EuroPHit

D2.6 Concept for a minimal monitoring of different buildings undergoing step-by-step energy-efficient refurbishment

INTELLIGENT ENERGY – EUROPE II

Energy efficiency and renewable energy in buildings

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EuroPHit

[Improving the energy performance of step-by-step refurbishment and integration of renewable energies]

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1 Introduction

When carrying out energy-relevant refurbishment measures, a frequent issue that arises is how big the intended savings in the form of a reduction in consumption actually are in reality. A separate scientific study cannot and should not be carried out for this purpose; it is enough to determine the total consumption of the building and to compare this with the consumption before the refurbishment, with as little effort as possible. For this, it is necessary to be able to differentiate between the areas for heating, hot water and electricity use by means of "minimal monitoring". In this connection the term "minimal monitoring" should be understood to mean "**an efficiency review of a building regarding its energy consumption using minimal effort**".

Already existing consumption meters that are used for billing should generally be used for this purpose. Depending on the task at hand and the configuration of meters, individual meters may also be necessary additionally. However, with this method the consumption values for "heat distribution" in a building can only be estimated as a rule.

The other - equally important - effects of energy-relevant refurbishment measures, such as a higher surface temperature of an interior wall and increased living comfort can only be ascertained and evaluated by means of additional specific measurements.

2 Reference values: measured value or calculated value?

The first issue which needs to be clarified for this approach concerns the reference values with which the energy consumption after the refurbishment is to be compared. This direct comparison is only meaningful if there are not any additional extensions or demolished parts (change in the heated/cooled volume) and there is no significant change in the utilisation of the rooms (occupancy density, commercial use instead of residential use etc.). For example, the treated floor area will increase if the top floor is extended to create living space. Of course, this must be taken into account in the comparison of the energy consumption.

There are two ways to determine the reference value:

1. **Consumption data**: evaluable documentation of consumption (e.g. monthly meter readings for heating/cooling, electricity use) of a sufficient duration (minimum: full heating period or complete cooling period) for the time before refurbishment. Information regarding the indoor temperature and the weather conditions (outdoor temperature, global horizontal radiation) prevailing during this period may be necessary in addition.

2. **Calculation (energy demand)**: a realistic estimate of the energy demand of the complete building is possible by use of a suitable energy balance (e.g. detailed PHPP calculation). For this, realistic estimation e.g. of the average indoor temperature is necessary.

Both possibilities - if properly conducted - will result in a meaningful reference value for the overall consumption of the building **before** the refurbishment measures. However, the effort required for this should not be underestimated.

Definition: A clear distinction must be made between energy consumption (measured value) and energy demand. As a rule, there is always a difference between the theoretical demand and the actual consumption. How big this difference is depends on the quality of the calculation or simulation model and the influencing parameters taken into account on the one hand, and the quality of the measurement on the other hand. Clear differentiation between the demand and the consumption must be made both in relation to language and content, especially when comparing measured values with previously prepared balance calculations (e.g. using the PHPP).

3 Verification limits and statistics

The method for "minimal monitoring" is designed to evaluate the overall consumption of a building. In the process, where possible, differentiation can and should take place according to the consumption areas for heating/hot water, cooling, and electricity use, so that these can also be evaluated. It is not possible to detect, differentiate and evaluate through metrological means any individual measures or the influence of different simultaneously implemented refurbishment steps.

Example: The windows in a building are renewed in a refurbishment step and the top floor is insulated at the same time. The energy consumption value (measurement) after the refurbishment cannot show any difference between the two measures and can only show the total energy consumption. A comparison with the consumption before the refurbishment measures will then show the actual amount of energy saved.

3.1 Step-by-step retrofits

Through minimal monitoring in step-by-step refurbishments it is possible to validate the amount of energy saved through the completed partial modernisations in the same way as after a complete overall refurbishment, provided that the testing period after a retrofit step covers a meaningful time period and the measures produce a measurable relevant effect. The period of time required for validating the change in heating energy consumption is at least one complete heating period – with otherwise the same boundary conditions for usage. For example, if insulation of the top floor ceiling is carried out, then it is possible to examine how this affects the heating consumption during the following winter. If the windows are replaced in the next year, then again the following winter must be analysed in order to measure the success of that retrofit step.

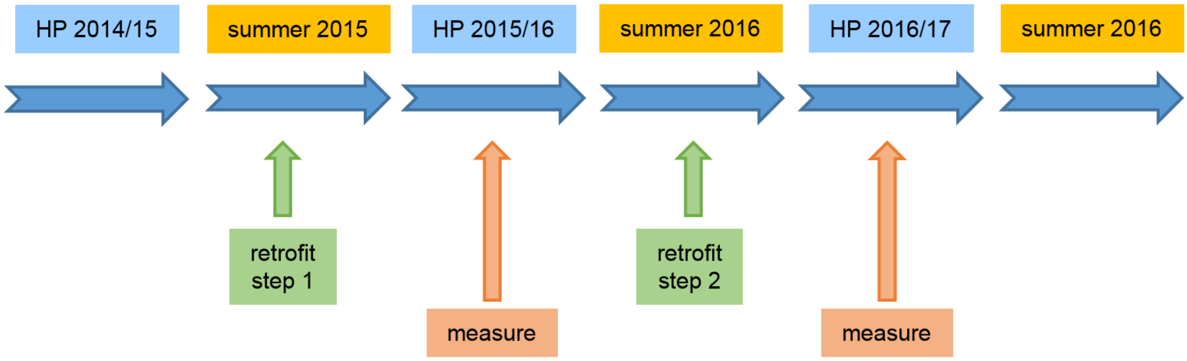

Figure 1: Example of the temporal course of a step-by-step retrofit with consumption measurements according to the respective partial step for examining the change in consumption (HP = heating period).

3.2 User behaviour

At the least, similar building use is a prerequisite for a before/after comparison. If an apartment is occupied by just one person before the refurbishment and e.g. 4 persons after the refurbishment, then building use will vary greatly, with different internal heat sources (body heat from persons, electricity use). These differences will be incorporated into the measured overall consumption value. If this is not taken into account, the corresponding effect (additional or less consumption) will be incorrectly allocated to the refurbishment measure.

This becomes apparent when one looks at the measured consumption values for heating in 32 Passive Houses (Figure 1), for example. These buildings are terraced homes which were built as four rows of eight houses each, so there are 8 end-of-terrace houses and 24 mid-terrace houses; all 32 houses were built to the same energy standard. However, the consumption values for heating show a typical significant scattering around the average value. These lower or additional consumption values between 30 to 40 % are due solely to building use. This occurs as a relative (not absolute!) quantity in all such measurements of consumption – **regardless** of the energy standard (non-refurbished existing building, low-energy house, Passive House).

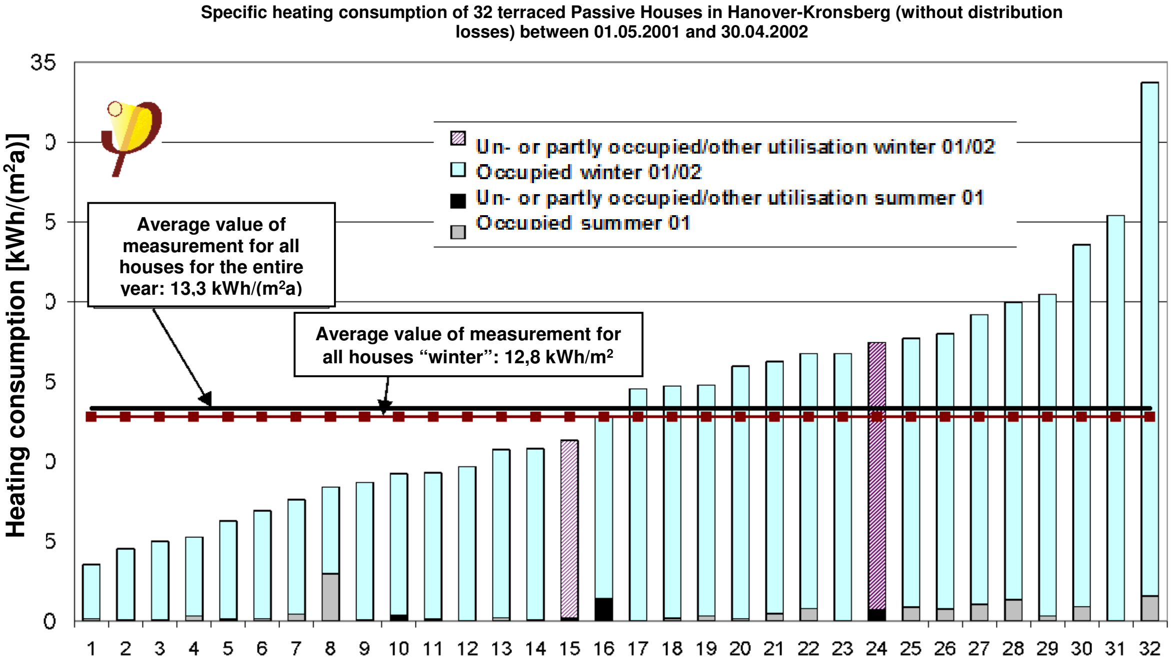

Figure 2: Specific heating consumption of 32 terraced Passive Houses in Hanover-Kronsberg (without distribution losses) in the period between 1.05.2001 and 30.04 2002 (third year of monitoring) [Peper/Feist 2002]. A distinction is made between the summer and winter heating consumption for each house and for the different types of occupation (occupied/partly occupied/unoccupied).

From a different viewpoint, this means that no conclusions can be drawn regarding the (not available) average value - that is, of the average utilisation pattern - if only measured data from a single building is available. Compared with the example from Figure 1, it remains unclear whether the available measured value of an individual building would be assigned to the lower, middle or upper range. The buildings in the example are so "tolerant" that they **function reliably** just as well at 5 kWh/(m²a) as at 25 kWh/(m²a)! Users were satisfied with both consumption values and there were no deficiencies of any kind. Only the use of the building is different.

This also makes it clear that the metrological verification of a single refurbishment measure requires a sufficiently large number of similar buildings in comparison with the normal user distribution. For example, **at least 5 to 15 similarly constructed buildings/apartments** will be necessary if a measure with a saving potential e.g. of 20 % is to be verified. Only then will the effect of the large user distribution become apparent. A reference value will then be necessary additionally (average value of the similarly constructed buildings without the measure being considered, or estimation using an energy balance calculation with e.g. the PHPP or dynamic simulation).

The limits of minimal monitoring have been outlined here. In order to proceed further, it is necessary to clarify what is needed to achieve the objective of "verification of success of refurbishment" and what is unnecessary. What is the extent of the conclusions of such an investigation and what exactly can or cannot be said about that building? The measurement e.g. of the total gas consumption is very easy, but determining the share for heating without hot water generation, distribution and conversion losses requires much more effort. The solutions presented here are based on at least monthly meter readings taking place manually without the use of a complicated data acquisition system. They are intended to enable an initial analysis of the building without major technical effort.

The following description with diverse key points concerning minimal monitoring with a focus on the estimation of the heating consumption are taken from the author's article [Peper 2012].

4 Technical equipment and configuration of meters

In order allow reliable statements about the energy consumption of a building to be made, at least **monthly meter readings** are required. In connection with the determination of the hot water consumption further below it is mentioned that weekly meter readings are more advantageous, but these are not essential.

The various billing meters that are normally present are used as a basis for monitoring. Typical meters have been listed in the table below. Accurate measurement is more difficult in the case of heating using pellets, firewood or crude oil since either the amount of heat generated can be measured using a heat meter (in which case losses due to generation are not included and must be estimated), or final energy use can be calculated and documented regularly on the basis of the quantity of wood used, by means of weighing if necessary.

Table 3: Normally used consumption meters and their usefulness in minimal monitoring

Medium	Measured using	Specific features
Heat	Gas meter, heat meter	Solar heating system requires a separate heat meter
Electricity	Electricity meter	Heat pump: separate electricity meter
		PV systems: separate electricity meter
Water	Water meter	Not necessary in the case of purely energy-relevant tasks

4.1 Configuration of meters

4.1.1 Heat consumption

The correct configuration of the meter for measuring final energy, which is the gas supply or even district heat supply in classic cases, comes about automatically with the billing meter. Nevertheless, as a precaution this should be reviewed critically. In the case of gas supply and central buffer storage, the gas meter is read on a monthly basis as a minimal requirement. The amount of energy utilised can be calculated from the energy content of the gas (e.g. natural gas, differentiation between L-gas and H-gas).

The use of a heat meter after the gas boiler (see Fig. 2) is more detailed. In this case the conversion losses of the gas boiler can be determined metrologically. Subsequent use of the heat for hot water generation and heating cannot be differentiated in this way. If more accurate statements are needed, one or two additional meters for hot water and/or heating can be used in an extended concept (Fig. 3).

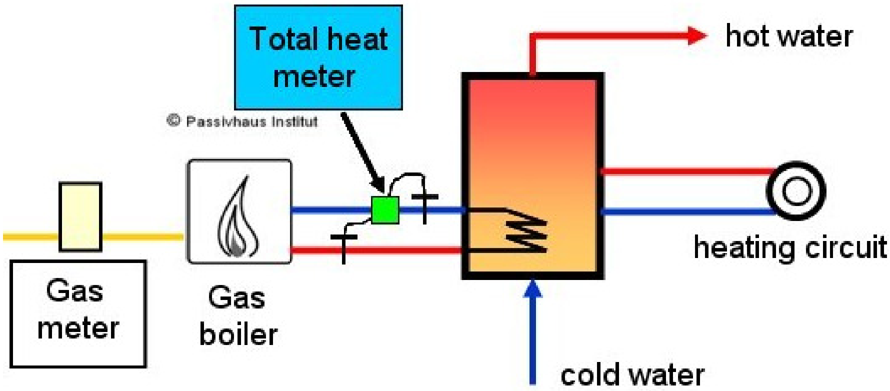

Figure 4: Minimum configuration for gas meters; supplemented with a central heat meter

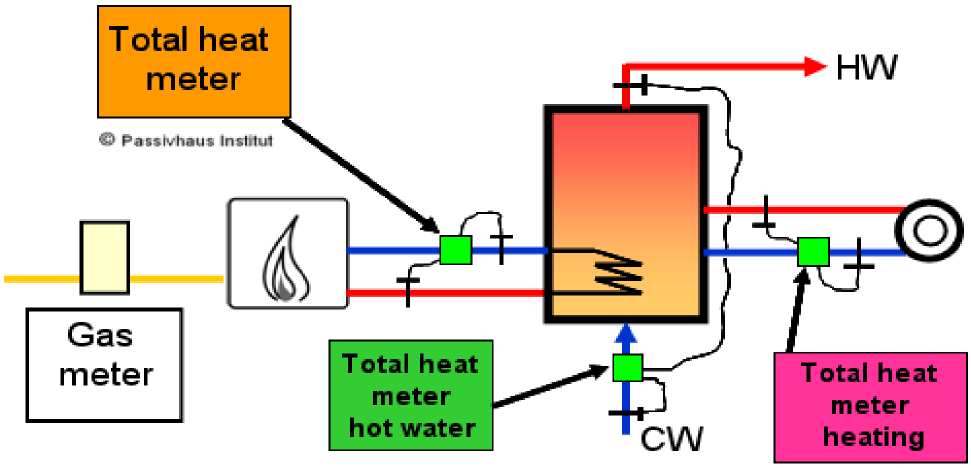

Figure 5: Supplemented meter configuration with gas meter and three heat meters in an example with central heat storage for heating and hot water [Peper 2012]

The configuration of the supply system described here is only an example. This is supposed to show the main principle of measuring final energy directly at the balance limit if possible. This approach can be applied for diverse other supply variants.

Heat Pump

If a heat pump is used, heat supply in the building takes place via electricity. In such cases it is imperative that the electricity used for the heat supply is measured separately. As a rule, there is no separate meter present at this position, since the main electricity meter also records other electricity consumptions in the building. Nevertheless, measurement of the electricity consumption of the heat pump or compact heat pump unit alone does not permit a reliable statement to be made about the amount of energy supplied. For that, a heat meter on the supply side would most certainly be necessary. If a statement is to be made about the source side of the heat pump as well, then a heat meter should also be provided here depending on the type of source where possible.

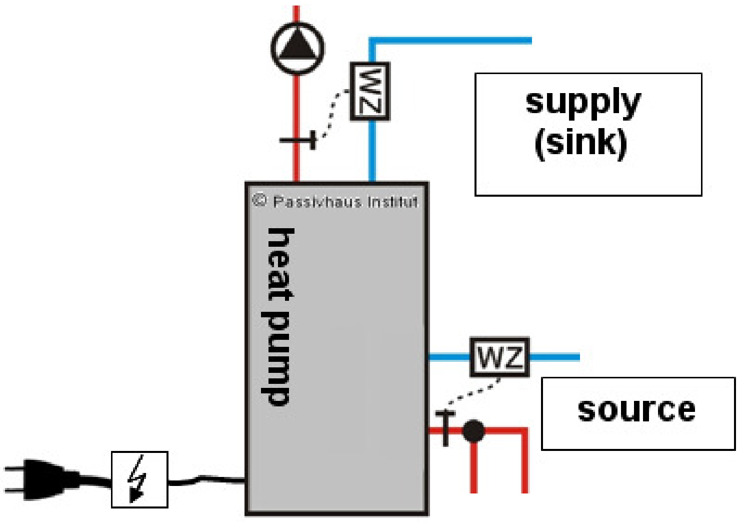

Figure 6: Meter configuration with heat and electricity meter for measurement in case of supply via a heat pump [Peper 2012]

4.1.2 Domestic electricity consumption

The electricity consumption is a decisive monitoring parameter for determining the total final energy supplied. The total electricity supplied to the building includes the electricity for building technology and domestic use. With the standard existing meter provided by the supplier, the correct device is already present at the right position. Sub-meters can be provided for further differentiation in the consumption areas technology, domestic use, lighting etc. Although these would be informative in the context of minimal requirements, they are not absolutely necessary.

4.1.3 Water consumption

In connection with minimal monitoring, water consumption is not directly relevant in terms of energy. Water consumption in residential buildings has a small influence on the energy balance of the building (e.g. heating up the cold water in WC cisterns), but these influences are not significant in the context of the procedure being presented here

However, in the overall picture of the consumptions in a building, this parameter may be of interest and monthly readings can often take place without much effort. These consumption values may possibly provide useful information about the absence of the occupants (e.g. during holidays).

5 Deviations from the calculated balance value

The complete energy balance of a building provides an energy demand value which corresponds with the entered quality of the building, the assumed type of utilisation and the climate data of the location used. There is often the naive expectation that exactly this calculated heating energy consumption will be achieved in use. The fact that it is not at all easy to measure the actual heating energy consumption without conversion and distribution losses and without hot water generation is not taken into account. The second essential demand value for primary energy is often not focused on, or is even unknown.

It must be taken into consideration that the heating energy consumption is noticeably affected by the diverse influencing factors, due to which it can vary considerably. In contrast, calculation of the demand must be carried out with realistic or fixed boundary conditions as far as possible. The most important influencing factors considered here are given in Fig. 5.

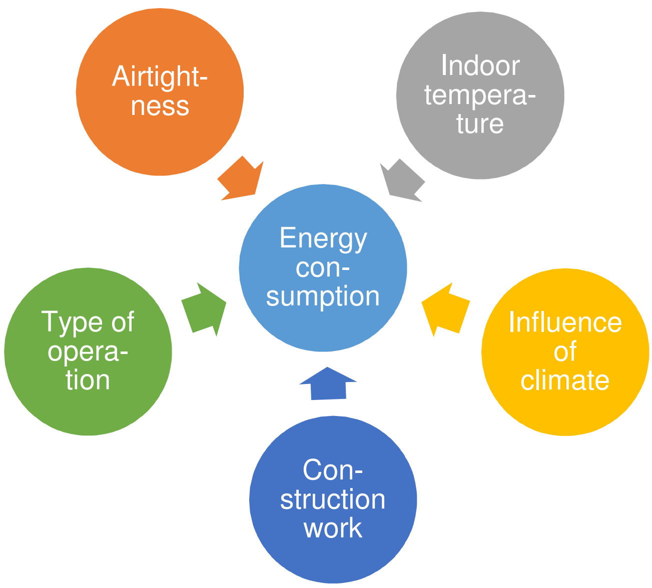

Figure 7: Important influencing factors affecting the energy consumption of a building

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5.1 Important influencing factors

The five influencing factors mentioned above are explained here and their order of magnitude estimated.

5.1.1 Influence of indoor temperature

The indoor temperature of a building significantly affects its consumption of heating or cooling energy. A typical value of 2 kWh/(m²a) for each kelvin of temperature difference in the range 20 °C is assumed for the heating consumption of an energy efficient building in Central Europe. This value is slightly different for each building. On account of the low energy consumption of Passive Houses, this results in proportionally large changes, typically between 12 and 15 % per kelvin of indoor temperature difference. The proportional influence is less in the case of a non-refurbished (existing) building, but the absolute influence is higher of course (ca. 7 to 10 %).

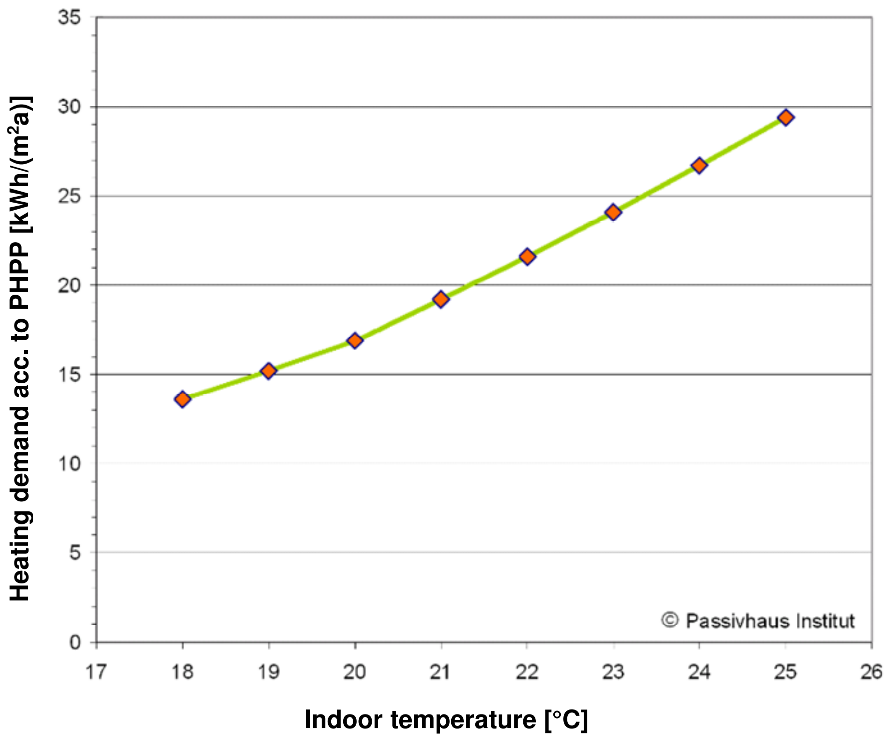

Figure 8: Influence of the indoor temperature on the heating demand of a Passive House during the heating period [Peper 2012-A]

It is therefore clear that with an indoor temperature of 22 °C on average, **an additional consumption of between 4 and 5 kWh/(m²a)** can be expected compared to the planned temperature of 20 °C. In Central Europe during the winter, the indoor temperature of monitored homes in energy efficient buildings was generally higher on average than the usual planned value of 20 °C; therefore accordingly higher consumption values can be expected on a regular basis. However, in the absence of any knowledge about the actual indoor temperature occurring later, the planning temperature of 20 °C is usually applied for the balance calculation. Specific uses such as hospitals, nursing homes or swimming pools are exceptions, since a higher temperature requirement than intended is already taken into account in the planning.

It must be taken into account that in uninsulated existing buildings, an average temperature of 20 °C does not normally prevail in the entire building. Often, only partial areas (e.g. the living room and kitchen) are heated. This leads to a lower average indoor temperature in the building. If a PHPP calculation of the existing state of the old building is also prepared for a comparison, then the lower average indoor temperature (e.g. 18 °C) must be used in order to obtain a realistic representation of the demand values.

5.1.2 Influence of climatic conditions

The second significant factor influencing the heating and cooling energy consumption is the actual outdoor climate during the measurement period. This quickly becomes apparent when an energy balance tool such as the PHPP is used for calculating a building in various locations by using different climate data sets. The heating demand will increase by an impressive 9 kWh/(m²a) if a sample end-of-terrace house in the Passive House Standard is moved from the mild location of Freiburg (Germany) to the cooler location of Harzgerode (Germany) in the calculation. Completely different variations will occur in reality. A scale of up to 5 kWh/(m²a) is used here for the deviation in the actual outdoor climate during the measurement period compared with the standard climate data set of the location.

5.1.3 Influence of airtightness

Airtightness has a direct influence on the energy consumption of the building. It is necessary for avoiding structural damage and unnecessary energy losses (exfiltration) and for the proper functioning of a ventilation system. The effect of different levels of airtightness on the energy demand can be estimated quite well in a theoretical analysis. The PHPP takes into account airtightness accordingly and this influence can be depicted quite well with otherwise identical conditions.

This influence can be seen for an example building as shown in Fig. 7. The calculated heating demand decreases significantly with improved airtightness. All components of the building (windows, insulation, ventilation etc.) remain the same otherwise. In reality, significantly higher n_{50}-values (>> 3 h^{-1}) result particularly in the case of existing buildings. Good airtightness values cannot be expected in a refurbishment if airtightness is not planned in detail.

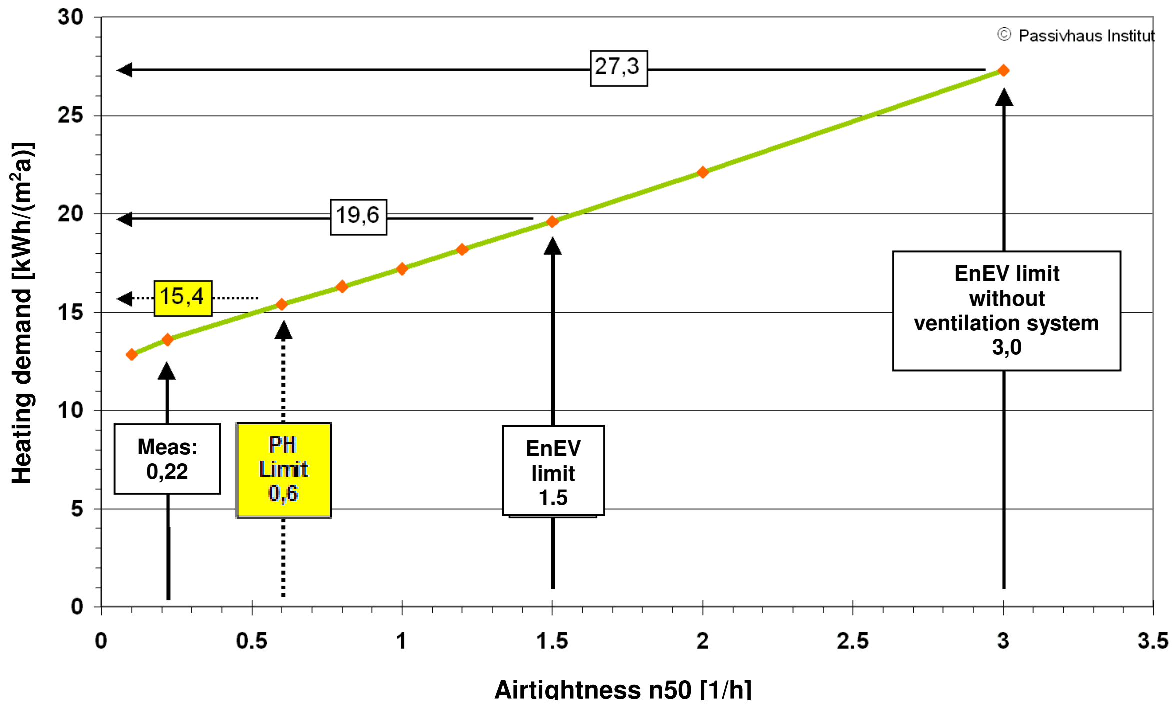

Figure 9: Influence of airtightness on the heating demand in an example building [Peper 2012]

For evaluating the building and comparison with the consumption data, it is essential to know the actual airtightness value of the building. An additional demand of e.g. 4 kWh/(m²a) may quickly arise with an airtightness value of $n_{50} = 1.5\ h^{-1}$ instead of the planned value of $n_{50} = 0.6\ h^{-1}$. Whether the variations are small or large can only be determined through measurement of the relevant building in individual cases. Airtightness measurements are therefore mandatory for Passive Houses, it is therefore assumed that this value is available.

5.1.4 Influence of construction work

As a rule, there are variations between the planning of a building and the actual implementation: a different quality of the materials is used intentionally or otherwise, slightly deviating solutions are chosen on site at short notice, and inaccurate execution of the work may result in deviations. The connection of a building component may be executed differently from the planned manner and an additional thermal bridge may result, or the proportion of steel in concrete is increased, which may result in increased heat emission in the relevant area. There are many conceivable design deviations which are ascertained on a regular basis during quality assurance work. To a certain extent, this is not a problem for the building and is due to the occurrences on-site. Often, these circumstances may not be identified by the construction management and quality assurance experts, or it may not be taken into account in the subsequent energy balance.

Altogether, this means that the calculation value (demand) in the energy balance will differ from the measured consumption value. The energy balance calculation is only as good as the updating using the actual constructions in the implemented building. An "armchair" calculation that is not followed up in the course of construction is not suitable for a realistic depiction of the building, therefore it should not be used for a comparison with the consumption values, or should be used only to a limited extent.

The scale of these extremely different potential design deviations cannot be expressed as overall figures as statistically utilisable studies regarding this are not available. Based on the experiences gained from the monitoring carried out by the Passive House Institute, an example value of **1 kWh/(m²a)** is used which can be caused e.g. by additional thermal bridges.

For a realistic balance calculation, it is imperative to know exactly the actual characteristics of the components used and to apply these in the calculation. This is one of the main reasons why the Passive House Institute conducts certification of the energy-relevant building component and insists on values that are as realistic as possible. If the quality of the components used varies from that in the planning, these actual values and conditions must certainly be taken into account. The influence of the heat recovery efficiency of the ventilation system, ventilation disbalance, efficiency factor of the heat generator etc. can have even greater effects on the consumption than the influencing factors listed above.

5.1.5 Consumption discrepancies due to type of operation

Altogether, energy efficient buildings behave in a very "tolerant" way. If utilisation deviates from the theoretical optimum, this usually does not pose a problem. In various monitored projects "additional consumptions" such as unwanted heating in summer, were recurrently identified. These were due to regularly occurring sub-optimal operation or deficient knowledge of the occupants. Among other things, these were:

- Delayed switch-off of the bypass function of the ventilation system before the start of winter
- Unwanted heating of the home in summer due to the lack of a central switch-off mechanism
- Incorrect operation due to lack of information or unclear user instructions (closing or shutting of valves etc.)

Usually it is easy to prevent or eliminate these influences. For this reason, the PHI recommends central switch-off mechanisms e.g. of the heating circuit pumps by means of a simple annual time switch and adequate information for users regarding the technical installations available. A Passive House is generally characterised by lean, uncomplicated technology which is easy to operate. Clear directions for tenants and operators as well as instructions for e.g. maintenance personnel for ventilation systems are also very effective (see also: user manuals for download at www.passivehouse.com).

The potential scale of the effects on heat consumption varies greatly and cannot be stated as an average. Additional consumptions of around **0.5 kWh/(m²a)** due solely to unwanted heating in summer have been measured several times.

In a non-refurbished building, it must be taken into account that as a rule, air exchange without a mechanical ventilation system is significantly lower than with a ventilation system. Lower air change rates mean a lower quality of indoor air and also lower heating energy consumptions. If a PHPP calculation of the existing state of the building is prepared for the purpose of comparison, then these lower air change rates must be taken into account.

5.2 Additional heat consumption

The sum total of all influences actually occurring in a building is always different and is only individually possible through extensive monitoring and comprehensive subsequent balance calculations.

In reality, all the potential additional consumptions mentioned above never occur at the same time and on a different scale. A few may also lead to a minor reduction in the heat consumption (higher airtightness, lower indoor temperature). In the context of minimal monitoring, at least the conceivable magnitudes must be known. The theoretical sum of all influences compiled here is in the same order of magnitude as the target value for heat consumption of a new Passive House (Fig. 8). This also shows the conceivable fluctuation range of the measured values in theory: if it is possible to measure only the heat consumption, this may be e.g. 20 or even 25 kWh/(m²a). In a building for which 15 kWh/(m²a) has been projected, this does not necessarily mean that there are any defects in the building!

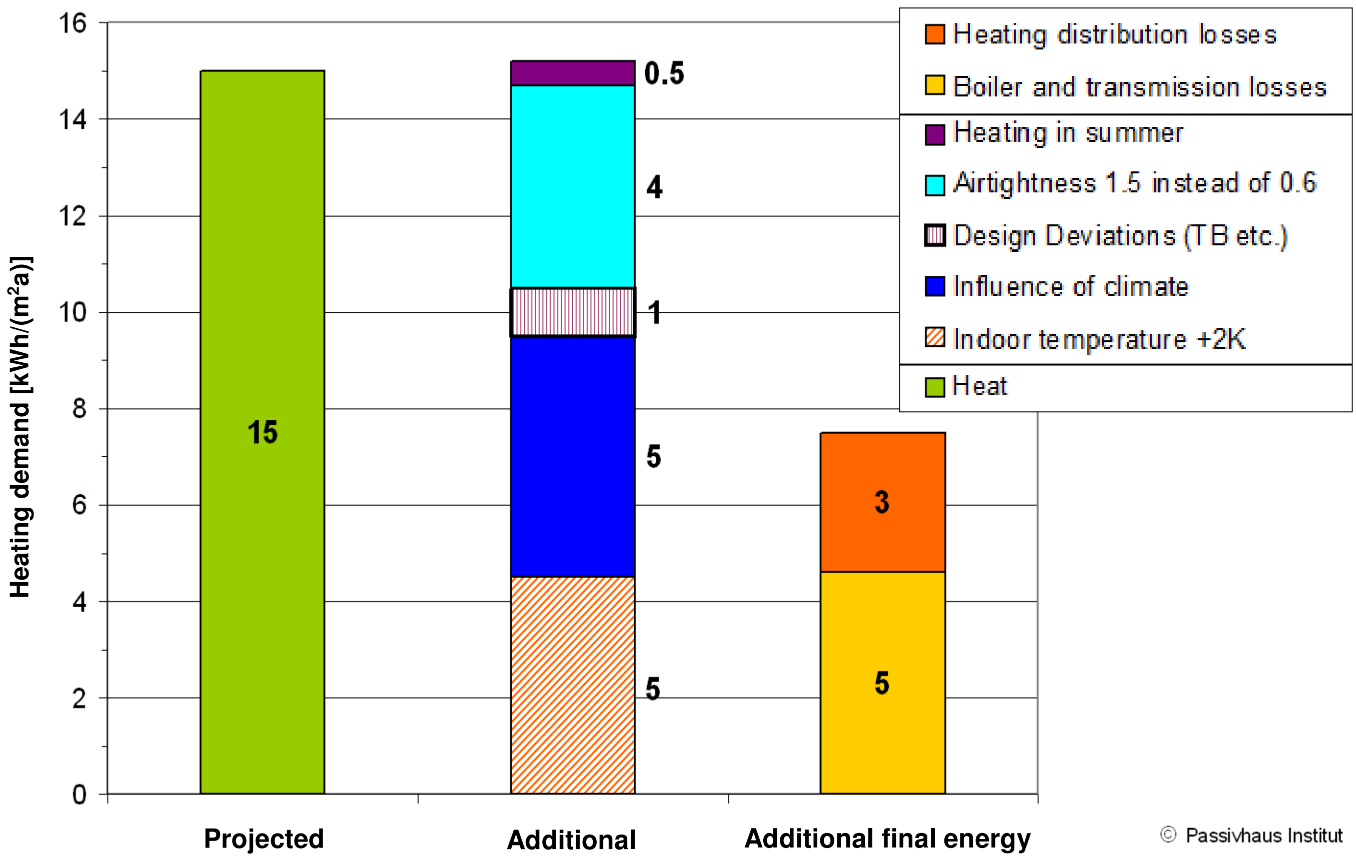

Figure 10: The size of the conceivable additional consumptions for the projected heating demand and the scale of the typical final energy consumptions which are not taken into account in the heating demand [Peper 2012]

Frequently, only the total final energy consumption including the conversion and distribution losses are acquired as a sum value through measurement, in which case other consumption values are also included in this. Typical figures can be 5 kWh/(m²a) for the boiler and system losses (e.g. heat exchanger, storage tank etc.) and 3 kWh/(m²a) for non-utilisable distribution heat losses; however, these values serve as an orientation only; again, they vary greatly depending on the type of mechanical systems, routing of lines and their length. If these applications are included in the measured value by means of meter configuration, this will naturally lead to higher consumption values. It becomes even more difficult to answer the question of whether there is any deviation from the projected value (demand).

The conversion, storage and distributions losses are taken into account in the calculation of the demand (PHPP) and are incorporated into the second required value of a maximum of 120 kWh/(m²a) of primary energy, but not in the heating demand (useful heat).

6 Energy for hot water generation

Depending on the type of energy supply, the energy expenditure for hot water generation is often included in the measurement of the entire final energy consumption of a building. If it is necessary to draw conclusions about the heating consumption only, then the consumption for hot water generation should also be known separately as a single value.

In order to obtain an idea of the possible scale and range of fluctuation, the measured data for hot water generation from various multi-storey buildings in Germany and Austria (a total of just under 6600 m² TFA) with central hot water generation were analysed in [Peper 2012]. The result is shown in Fig. 9, indicating that the energy for the average hot water consumption including distribution in the building is 17.5 kWh/(m²a). Energy expenditure is thus of the same scale as for heating in a Passive House. In addition, there is storage and distribution with 2.1 kWh/(m²a) on average in the plant room and the considerable share of 7.1 kWh/(m²a) for operation of the hot water circulation. From the experiences gained with projects in Germany and Austria, this results in a total of 26.7 kWh/(m²a) on average for all energy expenditure for hot water.

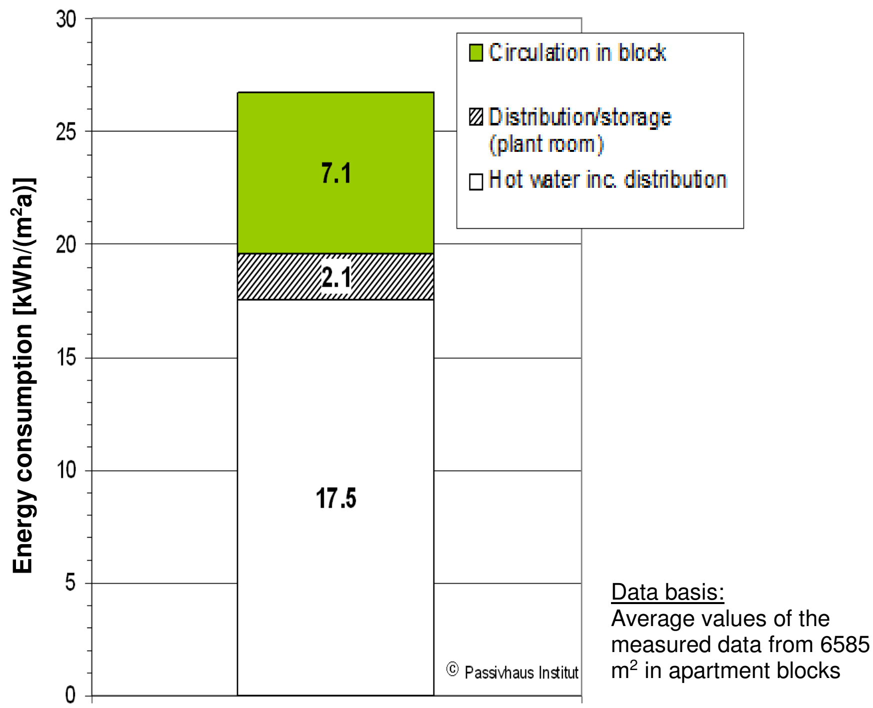

Figure 11: Average value of the energy expenditure for hot water supply in different apartment blocks [Peper 2012]

It must be considered that these are average values from apartment blocks. Significant variations are common when considering single homes. In the monitored project for a retrofit of an existing building using Passive House components in Tevesstrasse in Frank-furt (Germany) [Peper/Schnieders/Feist 2011], the measurements show the large scattering of the individual values over the period of three years (Fig. 10). Such distributions are typical and common in relation to hot water consumption. This means that for example in the case of a single house it is **not possible to make a realistic estimation of the energy consumption for hot water generation without a separate measured value**.

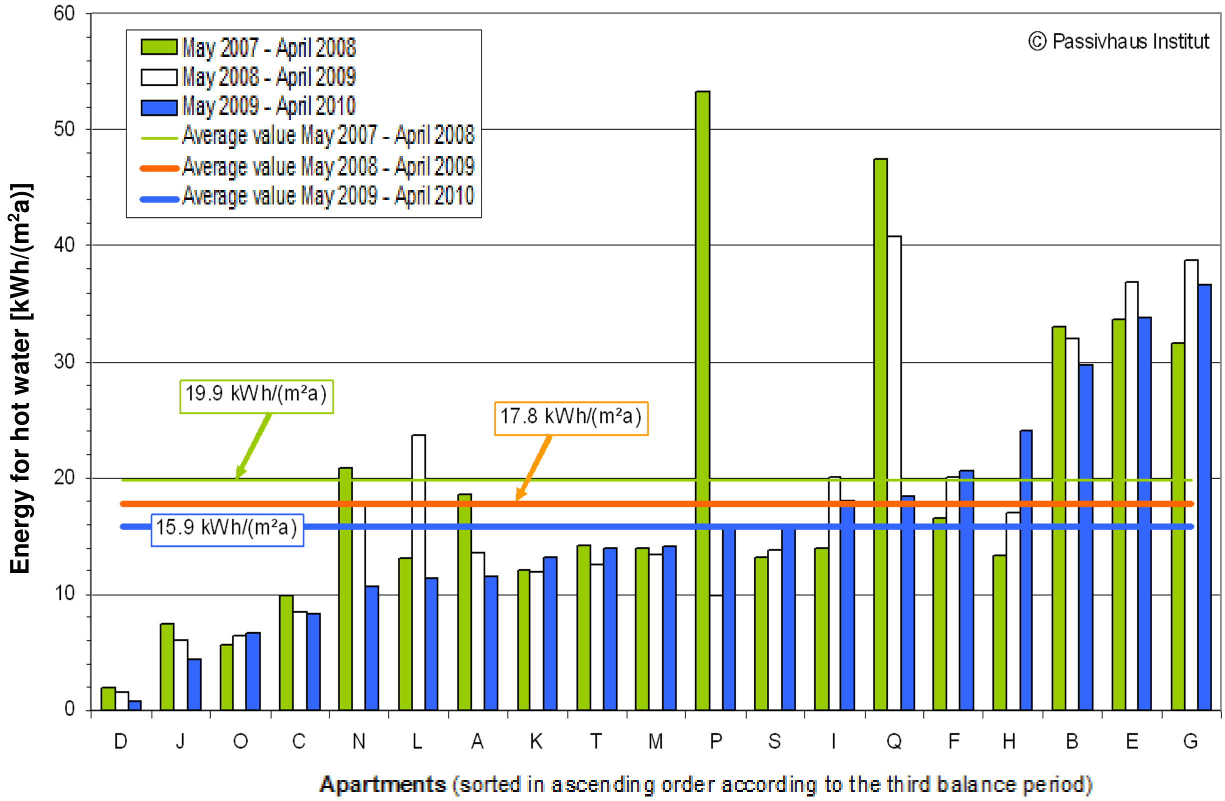

Figure 12: Energy content of the hot water utilised in 19 apartments over three annual balance periods and the three respective area-weighted average values. The measurements were carried out inside the apartments, therefore this only deals with useful heat for hot water [Peper/Schnieders/Feist 2011]

7 Procedure for minimal monitoring

The purpose of minimal monitoring is to demonstrate the energy-relevant effects of a complete refurbishment or a step-by-step refurbishment. It can also serve as an efficiency review in the case of a new build. The monthly meter readings are available as a starting point and basis for this purpose, from which the monthly consumption for e.g. heating, cooling, and total electricity use is calculated. An annual sum total can be ascertained from the data for 12 months. The specific yearly total consumption results with reference to the corresponding treated floor area of the building.

Example: After refurbishment, the gas consumption of a building results as 60 kWh/(m²a). This raises the question whether the building is functioning "as planned". In expectation of the normal values of 15 kWh/(m²a) for heating and e.g. 22 kWh/ (m²a) for hot water, i.e. a total of 37 kWh/(m²a), at first it is not clear why the result is 60 kWh/(m²a). As explained in the sections above, this can be due to several reasons.

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The procedure for minimal monitoring will be described here step by step with reference to the issue:

- "Does the Passive House function as planned?" and
- "What has been achieved with these refurbishment steps?"

Further optional steps can be carried out after the main steps in order to refine the result even further. However, other data or measurements will be necessary for this.

The procedure for new builds or refurbishment is basically the same. Consumption values for a sufficiently large number of months are always necessary. For simplification only the **heating period** (in the case of heating operation alone e.g. from October to April) or the **cooling period** (e.g. from May to September) can be used in order to shorten the required period of measurement. In these cases, the electricity consumption values for example would have to be extrapolated to the entire year, which is only possible with limited accuracy.

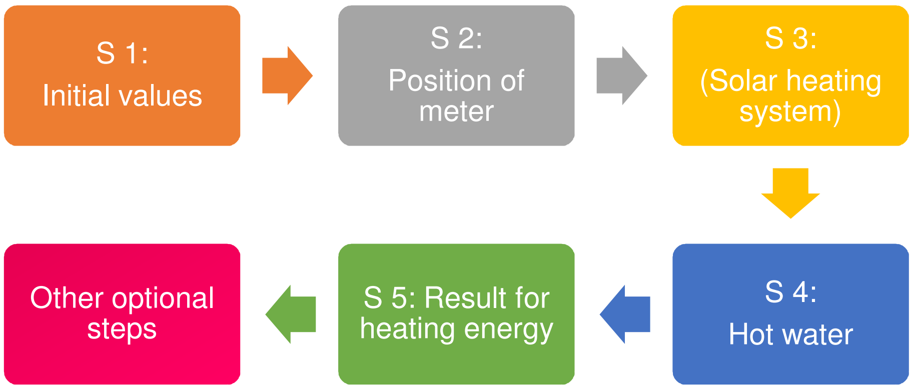

Figure 13: Steps (S) for carrying out minimal monitoring

An example is used to illustrate the procedure for gas or district heat supply (without cooling) in order to obtain an estimate for the heating consumption. Initially, the focus is not on the electricity consumption. A similar procedure can be used for other types of energy supply. The starting point for this description is e.g. a central meter for the heat supply (e.g. gas meter). If there are other sub-meters (e.g. a heat meter after the boiler, see Section 4.1.1.) then the corresponding steps may be omitted.

7.1 Step 1: Initial value of final energy

Monthly meter readings of the final energy meters in the building (e.g. gas, district heat, electricity) are a minimum requirement. In the case of energy supply with wood pellets, firewood or crude oil, the corresponding volume units must have been recorded. It is imperative that ALL existing supply mediums which are delivered to the building through the balance boundary are taken into account. The measurement period must extend over at least 12 months (exception: only heating or cooling period).

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Conversion: If the final energy is directly measured e.g. as the gas volume (m³) rather than in energy units (kWh), then it must be converted first. In the case of natural gas, the calorific value of the gas can be used for this, which can be found in the supplier invoice. The calorific value of the gas varies depending on the mixture ratio and gas type (H-gas or L-gas). For simplification, calculation can be carried out using the conversion rule "1 m³ natural gas roughly equals 10 kWh".

7.2 Step 2: Position of the heat generator

In this step, a distinction is made between the position of the supply and storage facilities: If the technical installations for energy supply or conversion of energy (district heat transfer station, gas boiler, heat storage) are situated outside of the thermal envelope of the building, then these do not serve to heat the building, therefore the conversion and storage losses must be taken into account as an overall amount.

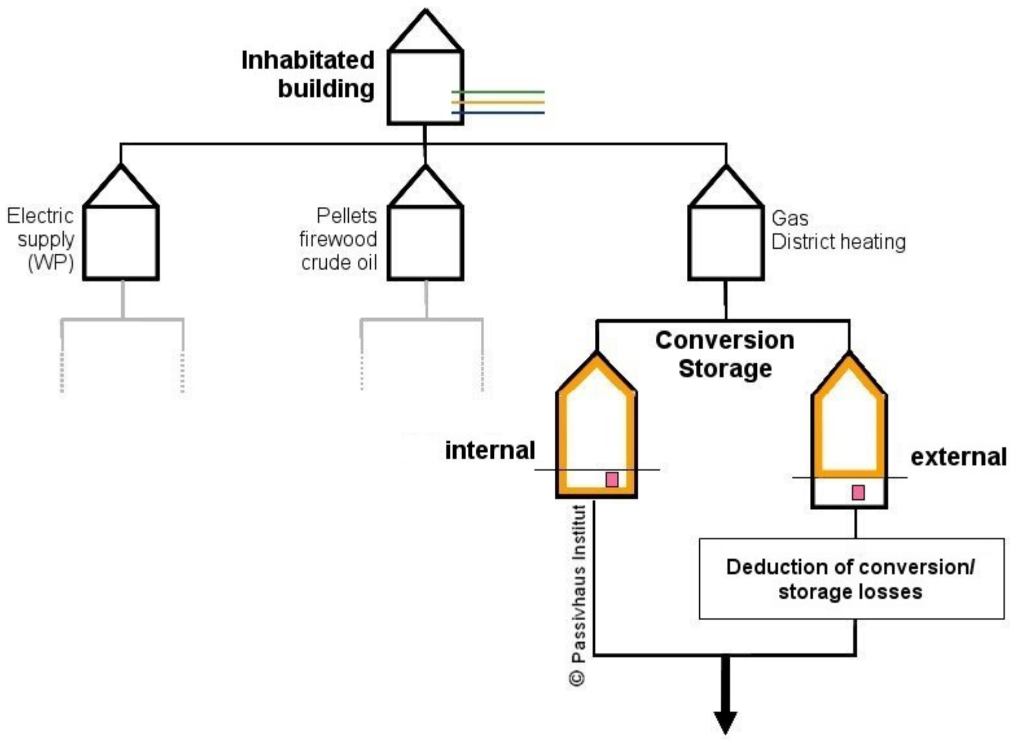

Figure 14: Flow chart showing Part 1 of minimal monitoring (the gas/district heat supply continues further in this example) [Peper 2012]

The amount of **conversion and distribution losses** depends on many technical circumstances: the type and size of the boiler, the type of operation of the boiler, insulation and length of distribution pipes etc. Within the framework of these guidelines, exact determination is not possible. The **heat loss from hot water or buffer storage** depends first and foremost on the size of the storage tank and on the quality of the thermal insulation. The losses can be estimated e.g. using the following chart.

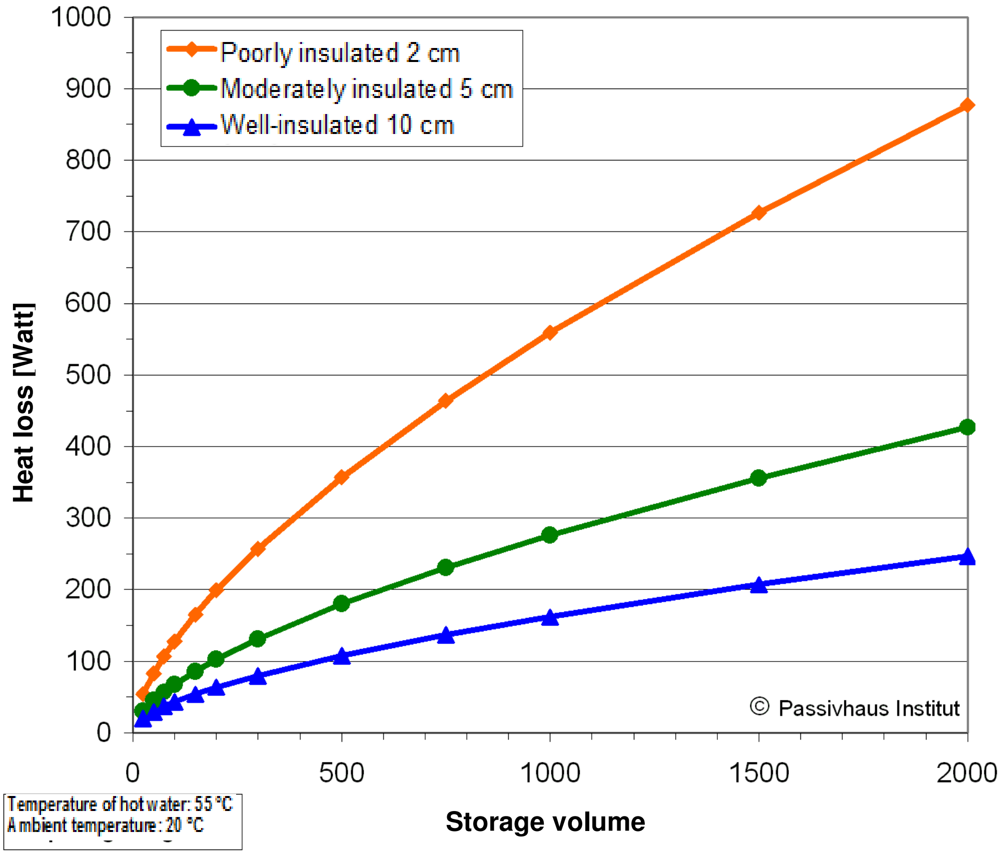

Figure 15: Heat loss from a hot water or heating water storage tank in dependence on the storage tank size and the thickness of the thermal insulation. The data has been taken from the PHPP Handbook (Source: [Peper 2012])

Overall approach: As a rough but acceptable approach, an **overall amount of 12 %** of the total final energy can be deducted for conversion and storage losses (this applies only for a refurbished energy efficient building). These do not occur within the thermal envelope of the building and therefore cannot be used for heating. This figure is an average value calculated from numerous monitored projects with typical modern heat engineering. Of course, further potential exists here for improving efficiency (compare PHI recommendations for insulation of pipes and fixtures as well as hot water storage tanks).

The heat quantity which was used within the thermal envelope of the building thus becomes available as an interim result. In the case of buildings in which the technical systems for heat supply and distribution are situated within the thermal envelope of the building, it is assumed that this fully benefits the building (NO deduction).

7.3 Step 3: Special feature: solar heating system

If a **solar heating system** is used in the studied building, then the energy gains which are supplied to the building additionally must be measured separately (additional heat meter for heat quantity possibly suitable for measuring a mixture of water/anti-freeze). Based on experience, due to various reasons a general estimate e.g. according to the solar radiation sum of the location will not lead to any useful results.

7.4 Step 4: Hot water

Since the building's heating and hot water generation takes place jointly with a single boiler (or with district heat), these two consumption parameters must be separated. An easy way to determine the energy expenditure for **hot water generation** is to separate the annual amount of energy for heating and hot water generation by ascertaining the so-called "hot water base". This refers to the basic consumption throughout a year to which the heating consumption in winter is added. This can be inferred from the graph (Fig. 14). The heat consumption in summer (e.g. June to August) is extrapolated to the whole year. **At least monthly consumption data are necessary for this estimate.**

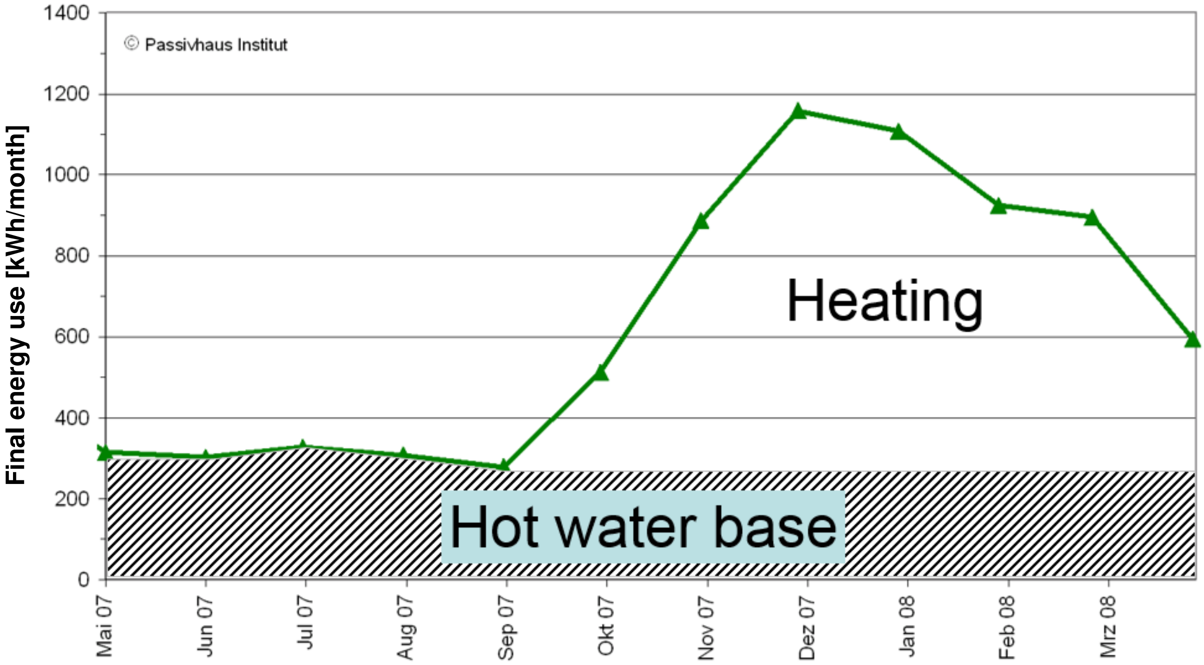

Figure 16: Determination of the scale of the so-called hot water base for the annual consumption by means of evaluation of the adjusted monthly final energy consumptions. [Peper 2012]

Note: minimal consumptions during summer ("summer slumps") are caused by holiday periods or other absences; sometimes these can also occur during other times. This is especially relevant in the case of small buildings (single-family and semi-detached houses). These periods must be taken into account if the energy expenditure for hot water generation is determined in the simplified manner described here. It becomes apparent that more frequent meter reading intervals are advantageous (Fig. 15).

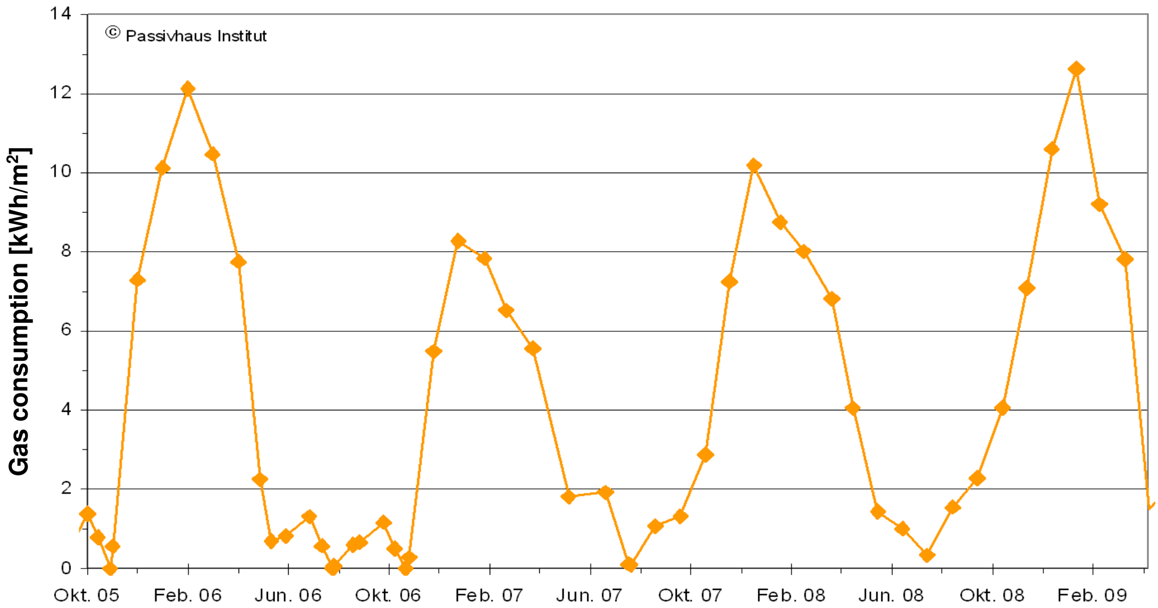

Figure 17: Gas consumption values from irregular meter reading intervals (monthly to weekly) of a terraced house with typical "summer slumps" [Peper 2012]

Normally there is a slight fluctuation in the summer/winter consumption of hot water in residential buildings; slightly more hot water is used in winter than in summer; energy expenditure in winter is slightly higher. This fluctuation is not taken into account in the simplified kind of evaluation of energy expenditure for hot water supply described here. The low consumption in summer is clearly evident despite a few outliers when looking at the example with measured values from an extensive monitored project with a double multi-storey building with 12 apartments in each block (Fig. 16). These are energy quantities for charging the central storage tank (not the actual amount of hot water that is drawn).

In order to test this method, using the data in Fig. 16 the energy consumption from each of the three summer months (June till August) was extrapolated for the whole year (per house and year) and the total was compared with the actual consumption for the whole year. This test revealed that the minimal monitoring method causes underestimation of the annual value by 5 to 16 %, with **9 % on average**.

The difference between the summer and winter consumptions on the hot water withdrawal side of the storage tank is even more pronounced than for storage charging being considered here. However, the seasonal differences are equalised because the circulation and storage losses are included in the measurement for charging of the storage tank. Since circulation and storage losses are included in the measurement for charging of the storage tank, the seasonal differences are equalised.

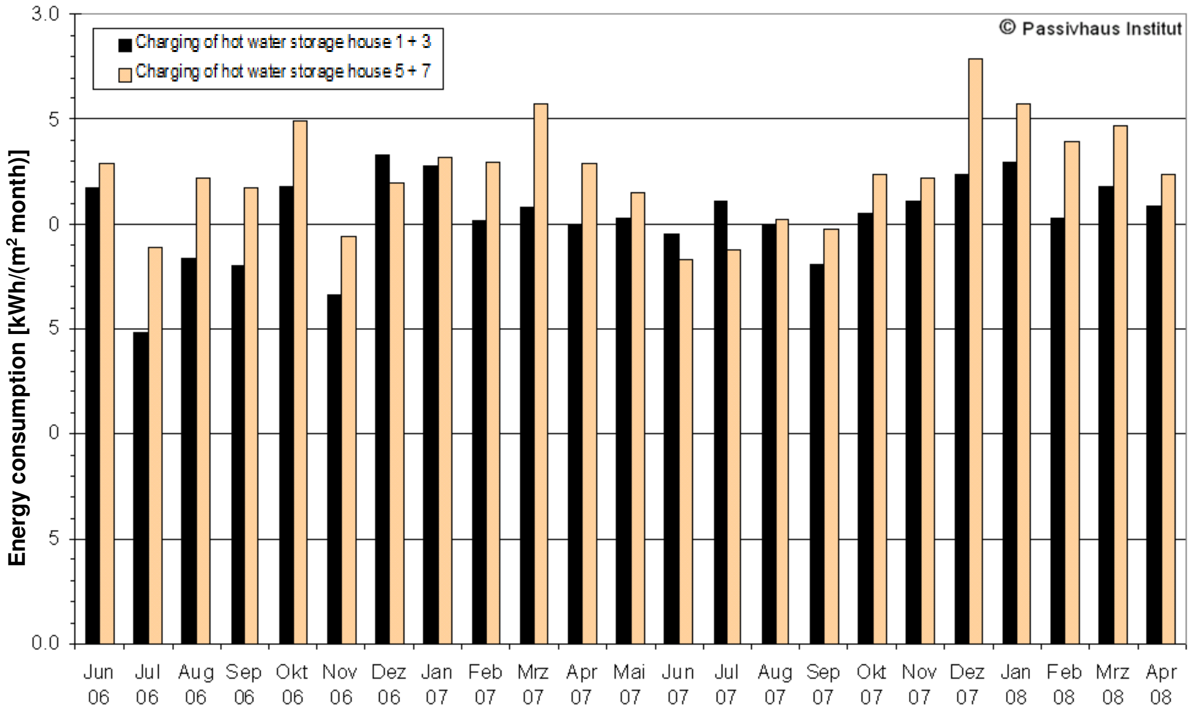

Figure 18: Energy expenditure for charging two central hot water storage tanks in two similar-sized apartment blocks with 12 apartments each (data taken from the project [Peper/Feist 2008]) (Source: [Peper 2012])

Procedure and taking into account for minimal monitoring:

In the simplest case, the fluctuation in the summer/winter consumptions should not be taken into account for minimal monitoring. A maximum of 10 % added to the values calculated from the three summer months can also be taken into account. It is imperative to mention the method used in the report of the results. The resident structure (old, young, user behaviour) and the size of the building (number of apartments) must be taken into account when doing so. Whether consideration of the fluctuation makes sense must always be decided individually in each case.

7.5 Step 5: Result for heat consumption

For a single house with the described type of energy supply, the amount of energy which is reduced by the (amount of the) consumption value for hot water generation represents the **estimated heat consumption value**. Further adjustments are not realistically possible without exact knowledge of the boundary conditions etc.

Additionally for multi-storey buildings: deduction of non-utilisable distribution losses

In an apartment block with central heat distribution outside of the thermal envelope, further deductions can be made for the non-utilisable heat quantity of heat distribution. Here too, there are fluctuations due to many influencing parameters (length of ducts outside of the thermal envelope, quality of the insulation etc.). Based on the energy efficient multi-storey buildings monitored by the PHI ([Peper/Feist 2008], [Peper 2009]) with typical modern (2010) heat engineering, an overall **deduction of 17 %** of the calculated heat quantity is suggested here.

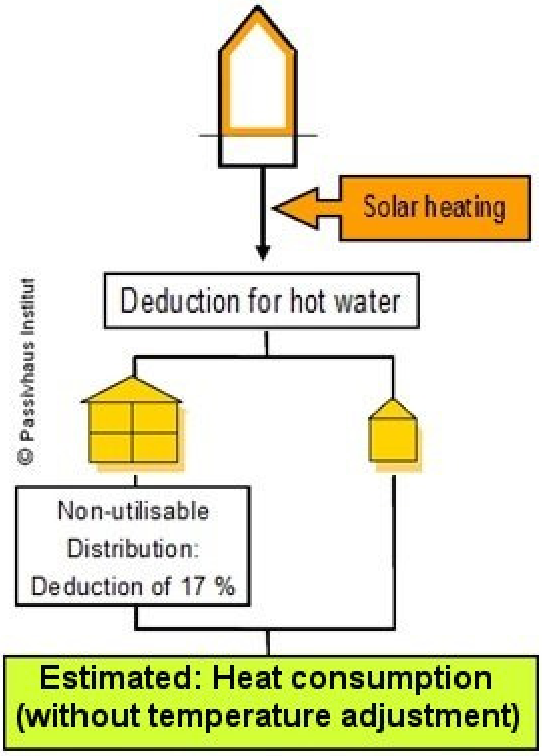

Figure 19: Flow diagram for minimal monitoring Part 2 [Peper 2012]

7.6 Step 6: Temperature adjustment (optional)

If the monthly average indoor temperatures of the building in winter are known, then adjustment of the heat consumption can be carried out optionally. As a rule, the actual temperature differs from that used in the calculation (see Section 5.1.1). What is important is:

- that the **temperature is representative** of the entire building and not just a single room with a specific use (kitchen, living room or bedroom),
- that the temperature measurement is not exposed to influences such as **direct sunlight** or cold air from open doors or windows and
- that the temperature measurement has a **reasonable level of accuracy** (≤ ±0.5 K) .

Information on carrying out a reliable measurement of the indoor temperature using data loggers is given in Section 8.

Adjustment can take place if a temperature measurement has been carried out which corresponds with the requirements given above. The safest way is to use the measured temperature in the current PHPP calculation in order to be able to estimate the difference in the heating demand. This value can then be applied in a simplified way for the consumption as well (the change is calculated for the demand, but is applied to the consumption).

If the PHPP is not available, or not available in digital form, then the difference between the measured winter temperature and the balance temperature (standard 20 °C) can be calculated first. A moderate overall deduction of 2 kWh/(m²a) for each kelvin of temperature difference can then be applied, as described in Section 5.1.1.

Adjustment on a test basis can be carried out for 19, 21 and 22 °C even without measuring the indoor temperature in order to estimate the scale of the potential difference in consumption.

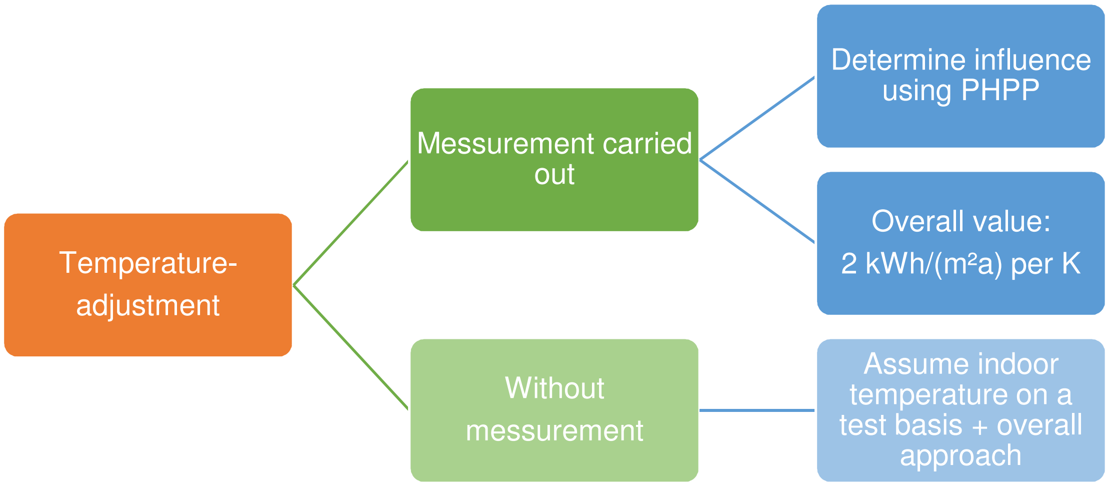

Figure 20: Flow chart for the temperature adjustment

To help with the estimation of usual indoor temperatures in winter, an overview of the results from [Peper 2012-A] is presented here. The measurements for the different monitoring projects show higher average indoor air temperatures than with the calculation approach using 20 °C.

Table 21: Measured average indoor air temperatures in winter in residential buildings (new builds and refurbishments) in different monitoring projects [Peper 2012]

Project	Average indoor temperature (winter)
RH Kranichstein	20.3 °C
RH Siedlung Kronsberg	21.6 °C
MFH Kassel Marbachshöhe	21.1 °C
MFH Frankfurt Grempstraße	21.6 °C
MFH Hamburg Pinnasberg	21.6 °C
MFH Frankfurt Tevesstraße	22.4 °C
MFH Ludwigshafen Hoheloogstraße	22.8 °C

Result for heating energy

The outcome obtained is an estimation of the heat consumption of the building **without other detailed adjustments e.g. of climate data**. (The influence due to different climate data alone has been discussed in Section 5.1.2). This estimation can be compared directly with the heating demand in the PHPP calculation. The calculated value can be used as an initial estimate in order to check whether further, more exact and complex investigations of the building would be expedient or necessary (e.g. by taking climate data into account). However, assessment of the reasons for any increased consumption values (technical malfunction etc.) cannot take place with this. Since this is a rough general method, the results should accordingly be treated with caution. Nevertheless, a valuable estimate of the heat consumption of the building can be achieved in this way. Comparisons of different buildings can be carried out using the same method (benchmarking).

7.7 Step 7: Adjustment of outdoor climate (optional)

For further, more exact analysis of the consumption data, adjustment of the actual outdoor climatic conditions during the measurement period can take place optionally as a next step. This will increase the effort and will exceed the context of simple "minimal monitoring". The influence of outdoor climate conditions has already been described in Section 5.1.2.

For this, climate data for the relevant location during the studied period is necessary: global radiation (horizontal and based on the four cardinal points) as well as the outdoor temperature as monthly average values. Different publicly available measuring networks, and to some extent, also services providers can be used for data acquisition, in which case the values from the closest station should be used.

As a rule, the weather stations do not record global radiation separately according to the four cardinal points, instead they only record the horizontal global radiation. Therefore, simplification must be carried out provided that an energy balance calculation in the form of the PHPP is available for the building. The measured data is entered into this as a new weather data set. The monthly average outdoor temperatures and the monthly sum of the horizontal global radiation can be entered directly. Separation of the global radiation according to the cardinal points can take place as a percentage based on the standard data set of the location. This is a rough simplification, but is acceptable for this purpose. In this way, a data set is generated for the corresponding period.

If the PHPP calculation is carried out with this new data set, the result for the heating demand can be compared with that of the standard climate of the location. The difference in the demand values is then also deducted from the measured consumption value in a simplified approach. An example of this for an actual building is shown in Fig. 19. A difference of 1.5 kWh/(m²a) results for the building. In order to be able to draw conclusions about the consumption for the standard climate, this amount would be deducted from the consumption value in a simplified approach. The influence of the weather conditions from different measurement years on the heating consumption of the building can be compared in this way.

The method for adjusting the climate conditions by means of **heating degree days** is not expedient for energy efficient buildings, as has been presented in [Peper 2012-A].

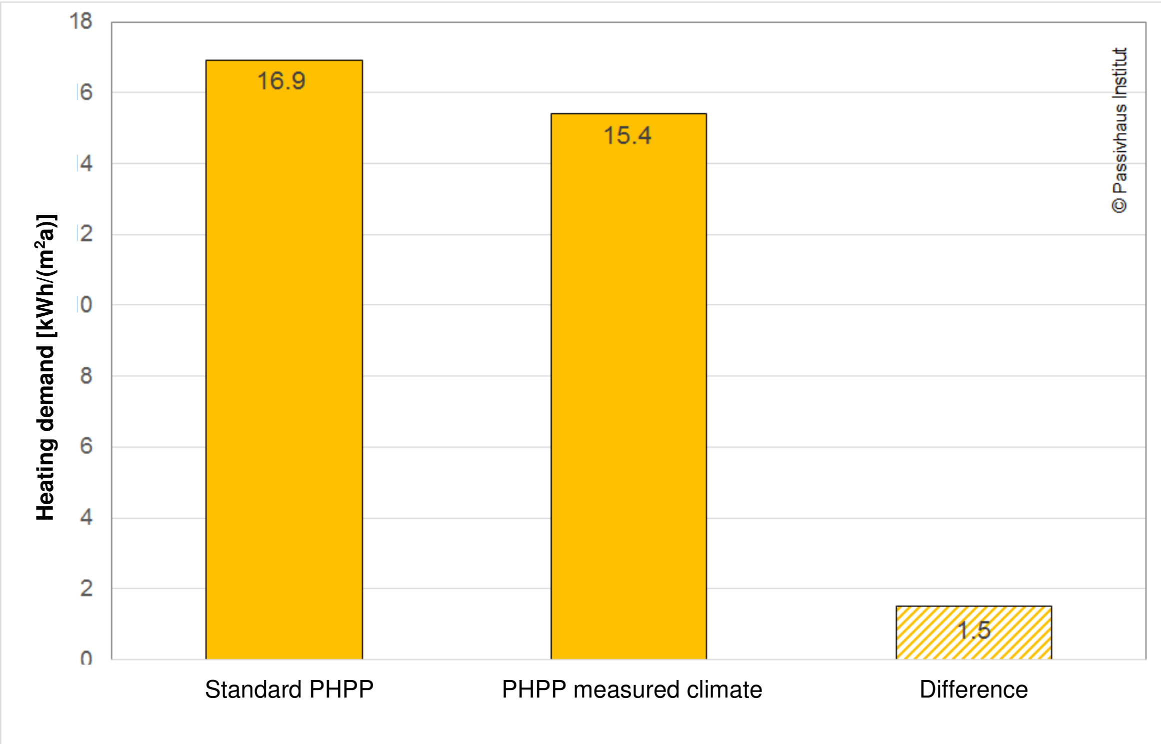

Figure 22: Influence of different climate data sets on the heating demand when different climate data sets are used in the PHPP for a refurbished building in Frankfurt.

7.8 Step 8: Primary energy (optional)

An overall picture of a building in terms of energy results with the evaluation of the supplied final energy taking into account the electricity used for household and technical applications.

For this, first the total final energy used for heat generation (heating/hot water) including all losses etc. (i.e. without any deductions) is evaluated using the corresponding primary energy factor (PE factor). These factors, also used for evaluation of the upstream process chain for energy generation, can be taken from the PHPP handbook, for example.

In case of supply with gas, the total natural gas used is multiplied by the PE factor of 1.1, while 0.8 to 1.5 is used for district heat supply (depending on the proportion of combined heat and power).

As the next step, the same is done for the total electricity used in the same balance year. This is assessed with the currently valid PE factor (at present 2.4 kWh/kWh in Germany). Both results which have been assessed in terms of primary energy are added together. For certification of Passive Houses, the limit value for this primary energy total amounts to 120 kWh/(m²a). In order to avoid exceeding this value, efforts for the reduction of domestic electricity consumption are particularly necessary besides an optimised building envelope and

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efficient building systems with minimal losses. Typical consumption values can be taken from the cross analysis in the article [Peper 2008] in Protocol Volume 38.

The calculation of the **primary energy consumption** is reliable due to the use of the total unadjusted end energy consumptions and can be used for testing compliance with the limit value for PE.

7.9 Example calculation for minimal monitoring

In order to elucidate the step-by-step method for minimal monitoring, an example of a Passive House which has a heated floor area of 150 m² and is supplied with gas is presented here:

Table 23: Example of a minimal monitoring calculation for a Passive House with a TFA of 150 m² [Peper 2012].

Step 1	Annual measured value for total final energy consumption (gas meter) after conversion 1 m³ natural gas equals 10 kWh, based on TFA of 150 m²	50.7 kWh/(m²a)
Step 2	Heat generator in basement, therefore overall deduction of 12 % for losses	44.6 kWh/(m²a)
Step 3	Solar heating system is not used	---
Step 4	Calculation of the annual energy expenditure for hot water generation from the three summer months (inc. circulation): 25 kWh/(m²a) Here: no further deductions for summer/winter fluctuation	19.6 kWh/(m²a)
Step 5	No deduction of distribution losses since this is a single house	---
Result	**Estimation of the heating consumption inc. distribution etc. without adjustment of indoor temperature**	**19.6 kWh/(m²a)**
Step 6	In order to adapt the heating demand to standard conditions of 20 °C, a deduction of 3 kWh/(m²a) results with 2 kWh/(m²a) for each kelvin of temperature increase if it is known that the indoor temperature is 21.5 °C	**16.6 kWh/(m²a)**
Step 7	Primary energy assessment: total final energy consumption x PE factor gas: 50.7 kWh/(m²a) x 1.1 kWh/kWh= 55.8 kWh/(m²a) Total electricity consumption multiplied by PE factor of electricity: 28.7 kWh/(m²a) x 2.6 kWh/kWh = 74.6 kWh/(m²a):	**130.4 kWh/(m²a)**

From the original measured value of 50.7 kWh/(m²a) of the total meter for heat supply, 19.6 kWh/(m²a) can be assigned to the heating consumption. This results in approximately 16.6 kWh/(m²a) for the standard conditions. The estimated heating energy consumption of the building (taking into account the uncertainties of minimal monitoring) is thus within the range for a typical Passive House.

The primary energy value of 130.4 kWh/(m²a) exceeds the limit value by almost 10 kWh (ca. 8 %). Although the ascertained electricity consumption of almost 29 kWh/m²a is lower than the German average of over 30 kWh/(m²a), there is significant potential for savings. In 18 households (with an advisory service for saving electricity) in the Passive House housing estate in Hanover Kronsberg (Germany), electricity consumption values of 20.2 kWh/(m²a) were measured (for all domestic applications including technology and ventilation system) [Peper/Feist/Kah 2001]. Specific electricity consumption values of just 11.7 kWh/(m²a) were even achieved in the Passive Houses in Darmstadt Kranichstein (Germany) [Feist 1997]. Such data reflects the achievable potential for saving electricity.

8 Measurement of indoor air temperature

If a simple air temperature measurement is to be carried out in a building during the heating or cooling period, it is possible to use data loggers which measure and record the temperature during the entire period. These "stand-alone" data loggers do not require any power supply or other devices for the measurement. They can be programmed and can simply be positioned in the building. After the measurement period they are collected together and read by a computer. Different qualities of these devices are supplied by various manufacturers.

The **measurement intervals** can be set at completely different time resolutions. 30 minute or hourly values are sufficient for measurement for such long periods of time.

Requirements for sensors: The measurement accuracy of the sensors should not exceed ±0.5 K; smaller deviations are more reliable (target value ±0.2 K). The manufacturer "Onset" states the accuracy of the data logger model "HoBo Pro v2" shown on the right in Fig. 20 as ±0.21 K for the 0 to 50 °C range. Also, the devices should have a sufficiently accurate internal clock so that drift is very small over a longer period of time.

Figure 24: Two examples of different stand-alone data loggers (an ordinary lighter is shown for size comparison)

Number and positioning: the data loggers must be positioned and distributed in the building so that a "representative" indoor temperature is measured. It would be best if at least one data logger is positioned in all rooms. Since this is too expensive and requires too much effort, there are restrictions for their use. The minimum requirement e.g. for a small apartment (on one storey) is a data logger in the "core zone" e.g. the living room or a central corridor (not near the entrance door). This should be placed about 1.2 m above the floor. In highly insulated buildings the temperature difference between the rooms is normally relatively small (see [AkkP 25]), therefore one data logger will suffice in such cases. Bedrooms, bathrooms or kitchens are not suitable as disrupting influences exist here. Accordingly more data loggers must be used in the case of a larger apartment or a house, or if larger temperature differences are expected due, e.g. to utilisation. Care must be taken that the measurements are not affected by direct exposure to sunlight or direct heat dissipation from lighting or electrical appliances.

If several data loggers are used, each data logger must be allocated to a floor area of the building, so that an average temperature based on the proportional area can be calculated using the measured data.

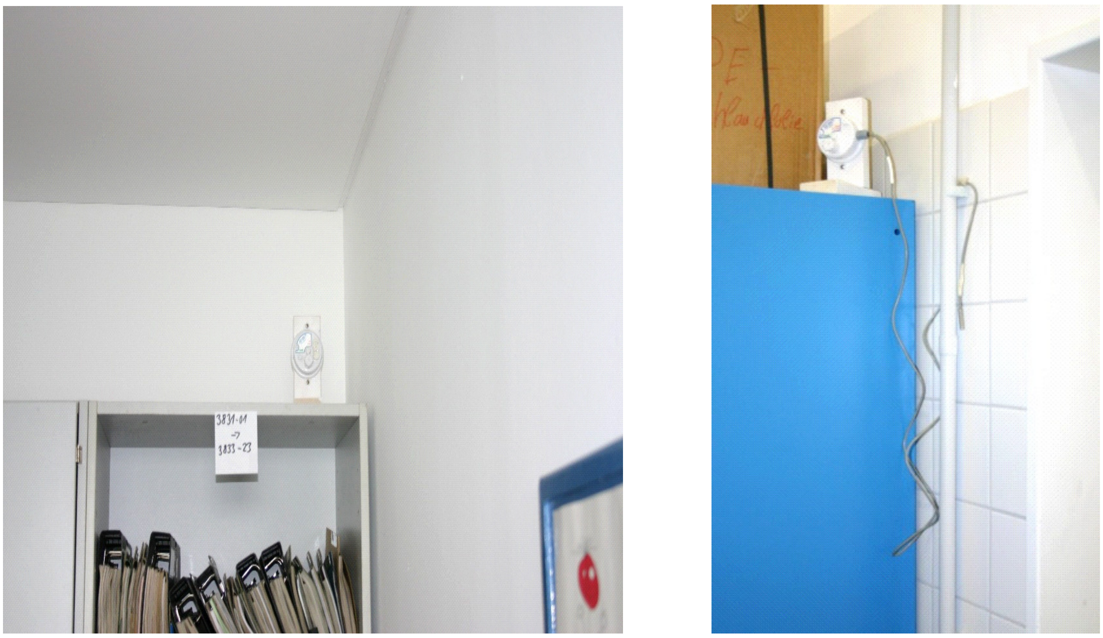

Figure 25: Data logger on wooden stands for measuring the temperature in a building

If data loggers are spread out in a building, it must be ensured that the position of the device remains unchanged for the entire duration of the measurement.

9 Summary of minimal monitoring

The most important points regarding minimal monitoring are summarised below:

- Monthly meter readings of all essential meters (electricity, gas, district heat) or specification of the procured quantities of firewood, wood pellets or crude oil.
- An additional heat meter is necessary in case of a solar heating system.
- Distribution and conversion losses are taken into account as a simplified overall value.
- The energy consumption for hot water generation is calculated from the consumption data of the summer months. An overall adjustment can be made here additionally in order to take into account the summer/winter fluctuation in consumption of hot water.
- In the case of apartment blocks, the non-utilisable distribution losses are taken into account as an overall value.
- Temperature adjustment of the consumption values can be carried out optionally if there are variations from the calculated value (standard 20 °C) and these are known.
- The total annual electricity consumption (domestic electricity and electricity for technology/auxiliary use) must be accounted (PV electricity must be taken into account using a separate feed-in meter.

Despite the limited accuracy of this method for **estimation of heat consumption** and disregarding of the various influencing factors, this provides a valuable overall picture for an initial assessment of the building. Further "refinements" such as taking into account of the climatic conditions during measurement periods can be added with more effort.

Calculation of the **primary energy use** is reliable due to the use of the total unadjusted final energy consumption and can be used successfully for checking compliance with the PE limit value.

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Attachment:

Comparison of measured energy consumption values using the PHPP heating energy balance (requirement value)

Pre-requisite

To compare the consumption and requirement values gathered in the planning stage, a **very realistic and current PHPP** of the entire building must be provided upon completion of construction. The PHPP must take into account all deviations from the plan (i.e. additional or altered thermal bridges, changes in insulation materials or airtightness).

The measurements must

- differentiate between domestic water heating and heating supply and
- the consumption values must remove conversion, distribution and storage losses, so as to obtain the effective heat value.

For further information on the subject of relevant interferences, please refer to protocol volume No. 45 “Accurate measurements in energy efficient buildings” [Peper 2012] of the cost-effective Passive House buildings working group “measurement concepts, disturbance variables and adequate solutions”.

Procedure

1. Weather conditions

1.1 Acquisition of the measured “outdoor temperature” and “horizontal global radiation” **weather conditions**. During the monitoring stage, data of the building’s location must be provided in the form of monthly values (identical to measured energy values).

Simplification 1 A: In case the weather conditions were not measured at the building itself, measurements of the nearest weather station must be used instead. The suitability of the data is to be examined in each case (e.g. distance, height above sea level, etc.).

1.2 Insertion of the measured weather conditions as a set of separate climate data in PHPP’s climate sheet (monthly values). After inserting the data, the climate data set needs to be named and selected.

Simplification 1 B: Sky temperature and dew points can be omitted in northern Europe.

Simplification 1 C: In case global radiation data cannot be ascertained as per the four compass directions, the distribution of horizontal radiation can be made in proportion to the four compass directions by using the original distribution of the global radiation data. The ratio of the global radiation to the respective compass direction will be transferred horizontally onto the measured global radiation.

2. Indoor temperature

The indoor temperature measured during the heating period (usually between 1 October and 30 April) must be entered into PHPP (verification sheet; indoor temperature winter). The average temperature of the building must be representative. A single measuring station in a non-representative room is not suitable. When using multiple measuring stations, the amount of heat losses must be taken into account. Ideally, median indoor temperatures are weighted for the estimated thermal heat conductance of the attached rooms:

$$T_{eff} = \sum_n \frac{(H_{Tn} * T_n)}{H_T}$$ (Median temperature weighted for transmission conductance)

Ventilation losses and infiltration also need to be taken into account.

Simplification 2 A: If the rooms of a building are being heated equally and the building is equipped with a highly insulated thermal envelope, averaged indoor temperatures may be used for the calculations.

3. Electricity consumption

The effective electricity consumption contributes to the amount of internal heat sources. In a conventional residence building, these amount to a value of 2.1 W/m². If measurements of the effective electricity consumption are available, they may be taken into account as well. To obtain the effective electricity consumption, the data in the electricity sheet needs to be adjusted accordingly.

A calculation of the effective internal heat sources is suitable if a reliable estimation of all sources can be made.

Simplification 3 A: By entering a "miscellaneous" consumer, electricity consumption will be set to its effective value (electricity sheet; miscellaneous section). Due to the data input in the electricity sheet, the results in the internal heat sources sheet will change as well. Availability is to be set to a typical value of 0.8. For negative values of the correction (lower consumption), the value for "within the thermal envelope" must be adjusted in the internal heat sources sheet, as it will not be taken into account otherwise (the line must not contain a "0").[1]

To use the effective internal heat sources for the PHPP calculation, "PHPP calculation (verification sheet)" must be selected in the "internal heat sources / type of used values" menu

[1] An addition can be made to the formula with the first „>", so that a "<>" will be used.

of the verification sheet.

4. Occupancy rate

If known, the **effective** occupancy rate can be entered into the verification sheet of PHPP as well. The changes in the occupants' heat transmission and usage intensity will be taken into account when calculating internal heat sources (refer to 3. for the conversion between internal heat sources and electricity).

Comparison

After these adjustments to the set of climate data, to the indoor temperature and possibly to the internal heat sources (electricity consumption) have been made, PHPP will show the heating demand of the object with changed parameters in the verification sheet. This value can only be compared to the measurement (heating demand). The highest overall accuracy of the balance calculation amounts to 3 kWh/m²a. The overall accuracy of the measurements depends on the instruments and cannot be universally indicated. The amount of deviations left indicates if further investigations need to be made.