Passivhaus Institut

Building Monitoring

Basics and Guidelines

Prepared within the framework of the EU Research Project Sinfonia

Sinfonia

SEVENTH FRAMEWORK PROGRAMME

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Building Monitoring
Basics and Guidelines

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Contents

1 Introduction

In the EU project Sinfonia, among other things, the renovation results in urban neighborhoods of Bolzano and Innsbruck are to be detected by measurement. For these reason, it is necessary to conceive suitable measurements for carrying out monitoring in buildings. The study of energy consumption and indoor air parameters like temperature, humidity and CO2 concentration of renovated buildings is in principle identical to the measuring technique to the measurements in new buildings. There are the same basic considerations and technical requirements. Differences are possible in the nature and possibility of laying cables in the building or the possible positions for central monitoring stations. These fundamentals and technical requirements will be discussed and explained in this text.

To compare the measured consumption values, the values from the calculated energy-balances (made with PHPP-Tool in WP7, Task 5) within the Sinfonia demo-projects will be used. Therefore it is necessary that the measurement data is in the appropriate form and accessible. For this comparison, monthly data are sufficient (averages and totals). To achieve and perform a unified evaluation for this, a template file "DataFormat_SINFONIA.xlsx" is provided by the PHI. From the detailed measurement data to be collected during the project Sinfonia a dataset on monthly base will be passed in the form of the template file for comparison.

Practical experience with numerous measurement projects that have been realised shows that the second step is often undertaken before the first step, or important aspects are simply forgotten during planning. It is therefore expedient to consider some basic rules and to deal with a few important boundary conditions in advance, for example the clear definition of a balance boundary.

The general content-related procedure of every monitoring process for a building is always the same. It starts with the **tasks** which need to be addressed. After that, in order to be able to resolve the issues that are raised, a suitable coordinated **measurement concept** is defined. In doing so, the type of measurement, the necessary degree of detail and differentiation from other issues and influences must be clarified. Only then are the necessary **measurement points**, the measurement method and the appropriate temporal resolution specified. This is followed by the actual **project planning** of the measurement technology, including dimensioning the technical requirements in accordance with the sensors and data collection and the choice of products. The procedure is shown as a schematic diagram in Fig. 1.

In this article, the points mentioned for monitoring are explained one by one in more detail, and dealing with other influencing factors (disturbance variables) is discussed and viable solutions are suggested.

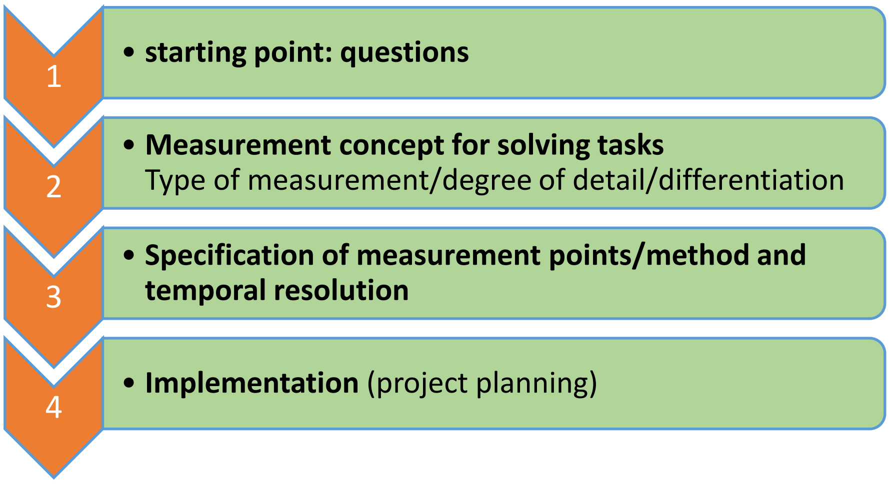

Figure 1: Rough procedure for monitoring of a building.

The basics and guidelines for the measurements in the Sinfonia project are a shortened, adapted and translated version of the publication "Measurement concept, disturbance variable and suitable solutions" [Peper 2012]. Here the the foundations and prerequisites are summarized for the successful implementation of building measurements. In addition, the specific plans and decisions in the level of detail for each measurement and each building must be made and carried out by the corresponding measurement teams.

2 Measurement task

With the planning and construction of energy efficient buildings, the questions that are raised and have yet to be resolved can be very complex and can vary greatly. They may concern an apartment, a building or an entire residential estate, or may relate to individual building functions (e.g. frequency of overheating, damp in basements) or only individual components (e.g. heat pumps, heat recovery systems).

As a rule, the usually unspecific interest in the performance of the building as a whole is generally the main focus of the preliminary considerations; this is the "checking the functioning of the building". The detailed tasks often have to be worked out first. It is therefore emphasised that this clarification must take place before all other considerations and planning. Successful measurements cannot be performed without exact clarification of the task. This may sound banal at first, but its importance must not be ignored.

Subsequently, either the functioning of the entire building is then tested and a few special issues examined in detail, or the specific questions are discussed.

3 Measurement concept

The measurement concept that is to be developed consists of completely different content-related and technical areas which must be dealt with separately. In doing so, usually all decisions are also always affected by the incurred costs and the existing or planned budget. An overview of the parts of a measurement concept that are decisive for building monitoring is shown in Fig.2. The individual points will be dealt with separately in the following text.

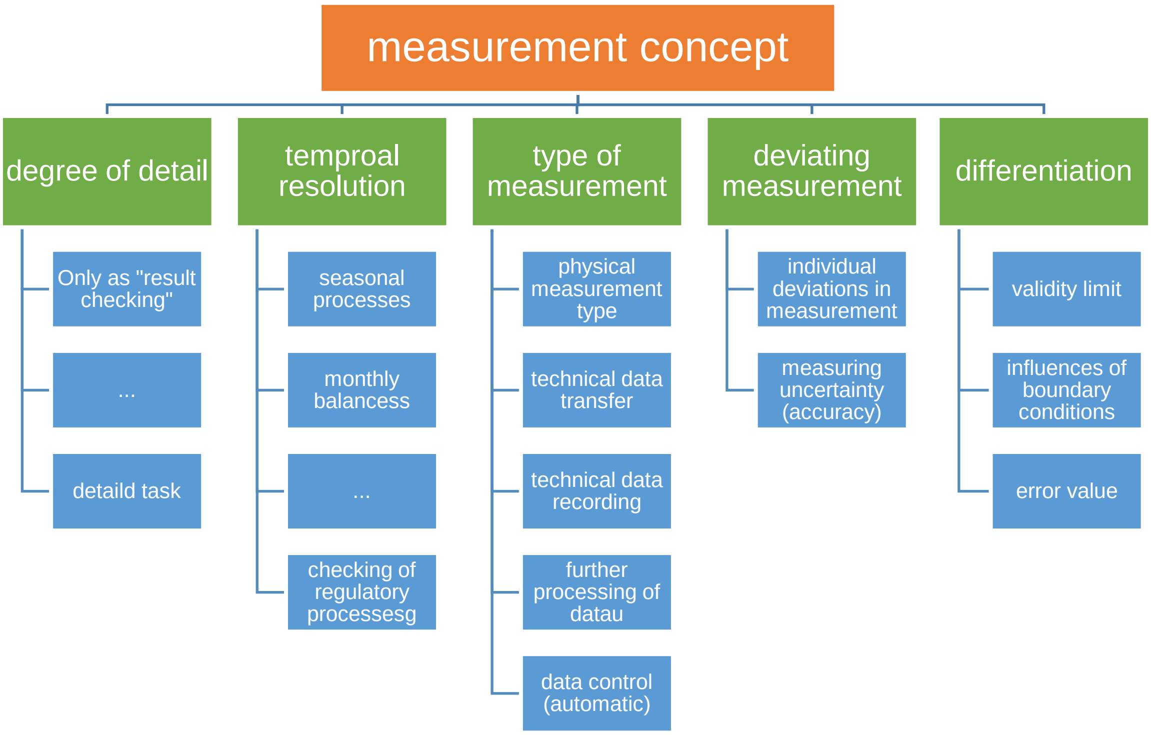

Figure 2: Parts of a measurement concept for building monitoring that need to be clarified.

3.1 Degree of detail

First of all, the degree of detail of the planned measurement must be determined. As mentioned before, this ranges from solely "result checking" to detailed questions relating to individual components. The amount of detail required for the individual measurement parameters and the areas to be examined must also be clarified. A simple example is the measurement of the heat quantity: is it sufficient to measure only the cumulative heat quantity, or are other parameters such as forward flow and return flow temperatures, flow rate and current capacity also of interest?

One of these considerations is deciding which **influencing factors** should be **measured**, which should only be **estimated**, and for which it will be enough make a simple **assumption**. For example, if one wishes to draw conclusions about the thermal comfort inside a room, then parameters such as air and radiant temperature, air humidity, air speed and degree of turbulence of the air must be ascertained metrologically. In contrast with this, the exact measurement of the number of occupants present, their degree of activity and the type of clothing requires much more metrological effort. Exact measurement of the passive solar gains of this room, or the exact amount of the internal heat gains (electricity consumption, waste heat from pipes, moisture released by plants etc.) would also be extremely complex to some extent. In this case, it must be determined in advance which influencing factors would allow estimations or assumptions to be sufficient.

Only timely planning of the sensors which are actually necessary will avoid the expensive subsequent need for equipment or conversely, large amounts of unnecessary data as a result of unnecessarily high numbers of measurement points. The non-usable measured data will also have to be checked over the entire measurement period and processed further during the subsequent evaluation. This will lead to a large amount of accumulated data which can be avoided - even though inexpensive storage possibilities are available today. The required measurement parameters must be identified from the very start of the measurement.

Note regarding data storage: As a principle, storage of the **unchanged original data** is absolutely essential. Only in this way will it be possible to investigate issues arising later and to exclude the possibility of an error occurring during data conversion.

3.2 Temporal resolution

As a next step, it makes sense to ascertain and define the necessary temporal resolution of the measurements. The same principle as for data storage mentioned above applies for choosing the temporal resolution: large amounts of unnecessary data (so-called "data graveyards") should be avoided.

3.3 Measurement deviations

The measurement deviations of individual sensors as well as the entire measuring chain (sensor, cables, conversion) must be taken into account from the start when developing the measurement concept. The decision for a corresponding quality of measurement accuracy must also be derived from the definition of the task.

3.4 Differentiation

It makes sense to think about the validity limits of the planned measurement even during formulation of the measurement concept. Rather than being shortcomings, these limits enhance the validity of the measurements. It becomes clear which statements can be made with certainty and which cannot. It is not possible to measure everything and what is measured, is subject to various limitations. Plausible assumptions must be made for the project parameters or influencing parameters which are not ascertainable.

Such differentiation is unavoidable for the validity of the measurement.

4 Energy balances

For a great many monitoring projects, preparing an energy balance for the building in question is a key element. In order to be able to prepare an energy balance with the help of the measured values, some basic principles must be taken into consideration.

4.1 Balance boundaries

When measuring the energy consumption of buildings, it is always necessary to define a clear balance boundary. Only in this way will it be possible to determine exactly which parameters and consumption values need to be measured and which can be left out. The energy consumption can thus be allocated to a specific volume or reference area etc. With the usual measurement periods e.g. of one year, since the amount of energy stored in the building is small compared with the energy gains or losses, these gains and losses are approximately the same - if they are based on the same balance boundary. An energy balance can then be prepared with reference to this balance boundary. The balance boundary of a measurement does not have to follow the same course as the thermal envelope of the building; however, this is usually the case in the measurement of complete buildings. Of course, partial areas can also be measured and balanced, for example building parts or even individual rooms. Clear definition of the boundaries is a prerequisite in every case. As a second step, it must then be clarified which information (measurement parameters) are necessary for clearly describing the boundary condition. For example, these would usually be the wall assembly and the internal and outdoor air temperatures in the case of an exterior wall which is adjacent to outdoor air. Depending on the definition of the task, however, solar radiation incidence on the wall will also have to be taken into account.

For a partition wall with an adjacent room, the wall assembly and the temperatures of the two rooms would be of interest.

4.2 Positioning of heat meters

The number and location of heat meters must be planned when considering metrological measurement of the relevant parameters in a building. For this purpose, reference is usually made to the hydraulic plan of the system. In this example, ascertaining the heating consumptions of the individual apartments is not intended; the overall consumption for the heating and separately, the hot water consumption are measured. The simplified hydraulic plan is shown in Figure 2 for this example.

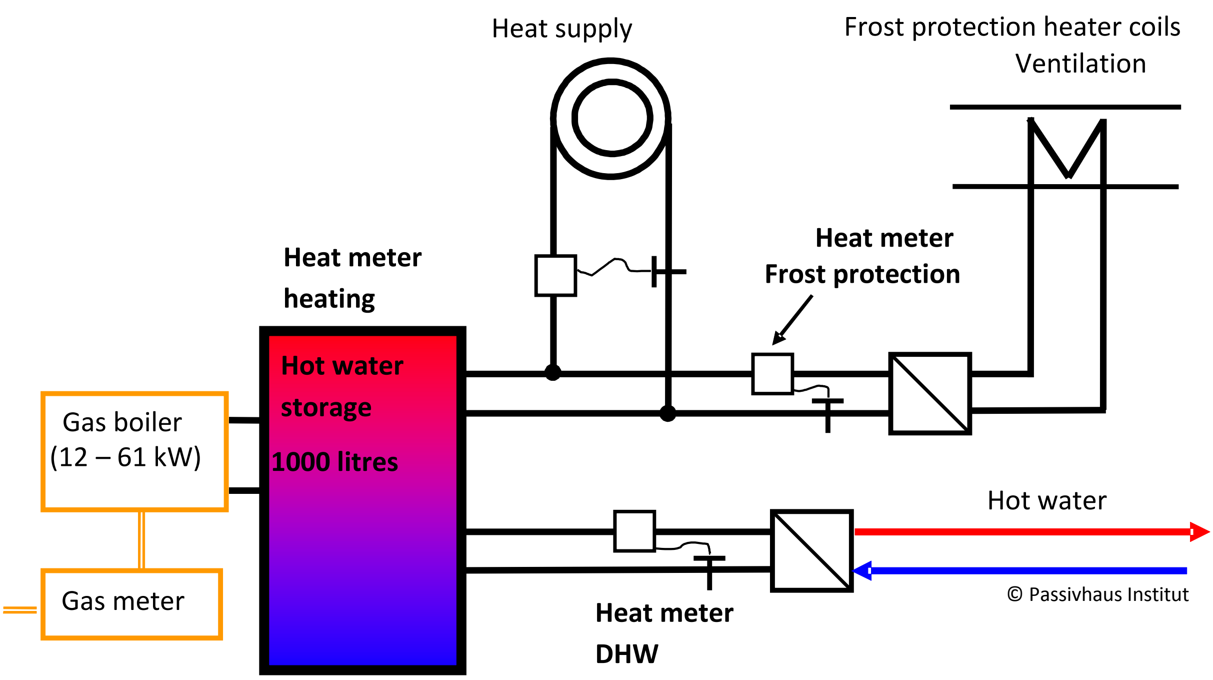

Figure 2: Simplified hydraulic plan of the supply centre with positioning of the three heat meters and the gas meter [Peper/Schnieders/Feist 2005].

The use of three heat meters sufficed here on account of the classic central heat supply with a gas boiler: heat quantities, hot water and "frost protection for the ventilation system". With this central arrangement, no conclusions could be drawn later about the following points in particular:

- Heating and hot water consumption of the individual apartments

- Heat dissipation from hot water pipes and heating pipes
- Conversion and standby losses of the gas boiler
- Losses from the hot water storage
- Conversion losses of the heat exchanger for hot water and frost protection

The monitoring team should be clear about this at the time of project planning. On the other hand, all the heat dissipated from pipes (incorrectly known as "distribution losses") and heat exchangers is fully included starting from the installation position. For the measurement and evaluation of the entire consumption in these areas, this is a workable solution as long as the heat meters are located within the thermal envelope.

As indicated above, the heat dissipated from distribution pipes does not entirely count as heat losses; however, this is often simply spoken of as "**distribution losses**". A closer look reveals that with pipes within the thermal envelope a distinction must be made between the share of the dissipated heat which can be utilised for desirable heating of the building, and the part that occurs at times when these heat gains are undesirable and therefore cannot be utilised. For example, the heat gains from sanitary hot water outside of the heating period lead to undesirable heating up of the building. The heat dissipated by heat distribution pipes within the thermal envelope during the heating period must therefore be taken into account when determining the heating consumption. If the heat gains are measured in a decentralised manner by means of several heat meters in individual apartments, then these shares of the dissipated heat from pipes must be ascertained and taken into account. Only then will the measured values be comparable with the demand values from the balance calculation. It was demonstrated in measured projects that these values are large enough to be taken into account. In the refurbishment project Tevesstrasse in Frankfurt for example, the usable share of the distribution was 2.2 kWh/(m²a), with a heating consumption of 21.4 kWh/(m²a) in the apartments [Peper/Schnieders/Feist 2011].

4.3 Balance boundary examples

4.3.1 Balance boundary: House partition wall

Another example of a balance boundary is that of the measurement for the "Passive House Existing Building Stock" (PhiB) refurbishment project Hoheloogstraße in Ludwigshafen, [Peper/Feist 2008], where there is a partition wall between two directly adjacent buildings. On account of the different levels of thermal protection after refurbishment, the heat consumption values were measured separately in both buildings. It became apparent that due to the different indoor temperatures in the apartments adjoining the partition wall, there is significant heat flow from one building into the other. Based on the temperature measurement, this was estimated as a considerable additional consumption of about 2 kWh/(m²a) for the building that was warmer on average.

For the calculation of the balance, identical temperatures (commonly 20 °C) are normally assumed for both apartments in case of residential use. This results in a difference between the measured and calculated values solely on account of the actually deviating indoor temperatures in this project.

4.4 Calculation of the residual balance

Preparation of the energy balance is often a fundamental task in measurements of buildings. For this purpose, determining the "output value" of the balance and measuring this to a high standard is of key importance. This will then form an unchangeable fixed base value for this analysis. In Figure 3 the starting parameter is the total heat quantity ascertained from the measured gas consumption.

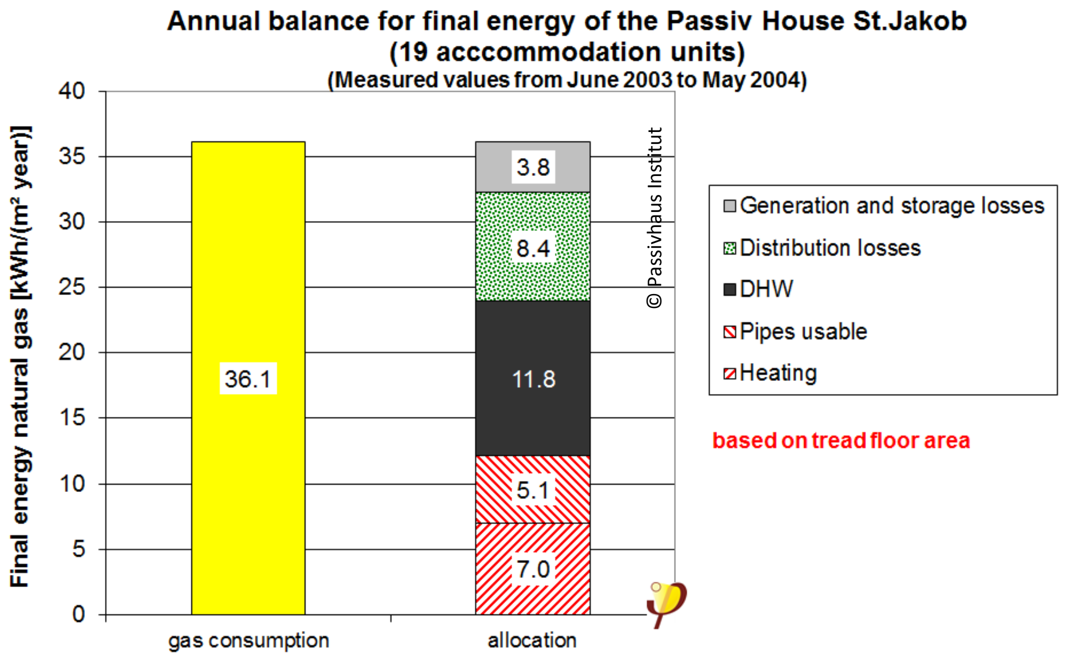

Figure 3: **Example of an energy balance calculated from measured values, with "gas consumption" as the main base value [Peper/Feist/Pfluger 2004].**

The allocation of this base value by e.g. other consumption meters always results in a non-measurable "**residual balance**". Even if all sub-consumers could be measured separately - which is rarely the case - "residual balances" of the base value will remain due to heat dissipation from pipes and measurement deviations. In this case, care must be taken with the allocation and designation of the heat quantities. This is particularly important when measurement of all sub-consumer is not possible and the missing value is simply calculated as a residual balance, in which case all measurement deviations would be incorrectly allocated to the calculated value. For example, if the missing consumption value "Consumer 3" is calculated in the following manner:

Base value – Consumer 1 – Consumer 2 = Consumer 3

then all dissipated heat from the pipe network would be allocated to "Consumer 3". This can lead to fatal errors, therefore dealing carefully with this subject and using clear designations is necessary.

5 Definitions for measurement and evaluation

For measurement and evaluation, it is essential that some of the terms used should be clarified, the most important of which are explained below.

5.1 Demand/consumption

A clear distinction should be made between the calculated energy DEMAND and the measured energy CONSUMPTION. Normally the theoretical demand and the actual consumption are always different. How significant this difference is, is a question of the quality of the calculation or simulation model and the influencing parameters taken into account. A clear distinction must be made in terms of language and content especially when comparing measured values with previously prepared balance calculations (e.g. using the PHPP).

5.2 Useful, final and primary energy

In connection with monitoring the definitions of the different types of energy have already been explained in an article [Peper 2008] in Protocol Volume AK 38. The relevant section of the article is cited here with some adaptations:

For the parameter "**final energy**", all energy quantities that have been supplied to the building across the balance boundary "building envelope" are taken into account (see Figure 4). This include e.g. the energy content of the supplied quantity of gas, district heating, or pellets, as well the amount of electricity supplied. Solar energy that is passively supplied to the building, e.g. through window areas, remains unaccounted for in the measurement. The realised performance of buildings ("as built") can be evaluated using the "final energy" parameter according to the quantity of final energy (work load) required.

If solar thermal systems are present, these must be taken into account as an input into the building services, in which case the solar energy gains should preferably be measured separately.

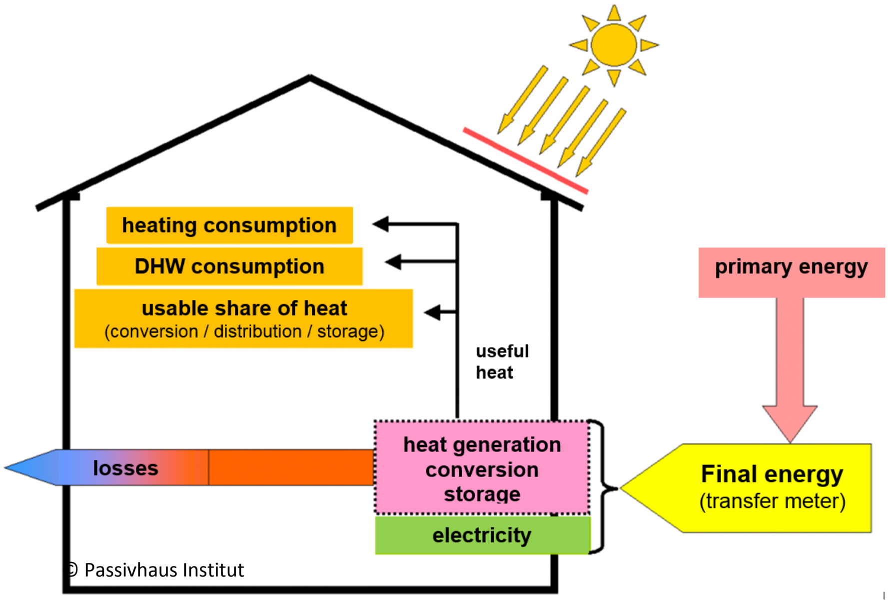

Figure 4: **Definition of the measurement parameters and designations [Peper 2008].**

Depending on the supply medium, the final energy amounts that have been supplied can be converted into the evaluation parameter "**primary energy**" using the corresponding primary energy factors. For this, the factors based on [Gemis] are used for example, so that the respective upstream process chain (production, transport etc.) can also be taken into account. Evaluation based e.g. on the released CO2 equivalents are also conceivable; instead of being a measured value, this would then be an evaluated parameter.

The amount of energy supplied (e.g. gas, pellets, electricity from heat pump) is converted into heat and usually stored temporarily in hot water storage tanks. Some of the energy is accounted as losses during heat generation, conversion and storage. The course of the balance limit is decisive for this (see Figure 5). Heat losses must be distinguished from the amounts which are directly or indirectly usable; if heat dissipation during the heating period arises within the thermal envelope this will contribute to heating of the building as an internal heat source and, provided that it can be utilised, will reduce the amount of heat which is supplied directly. This share is accounted not as losses but as "usable share of heat" due to conversion, distribution and storage. This is added as useful heat to the heat measured by the heat meter in the apartment. In contrast with this, the non-usable share which arises outside of the heated building volume and/or does not occur during the heating period, or is in the form of "free heat" which is no longer utilisable, is accounted as a heat loss.

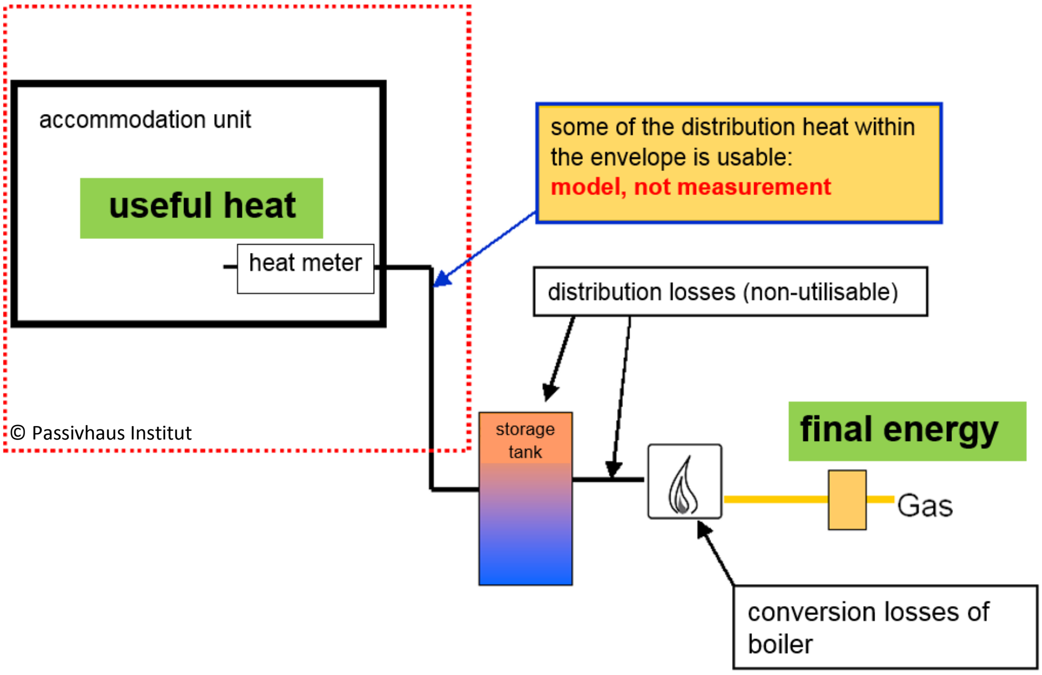

Figure 5: **Example of the conversion path from final energy to useful heat in an apartment supplied with gas, with heat generation taking place outside of the thermal envelope of the building (.....), e.g. in the basement.**

In the example shown in Figure 5 the "**useful heat"** comprises the measured **heating consumption** and the **usable share of the heat dissipated by the distribution pipes** within the thermal envelope of the building. The heat released during conversion, storage and remaining distribution arises outside of the thermal building envelope but within the balance boundary. It comprises part of the final energy that is supplied. Separation into utilisable and non-utilisable shares is often difficult and normally it can only be calculated.

5.3 Treated floor area

For comparing different buildings, energy standards etc., it makes sense to base the absolute energy consumption on the heated area. Only then will it be possible to allocate the values appropriately. The actual heated area is used as the reference value, for which the term "treated floor area" (TFA) was introduced. The TFA is identical with the living area e.g. of an apartment, minus the unheated areas such as balcony or terrace areas etc. Other rules apply for accounting access areas and basement areas in non-residential buildings, for example (this is discussed in the [PHPP] handbook).

If the absolute consumption Q for a period of time (month, year etc.) is divided by the treated floor area TFA, this results in the specific energy consumption $Q_{spec.}$:

$$Q_{spec.} = \frac{Q}{A}$$

Usually the $Q_{spec.}$ is given as an annual value in the unit kWh/(m²a).

6 Influences on the heating consumption

There are many different influencing factors that affect the monitoring results of a building. With a focus on the heating consumption, the weather conditions during the measurement period and the indoor air temperature are particularly noteworthy. These will be discussed here.

6.1 Influence of weather

The weather conditions prevalent during the measurement period have a major influence on the energy consumption. They may lead to substantial deviations from the theoretically determined energy demand values.

The amount of utilisable solar radiation that is available on cold days and the length of time overcast periods with temperatures around zero degrees last are decisive for an energy efficient building; the total degree days and radiation data do not provide any information about these. These interrelationships are examined in detail in [Feist 2005] and verified using measured results from more than 150 accommodation units.

The PHPP monthly method can be used effectively for depicting the influence of the measured weather conditions on the heating demand. In the process, the indoor air temperature is assumed to be constant. Monthly total or average values must be ascertained from the radiation and temperature measurement data and used in the PHPP calculation.

Only the use of a suitable balancing tool such as the PHPP will provide the required information. The influence of deviating weather conditions can be clarified in this way.

6.2 Influence of indoor temperature

The indoor temperature of a building has a large influence on the heating consumption. In terms of percentage, a deviating indoor temperature will have a much stronger effect on a particularly efficient building than on a building with a lower standard of thermal protection. The exact value is always dependent on the building. For the example of a housing block in Tevesstrasse in Frankfurt (Germany) with 20 apartments, a change in the average temperature for example from 20 °C to 21 °C indoor temperature will lead to an additional heating demand of 2.3 kWh/(m²a) according to the PHPP. This equates to 14 %, which is the normal range for energy efficient buildings.

The influence of the indoor temperature is usually one of the biggest influencing factors when evaluating measurement data. When comparing measured data with the calculated data from e.g. the PHPP, this must be taken into account where possible

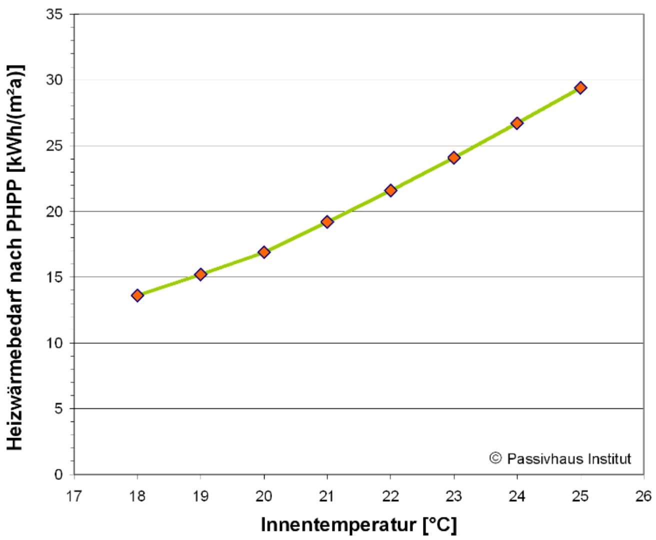

Figure 6: Heating demand for different average indoor temperatures for the example building in Tevesstrasse in Frankfurt (Germany). Calculated according to the PHPP.

An indoor temperature of 20 °C is normally used in the PHPP for residential buildings for calculating the demand.

7 Comparison with the energy balance of the building

7.1 Identical boundary conditions

Frequently, with the aid of monitoring it is intended to check whether the advance calculation of the heating demand of the building actually matches the reality (heating consumption). On the one hand, a a precise and actual PHPP must be available for this; the deviations occurring in the building which are relevant in terms of energy (e.g. modified thermal bridges, actual airtightness, modified shading by adjacent buildings or trees etc.) must be updated in the PHPP. Only then will it be possible to obtain suitable realistic demand values for comparison. On the other hand, the known deviations from the measured data must be taken into account. In particular, these include the two parameters "weather" (temperature and solar radiation) and "indoor temperature" as mentioned above.

The PHPP calculations are carried out during the planning period using the standard climate of the location and the standard indoor temperature of 20 °C.

In the study by [Peper 2008] the calculated values according to the PHPP are presented in a comparison with the measured values from nine monitoring projects. The different close correlations can be seen in the illustration from this study (Figure 7). There are various reasons for this; sometimes the differences are a result of balance calculations that have not been updated accurately, or due to the often restricted scope of a measurement. The values for the potential accuracy of the balance and the measurement as mentioned above are compelling however. It is also clear that everything is happening at a much lower consumption level in actual fact. Compared with other building standards, the actual measured consumption values are extremely low.

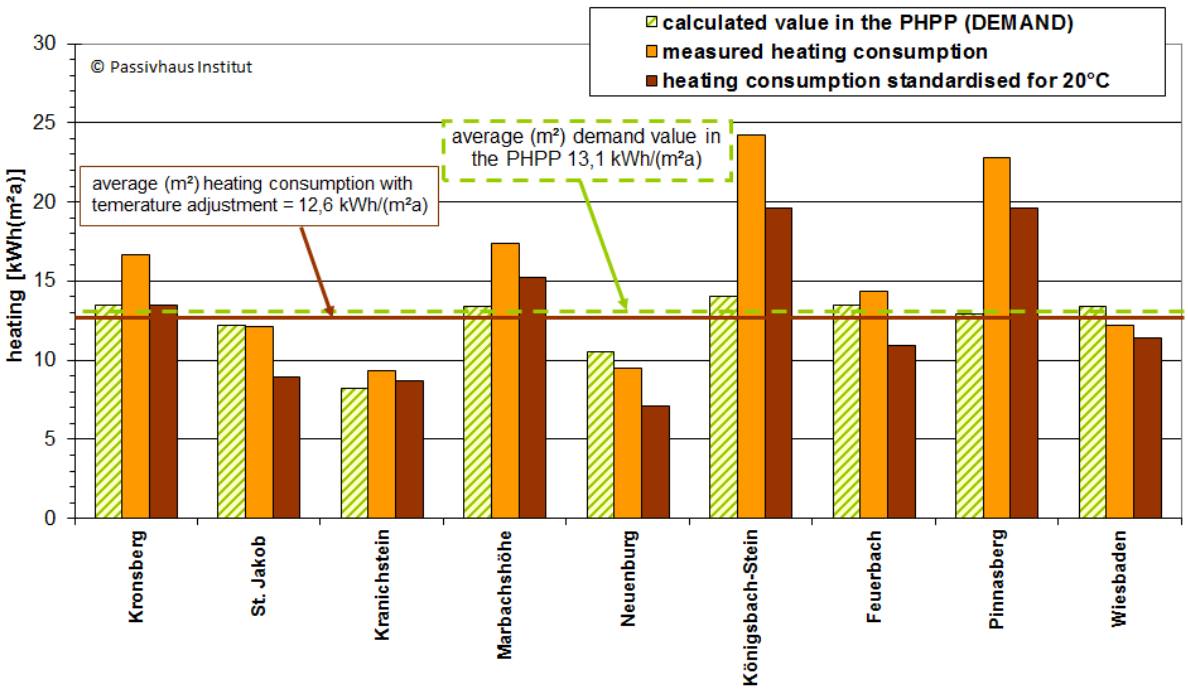

Figure 7: **Heating consumption in metrologically tested projects in comparison with projected values**

of the PHPP [Peper 2008].

Another example of a deviation between the demand and consumption value, outside of residential housing, can be found in [Peper/Kah/Pfluger/Schnieders 2007]. The reasons for the deviation between the demand and measured values were examined and clarified in this research report on a Passive House school in Riedberg in Frankfurt (Germany). In particular, the differences in occupancy rates of the school (significantly lower number of occupants) and altered air exchange are worth mentioning here, as this leads to a deviation between the measured and demand values. However, even with the altered boundary conditions and the resulting slightly higher consumption values, there is a huge reduction in the heating energy from 88 or 90 % compared with other schools (in a comparison with 30 existing schools in Frankfurt and 170 other existing school respectively). The building functions well even with slightly higher consumptions because the technology used is very tolerant.

7.2 User variance

Where possible, statistically a sufficiently large number of buildings is necessary for comparison of the heating consumption with calculated or even required values. Reliable statements can only be made if the deviations (caused by varying uses) can be averaged out. It is the average value which provides a reliable value for comparison. This is apparent from Figure 8: the consumption values have a normal scattering as a rule; statements regarding the energy-relevant standard are only possible with the average value. The figure shows that the energetically optimised Passive Houses actually save 90 % heating energy compared with the existing buildings and 76 % heating energy compared with the low energy houses. However, if only individual houses or apartments are considered, then clear assignment to a particular consumption group is not always easy. The lowest consumption values of the existing housing estate in Kassel could just as well be the highest consumption values of the low energy houses. If just a single building is monitored, then no information is possible about the statistical position of the measured value; it therefore does not make sense, or it is not possible, to make generalisations regarding the deviations from the theoretical calculated value. For that, knowledge of the measured influencing factors such as the indoor temperature, internal heat sources (electricity use) etc. would then be necessary.

Explanations regarding the statistical evaluation of measured data for heating consumption are given in Protocol Volume No. 28 in this series of publications [Feist 2004].

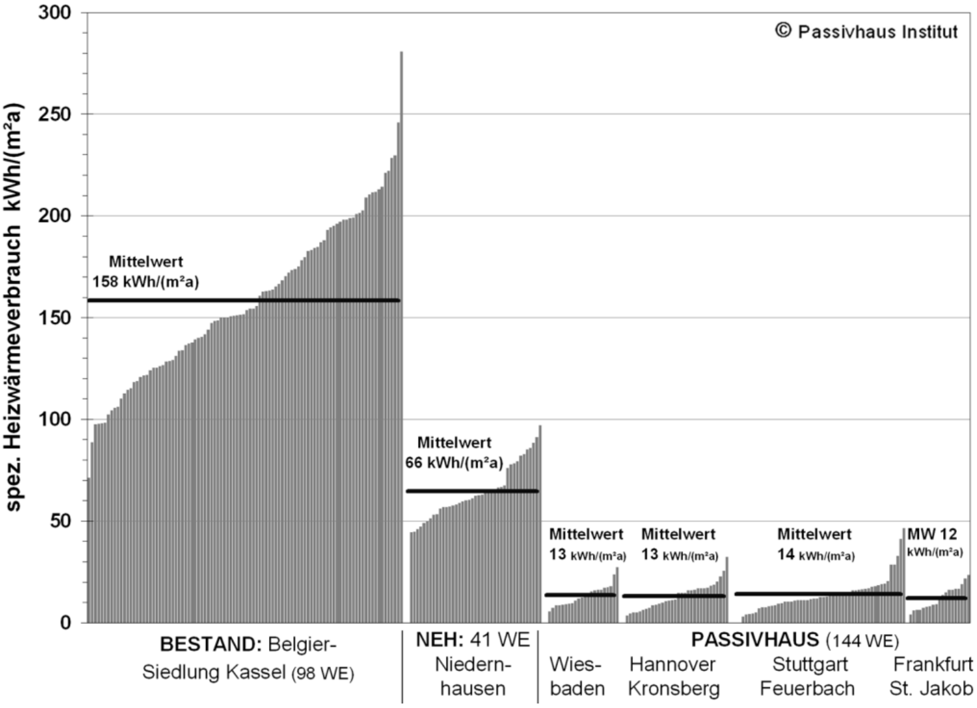

Figure 8: **Comparison of the consumption statistics for groups of identical terraced house units; left: 98 existing buildings; in the middle: 41 low energy houses in Niedernhausen; right: four Passive House estates with a total of 144 accommodation units. The average consumption values are: 158 kWh/(m²a) for the existing buildings, 66 kWh/(m²a) for the low energy houses and about 13 kWh/(m²a) for the Passive Houses (adapted from [Feist 2004]).**

In a correctly dimensioned and energetically optimised building, user influences do not lead to any problems during operation. This is a frequently heard but inaccurate misconception. The comfortable temperatures desired by occupants prevail in the Passive Houses with the lowest heating consumption as well as in those with the highest heating consumption. The numerous monitoring projects demonstrate that the building behaves in a thermally inert manner on account of the high time constants and react to different user behaviours in a very tolerant way.

Of course, the different user behaviours do have a clear influence on the consumption values; this has already been shown by Figure 8. However, just considering the heating energy does not go far enough. A noteworthy contribution to heating can naturally also be achieved with high electricity consumption (e.g. with inefficient lighting, such as high output uplights); the heating consumption may then decrease considerably. Only the total of the three consumption areas electricity, heating and hot water will reveal the full range of different user behaviours.

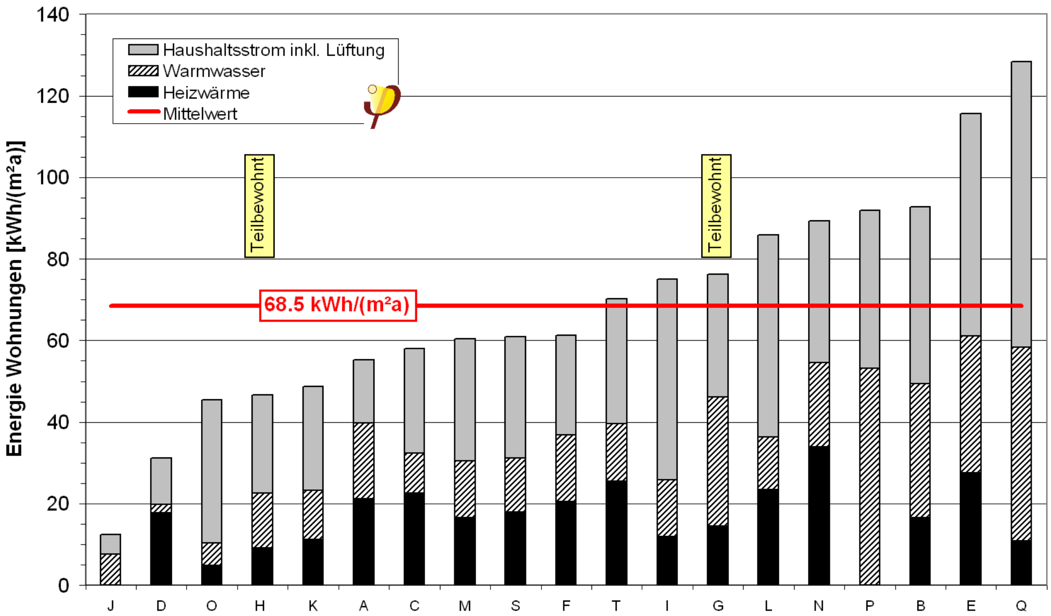

Figure 9: **Measured energy consumptions, separated for electricity, heating and hot water in 19 centrally supplied apartments of the monitoring project "Refurbishment of an existing building using Passive House components" in Tevesstrasse in Frankfurt. The consumptions are measured directly in the apartments, therefore these do not include any distribution losses etc. [Peper at al. 2009].**

In the monitoring project in Tevesstrasse in Frankfurt ("Refurbishment with Passive House Components"), the analysis was presented separately for an apartment block (from [Peper at al. 2009]). The electricity, heating and hot water consumptions measured directly in the 19 apartments are listed in Figure 9. The aggregate measured values were between 12.3 and 128.3 kWh/(m²a). The area weighted average value was 68.5 kWh/(m²a). There were some households which used very little or no heating, but had considerably higher electricity and/or hot water consumption values. However, the reverse situation was also true. This revealed the full range of different uses of the apartments. The size of the apartments was between 34 and 86 m² of treated floor area (average value 68.9 m³). The apartments were occupied by one to three persons at the time of the calculation.

8 Literatur

[Feist 2004]	W. Feist: ***Wärmeübergabeverluste im Licht der Baupraxis. In: Wärmeübergabe- und Verteilverluste im Passivhaus.*** Protokollband Nr. 28 des Arbeitsreises kostengünstige Passivhäuser Phase III, Passivaus Institut, Darmstadt 2004.
[Feist 2005]	W. Feist: ***Heizlast in Passivhäusern – Validierung durch Messungen.*** Endbericht im Rahmen des IEA SHC TASK 28 / ECBCS ANNEX 38. Passivhaus Institut, Darmstadt, Juni 2005; Download: www.passiv.de
[GEMIS]	Hessisches Ministerium für Umwelt, Energie, Jugend, Familie und Gesundheit / ***Öko-Institut: Gesamt-Emissions-Modell integrierter Systeme (GEMIS);*** Wiesbaden
[Peper 2008]	S. Peper: ***Passivhaus-Heizsysteme in der Praxis. Ergebnisse und Erfahrungen aus der Feldmessung.*** In: Protokollband 38 des Arbeitskreises kostengünstige Passivhäuser Phase IV; Passivhaus Institut; Darmstadt 2008
[Peper 2012]	Peper, S.: **Messkonzept, Störgrößen und adequate Lösungen** (Measurement concept, disturbance variables and suitable solutions). In: Protokollband 45 „Richtig messen in Energiesparhäusern“ des Arbeitskreises kostengünstige Passivhäuser, Phase V; Passivhaus Institut; Darmstadt 2012
[Peper at al. 2009]	S. Peper; J. Grove-Smith; W. Feist: ***Sanierung mit Passivhauskomponenten. Messtechnische Untersuchung und Auswertung Tevesstraße Frankfurt a.M. Passivhaus Institut;*** Darmstadt Februar 2009; Download: www.passiv.de
[Peper/ Schnieders/Feist 2011]	S. Peper; J. Schnieders; W. Feist: ***Monitoring Altbausanierung zum Passivhaus, Verbrauch, Raumluftqualität, Kellerfeuchte.*** Messtechnische Untersuchung an den Sanierungsgebäuden Tevesstraße Frankfurt a.M. Passivhaus Institut, Darmstadt Juli 2011; Download: www.passiv.de
[Peper/Feist 2008]	S. Peper; W. Feist: ***Gebäudesanierung „Passivhaus im Bestand“ in Ludwigshafen / Mundenheim. Messungen und Beurteilung der energetischen Sanierungserfolge.*** Passivhaus Institut, Darmstadt, Dezember 2008; Download: www.passiv.de
[Peper/Feist/ Pfluger 2004]	S. Peper; W. Feist; R. Pfluger: ***Ein nordorientiertes Passivhaus, Messtechnische Untersuchung und Auswertung von 19 Wohnungen im Passivhaus-Standard in Frankfurt-Bockenheim, Grempstraße.*** Passivhaus Institut, Darmstadt 2004; Download: www.passiv.de

[Peper/Kah/ Pfluger/ Schnieders 2007]	S. Peper; O. Kah; R. Pfluger; J. Schnieders: ***Passivhausschule Frankfurt Riedberg. Messtechnische Untersuchung und Analyse.*** Passivhaus Institut, Darmstadt, Juli 2007; Download: www.passiv.de
[PHPP]	W. Feist; R. Pfluger, J. Schnieders; O. Kah, B. Kaufmann; B. Krick, Z. Bastian und W. Ebel: ***Passivhaus Projektierungs Paket 2013, Das Energiebilanzierungs- und Passivhaus-Planungstool für qualitätsgeprüfte Passivhäuser und EnerPHit-Modernisierungen.*** Darmstadt, Passivhaus Institut, 2013