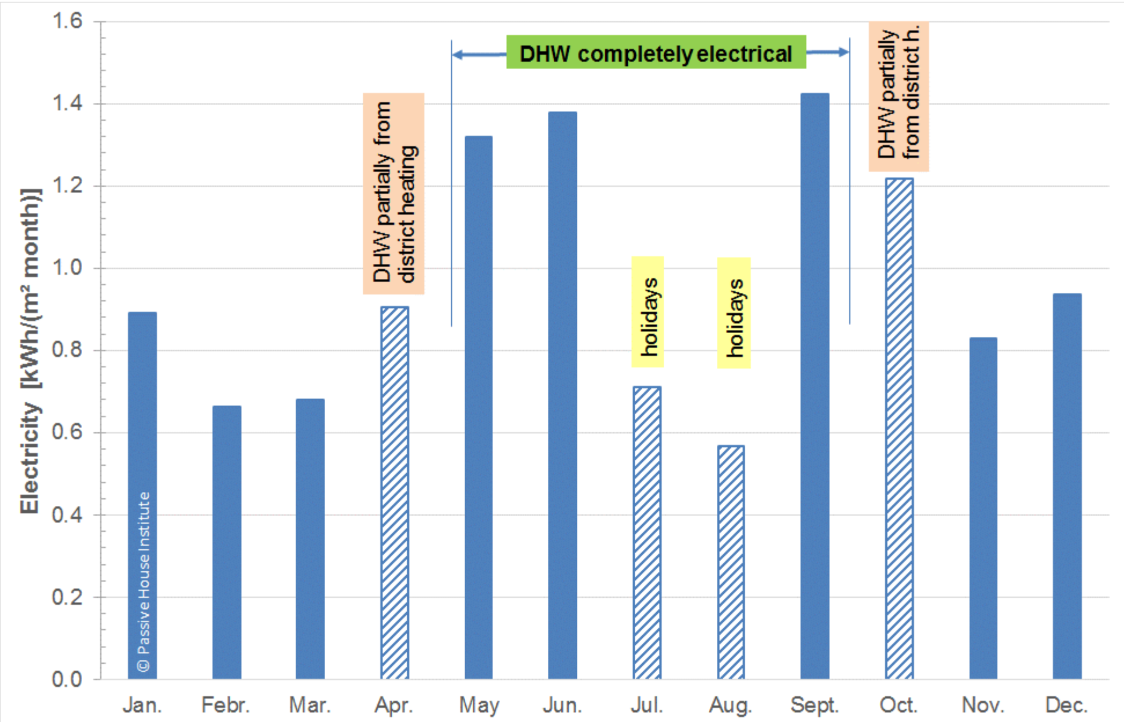


Figure 19: EnerPHit student hostel, Ergli, Latvia: Annual electricity consumption in 2014, © Passive House Institute.

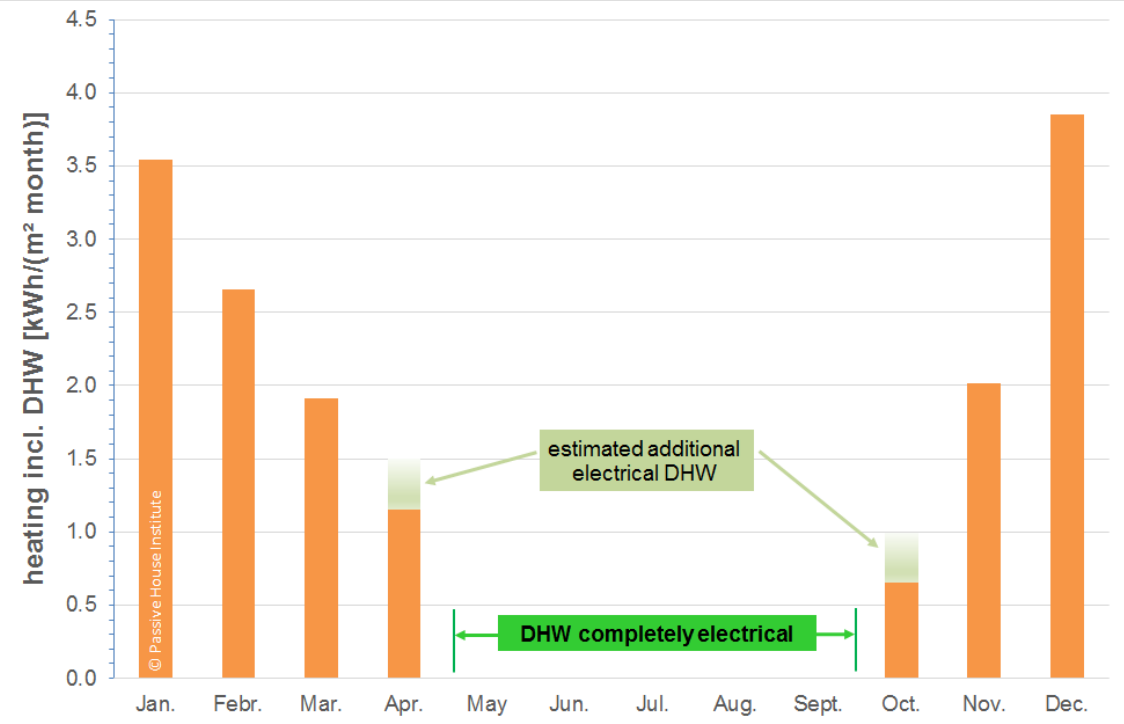


Figure 20: EnerPHit student hostel, Ergli, Latvia: Annual space heating consumption, including DHW, in 2014, © Passive House Institute.

5.3 Comfort

5.3.1 Introduction

In PassREg many beacon projects have been selected, supported and analysed. When it comes to comfort conditions and user behaviour, the following information provides a common evaluation of the beacon projects implemented within the PassREg project.
These buildings, see Annex I, represent real examples which have an important role in order to help the development of successful models related to passive houses with integrated renewable energy systems and the widespread of the nZEBs.

In some beacon projects, a survey was conducted to have feedbacks and information from buildings users on their thermal comfort conditions, behaviours and ways to use their passive houses buildings. For this aim, in the beacons where possible, the occupants filled in a questionnaire, which was developed by the Passive House Institute, distributed and managed by all the PassREg consortium partners and collected by the eERG Group of Politecnico di Milano.

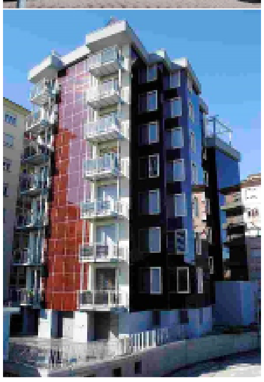
The questionnaire asked on aspects related to indoor thermal comfort and air quality perception. In addition, the user behaviour was also investigated about the ways how mechanical or natural ventilation are used and the level of knowledge on heating and cooling systems. Questionnaires covers more than an entire yearly period, with heating, cooling and intermediate seasons, with separate questionnaire for each period. A total of twenty building users were involved in 8 different buildings, where the questionnaires completion was possible.

The considered beacon projects show an interesting variety in their building typologies, dimensions and ways of use. They are all Passive Houses with integrated renewable energies supply.
The buildings are located in different climatic regions both in heating dominated climates as well as in cooling dominated contexts.

5.3.2 Beacon Passive Houses considered for the analysis

Among all the selected beacons during the PassREg project, 8 buildings were involved in this survey. The considered beacon projects show an interesting variety in their building typologies, dimensions and ways of use, see Table 2. They are all Passive Houses as per PHI definition [PHI_building_criteria] with integrated renewable energies supply.
The table in the following page shows all the buildings in question, with indicated locations, typologies and whether new or renovated ones. We can recognize small and larger buildings, private and public, residential and for other uses, single or multi-family ones. Some of them are new buildings, while other are retrofitted ones, also with the ambitious EnerPHit target [PHI_building_criteria], including large renovation projects. The buildings are located in different climatic regions across Europe.

Table 2: Beacon passive houses considered for the analysis.

	Smart Zero Energy Building - Botticelli project (certified Passive House, ID 2123 www.passivehouse-database.org) Detached single family house - New building *Mascalucia (Catania), Sicily - Italy*
	Passive house Cantù Detached single family house - New building *Cantù (Como) - Italy*
	Energy efficient reconstruction of the service hotel of Ērgļi vocational secondary school with application of elements of passive buildings (EnerPHit-Standard, ID 2913 www.passivehouse-database.org) Public building for school - Retrofit *Vidzeme - Latvia*
	Low energy refurbishment of two buildings: school and dormitories (EnerPHit-Standard, IDs 4450 and 4451 www.passivehouse-database.org) Public buildings for school - Retrofit *Tiskadi , Region of Rezekne - Latvia*
	Generatiewooncomplex Landgoed Oosterhout (ID 3887 www.passivehouse-database.org) Group of detached single family house - New buildings *Oosterhout, Nijmegen - Netherlands*
	22 Zorgappartementen Vroomshoop (ID 3004 www.passivehouse-database.org) Social housing apartments building - New building *Vroomshoop, Nijmegen - Netherlands*
	Orduynenstraat Den Bosch (ID 4379 www.passivehouse-database.org) Single family house - Retrofit *Den Bosch, Nijmegen - Netherlands*
	Palazzo Positivo (certified Passive House, ID 2923 www.passivehouse-database.org) Multi-family building - Retrofit *Chiasso - Switzerland*

5.3.3 Comfort and user behaviour questionnaires

The survey was conducted to have feedbacks and information from buildings users on their thermal comfort conditions, behaviours and ways to use their passive houses buildings. In the beacons where possible, the occupants filled-in a questionnaire, which was developed by the Passive House Institute.

The questionnaire includes aspects related to indoor thermal comfort and air quality perception. In addition, the user behaviours were also investigated about the ways how mechanical or natural ventilation are used and the level of knowledge on heating and cooling systems. Questionnaires covers more than an entire yearly period, with heating, cooling and intermediate seasons, with separate questionnaire for each period, which respectively are:

- winter - heating period 2013/2014 (October 2013 - April 2014),
- spring 2014 (September - beginning of October 2014),
- summer - cooling period 2014 (June - August 2014),
- autumn 2014 (April - May 2014),
- winter - heating period 2014/2015 (October 2014 - April 2015).

A copy of the questionnaire with the details of all the questions can be seen in the following page in figure Figure 21.

A total of 20 building users were involved in 8 different buildings, where the questionnaires completion was possible. The same persons were interviewed for all the considered periods, when they were occupying the buildings.

PassREg / Task 5.4.1 Follow-up of the beacon regions

Questionnaire for beacon regions

Thermal comfort

Conducting the questionnaire: Interview of an adult person personally or by telephone.
The same person must be questioned each time.

Allocation (building/apartment/person):

____

Survey date / period:
for example: WINTER 2014/2015 - heating period (October 2014 - April 2015)

The questions should be asked regarding the state/condition in the considered survey period.

1. How do you assess the indoor temperature in your apartment/the rooms used by you?

☐ very good ☐ good ☐ poor ☐ inadequate

2. How do you assess the indoor air humidity in your apartment/ the rooms used by you?

☐ definitely dry ☐ slightly dry ☐ just right ☐ slightly humid ☐ definitely humid

3. How do you assess the indoor air quality in your apartment/ the rooms used by you?

☐ very good ☐ good ☐ poor ☐ inadequate

4. How do you ventilate rooms at the moment? ("VHR"= Ventilation system with heat recovery)

☐ Window ventilation only ☐ VHR and windows (opened for a long time) ☐ VHR and windows (minimum opening) ☐ Only VHR (windows closed)

5. Do you feel that draughts are caused by the ventilation system?

☐ no draughts ☐ very slight draughts ☐ slight draughts ☐ strong draughts

6. Do you understand how to use the heating, cooling and ventilation systems?

☐ no, not at all ☐ yes, partly ☐ yes, mostly ☐ yes, completely

Figure 21: Example of the distributed questionnaires on comfort and users behavior in the beacon projects.

5.3.4 Results and analysis

All the answers were collected and analysed. Related graphs and outcomes have been presented in the following pages. Particularly Figure 22 shows the answers distribution for each question for all the interviewed occupants in all the buildings and all periods.
The perception related to the thermal comfort is very good with the large majority (more than 90%) of the answers that are positive and very positive (i.e. good, very good, etc.). In addition, the indoor air quality is perceived as good with positive and very positive answers.
We can see that the most negative answers are completely absent or almost null.
This reflects a satisfactory perception from the occupants of the considered buildings.

About how occupants ventilate their rooms, we can see they use regularly the mechanical ventilation systems with heat recovery (VHR), as foreseen in the passive house strategy. The answers show that nobody avoid using the ventilation systems adopting only natural ventilation by windows opening.
More than the 50% of the respondents declares that they used almost only VHR system opening the windows only for minimum and very limited periods. Another part of the occupants (about the 25% of the respondents) states that they use only VHR system to provide ventilation and indoor air quality to their rooms. While another about one quarter declare that use VHR systems opening windows for some periods.

We can deepen these outcomes on occupants behaviour about rooms ventilation considering better the evolution in time of the answers to the same question (‘*How do you ventilate rooms at the moment?*’). Figure 24 and Figure 25 show the responses distribution separately for each period, respectively for climate contexts where the heating period is more severe (buildings in Latvia and Netherlands), in Figure 24, and in regions where the cooling period is also relevant (buildings in Italy and Chiasso, Switzerland), in Figure 25.
We can recognize that buildings occupants tends to use more the natural ventilation by windows openings in climate contexts where the cooling needs are greater, like Italian regions, and in general during summer. Windows opening is used also in some intermediate seasons as spring and in autumn, less in winter.

This reflects that occupants basically are used to choose mechanical VHR option, with the related advantages in terms of heat recovery and savings of energy. While however they are free to open the windows, doing it mainly when the outdoor climate conditions allow it. In general this can provide benefits in term of free cooling and natural ventilation, with energy savings for thermal comfort and indoor air quality. In some situations, we could consider also the opportunity to further optimized the windows openings by the occupants with suggestions and simple training activities for them on the best use of the natural ventilation.

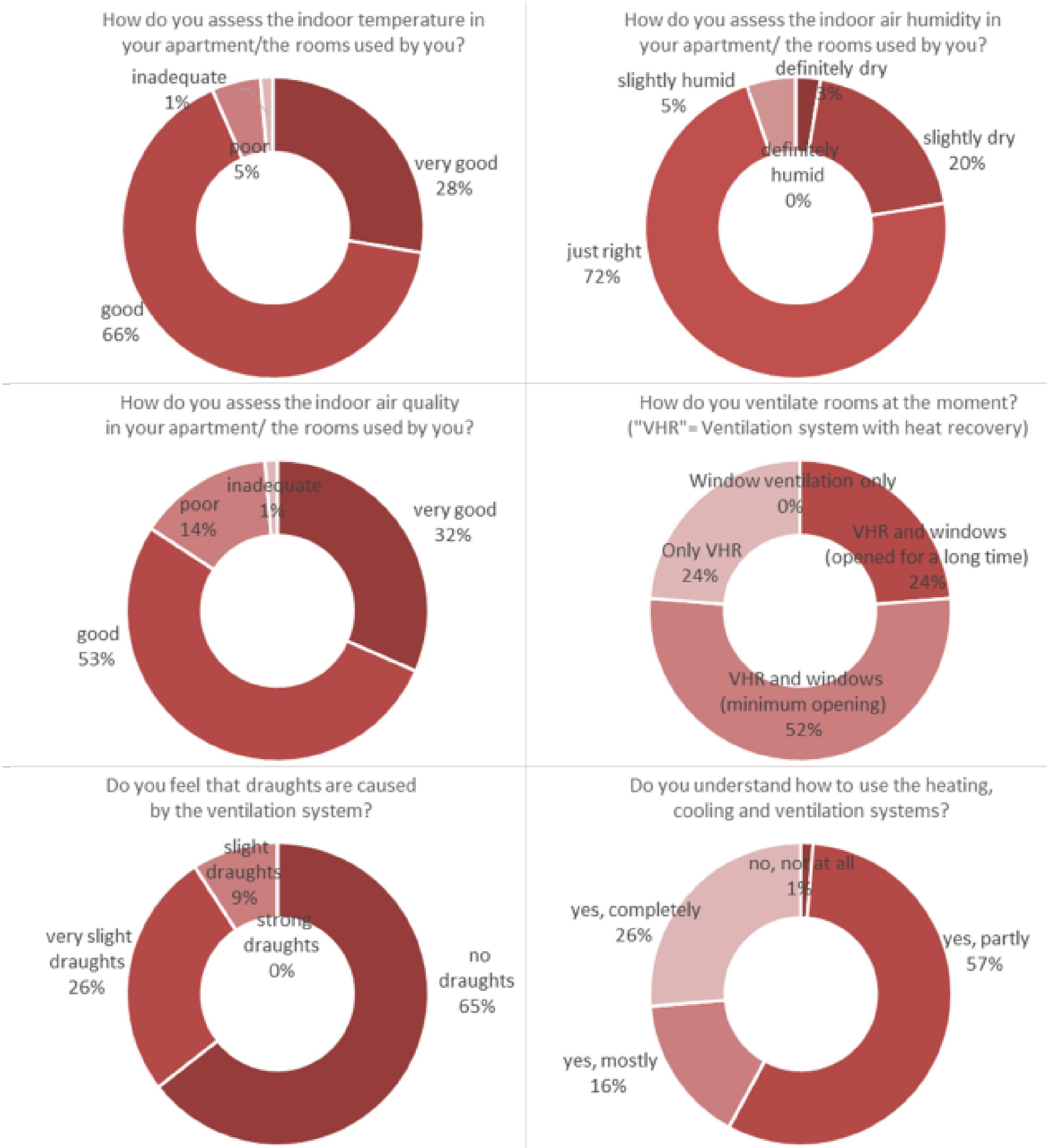


Figure 22: Percentages of different answers for each question in the questionnaires (all the considered buildings and periods), © eERG.

Occupants express satisfaction about air distribution by the mechanical ventilation systems. The large majority of the responses on this is very positive and positive (with no or very slight draughts). Nobody felt strong draughts due to the mechanical ventilation systems.

In general we could say that passive houses users have to deal with simple systems. Often the knowledge that the occupants need to switch on/off and control the heating, cooling and ventilation systems are quite simple and common: often this could be related only to the control of one system, which is the ones providing ventilation, heating and cooling. Of course more have to be done in order to manage and commission correctly the systems, but often this is not the role of the building users. Although simple, the systems controls could represent something new for occupants who are used to old solutions and technologies. Designing and installing simple, easy to use systems is key to success.

However the question '*Do you understand how to use the heating, cooling and ventilation systems?*' leaded to positive responses with many occupants (about the 42% of the respondents) who declare they understood completely or mostly how to use the systems. A good part (about the 57% of the respondents) said that they understand how to use the system in partial way (answering '*yes, partly*'). Almost nobody (only 1%) declared not to understand how to use the systems. And if we deepen this, we can see that this last response was given about the first period considered, probably at the beginning of the occupation by the user. Indeed, we can see this in the graph in figure Figure 23 where the responses evolution for this question in the different periods.

We can see that confidence and knowledge of the occupants rise in the following period and the number of the most positive responses 'yes, completely' rise during the survey periods, while other responses decrease. This show the positive impact of the further information and simple training given by buildings responsible (designers, builders, etc.) to the occupants.

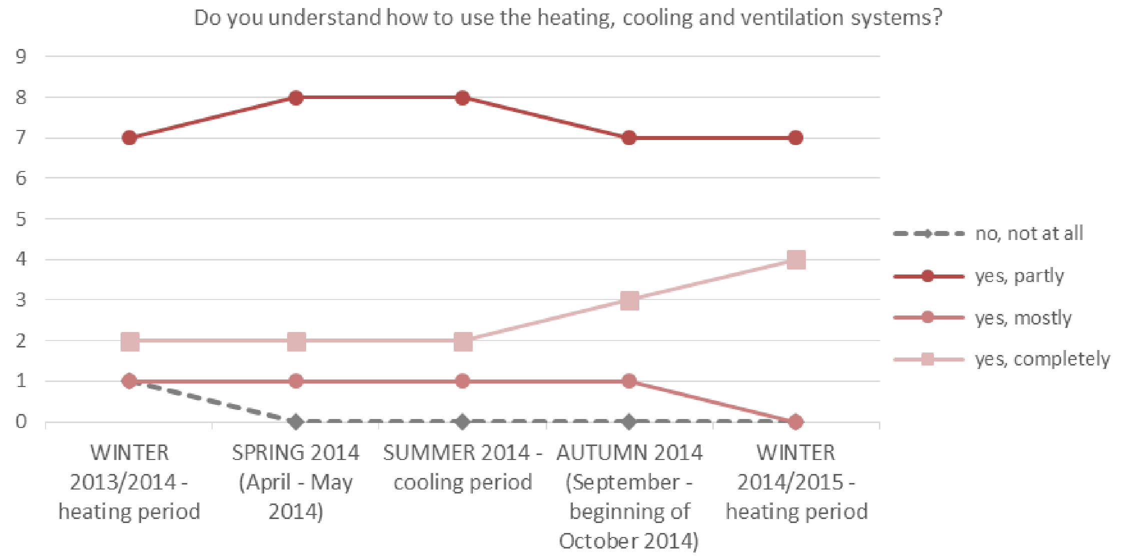


Figure 23: Evolution during the different periods of the responses about knowledge of use of systems by the occupants, © eERG.

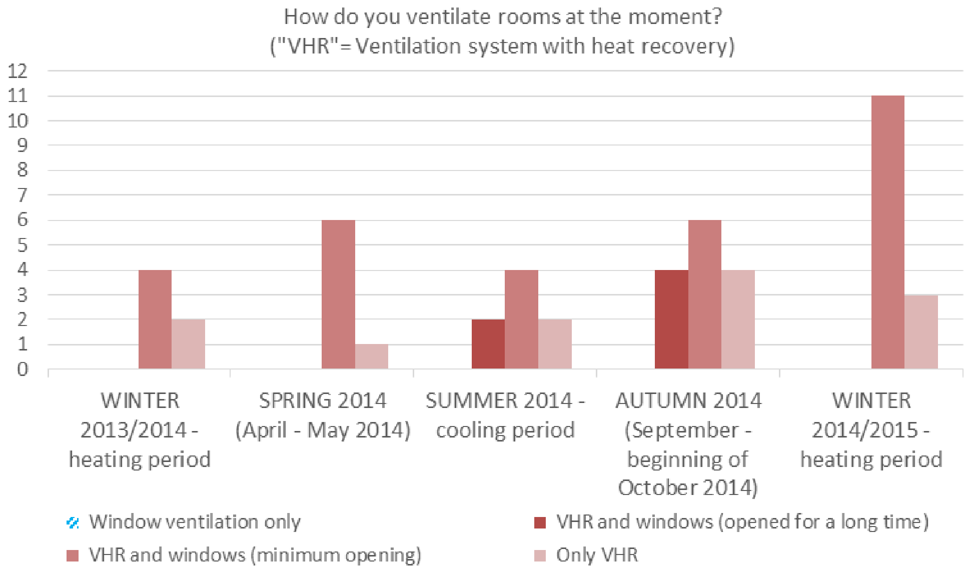


Figure 24: Evolution during the different periods of the responses on the used ventilation strategies in climate contexts where the heating period is more severe (buildings in Latvia and Netherlands), © eERG.

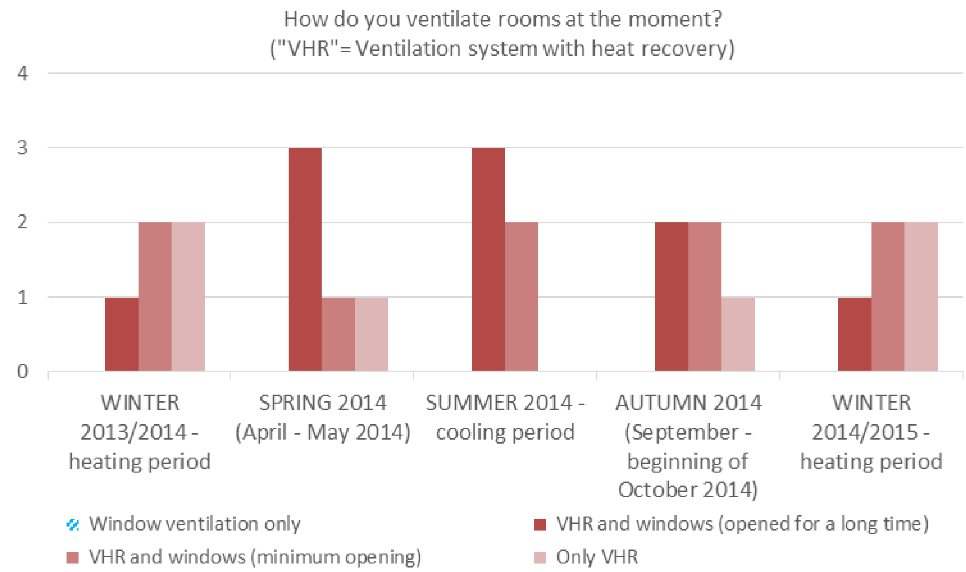


Figure 25: Evolution during the different periods of the responses on the used ventilation strategies in climate contexts where the cooling period is also relevant (buildings in Italy and Chiasso, Switzerland), © eERG.

5.4 Costs

The matrix in Annex I also displays the costs based on information provided by the PassREg partners and project teams in euros per m². Various projects were remarkably low-cost or realised/designed at competitive costs although being pilots of highly energy-efficient buildings which proves that an extraordinary energy performance does not directly correlate with high costs. For Austria, the recent study by Energieinstitut Vorarlberg, see [Klimaaktiv_2015], shows that Passive House buildings are the cost-optimum if life-cycle costs are taken into account.

This confirms previous investigations, e.g. on school buildings by the City of Frankfurt/Main, Germany, see [Bretzke_2009]. [AKKP42] gives an overview on how to evaluate costs and savings in a realistic way and gives examples for the economic feasibility of investments in energy efficiency. For further information, please see the affordability section in the Passive House resource Passipedia, [Passipedia_Affordability].

An outstanding example is the Sun kindergarten in Bulgaria. Although being the first of its kind in Bulgaria, it has construction costs of less than 400 Euro per m², leading to an incremental cost of 7.2% compared to the same building built to the current Bulgarian norms. This difference, however, pays off in just 7.5 years from the energy savings alone, without taking into account the benefits in terms of improved comfort and air quality.

6 CONCLUSION

Based on the findings from evaluating the monitoring information sent to the Passive House Institute, the following conclusions can be drawn.
All in all, the beacons planned with the energy balance and Passive House verification tool PHPP perform well as promised. Display of renewable energy generation is possible with the PHPP from Version 9 (2015) onwards, see Annex IV, and makes the optimization potential visible.

The good energy performance is proven by the monitoring results and feedback given by involved parties. Those beacon projects designed with PHPP but still in planning/construction phase can thus be expected to become highly energy efficient Passive Houses which will be able to cover most of the small remaining energy demand by renewable energy sources. Moreover, renewables can even be easily installed at a later stage and their capacities extended without mayor difficulties as the beacon project in Ergli, Latvia, see chapter 5.2.1, shows.
Focus should be laid on and further improvements can be made in terms of keeping the building services simple and highly energy efficient. Here, also storage and distribution losses can be reduced further.

Moreover, positive results could be displayed regarding the cost follow-up: Various projects were remarkably low-cost or realised/designed at competitive costs although being highly energy-efficient which proves that an extraordinary energy performance does not directly correlate with high costs.

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7.2 National information

Passive House database entries, factsheets, PHPPs and filled-out follow-up questionnaires from various PassREg partners based on templates set up by the Passive House Institute.

Disclaimer:
The sole responsibility for the content of this report lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the EACI nor the European Commission are responsible for any use that may be made of the information contained therein.

Annex I – Matrix of the beacons

Beacon	New/ retrofit	FR / AR / other	Location	Region	Country	Building phase	ID	Partner	Energy consumption	Comfort	Costs	Monitoring
Burry Port Primary School	New	AR	Cardiff	Wales	GB	design	not yet	**BRE**	PHPP ok	design ok	3.8 million british pounds	-
Visitor Information center in PA	New	AR	Burgas	Burgas	BG	design	-	**Burgas Municipality**	PHPP	design ok	-	-
Art Gallery	New	AR	Burgas	Burgas	BG	design	4458	**Burgas Municipality**	PHPP	design ok	-	-
Social Housing Case Finali	New	AR	Cesena	Cesena	IT	under construction	3980	**City of Cesena**	PHPP ok	design ok	1079 euro/m²	-
Multi residence	New	AR	Cesena	Cesena	IT	under construction	4086	**City of Cesena**	PHPP	design ok	1500 euro/m²	-
GWLO Landgoed Oosterhout	New	AR	Nijmegen	Nijmegen	NL	built	3887	**DNA**	PHPP ok	ok	1100 euro/m²	winter 13/14 - winter 14/15
22 Zorgappartementen Vroomshoop	New	AR	Vroomshoop	Nijmegen	NL	built	3004	**DNA**	PHPP ok	ok	1031 euro/m²	spring 2014 spring 2015
Bake House Erichem	Retrofit	AR	Erichem/tiel	Nijmegen	NL	built	not yet	**DNA**	PHPP	ok	-	autumn 2012 - spring 15
Orduynstraat Den Bosch	Retrofit	AR	Den Bosch	Nijmegen	NL	built	4379	**DNA**	PHPP ok	ok	920 euro/m²	summer 14 - spring 15
Portiekflats Presikhaaf	Retrofit	AR	Arnhem	Nijmegen	NL	under construction	not yet	**DNA**	PHPP ok	design ok	-	-
Botticelli project - smart Zero Energy Building	New	AR	Mascalucia	Catania	IT	built	2123	**eERG-PoliMI**	PHPP	ok	1000 euro/m²	yes
Leaf House	New	AR	Ancona	Marche	IT	built	-	**eERG-PoliMI**	Dynamic simulation	ok	-	yes
Certified Passive House Villa del Sole	New	AR	Lonato del Garda	Brescia	IT	built	2939	**eERG-PoliMI**	PHPP	ok	-	-
Certified multi-family house Casa Light	New	AR	Lonato del Garda	Brescia	IT	built	2416	**eERG-PoliMI**	PHPP	ok	-	-
Passive House Cantù	New	AR	Cantù	Como	IT	built	-	**eERG-PoliMI**	-			
Palazzo Positivo retrofit multi-family building	Retrofit	AR	Chiasso	Ticino	CH	built	2923	**eERG-PoliMI**	PHPP	ok	-	-
Scuola Raldon	New	AR	Frazione Raldon San Giovanni Lupatoto	Veneto	IT	built	4150	**eERG-PoliMI**	PHPP	ok	1423 euro/m²	-
Mediterranean PH project	New	AR	Portobello di Gallura, Aglientu	Sardinia	IT	design	not yet	**eERG-PoliMI**	PHPP	ok	-	-
Kindergarten "Sun"	New	other	Gabrovo	Gabrovo	BG	under construction	2996	**EnEffect**	PHPP	ok	-	-
Lodenareal	New	FR	Innsbruck	Tyrol	AT	built	1225	**IG Passivhaus Tyrol**	Monitoring	ok	1600 euro/m²	2010, 2011
Olympic village O3	New	FR	Innsbruck	Tyrol	AT	built	3856	**IG Passivhaus Tyrol**	PHPP	ok	-	-
Residential home for older people	New	FR	Innsbruck	Tyrol	AT	design	4329	**IG Passivhaus Tyrol**	PHPP ok	design ok	-	-
Service hotel of Ērgļi vocational secondary school	Retrofit	AR	Ergli	Vidzeme	LV	built	2913	**LEIF**	PHPP EnerPHit, see repo	ok	-	2014
Tiskadi school	Retrofit	AR	Tiskadi	Rezekne	LV	under construction	4450	**LEIF**	PHPP EnerPHit	ok	-	-
Tiskadi dormitories	Retrofit	AR	Tiskadi	Rezekne	LV	under construction	4451	**LEIF**	PHPP EnerPHit	ok	-	-
Timber frame office Building	New	AR	Bordeaux	Aquitaine	FR	design	not yet	**Nobatek**	-	-	-	-
First certified PH in Aquitaine	New	AR	Arcangues	Aquitaine	FR	built	2699	**Nobatek**	PHPP	ok	-	-
	New											
Bahnstadt	New	FR	Heidelberg	Heidelberg	DE	built/under construction	3879, 3858	**PHI**	PHPP	ok	1875 euro/m² gross average for residential	2014
Port Railway Building on Spreehaven Island	New	other	Hamburg	Hamburg	DE	built	-	**PHI**	-	-	-	-
Nieuw-Zuid	New	AR	Antwerp	Antwerp	BE	under construction	-	**PHP**	-	-	-	-
Avenue des Familles	New	FR	Brussels	Brussels	BE	built	-	**PMP**	PHPP	-	affordable	yes
51 apartments, school and offices for ONE	Retrofit	FR	Brussels	Brussels	BE	built	-	**PMP**	PHPP	-	17% cheaper than common market price	yes
30 Apartmenst and eco-neighbourhood in Harenberg	New	FR	Brussels	Brussels	BE	built	-	**PMP**	PHPP	-	9% cheaper than common market price	yes
zero:e-park Hannover	New	FR	Hannover	Hannover	DE	under construction	not yet	**proKlima**	-	-	-	yes
Zero emission single house - Family Messer	New	FR	Hannover	Hannover	DE	built	-	**proKlima**	PHPP	-	-	yes
Retail building - Rewe supermarket	New	FR	Hannover	Hannover	DE	built	3930	**proKlima**	PHPP	ok	1420 euro/m²	yes
Retrofit apartment house - Dr. Stiebel	Retrofit	FR	Hannover	Hannover	DE	built	1156	**proKlima**	PHPP	ok	-	-
Apartment house	New	FR	Hannover	Hannover	DE	built	775	**proKlima**	PHPP	ok	2145 euro/m²	-
Retrofit apartment houses - Quellengrund	Retrofit	FR	Hannover	Hannover	DE	built	-	**proKlima**	PHPP	-	-	-
Primary school building - In der Steinbreite	New	FR	Hannover	Hannover	DE	built	2816	**proKlima**	PHPP	ok	-	-
Retrofit of a townhouse - Family Reuter	Retrofit	FR	Hannover	Hannover	DE	built	1877	**proKlima**	PHPP	ok	1543 euro/m²	-
daycare centre - Im Wiesengrunde	New	FR	Hannover	Hannover	DE	built	-	**proKlima**	PHPP	ok	-	-
Retrofit of an office building - AS Solar	Retrofit	FR	Hannover	Hannover	DE	built	-	**proKlima**	PHPP	ok	-	-
Retrofit of a school building towards apartments	Retrofit	FR	Hannover	Hannover	DE	built	-	**proKlima**	PHPP	ok	-	-
PPP-Project - 8 day care centers	New	FR	Hannover	Hannover	DE	built	-	**proKlima**	PHPP	ok	1500 euro/m²	yes
Redevelopment Memorial Ahlem	New	FR	Hannover	Hannover	DE	under construction	-	**proKlima**	PHPP	ok	-	-
Sunny House	New	AR	Zagreb	Zagreb	HR	built	-	**City of Zagreb**	-	-	-	-
M6 house	New	AR	Zagreb	Zagreb	HR	built	-	**City of Zagreb**	PHPP	-	-	-
Patio House	New	AR	Sevilla		ES	under construction	4162	**PHI**	PHPP	ok	770 euro/m²	-
Granadilla de Abona	New	AR	Teneriffe		ES	under construction	4418	**PHI**	PHPP	ok	1250 euro/m²	-
Casa Genova	New	AR	Mallorca		ES	built	4459	**PHI**	PHPP	ok	1500 euro/m²	-

Annex II – Follow-up questionnaire ENERGY CONSUMPTION Example Ergli beacon
Heating supply, page 1:

Please send these monthly meter readings to the Passive House Institute every three months

Send to: soeren.peper@passiv.de

PassReg

Monitoring of energy use / Page 1: Heating

Building designation: **Ergli, Vidzeme region, Latvia**

Heat supply [x] inc. hot water generation

please cross:

[ ] Gas meter [x] Heat meter [ ]

Is consumption for gas cookers included in measu yes [ ] no [ ]

Which meter (position/area): heating circuit in basement from district heating system

#	Date / time	Meter reading		Remarks
	2014	Unit:		
		0	*MWh*	
1	Jan.	12,47	MWh	incl. DHW
2	Febr.	21,82	MWh	incl. DHW
3	Mar.	28,56	MWh	incl. DHW
4	Apr.	32,63	MWh	partially with DHW
5	May			DHW completely electrical
6	Jun.			DHW completely electrical
7	Jul.			DHW completely electrical
8	Aug.			DHW completely electrical
9	Sept.			DHW completely electrical
10	Oct.	34,93	MWh	partially with DHW
11	Nov.	42,03	MWh	incl. DHW
12	Dec.	55,6	MWh	incl. DHW
13				
14				
15				

Heating supply, page 2:

Electrical heat supply (ONLY heating/cooling/hot water; NOT domestic electricity)

Information about the application being measured/meter identification:

Ventilation system with heat recovery post and pre-heating

#	Date / time	Meter reading Unit:		Remarks
			kWh	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10	20.10.2014	0	kWh	This meter was set at the beginning of heating season
11	23.12.2014	6064	kWh	
12	02.01.2015	11473	kWh	
13				
14				
15				

Electricity supply:

Please send these monthly meter readings to the Passive House Institute every three months

Send to: soeren.peper@passiv.de

PassReg

Monitoring of energy use / Page 2: Electricity

Building designation: Ergli, Vidzeme region, Latvia

MAKE A COPY OF THIS SHEET AND FILL ONE IN FOR EACH ELECTRICITY METER THAT IS USED

Which meter: Electricity meter

Electricity for domestic and technical uses

What is measured by the meter:

- [x] domestic electricity (lighting, TV, fridge,...) → [x] inc. electric cooker
- [x] auxiliary electricity for building services (pump(s) for heating, regulation,...)
- [x] ventilation system
- [ ] elevator   [ ] underground car park (lighting/ventilation)
- [x] outdoor lighting   [ ] ______
- [ ] cooling unit
- [ ] consumption outside of the building envelope: ______

#	Date / time	Meter reading		Remarks
		Unit:		
		0		
1	Jan.	3137	kWh	
2	Febr.	5474	kWh	
3	Mar.	7868	kWh	
4	Apr.	11058	kWh	DHW production partially inculded
5	May	15704	kWh	DHW production included
6	Jun.	20556	kWh	DHW production included
7	Jul.	23057	kWh	DHW production included
8	Aug.	25053	kWh	DHW production included
9	Sept.	30066	kWh	DHW production included
10	Oct.	34348	kWh	DHW production partially inculded
11	Nov.	37271	kWh	
12	Dec.	40567	kWh	

Annex III: Excerpt from PHPP verification worksheet (Ergli beacon project)

Year of Construction:	1972	Interior Temperature:	20,0	°C
Number of Dwelling Units:	1	Internal Heat Gains:	4,1	W/m²
Enclosed Volume V_e:	15613,2			
Number of Occupants:	100,6			

Specific building demands with reference to the treated floor area — use: Monthly method

		Value	Unit	Requirements	Fulfilled?*
	Treated floor area	3521,3	m²		
Space heating	Annual heating demand	**10**	**kWh/(m²a)**	25 kWh/(m²a)	**yes**
	Heating load	**13**	**W/m²**	-	**-**
Space cooling	Overall specific space cooling demand		**kWh/(m²a)**	-	**-**
	Cooling load		**W/m²**	-	**-**
	Frequency of overheating (> 25 °C)	7,1	%	-	-
Primary Energy	Space heating and cooling, dehumidification, household electricity.	**98**	**kWh/(m²a)**	120 kWh/(m²a)	**yes**
	DHW, space heating and auxiliary electricity	68	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	-
Airtightness	Pressurization test result n_{50}	**0,6**	**1/h**	1 1/h	**yes**

* empty field: data missing; '-': no requirement

EnerPHit building retrofit (acc. to heating demand)?	**yes**

Annex IV: Excerpt from PHPP 9 (2015) verification worksheet with new primary energy renewable evaluation highlighted