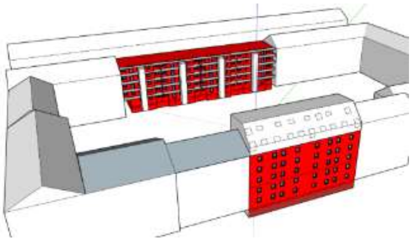
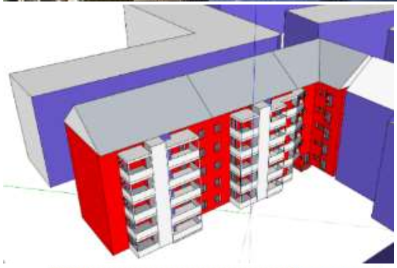
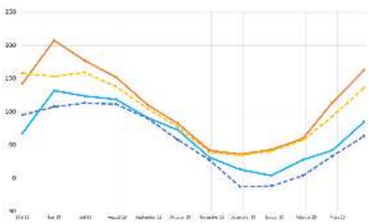
COMPARISON OF MEASURED AND CALCULATED ENERGY DEMAND AND ASSESSMENT OF THE RESULTS

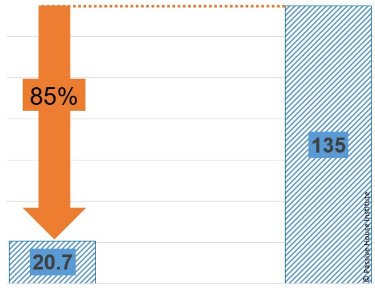
Innsbruck

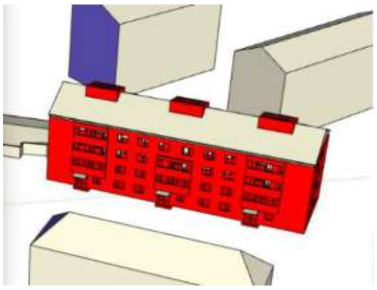











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D5.22 ANNEX Task 5.7

SINFONIA

(**S**mart **IN**itiative of cities **F**ully c**O**mmitted to i**N**vest in **A**dvanced large-scaled energy solutions)

Anonymised version of the partial report D5.22 ANNEX Task 5.7 (Part Innsbruck)

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1. INTRODUCTION AND SUMMARY (INNSBRUCK)

In the "Smart City" EU project SINFONIA (FP7), the core task was to transform selected quarters in the two cities of Innsbruck and Bolzano in an energetically sustainable way. In Innsbruck, the focus was on a number of large apartment buildings or building ensembles with a (heated) area of over 46 000 m² (TFA) as well as three schools. Their ambitious energy refurbishments were planned, calculated in advance and evaluated using measurement technology as part of the project. The schools were completely refurbished and step-by-step refurbishment strategies were mainly planned for the residential buildings. The University of Innsbruck (AB Energieeffizientes Bauen) carried out measurements of consumption and comfort, etc. in the buildings mentioned above. The consumption data for heating reflect the current stage of refurbishment. Usually, both the calculations and the measurements are carried out on the entire building. The situation in the neighbourhoods proved to be much more complicated, however. In many of the old buildings, there have been various changes in the way people live. Different systems and energy sources (electricity, gas, district heating, wood, coal) were involved in heating generation, and there were generally no meters for the buildings as a whole, as the supply was decentralised. Only in one of the residential buildings could the central district heating supply of all dwellings be evaluated. In the other cases, individual dwellings were measured instead of the total buildings, for which the consent of the respective residents had to be obtained. From these random samples, extrapolations were made to the associated buildings and the associated statistical errors were determined.

The Passive House Institute carried out quality assurance during the planning phase and during the renovation. The basis of the energy design was calculation using the PHPP (Passive House Planning Package) balance sheet method. Based on dynamic simulation and practical experience, the PHPP was specially developed to be able to design and optimise buildings, especially those with very low energy consumption. The method has been validated by numerous extensive measurement projects and has shown that planning and implementation is possible "without a performance gap" [CEPHEUS 2001], [Passipedia], [Johnston et al. 2020], [Mitchel/Natarajan 2020]. In the present study, the expectancy range in which statistically 95% of the measurement results will lie (confidence interval) is relatively large, due to the limitations mentioned above.

For the SINFONIA projects, the PHPP was generally used to asses in detail the condition of the old building, the current renovation step and the final state of the renovation.

In addition, BEST-Sheets (Building Energy Specification Table) specified by the EU Commission and energy performance certificates (“Energieausweise”) were prepared for the buildings prior to the start of refurbishment in accordance with the procedures prescribed by law in Austria (OIB Directive 6). These procedures have their own calculation rules, which focus on the comparability and classifiability of the buildings rather than a realistic representation of the energy demand. The reference areas for the energy performance certificates are also determined according to legal regulations and refer to gross dimensions. These gross floor areas (GFA) are always significantly larger than the net areas based on the utility value (usually also part of the contract, e.g. with tenants). The net areas are therefore systematically used by the PHI for planning, quality assurance and measurement evaluation (heated residential or usable areas = energy reference area, "TFA, treated floor area"). This results in different numerical values for e.g. the measured consumption value. These calculation results of the space heating according to BEST-Sheet and energy performance certificate (“Energieausweis”) are compiled for each project. The buildings within the project are designated with the abbreviation BEST plus a number (e.g. BEST07).

In this report the measured data, after preparation, are compared with the PHPP's projections. In addition to the standard boundary conditions (with typical average use, a winter indoor temperature of 20°C and a climate data set corresponding to the long-term average in Innsbruck), in a further variant, as far as known, the actual conditions at the building are used to enable a realistic comparison. All these calculations are determined with the PHPP as a realistic tool that correctly represents the decisive parameters. In this way, a comparative value of the heating requirement is obtained, which can be compared with the measured consumption, taking into account the remaining uncertainties.

An overview of the measurement results of the 8 residential buildings and 2 schools is shown in Figure 1. For one housing project and one of the three schools, no assessable measurement data are available. On average, the refurbishments reduce the heating consumption values for useful heat to only

31.8 kWh/(m²a)

(reference: heated surface "TFA"). As not all of the projects have been completely refurbished in the first step from step-by-step retrofit, especially the windows and the ventilation equipment with heat recovery, the results vary considerably between 10 and 58 kWh/(m²a). The results are the unchanged measured values, without a mathematical correction of the consumption values due to deviating room

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temperature. Therefore the measured values correspond to the actual room temperatures ("real" °C). The project with the highest consumption (BEST19) has a particularly large confidence interval, which is due to the small number of flats measured. In this project, it must be taken into account that no ventilation technology with heat recovery has yet been implemented in the measured flats.

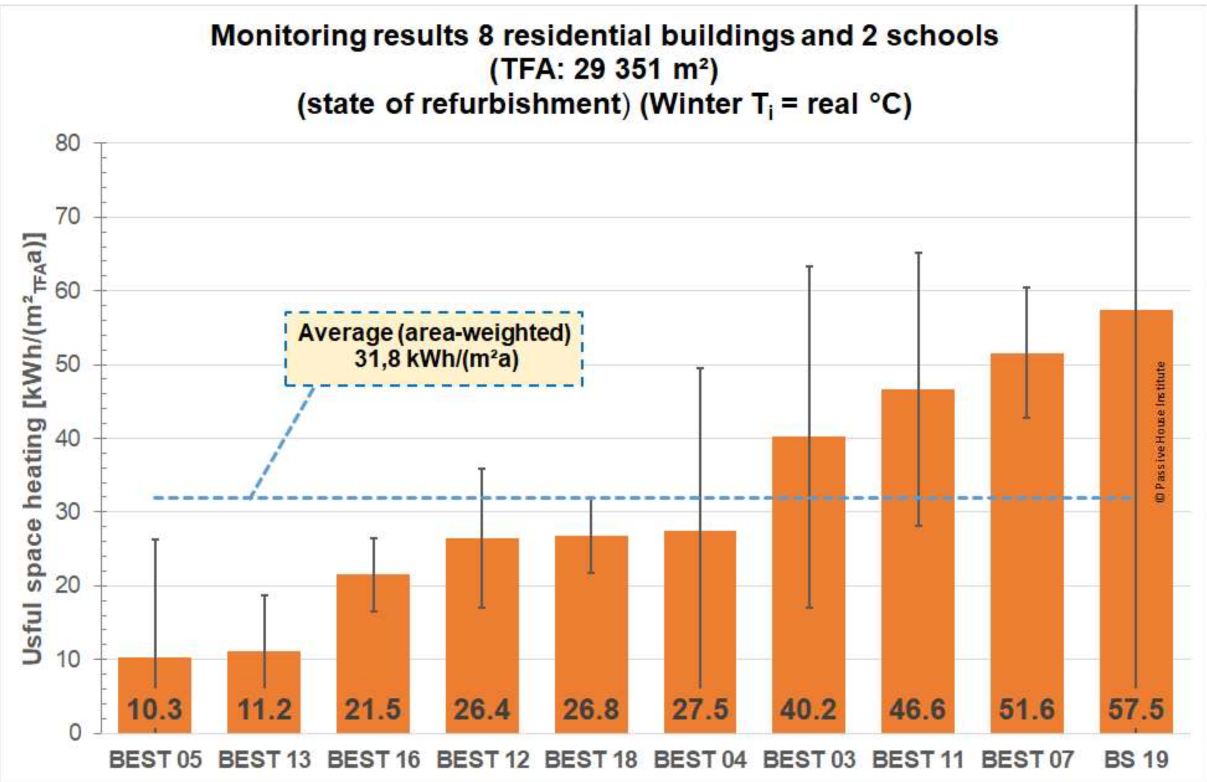

FIGURE 1: MEASURED CONSUMPTION VALUES FOR THE HEATING ENERGY OF THE 8 RENOVATED RESIDENTIAL BUILDING PROJECTS AND 2 SCHOOLS IN INNSBRUCK WITH THEIR RESPECTIVE STANDARD DEVIATIONS OF THE MEAN VALUES. THE MEAN VALUE AT THE CURRENT STAGE OF REFURBISHMENT IS 31.8 KWH/SQM PER YEAR (PARTIAL REFURBISHMENT ACCORDING TO THE ENERPHIT REFURBISHMENT PLAN). THE REFERENCE AREA HERE IS THE (NET) LIVING AREA AS USED IN THE PHPP (TFA).

The measurement results can also be related to the gross area of the building projects (BEST-Area) - in contrast to the usual procedure here. Since this is a significantly larger reference area, the specific consumption values are correspondingly smaller. This is necessary to make a comparison with the BEST-Sheets. In this consideration, the average value is 23.7 kWh/(m²a) due to the changed area references (see Figure 2).

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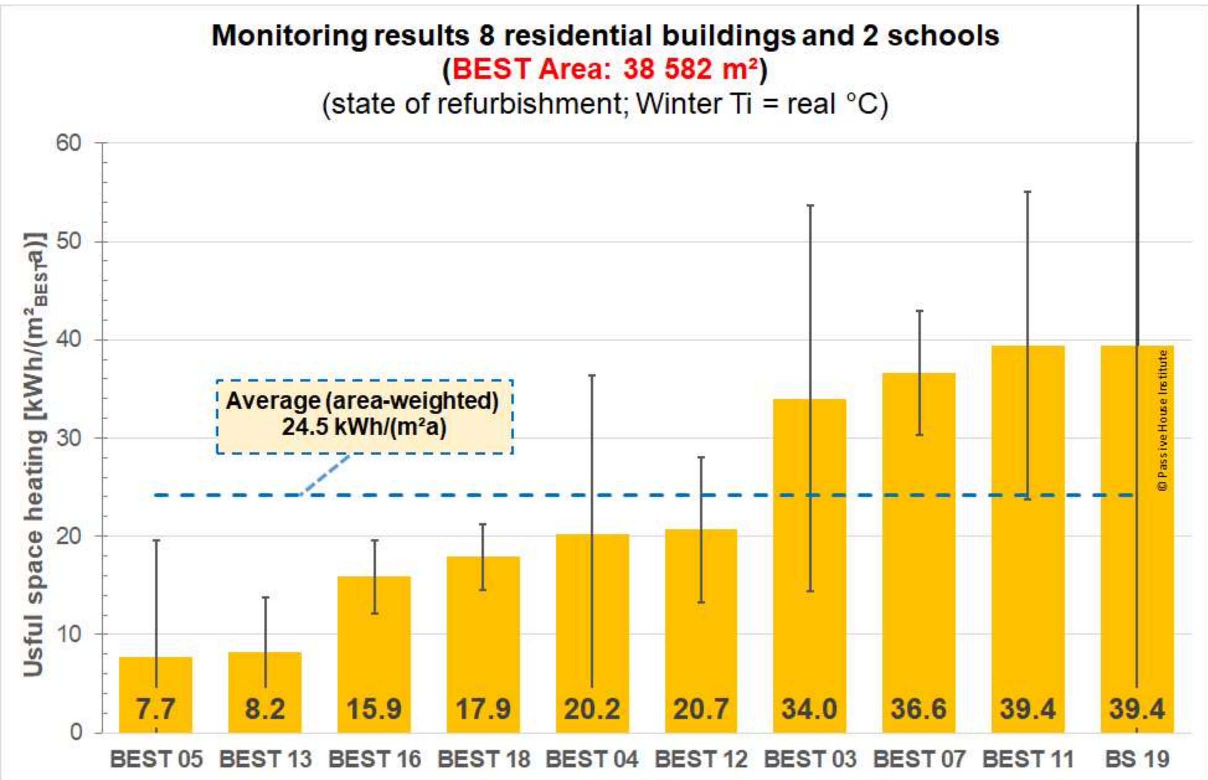

FIGURE 2: MEASURED CONSUMPTION VALUES FOR THE HEATING ENERGY OF THE 8 RENOVATED RESIDENTIAL BUILDING PROJECTS AND 2 SCHOOLS IN INNSBRUCK WITH THEIR RESPECTIVE STANDARD DEVIATIONS OF THE MEAN VALUES. THE MEAN VALUE AT THE CURRENT STAGE OF REFURBISHMENT IS 23.7 KWH/SQM PER YEAR (PARTIAL REFURBISHMENT ACCORDING TO THE ENERPHIT REFURBISHMENT PLAN). THE REFERENCE AREA HERE IS THE (GROSS) REFERENCE SURFACE AREA AS USED IN THE BEST-SHEET.

Since the BEST-Sheets prepared before the start of the project assume a standard room temperature of 20°C during the heating period, it is necessary to estimate how the measured consumption values would change when heating to 20°C. The difference is calculated with the respective PHPPs of the buildings by performing the balance calculation for these buildings at the measured room temperature in winter (measured temperature) and additionally at 20°C. The measured value is adjusted by the difference between the two calculations and based on the area of the BEST-Sheets. This method is nevertheless suitable as an estimate for the standard situation at 20°C. However, it must be noted that the results are no longer pure measured values. This also increases the uncertainty of the statements. The result of the calculations can be seen in Figure 3. The mean value of the buildings is thus 19.7 kWh/(m²a).

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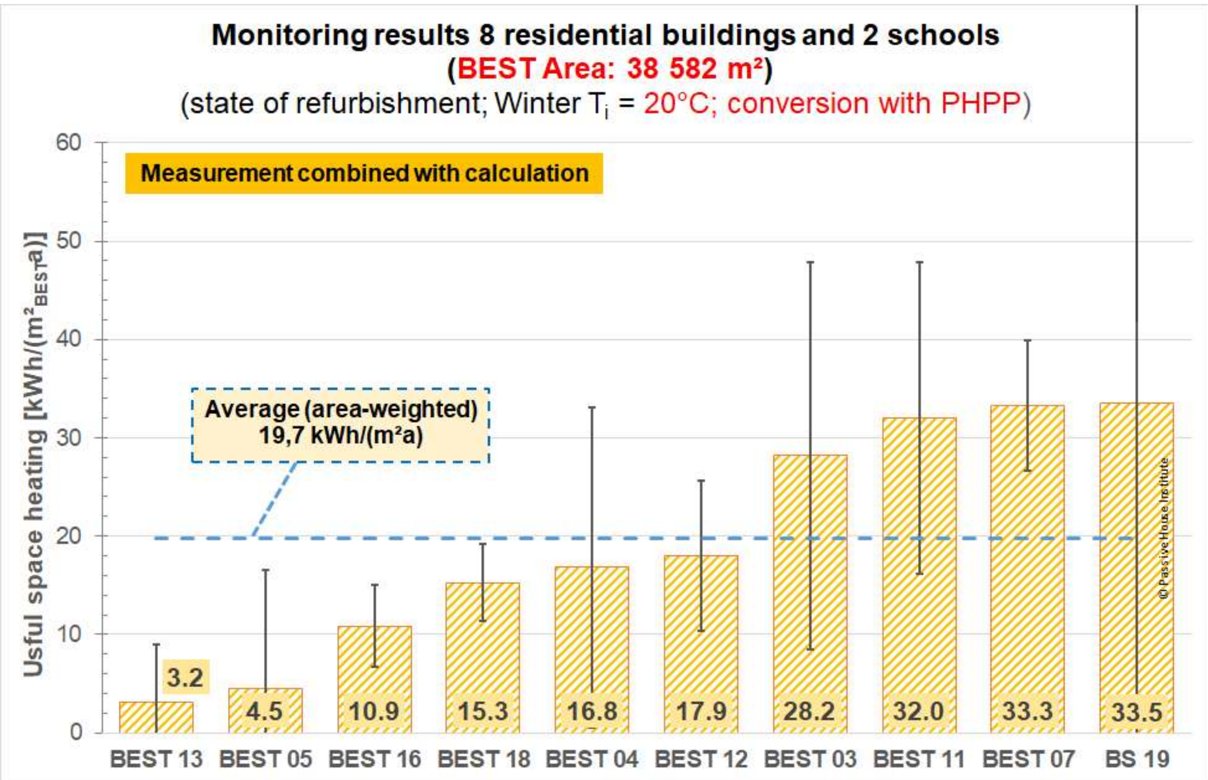

FIGURE 3: MEASURED CONSUMPTION VALUES FOR THE HEATING ENERGY MINUS THE CALCULATED ENERGY REQUIREMENT FOR HEATING ABOVE 20°C (8 RENOVATED RESIDENTIAL BUILDING PROJECTS AND 2 SCHOOLS IN INNSBRUCK). WITH THEIR RESPECTIVE UNCERTAINTY. THE MEAN VALUE AT THE CURRENT STAGE OF REFURBISHMENT IS 19.7 KWH/SQM PER YEAR (PARTIAL REFURBISHMENT ACCORDING TO THE ENERPHIT REFURBISHMENT PLAN). THE REFERENCE AREA HERE IS THE (GROSS) REFERENCE SURFACE AREA AS USED IN BEST-SHEET.

In the further illustrations, the measured and calculated values are again exclusively related to the actual heated surface (TFA).

The comparison of the average consumption of all 8 residential buildings and the two schools with the calculated values of the PHPP shows a good agreement in the context of the accuracy of the recording, especially of the measured data (Figure 4). This once again confirms that the PHPP is a reliable planning tool that is also very well suited for refurbishment.

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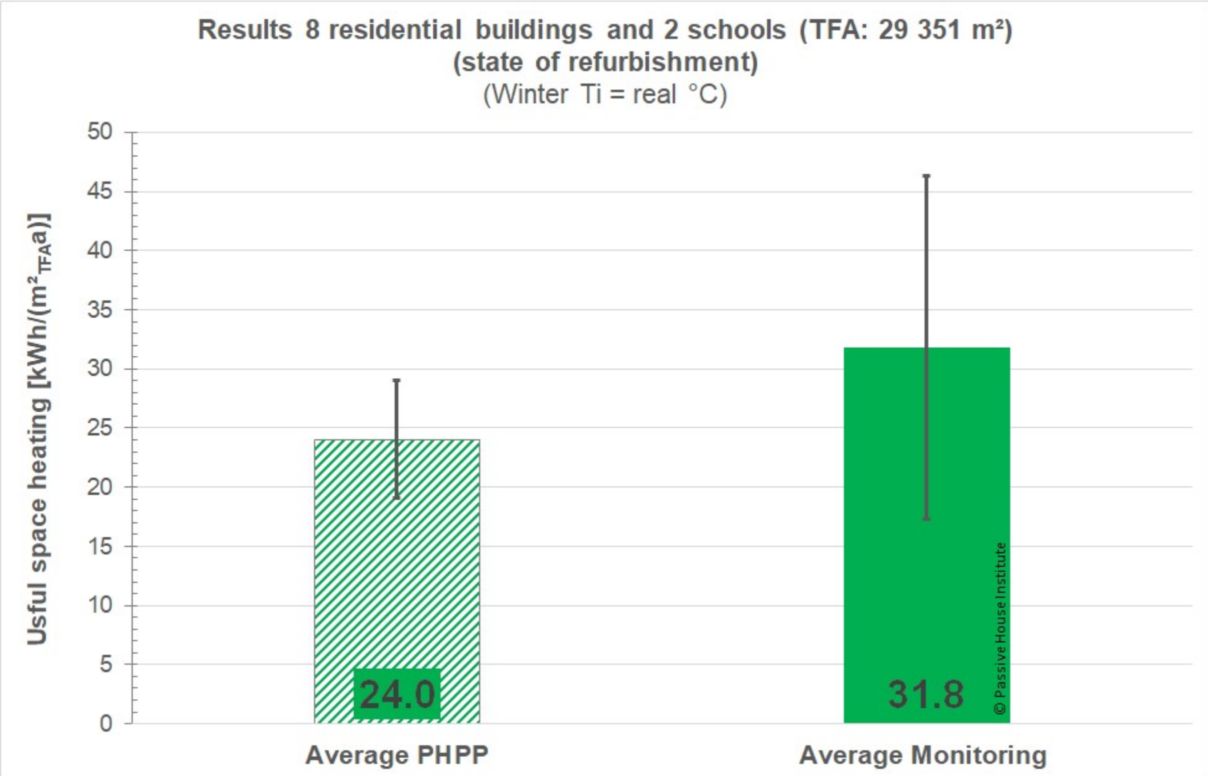

FIGURE 4: COMPARISON OF THE USEFUL HEATING ENERGY OF THE 8 RENOVATED RESIDENTIAL BUILDING PROJECTS AND 2 SCHOOLS IN INNSBRUCK: THE CALCULATED DEMAND VALUE (TOOL: PHPP) OF THE REALISED RENOVATION (LEFT) VERSUS THE AVERAGE VALUE OF ALL MEASURED CONSUMPTION VALUES (RIGHT). THE CALCULATION OF THE VALUES IS AREA-WEIGHTED IN BOTH CASES. UNDER CONSIDERATION OF THE BALANCE AND MEASURING ACCURACIES, A CORRESPONDENCE IS TO BE DETERMINED. REFERENCE AREA: TFA (USEFUL LIVING SPACE).

Figure 5 shows the detailed representation from Figure 4 of all measured values in comparison to the calculated values with the energy balance tool PHPP: With a well-maintained and complete PHPP, reliable predictions can already be made during the planning phase. In these projects, the statistical uncertainties are higher than when measuring the entire building due to the limited scope of measurement or the random individual measurement of flats. When measuring entire buildings, the agreement is usually even higher (cf. Figure 9). Despite all the differences between the projects examined here, it is clear that the planning values can be well achieved with careful renovation and a suitable balance tool.

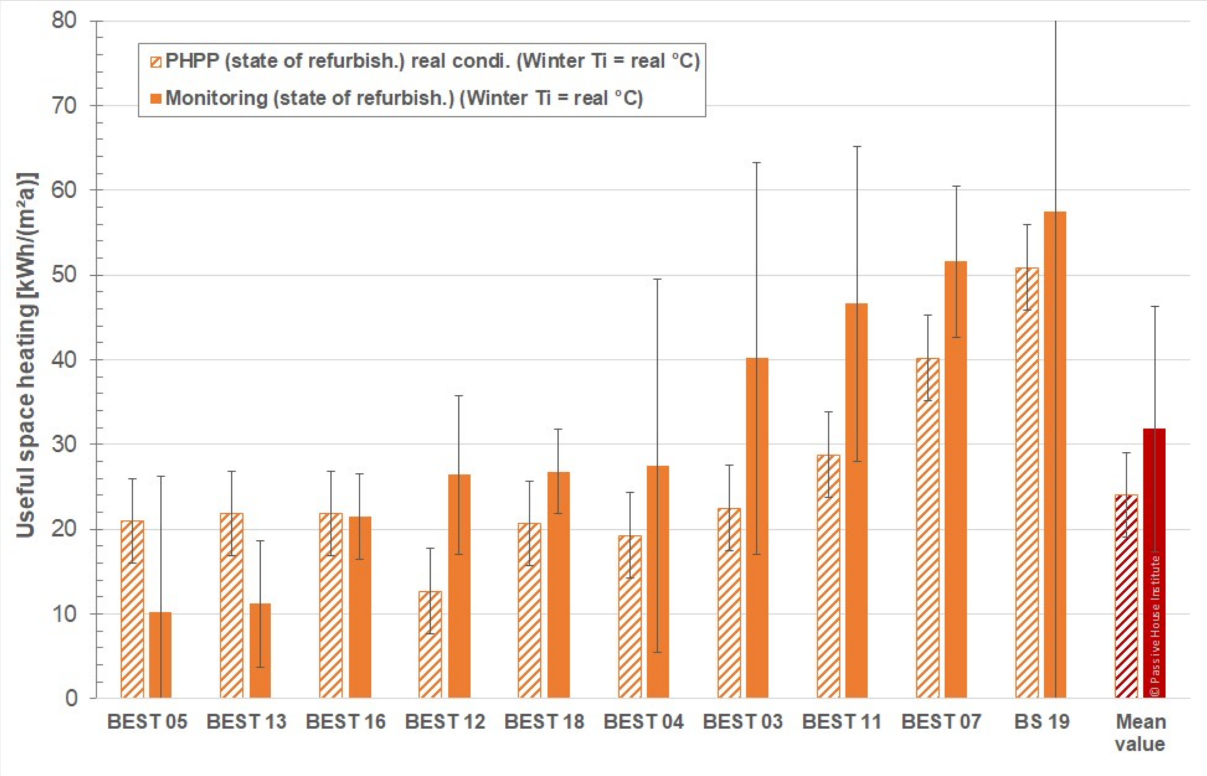

FIGURE 5: COMPARISON OF THE USEFUL HEATING ENERGY OF THE 8 RENOVATED RESIDENTIAL BUILDING PROJECTS AND 2 SCHOOLS IN INNSBRUCK: THE CALCULATED DEMAND VALUE (TOOL: PHPP) OF THE REALISED RENOVATION VERSUS THE AVERAGE VALUE OF ALL MEASURED CONSUMPTION VALUES FOR THE 8+2 PROJEKTS. THE CALCULATION OF THE MEAN VALUES (BOTHE RIGHT COLUMNS) IS AREA-WEIGHTED IN BOTH CASES. REFERENCE AREA: TFA (USEFUL LIVING SPACE).

The average measured value of the heating consumption of the buildings investigated of 31.8 kWh/(m²a) over a total of 29 300 m² can be compared with the heating requirements of the "old" buildings before refurbishment. The data of the old buildings are calculations using the PHPP of the uninsulated (or only partially insulated) buildings, with old windows and poor air-tightness, and without ventilation systems. For this purpose, the calculations are based on the standard conditions described above for the long-term climate in Innsbruck and typical conditions of use. The area-weighted average value of all residential buildings is 140 kWh/(m²a). Compared to the measured value, this results in a saving of 77% of the useful heat for heating the buildings.

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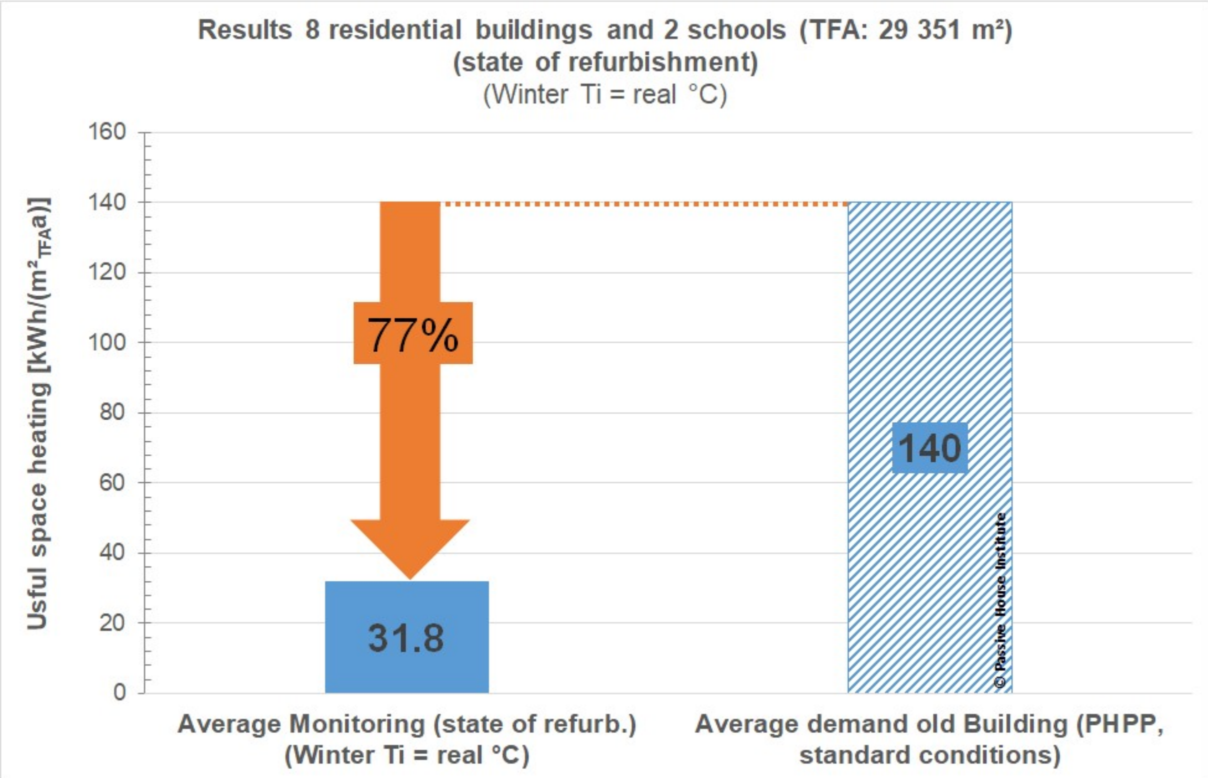

FIGURE 6: COMPARISON OF THE MEASURED USEFUL HEATING ENERGY CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (DESIGN TOOL: PHPP, STANDARD CONDITIONS) OF THE OLD BUILDINGS FOR ALL PREVIOUSLY EVALUATED 8 RENOVATED RESIDENTIAL BUILDING PROJECTS AND 2 SCHOOLS IN INNSBRUCK. THE CALCULATION OF THE VALUES IS AREA-WEIGHTED IN BOTH CASES. REFERENCE AREA: TFA (USEFUL LIVING SPACE).

In order to determine the magnitude of the savings, the heated area of the 8 residential building projekts evaluated, as well as the two schools (29 351 m² living space TFA), can be calculated with the difference between the measured consumption value and the calculated requirement value of the non renovated old buildings: For the buildings the realised savings are about 3 182 000 kWh per year (3.2 GWh/a).

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Savings of all projects in Innsbruck

It is possible to estimate the total savings of all SINFONIA buildings (except school BEST17), including the residential building BEST08 (TFA area 5 197 m²), where no measured data are available. For this purpose, the data on heating energy from the PHPP calculations of the refurbishment steps already achieved are used.

This results in a total area of all 9 residential buildings and the 2 schools in SINFONIA of 34 547 m²; the average heating consumption (including projections) is

32.6 kWh/(m²a).

The initial value for the heating demand of the existing buildings before renovation is

135 kWh/(m²a).

The total saving for the useful heat of the heating system is the considerable value of

76%

which corresponds to around 3 540 000 kWh per year (3.5 GWh/a).

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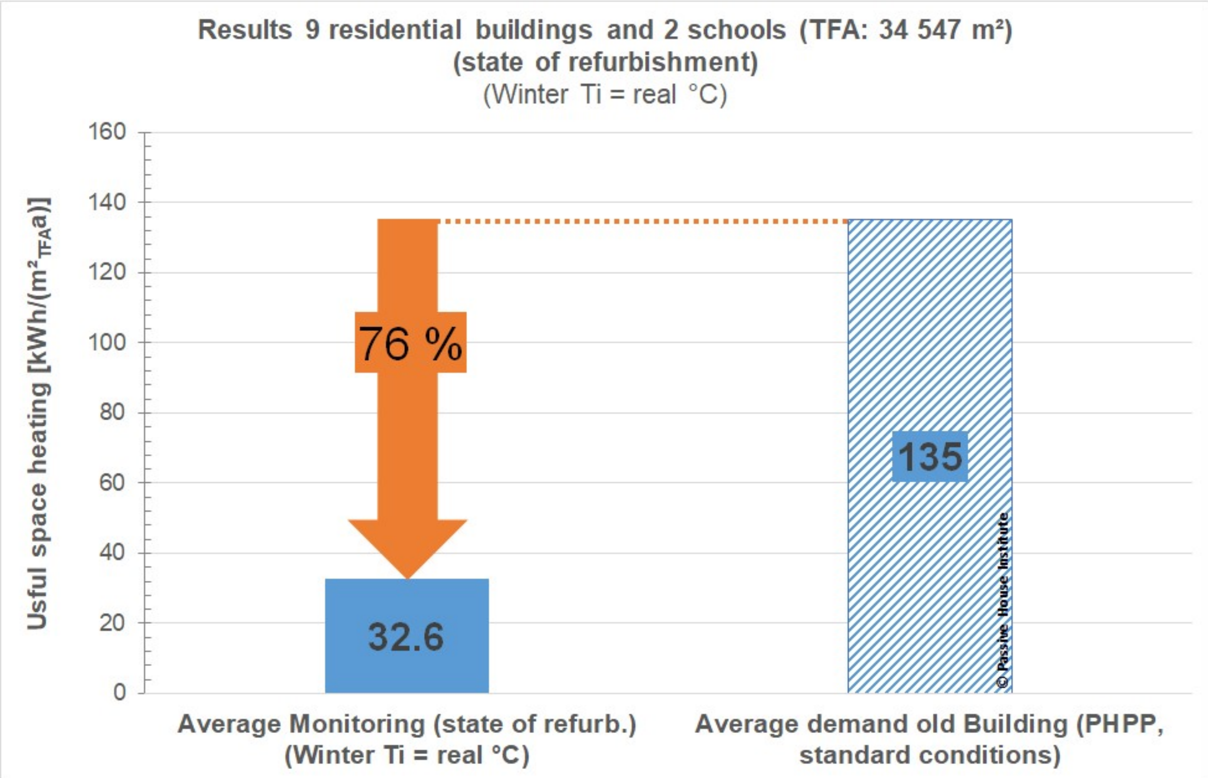

FIGURE 7: COMPARISON OF THE MEASURED USEFUL HEATING ENERGY CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (DESIGN TOOL: PHPP, STANDARD CONDITIONS) OF THE OLD BUILDINGS FOR ALL THE PREVIOUSLY EVALUATED 9 RENOVATED RESIDENTIAL BUILDING PROJECTS AND 2 SCHOOLS IN INNSBRUCK. THE CALCULATION OF THE VALUES IS AREA-WEIGHTED IN BOTH CASES. REFERENCE AREA: TFA (USEFUL LIVING SPACE). FOR EXPLANATIONS SEE TEXT.

Potential during full refurbishment

In the case of the refurbishments in Innsbruck, it is of particular interest how large the savings for the overall project will be, once all refurbishments have been completed. To this end, additional ventilation systems with heat recovery and thermally optimised windows are to be retrofitted. For the 9 residential building projects and the 2 schools a saving of 85% compared to the old building condition is expected. The value for the average heating consumption will drop to about 21 kWh/(m²a). This would save around 3 950 000 kilowatt hours of heating energy per year (equivalent to 3.9 GWh/(m²a)). In this way, the heat consumption of "almost zero" required by the EU will be achieved.

The enormous potential of building refurbishment and thus energy efficiency is thereby clearly demonstrated. The project proves that these can be achieved not only in theory but also in practical

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implementation. Efforts in this direction must be intensified urgently. The know-how and the necessary products are available to enable mass scaling. No further reservations should be discussed, but rather the possible measures should be implemented urgently throughout the EU and worldwide. The SINFONIA project with its proven successes is an encouraging pioneer in this respect.

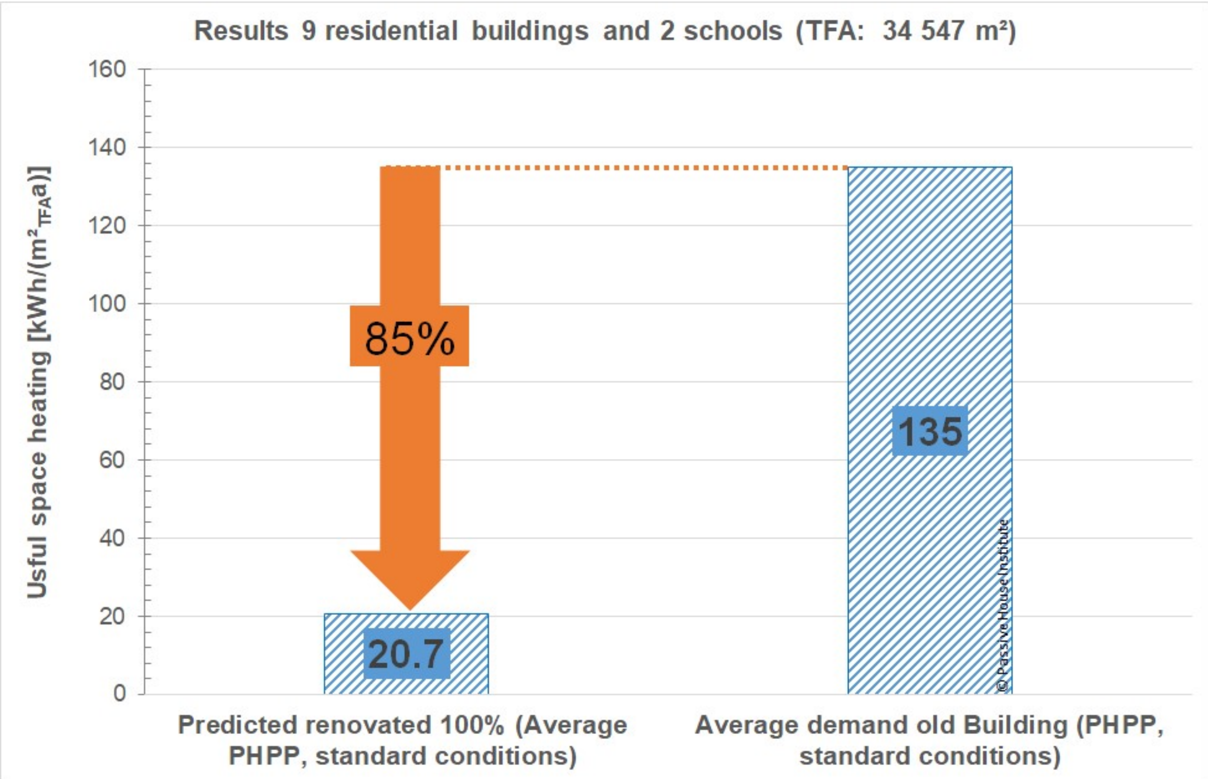

FIGURE 8: ENERGY SAVING POTENTIAL OF ALL SINFONIA RESIDENTIAL BUILDINGS AND 2 SCHOOLS. COMPARISON OF HEATING DEMAND BEFORE AND AFTER COMPLETE REFURBISHMENT, BASED ON PHPP CALCULATION WITH STANDARD CONDITIONS (REFERENCE AREA: TFA (LIVING AREA)).

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2. INNSBRUCK BUILDINGS

The residential buildings and schools in Innsbruck that were renovated and investigated as a part of the EU project SINFONIA are examined regarding their heating consumption (useful heat). The calculations of requirements are compared with the consumption values.

2.1 DESCRIPTION OF THE PROCEDURE

2.1.1 REQUIREMENT CALCULATIONS

There are three different types of calculations for the buildings involved:

(1) **BEST-Sheets**: These calculations (BEST: Building Energy Specification Table) were carried out by the housing companies at the beginning of the project. They serve to determine the data of the buildings to be refurbished, including their demand forecast after refurbishment. The calculation basis of the area and the demand values were based on the EU template. The basis for these calculations is the national energy performance certificate, however, deviating characteristic values are used (e.g.: HWB incl. system losses, which are not shown in this form in the energy performance certificate according to (2)). Further detailed information on the procedure (calculation method) is not available. These calculations are not adapted to current changes during the renovation. Standard weather data are used as climate data; the indoor temperature cannot be changed.

(2) Energieausweise (Energy Certificate): The calculations of the "Energy Performance Certificate for Residential Buildings - Planning" are the national calculation standard for residential buildings in Tyrol according to "OIB Guideline 6". It is therefore the legally required and necessary calculation rule of the "Österreichisches Institut für Bautechnik" (OiB). For school buildings, "Energy certificates for non-residential buildings" were calculated according to ÖNORM H5055 and Directive 2002/91/EC. These calculations were carried out on behalf of the housing associations or were prepared by them. They will be adapted to current changes after the refurbishment has been carried out. Standard weather data are used as climate data; the indoor temperature cannot be changed.

(3) **PHPP**: The "Passive House Planning Package" [PHPP] is published by the Passive House Institute (PHI) for energy balance calculations and planning of especially energy-efficient buildings. In the project, it was used in particular for quality assurance and for determining the renovation steps. The program has been validated hundreds of times using real measured values. With a realistically completed PHPP, the actual average consumption value for normal use (climate data set, indoor temperature, etc.) can be calculated with a high degree of certainty [Johnston et al. 2020] [Mitchel/Natarajan 2020]. In terms of the benefits provided, the reference area is based on the actual heated living or usable area of the building. The reference area defined in this way is called the Treated Floor Area (TFA) according to PHPP [CEPHEUS 2001]). The calculations for each building are continuously adapted to current changes during the entire project phase (planning to completion), so that results of the demand values can be delivered as realistically as possible. The PHPP serves

not only as a verification tool but also as a project planning tool. The climate data used for the advanced calculation are long-term mean values of the standard climate data set from the Innsbruck site. For the comparison of the calculation with the measured values, a further climate data set is then generated and used from the measured values (outside temperature, global radiation) for the measuring period [UIBK 2020]. All relevant usage parameters can be adjusted in PHPP. The indoor temperature has a particularly high influence on the heating consumption, therefore it should be recorded, as well as the relevant weather data, in order to be able to make a meaningful comparison. For the pre-calculation and certification of buildings, the calculation is always based on a standard indoor temperature of 20°C. For comparison with the measured values, the level of the indoor temperature is set to the actual measured value during the heating period (winter months, usually October to April). The calculation values generated in this way can be compared directly with the measured data. The PHPPs for each project were calculated by the Passive House Institute Innsbruck during the planning phase.

Due to the very different calculation methods and fundamentals, the three different methods are not suitable for direct comparison of results. Even the reference surfaces differ considerably and do not allow a direct comparison of the specific values. Since all three methods are important and used in SINFONIA, the following section will compare all three methods with the measured data. Only the (gross) reference surface from the BEST-Sheets is used for the BEST-Sheets and the Energieausweise. When considering the values from the PHPP calculations, the TFA (heated living area or usable area) is used as the reference area.

The balancing of the buildings in Innsbruck that have been or are to be renovated step by step with the PHPP distinguishes between variants according to the progress achieved in renovation. As a rule, a distinction is made at least between the condition of the unrenovated building, the currently implemented renovation step and the complete renovation. Only the school buildings (BEST16, BEST17, BEST18) could be completed as a comprehensive full refurbishment. Most of the residential buildings, however, have not yet been fully refurbished, but have been partially refurbished. The thermal insulation of the building envelope has often been improved, but only some of the windows have been replaced and, in particular, ventilation systems with heat recovery have been retrofitted in only some of the apartments. The reason for this is that the tenants have to give their consent for work done inside the apartment, which is often not readily provided. In several buildings, there is no exact information on the windows (number, quality, data sheets, etc.), the heating (heating medium for decentralized systems), and the ventilation (number and data sheet for decentralized systems) at the time of the measurement evaluation. Here, the completion of the PHPPs had to work with assumptions in order to try to depict the situation of the renovation as realistically as possible. This weakened the

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quality of the PHPP statement on the current remediation step compared to an exact balance sheet. This circumstance of limited accuracy has to be considered for the assessment.

According to [Feist 2001] the accuracy of balance calculations can be set at ±3 kWh/(m²a). This results from uncertainties in the properties of the materials and components as well as from variability in the execution of construction. This uncertainty is always given, especially independent of the calculation method used. The additional uncertainties described above regarding the condition of the building have been taken into account by increasing the uncertainty to ±5 kWh/(m²a).

2.1.2 MEASURED VALUES HEAT CONSUMPTION AND PROCEDURE FOR COMPARISON

The measurement of the consumption data in the buildings in Innsbruck as well as all other measured variables (e.g. indoor temperatures) is carried out by the University of Innsbruck. The data are stored on a central data server in Innsbruck. Sections of the consumption data and room temperatures (totals or average values) were sent to the PHI for evaluation on a monthly basis. Further data on the boundary conditions in the apartments (inhabited/uninhabited, resident structure, special features) are not known in detail. The data are assigned to the data point and the consumption unit according to their identification.

For the comparison of demand values with measured consumption values, measurement data of the entire building are required, since the balance calculations always refer to the entire building. This regularly results in very good agreement between the balance calculation and the measurement (see Figure 9). In the SINFONIA project, however, the measurements could only be taken in apartments in which the residents agreed to the measurement (see section 2.1.1 above). The dispersion of consumption values for individual dwellings in an apartment building is relatively large. This fact was investigated and proven for energy-efficient multi-family houses at a very early stage, and is also generally known. In [Pfluger 2001] a range of 0.13 to 46 kWh/((m²a)) was found for the multi-family passive house in Kassel-Marbachshöhe (mean value 17.1 kWh/((m²a)). Besides the location of the dwelling, the cause is in particular the transverse heat flows due to the temperature differences between the dwellings. Similar results are shown by measurements in old buildings renovated with Passive House components [Peper/Feist 2008], [Peper/Grove-Smith/Feist 2009]. A small sample of apartments in a building therefore has a direct effect on the reliability of the results.

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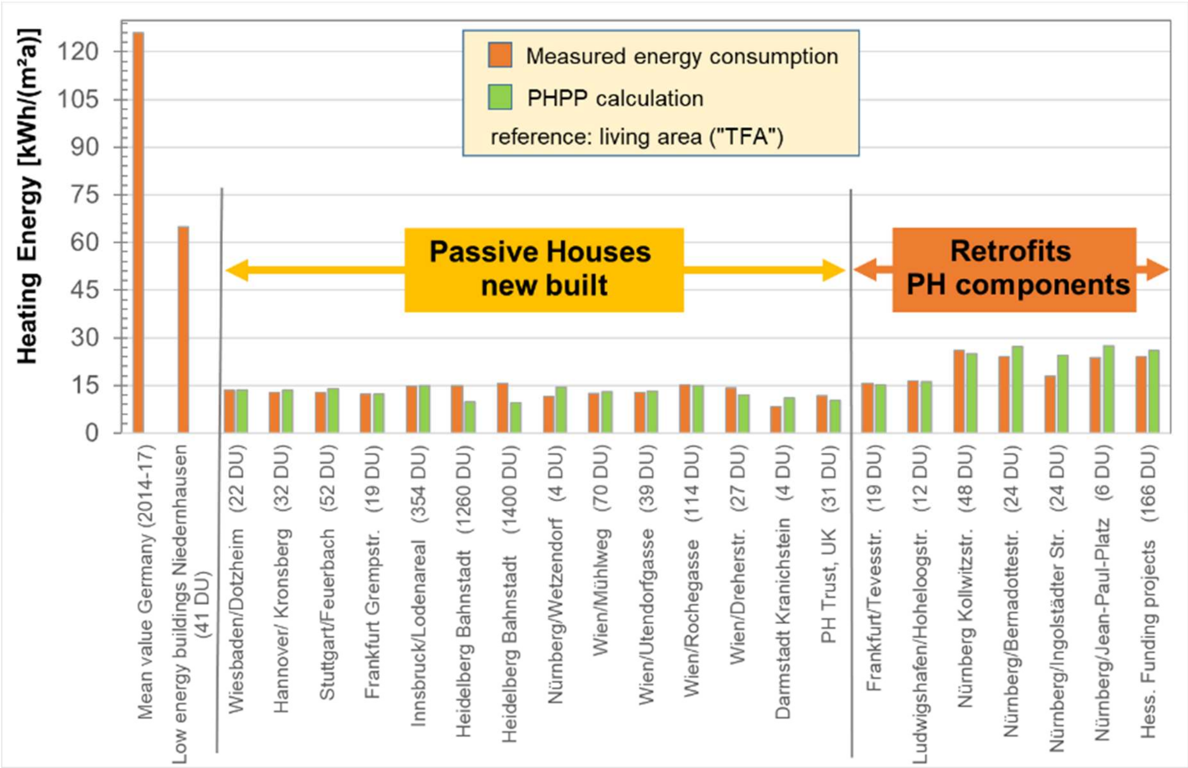

FIGURE 9: COLLECTION OF MEASURED SPECIFIC ANNUAL SPACE HEATING ENERGY CONSUMPTIONS FOR SEVERAL NEW BUILT AND RETROFITTED PH BUILDING PROJECTS, A LOW-ENERGY PROJECT AND THE MEAN VALUE FOR EXISTING DWELLINGS IN MULTIFAMILY BUILDINGS IN GERMANY. FOR THE PH AND ENERPHIT PROJECTS, THE PHPP DEMAND CALCULATIONS ARE SHOWN AS GREEN COLUMNS. THERE IS A VERY GOOD AGREEMENT BETWEEN THE CALCULATION OF REQUIREMENTS AND THE MEASURED VALUES. [PEPER, FEIST 2016], [JOHNSTON ET AL. 2020]. REFERENCE: TFA (USEFUL LIVING AREA).

The supply structure within the apartment buildings is not homogeneous: In some cases, two to four different types of heat supply are used in a building for heating only (individual room wood heating, coal stove, electric night storage heater or gas boiler). The reason for this is historically due to individual apartment modernizations. The supply of wood or coal could not be measured within this project. The measurement data for the heat supply originate partly also within a building from different sources: gas or electricity consumption. With only one exception for residential buildings (BEST07: district heating), the data are measured per dwelling. They do not include distribution losses outside the thermal envelope. The heat consumption values can therefore be used directly as heating consumption values (useful heat).

With the exception of one residential building (BEST07) and the school buildings, evaluable measured data on heat consumption is only available for a smaller number of apartments in the buildings or building projects. The percentage of the measured dwellings to the total area (TFA) is between 9% and 29% per project. The apartments for which measurements are carried out could not be selected representatively. The selection was based on "chance". In other words, which tenants additionally agreed to a measurement and whether the measurements could be carried out successfully. Only if evaluable and plausible measurement data were available and if these data could also be clearly assigned to a heated area, then these data were taken into account.

This means that there are no "typical" average consumption values for the individual apartments in the building, but rather random examples of the heat consumption of partial areas. These individual values were then used to calculate a space-weighted average value only for the measured residential units, which does not represent the actual average consumption value of the building as a whole. Due to the lack of central meters for the total consumption of a building, this extrapolated measured value is used for the entire building. In order to be able to depict the associated statistical uncertainty, the standard deviation of the mean value was calculated from the individual measured values for each building, as well as the 95% confidence interval for the average energy consumption. This provides a measure of the uncertainty associated with the mean value. This fluctuation range (e.g. ±6.2 kWh/(m²a)) is indicated for the measured values when comparing them with the PHPP demand values. In general, the smaller the number of individual measured values and the greater their dispersion, the greater the standard deviation of the mean value and the confidence interval. In other studies with measurements of all apartments or identical terraced houses (low-energy and passive houses), standard deviations of the mean value of about 0.8 to 2.1 kWh/(m²a) were usually determined [Feist 2004]. In the figures of the comparisons for the residential buildings, the 95% confidence intervals for the average energy consumption are usually shown.

Depending on the supply system of an apartment, the measured data include not only the heating energy but also the energy for hot water production. Separate measurements were not available in some cases. Separation is achieved by defining the summer consumption as the "consumption base" for hot water preparation. This base is extrapolated for the whole year and deducted from the measured annual consumption. The uncertainty of the heating consumption is further increased in this way. Usually the simplified procedure leads to a slight overestimation of the heating consumption due to the slightly higher hot water consumption in winter.

As a rule, the annual period **October 2019 to September 2020, the year 2020 or February 2020 to January 2021** was evaluated as the **measurement period**. In the case of BEST19, an additional measurement period is available: **June 2020 to April 2021**. Only in this project, the heating consumption had to be extrapolated for the missing month of May 2021. Since virtually no heating consumption is to be expected at this time, the error is negligible. For the extrapolation the forecasts of the monthly share of annual consumption from the PHPP are used. For two SINFONIA projects in Innsbruck there are no evaluable measurement data available.

In order to adjust the PHPPs, it is necessary to take into account not only the weather data (outdoor temperature and global radiation) appropriate for the period, but also the measured indoor temperatures. For this purpose, the indoor temperatures of the winter months (October to April) were filtered from the monitoring database only for those apartments which could be evaluated energetically. These measured temperatures were - analogous to the consumption data - summarised in a surface-weighted average value of the measured flats and considered in the PHPP. Usually these temperatures are significantly higher than the 20°C set in advance in the standard case, which increases the calculated heating demand. By contrast, the climatic conditions (outside temperature and global radiation) of the investigated period lead to a significant reduction of the heat demand, since the weather conditions during the measurement period were warmer than in the long-term climate data set. Thus, these effects partly compensate each other.

The BEST-Sheets used in all projects include the specification "Heating + Ventilation" (lines 30 and 31). According to the heading, these specifications also include the "system losses". Since the measured values of the individual apartments are evaluated here (exception BEST07), the measured values do not include any "system losses". For this reason, the amounts of distribution losses entered in the BEST-Sheets were deducted again prior to the application. In some cases, there were no entries in the calculation cells; in this case, the value was transferred unchanged.

Deviations and special features compared to the above description for a project are indicated in the following evaluation of the building.

2.2 BUILDING BEST03

2.2.1 BRIEF INTRODUCTION OF THE BUILDING BEST03

FIGURE 10: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the BEST03 building can be found in the following table.

TABLE 1: INTRODUCTION OF THE BUILDING BEST03

	Subject area	**Specifications**
1	Position	Innsbruck
2	TFA / BEST-Sheet area [m²]	1 791 / 2 115
3	year of construction/ refurbishment	1940 / November 2016
4	number of apartments total/monitoring energy	34 / 8 (23% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (100%), airtightness upgraded, ventilation systems partly (38%)
6	Period Data analysis	January to December 2020
7	average indoor temperature (winter) of the measured apartments	22.6 °C

2.2.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

Figure 11 shows an overview of the data of the BEST-Sheets without distribution losses, the energy performance certificate and the measured data in relation to the BEST-Sheet area. On the left-hand side of the diagram, the demand value for the old building after the calculation in the BEST-Sheet is shown first. Next follow two values from the BEST-Sheet for a fully implemented refurbishment: the national minimum requirements from 2006 for the standard conditions of the calculation ("Nat. regulation 2006, stand. condi.") and the refurbishment objectives set with the BEST-Sheet for the standard conditions ("BEST-Sheet, stand. condi.").

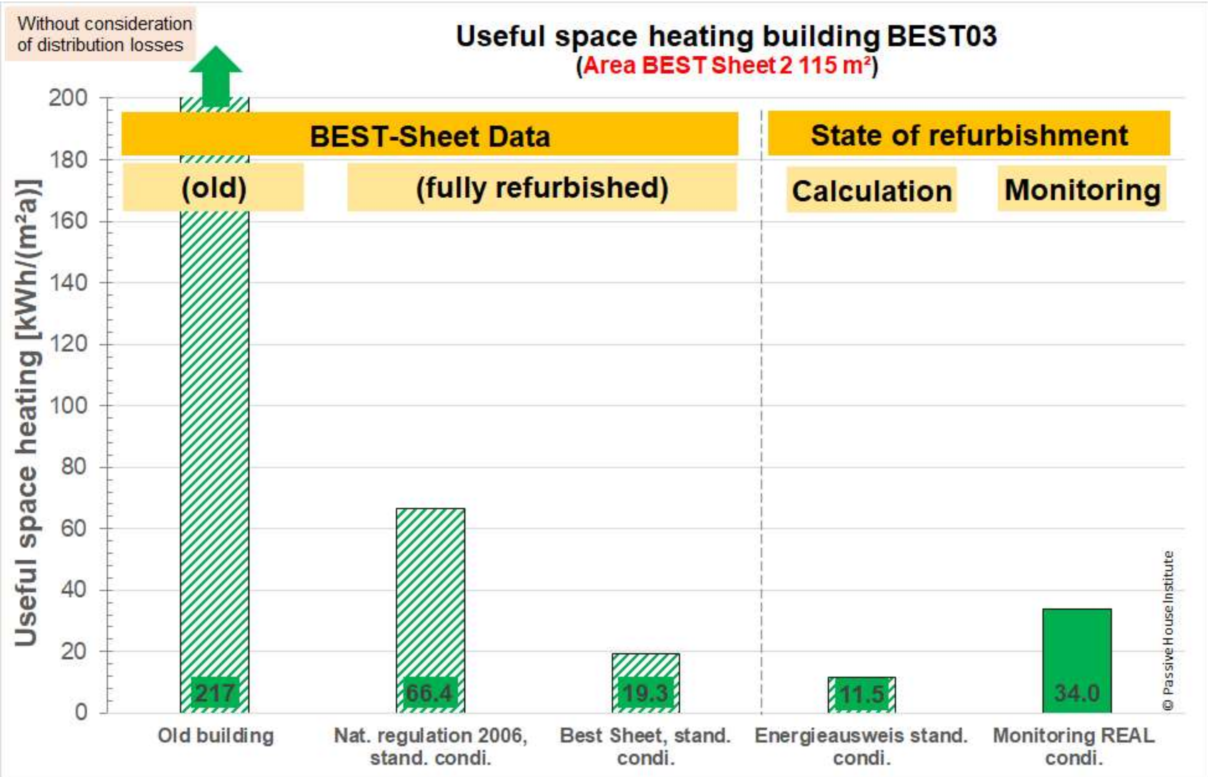

FIGURE 11: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS"(ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

On the right side of the diagram is the result of the calculation, the Energieausweis for the standard conditions ("Energieausweis stand. condi."), which was adjusted after the renovation. This value represents the target value for the heating requirement of 11.5 kWh/(m²a) before using this calculation method. The measured value of the sample is the last one on the right-hand side. With

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reference to the BEST-Sheet area, this is almost three times higher at 34.0 kWh/(m²a). In this comparison it should be noted that no government calculation rule has been established to reflect the later reality as accurately as possible. It serves as a uniform procedure with a standardised calculation rule to implement the requirements chosen by the legislator. Such calculation rules are designed for average building qualities and not for particularly energy-efficient ones. Therefore the suitability for consumption prediction is clearly limited.

2.2.3 COMPARISON B: PHPP AND MONITORING

For the energy balance of the building BEST03 using PHPP the Treated Floor Area (TFA) is used as reference value. With a heating requirement of only 18.1 kWh/(m²a), the calculation shows the potential of complete refurbishment (Figure 12, left column, completely refurbished, standard conditions and internal temperature of 20°C). For a renovated old building these are excellent demand values. For the refurbishment steps realised so far, a demand value for heating energy of 31.5 kWh/(m²a) is calculated for standard boundary conditions (long-term climate data Innsbruck, indoor temperature 20°C) (second column from left).

In the measurement year under investigation (2020), the milder weather conditions and the significantly increased indoor temperature (22.6°C) lead to a demand value of only 22.5 kWh/(m²a) (third column from left). This adjustment reduces the demand value by 9.0 kWh/(m²a). The measurement of the sample of the 8 apartments of the building leads to a measured heating consumption of 36.9 kWh/(m²a) (area reference here: TFA according to PHPP). From the measured values it can be concluded that the average consumption of the renovated flats lies between 17 and 63 kWh/(m²a) with a probability of 95% (confidence interval 23.1 kWh/(m²a)). Taking into account the reduced accuracy of the balance calculation (see Section 2.1.2), the result of the measurement is within the expected measurement range. It can therefore be assumed that there is good agreement with the model despite the small number of measured dwellings. After the completion of the refurbishment with the next step, the desired goal can be achieved. Also the 40.2 kWh/(m²a) already realised are a good result for a refurbished old building.

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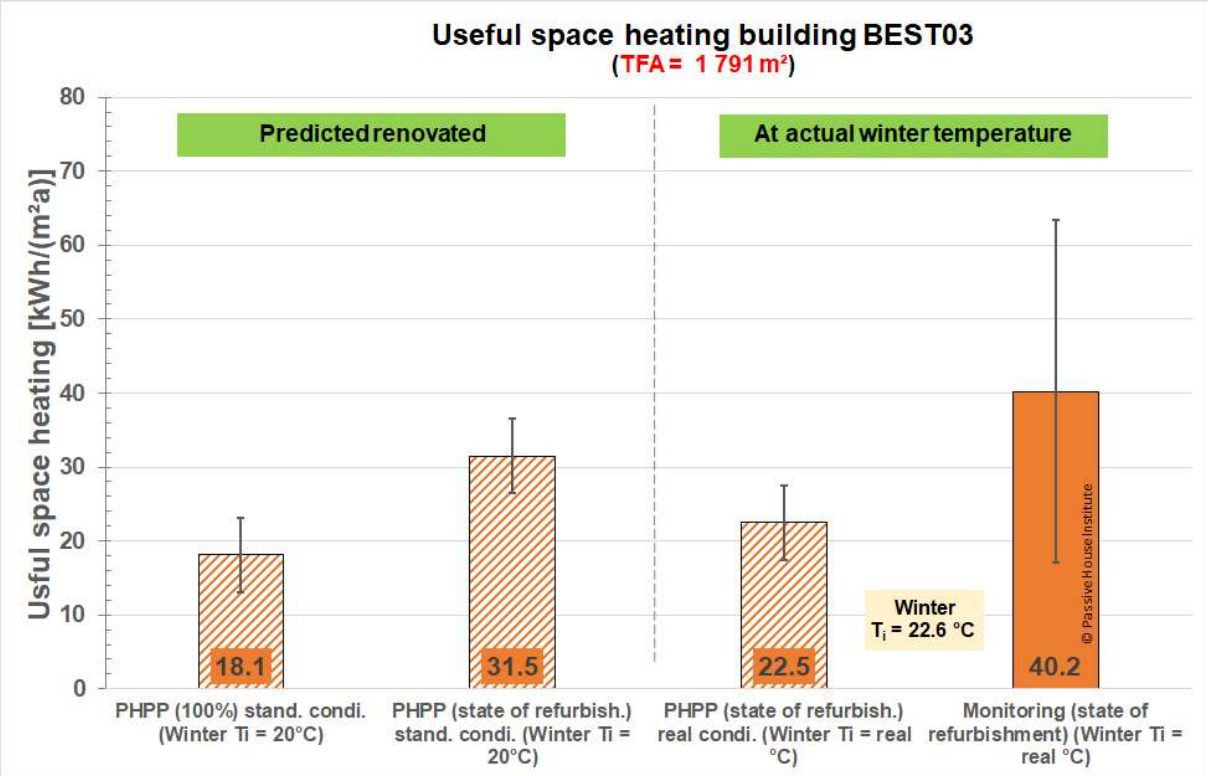

FIGURE 12: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

The building has been balanced with 149 kWh/(m²a) in the old building condition (PHPP, standard conditions). This means that a reduction of 73% in the area of heating was already achieved in the current renovation (see Figure 13).

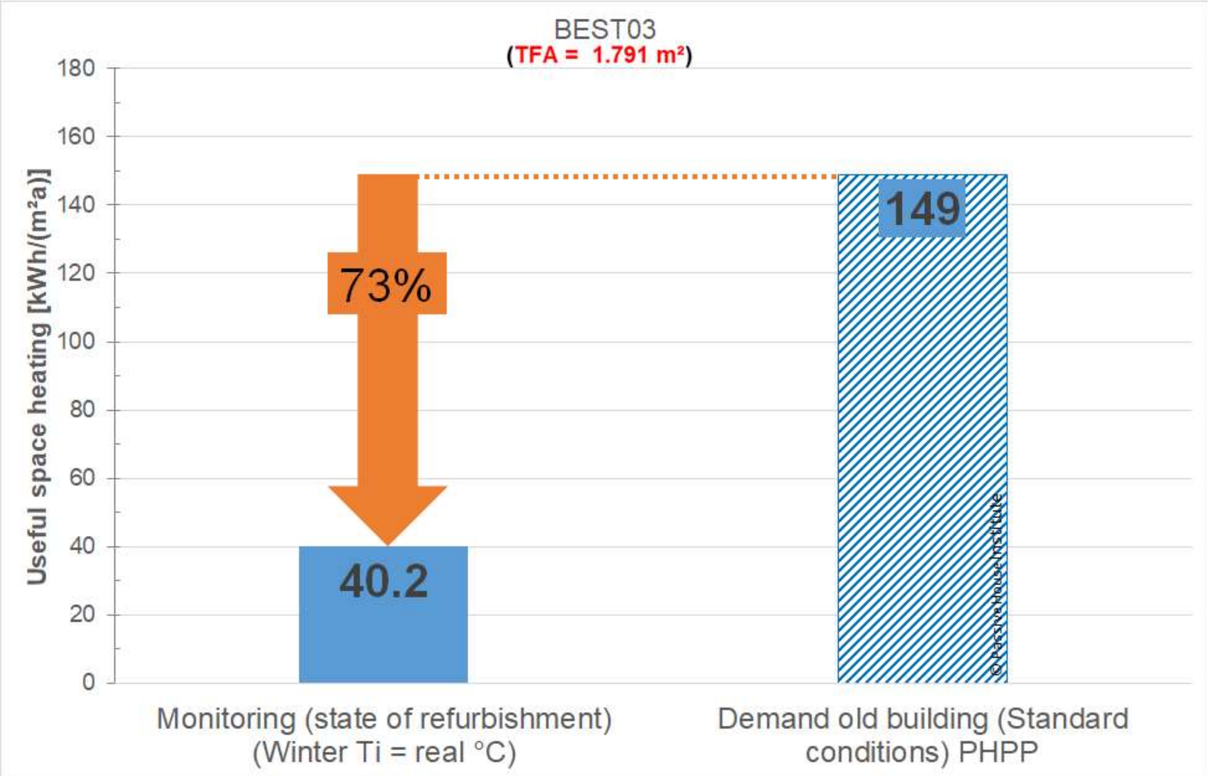

FIGURE 13: COMPARISON OF THE MEASURED CONSUMPTION VALUE AND THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST03 (PHPP).

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2.3 BUILDING BEST04

2.3.1 BRIEF INTRODUCTION OF THE BUILDING BEST 04

FIGURE 14: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the building BEST04 can be found in the following table.

TABLE 2: INTRODUCTION OF THE BUILDING

	Subject area	**Specifications**
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	2 680 / 3 650
3	year of construction/ refurbishment	1941 / December 2019
4	number of apartments total/monitoring energy	39 / 6 (14% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (100%), airtightness upgraded, ventilation systems partly (33%)
6	Period Data analysis	January to December 2020
7	average indoor temperature (winter) of the measured apartments	21.6 °C

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2.3.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

The content and structure of the following diagram has already been explained in section 2.2.2. For the project in Schubertstraße, the calculation procedure for the energy performance certificates results in a target value of 11.4 kWh/(m²a) for the heating requirement. The specific measured value for heating consumption from 6 of the 39 apartments is only 20.2 kWh/(m²a), which is significantly lower than BEST03.

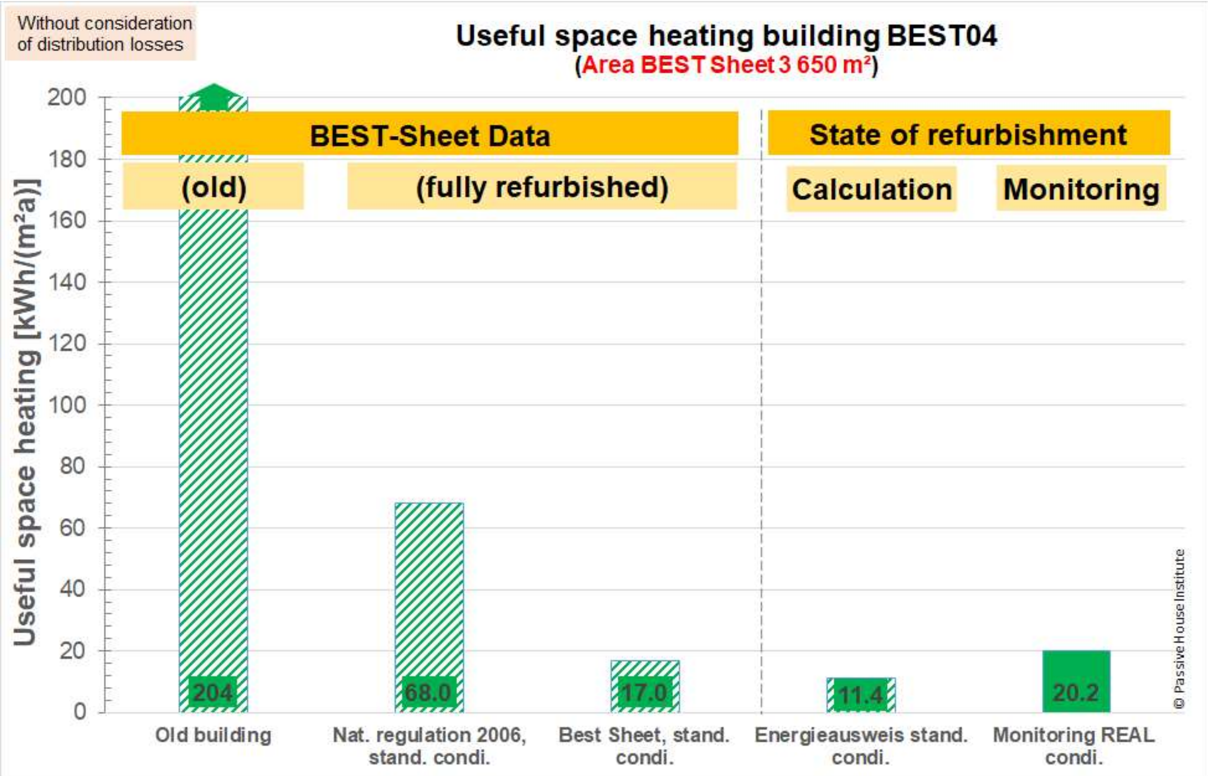

FIGURE 15: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIEAUSWEIS" (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

2.3.3 COMPARSION B: PHPP AND MONITORING

The structure of the graph and the corresponding explanation of the comparison of the PHPP calculations with the measured value has also been given above (Section 2.2.3). The potential to be expected with a complete remediation is 17.8 kWh/(m²a), the previous remediation step allows 31.6 kWh/(m²a) to be expected under standard conditions. The conditions in the measurement year (2020) indicate a heating consumption of 19.3 kWh/(m²a). The measurement result of 27.5 kWh/(m²a) is sufficiently close to the expected value despite the small sample.

The measured data of 27.5 kWh/(m²a) represent a very good result of a refurbishment.

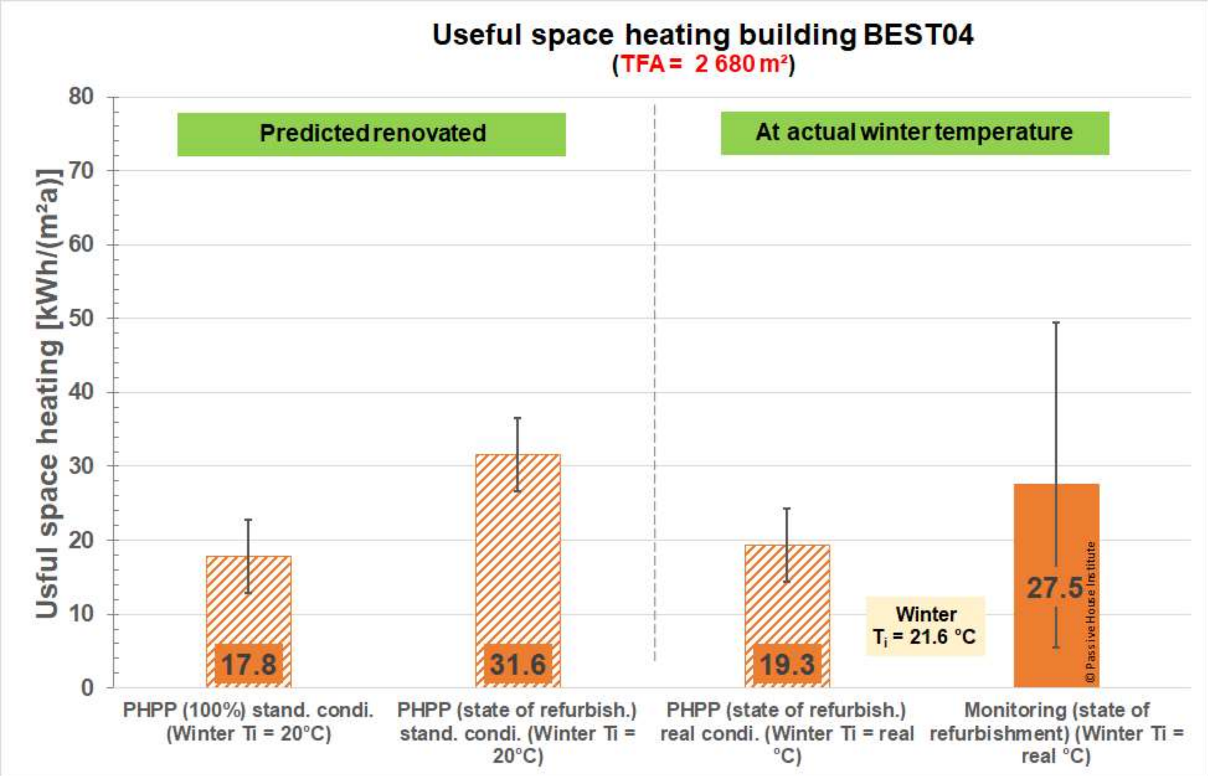

FIGURE 16: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

The comparison of the measured value with the calculation of the heating requirement of the old building situation (standard conditions, 20°C) shows the enormous saving of 77% already after this renovation step.

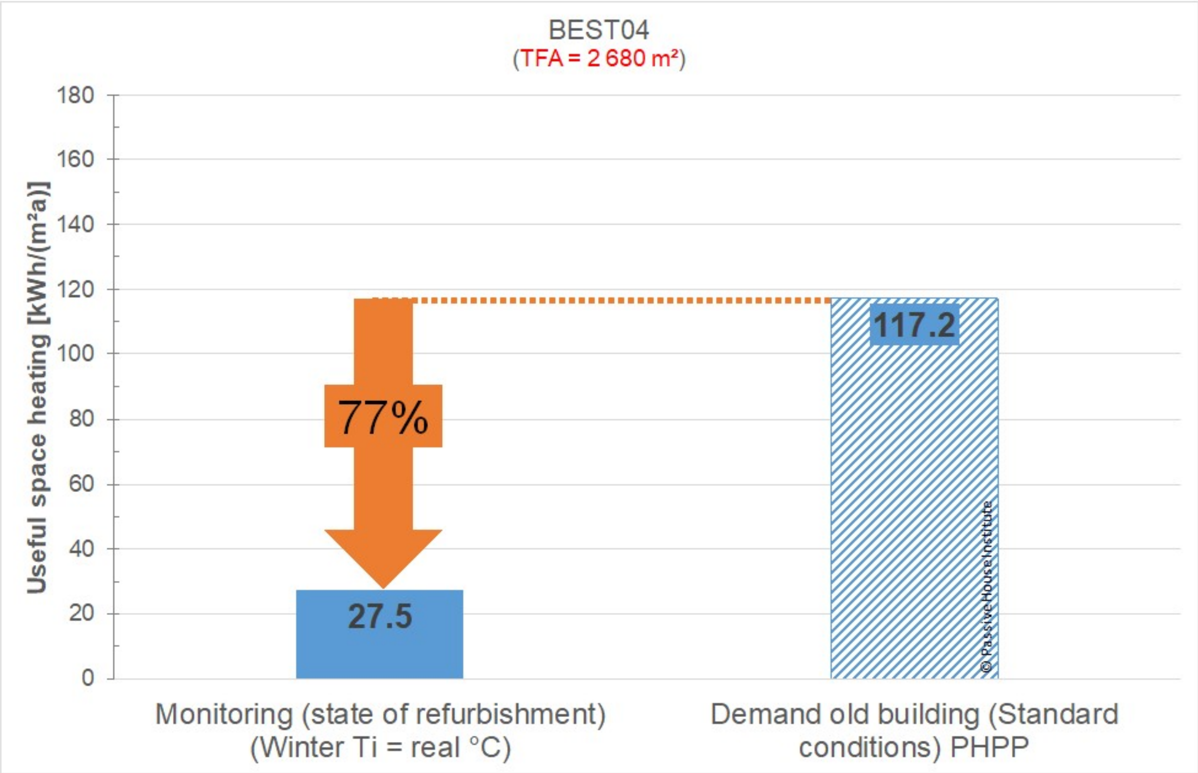

FIGURE 17: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST04 (PHPP).

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2.4 BUILDING BEST05

2.4.1 BRIEF INTRODUCTION OF THE BUILDING BEST05

An overview of the most important points concerning the building BEST05 can be found in the following table.

TABLE 3: INTRODUCTION OF THE BUILDING

	Subject area	Specifications
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	1 417 / 1 897
3	year of construction/ refurbishment	1941 / December 2019
4	number of apartments total/monitoring energy	20 / 4 (19% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (100%), airtightness upgraded, ventilation systems partly (60%)
6	Period Data analysis	January to December 2020
7	average indoor temperature (winter) of the measured apartments	21.6 °C

2.4.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

The content and structure of the following diagram has already been explained in section 2.2.2 For the project BEST 05, the calculation method of the energy performance certificates results in 11.9 kWh/(m²a) as the target value for the heating requirement. The specific measured value for heating consumption from 4 of the 20 apartments is, however, even lower at only 7.7 kWh/(m²a).

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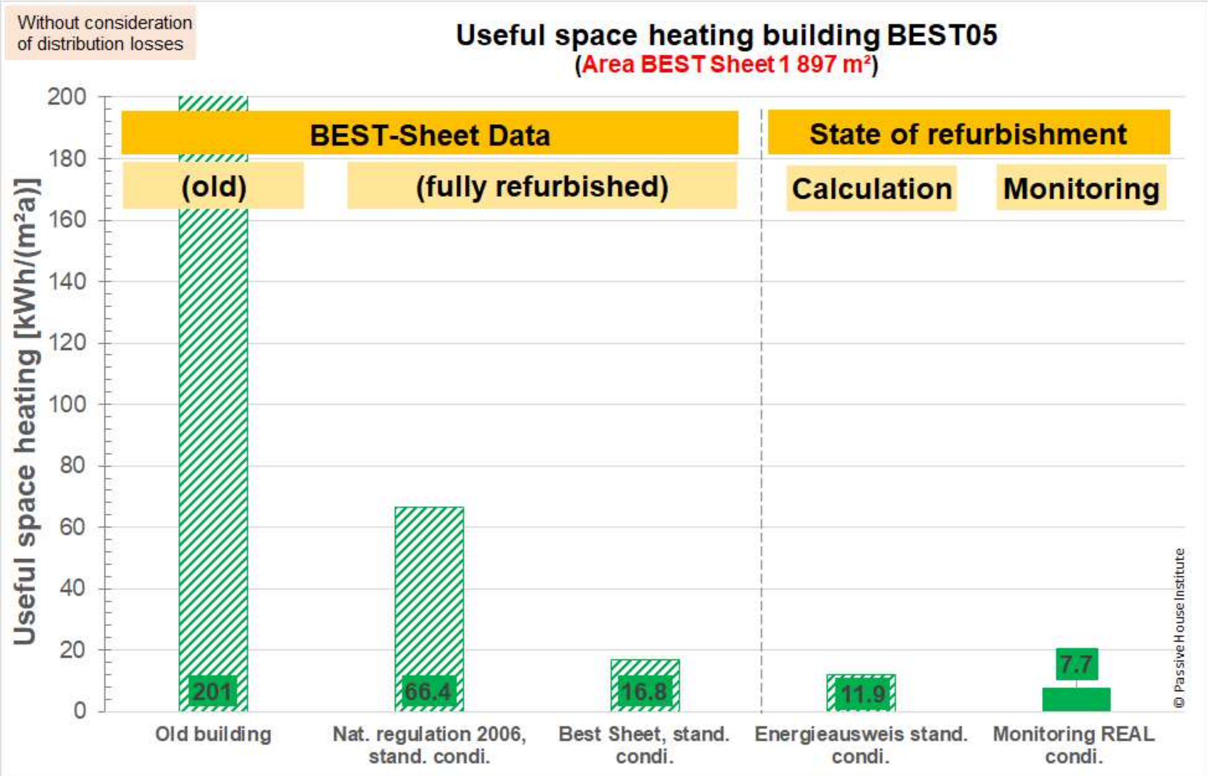

FIGURE 18: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIEAUSWEIS" (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

2.4.3 COMPARSION B: PHPP AND MONITORING

The structure of the graph and the corresponding explanation of the comparison of the PHPP calculations with the measured value has also been given above (Section 2.2.3).

The potential to be expected in the case of a complete refurbishment is 19.5 kWh/(m²a) for BEST05, the previous refurbishment step allows for 27.4 kWh/(m²a) under standard conditions. The conditions in the measurement year (2020) allow for a heating consumption of 21.0 kWh/(m²a). The monitoring result of 10.3 kWh/(m²a) is extremely low, although a relatively high indoor temperature was documented (21.6°C).

Here, too, the small sample limits the informative value. Therefore, the standard deviation of the mean value of 16.0 kWh/(m²a) is relatively large at the low mean value. The measured data with 10.3 kWh/(m²a) represent an extremely good result of a renovation.

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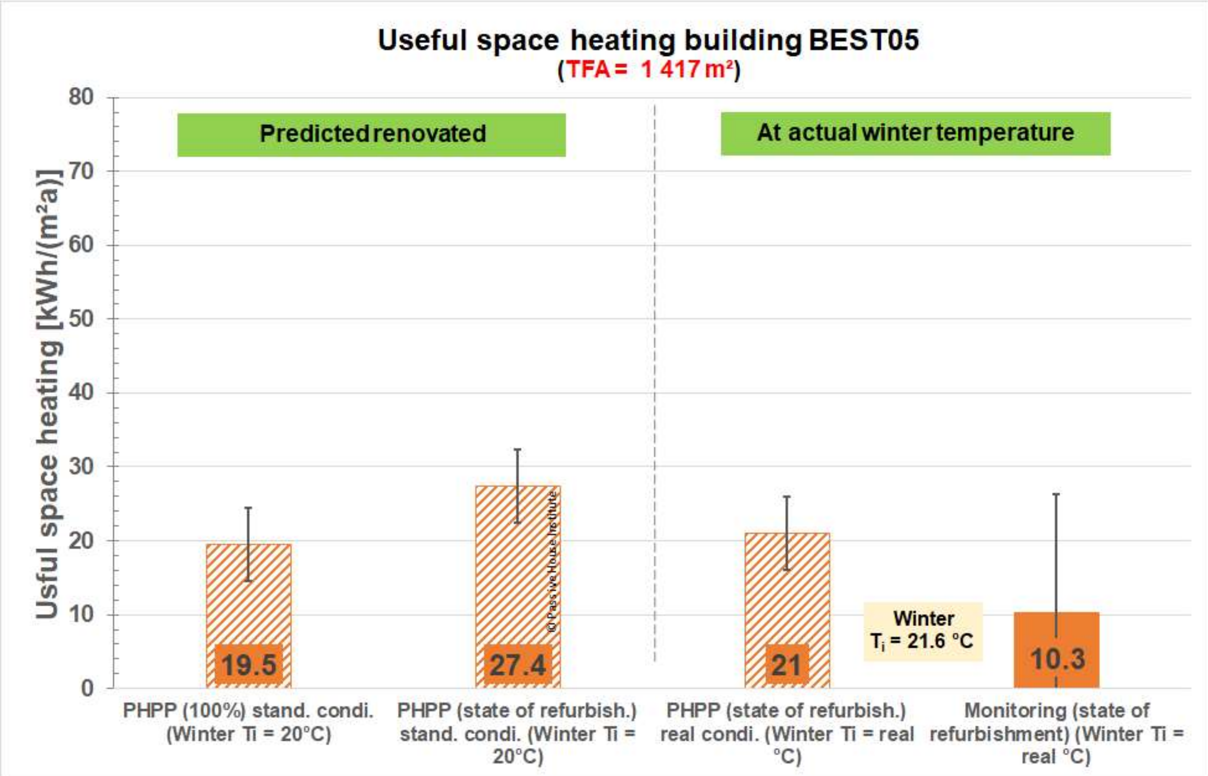

FIGURE 19: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

Due to the very low monitoring result, there is a very high saving of 91% compared to the calculation of the heating requirement of the old building situation (standard conditions, 20°C). Such high savings have also been achieved in other systematic renovations with Passive House components. However, these are always complete renovations.

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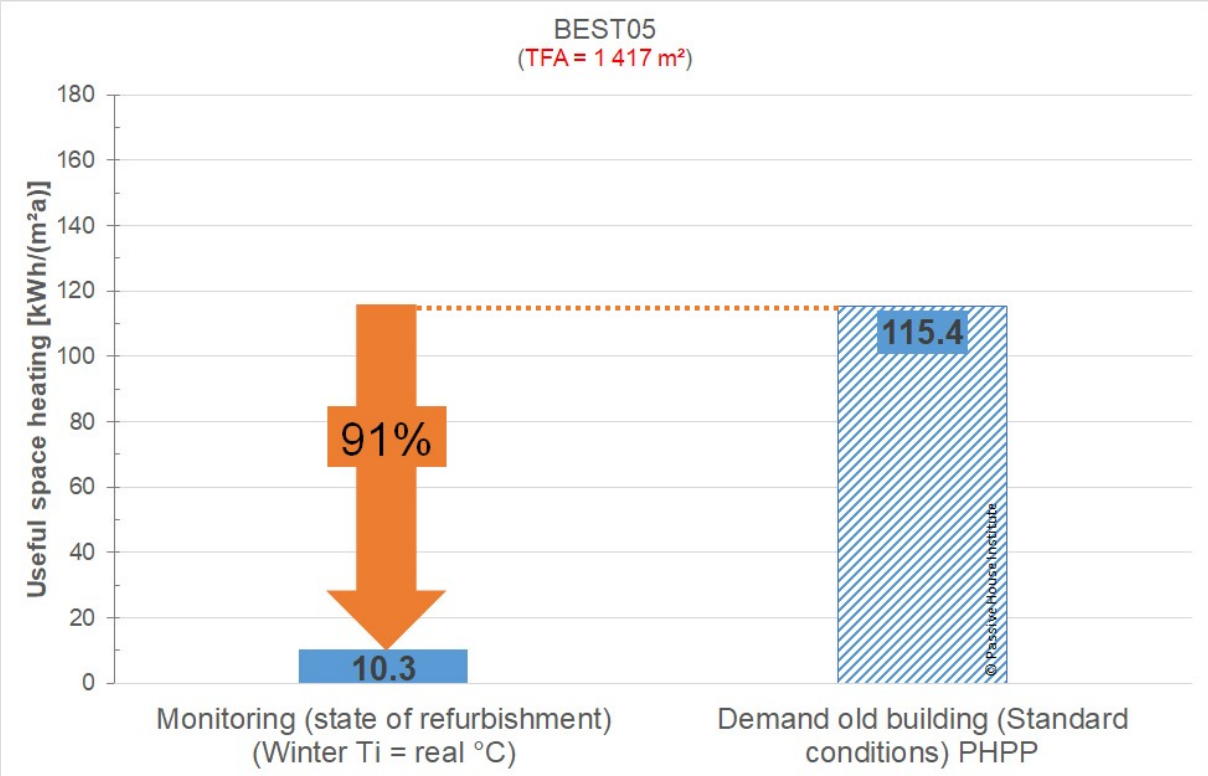

FIGURE 20: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST05 (PHPP).

2.5 BUILDING BEST16 (SCHOOL)

2.5.1 BRIEF INTRODUCTION OF THE BUILDING BEST16:

FIGURE 21: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: GOOGLE.COM)

An overview of the most important points concerning the school building can be found in the following table.

TABLE 4: INTRODUCTION OF THE BUILDING

	Subject area	Specifications
1	position	Innsbruck (school)
2	TFA / BEST-Sheet area [m²]	2 352 / 3 185 (South building of the school)
3	year of construction/ refurbishment	1956 / Nov. 2018
4	Building sections	South building of the school
5	state of refurbishment	Refurbishment fully completed
6	Period Data analysis	February 2020 to January 2021
7	average indoor temperature (winter) of the measured apartments	22.5°C

2.5.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

For the school the BEST-Sheets show demand values for the unrenovated school of 120 kWh/(m²a) compared to the full renovation of 32.2 kWh/(m²a). The Energieausweis take into account the renovation work carried out and the demand value is 14.1 kWh/(m²a). The measured value shows only

15.9 kWh/(m²a) if the reference area of the 3 185 m² is taken into account. An explanation of the diagram structure can be found in section 2.2.2.

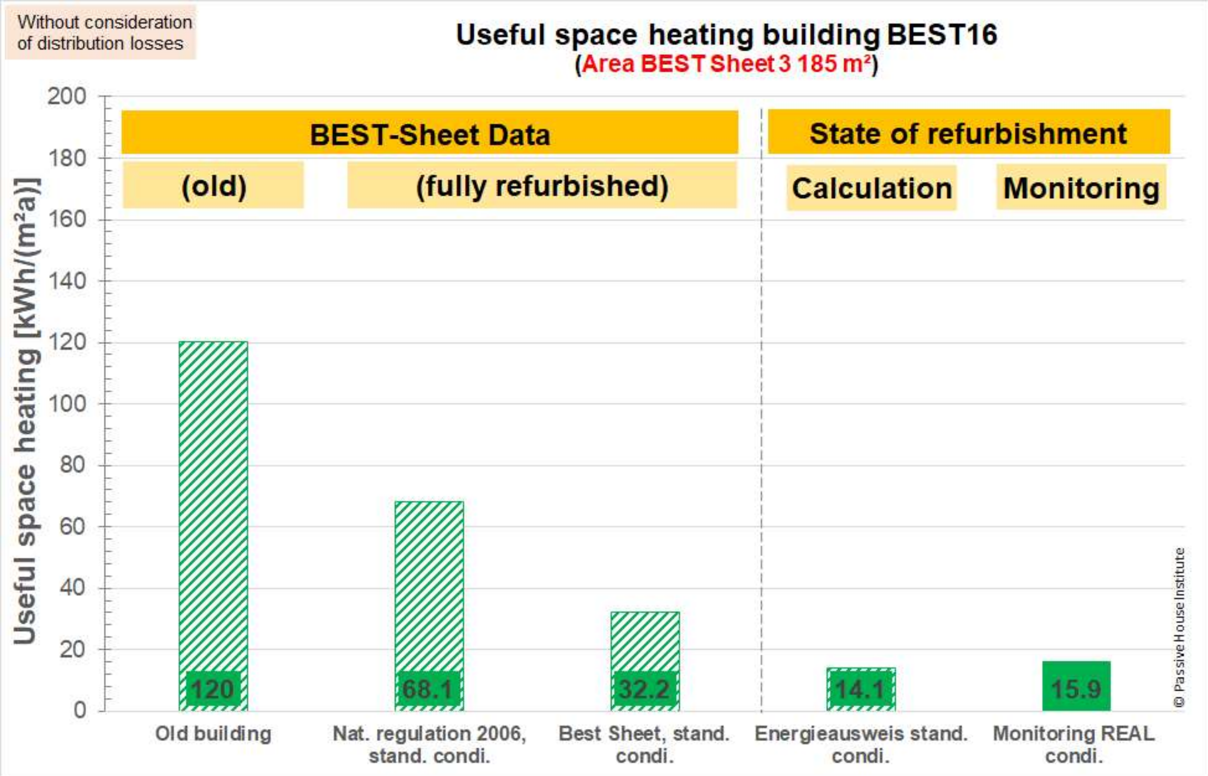

FIGURE 22: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS" (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

2.5.3 COMPARSION B: PHPP AND MONITORING

The investigation of the complete school refurbishment with the PHPP balance tool already leads to a moderate 23.7 kWh/(m²a) under standard conditions (for information on the diagram see Section 2.2.3). The real conditions from the period February 2020 to January 2021 result from the measured indoor temperature of 22.5°C to the even lower demand value of only 21.9 kWh/(m²a). The annual consumption value shows with 21.5 kWh/(m²a) and extremely low consumption despite the relatively high indoor temperature. A usual value of ±5 kWh/(m²a) is assumed here as the measurement uncertainty. Nevertheless, the generally great success of the renovation work carried out can be determined with a high degree of certainty: Operating a school building with consumption values around than 20 kWh/(m²a) is ambitious in any case.

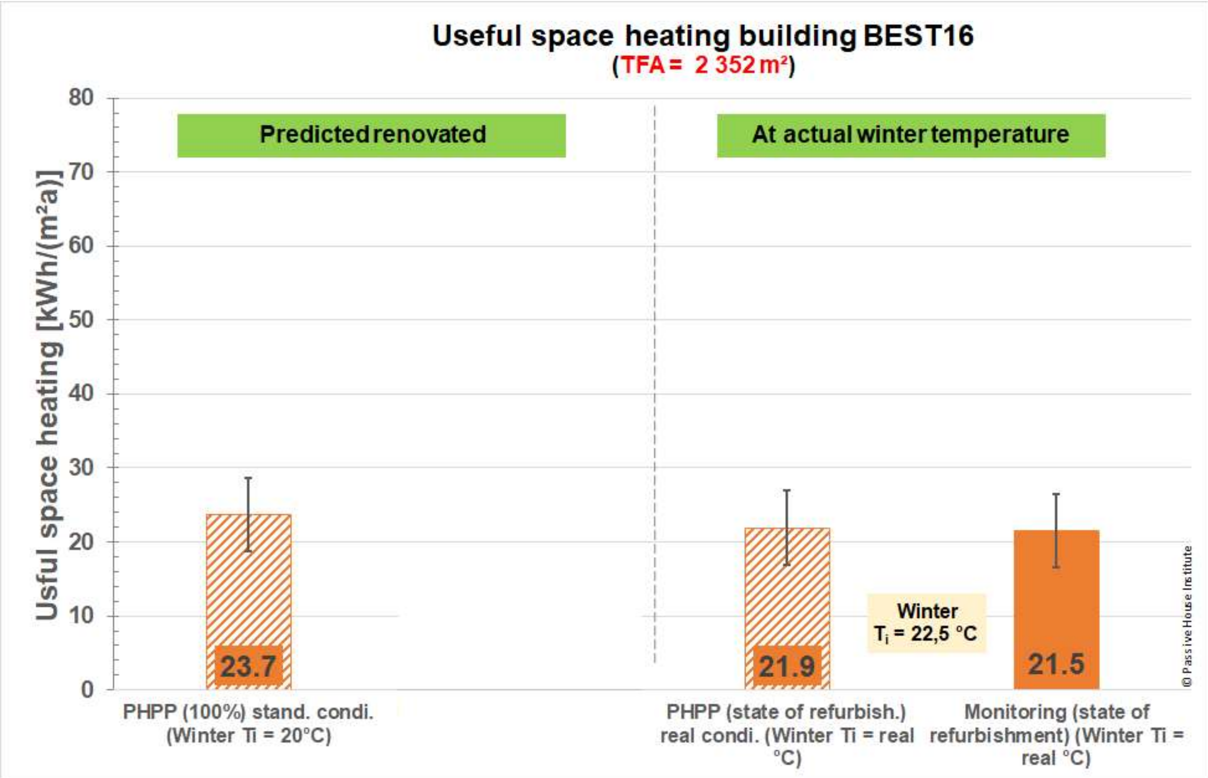

FIGURE 23: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

The calculation of the conditions before the refurbishment using PHPP under standard conditions leads to a heating requirement of 209 kWh/(m²a) for the school building. Compared to the measured value after the refurbishment, the following figure shows the massive savings of over 90%. This shows the actual success of the thermal refurbishment of the building.

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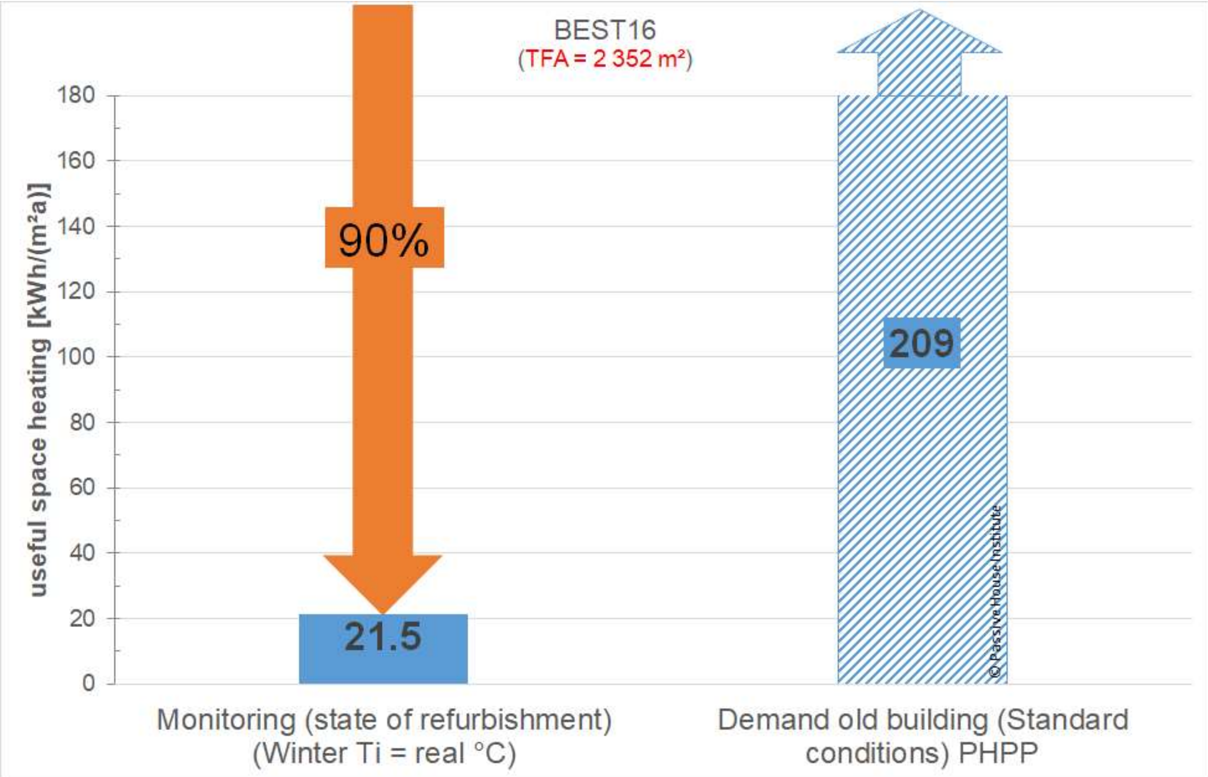

FIGURE 24: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST16 (PHPP).

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2.6 BUILDING BEST17 (SCHOOL)

2.6.1 BRIEF INTRODUCTION OF THE BUILDING BEST17:

FIGURE 25: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: GOOGLE.COM)

An overview of the most important points concerning the school building can be found in the following table.

TABLE 5: INTRODUCTION OF THE BUILDING

	Subject area	Specifications
1	position	Innsbruck (school)
2	TFA / BEST-Sheet area [m²]	- / 5 616
3	year of construction/ refurbishment	1960 / Jan. 2016 and Nov. 2018
4	Building sections	building parts BA1 + BA2
5	state of refurbishment	Refurbishment fully completed
6	Period Data analysis	not available
7	average indoor temperature	not available

2.6.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

For the school the BEST-Sheets show demand values for the unrefurbished school of 135.2 kWh/(m²a) compared with the full refurbishment of 69.3 kWh/(m²a). The Energieausweis takes into account the renovation work carried out and the demand value is 65.9 kWh/(m²a).

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The measurements required for the determination of the consumption data are not available. However, it is possible to refer to the work of [Sengel 2018], although the evaluation there was not carried out according to the same procedure as in this analysis. For the heating consumption, Sengel reports 118.6 kWh/(m²a) in the unrefurbished state. After the refurbishment, the consumption for 2017 was 35.7 kWh/(m²a) according to Sengel. The temperature measurements showed an indoor temperature of 24.5 °C. Since the data cannot be directly compared with those in this report, the values are not used further here.

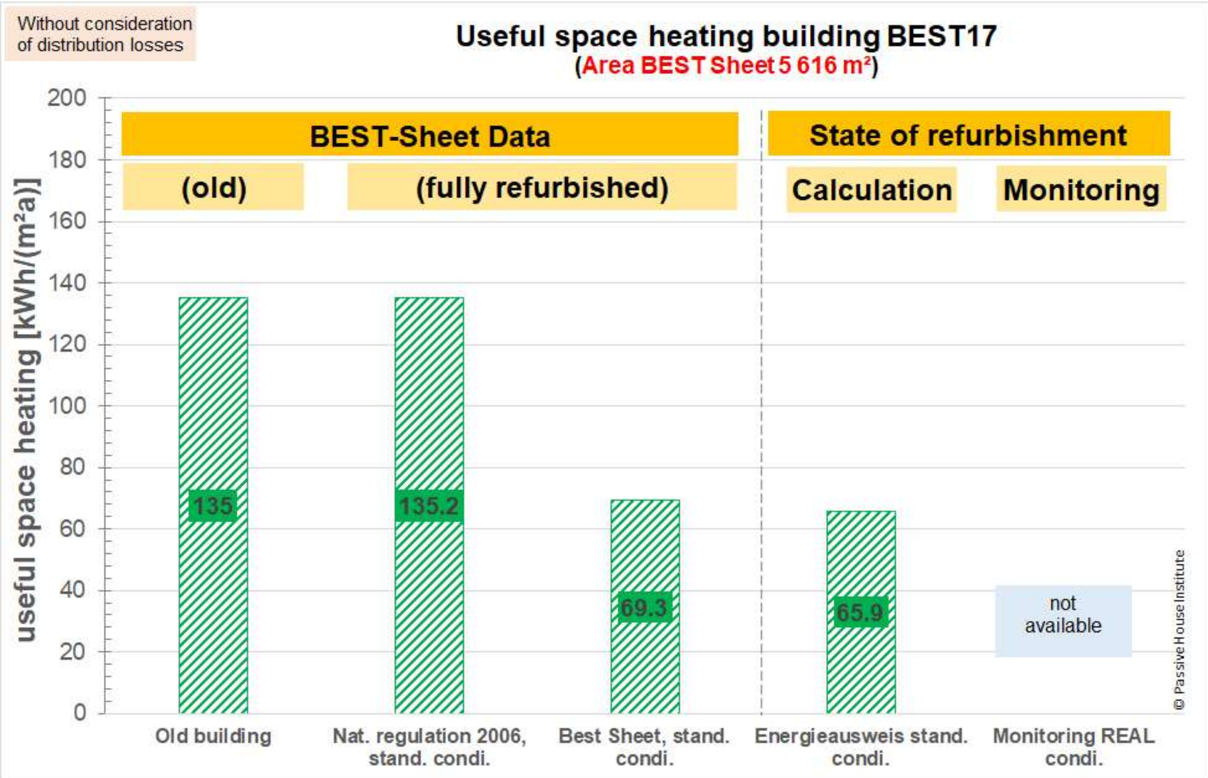

FIGURE 26: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS" (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS). THE MEASURED CONSUMPTION VALUES ARE TO BE ADDED.

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2.7 BUILDING BEST18 (SCHOOL):

2.7.1 BRIEF INTRODUCTION OF THE BUILDING BEST18:

FIGURE 27: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: GOOGLE.COM)

An overview of the most important points concerning the school building can be found in the following table.

TABLE 6: INTRODUCTION OF THE BUILDING

	Subject area	Specifications
1	position	Innsbruck (school)
2	TFA [m²] Energieausweis area [m²] BEST-Sheet area [m²]	2 050 (only building part BT1 + BT2) 3 073 (only building part BT1 + BT2) 5 139 (whole school)
3	year of construction/ refurbishment	1956 / Nov. 2016
4	Building sections	building parts BT1 + BT2
5	state of refurbishment	Refurbishment fully completed (building part BT1 + BT2)
6	Period Data analysis	February 2020 to January 2021
7	average indoor temperature (winter) of the measured apartments	21.4 °C

2.7.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

In the case of the school building, the total area of the school buildings (5,139 m²) was used when the BEST-Sheet was prepared. However, only the south wing of the school was renovated and examined.

According to the Energy Performance Certificate, this part has a total area of 3,073 m², and according to the PHPP calculation a TFA of 2,050 m². For this reason, the diagrams are splitted. For the entire school the BEST-Sheets show demand values for the unrefurbished whole complex of 157 kWh/(m²a) compared to the full refurbishment of 30,3 kWh/(m²a).

The Energieausweis take into account the renovation work carried out and calculate the demand at only 13.4 kWh/(m²a) for the underlying 3,073 m². The measured value for the south wing, on the other hand, shows 17.9 kWh/(m²a).

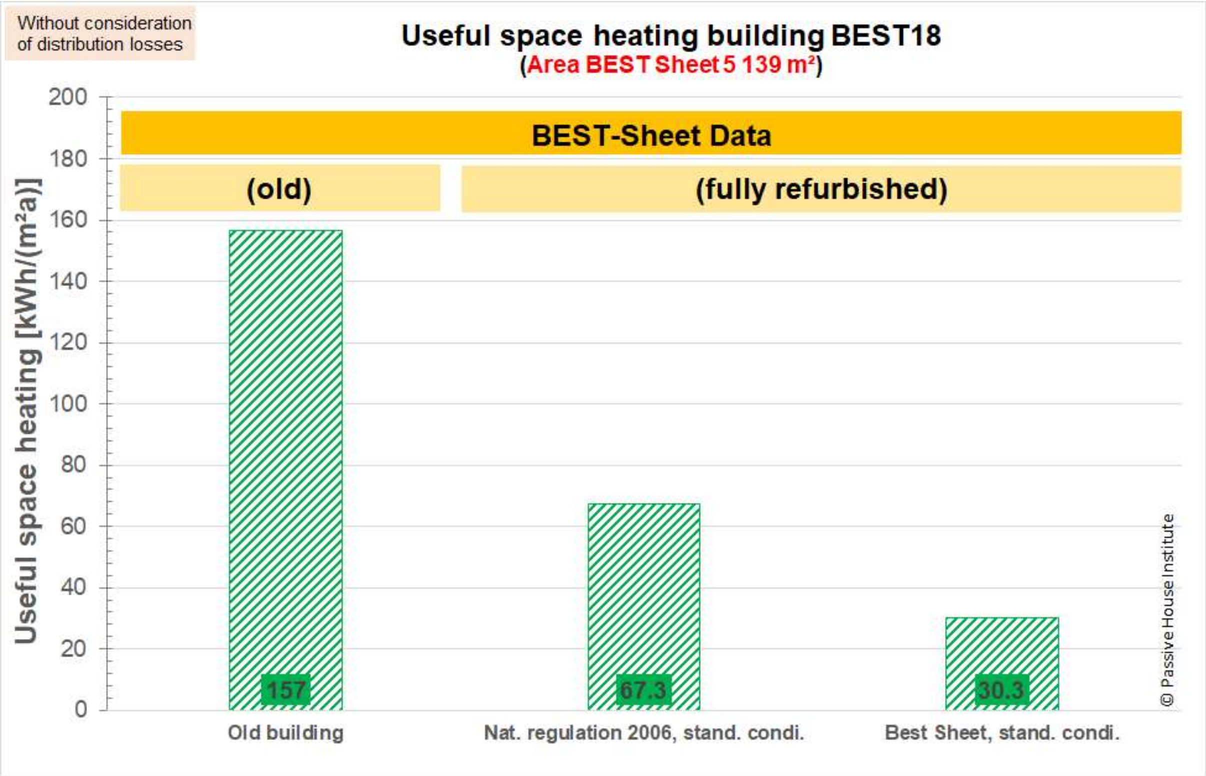

FIGURE 28: THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO BEST-SHEETS IN RELATION TO THE BUILDING AREA ONLY OF THE BEST-SHEET FOR THE WHOLE SCHOOL (PART BT1 TO BT4).

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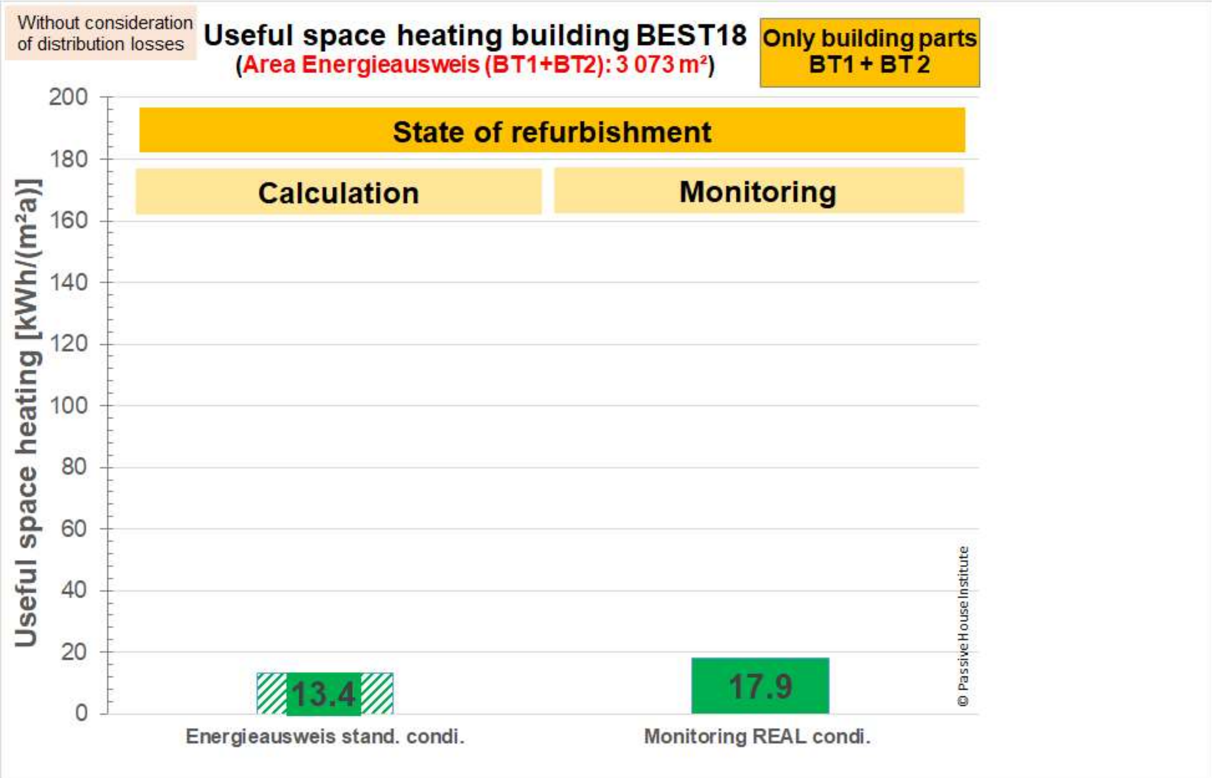

FIGURE 29: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS" (ENERGY CERTIFICATE) WITH THE MEASURED CONSUMPTION VALUES ONLY FOR THE PART OF THE BUILDINGS BT1 + BT2.

2.7.3 COMPARSION B: PHPP AND MONITORING

At the school a complete renovation was carried out for the BT1 and BT2 wings. Due to the full refurbishment, the version for the "current refurbishment step" is identical to the full refurbishment when calculating using PHPP. The calculation for the renovated building results in a heating requirement of 24 kWh/(m²a) using the long-term Innsbruck climate data set and 20°C standard indoor temperature.

If the balance calculation is adjusted to the actual conditions of the measuring period (weather 2020/2021, indoor temperature 21.4°C), the calculated result is 20.7 kWh/(m²a), which is slightly below the measured value of 26.8 kWh/(m²a). Using the present uncertainties of the boundary conditions of the balance calculation, as well as the measurement, the agreement is very good. Usually the measurement uncertainty is ±5 kWh/(m²a) in this case.

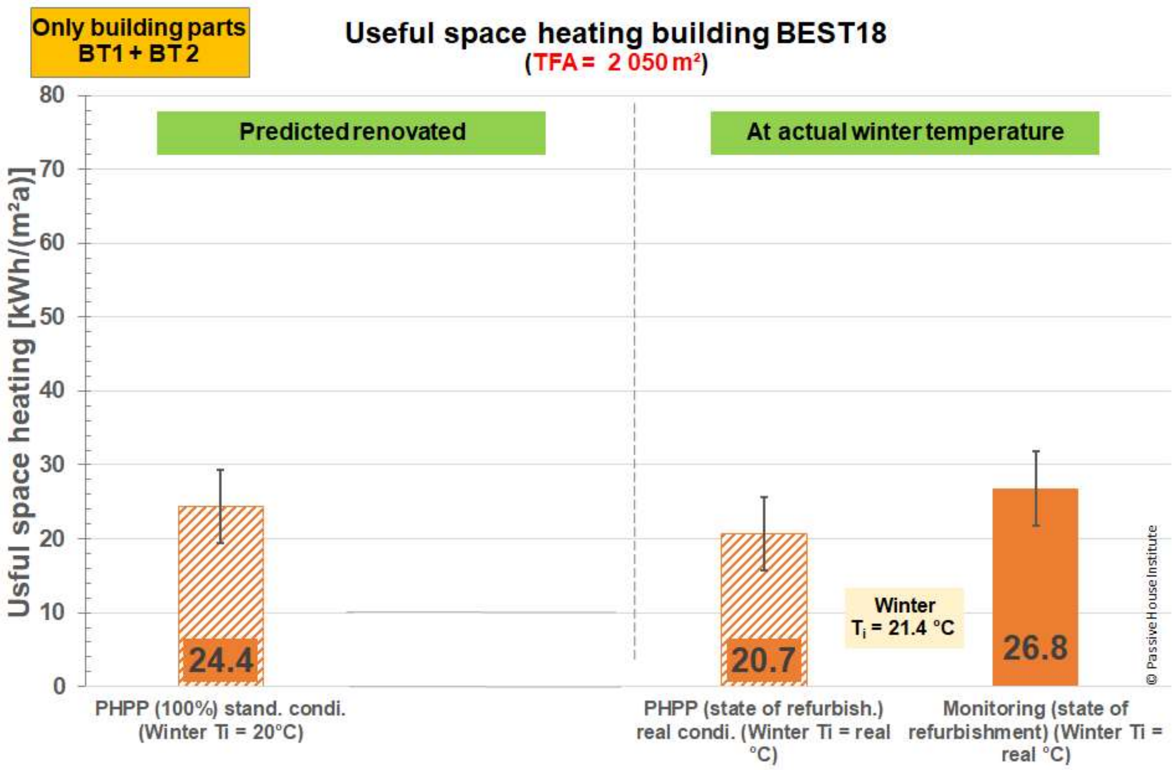

FIGURE 30: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

For this school building too, the condition of the old building was balanced with the PHPP in order to be able to estimate the heating requirements before the refurbishment. Figure 31 shows that a saving of almost 90% was achieved. This corresponds to a saving of about 390 000 kWh per year in heating energy for the two building components (BT1 + BT2) of the school.

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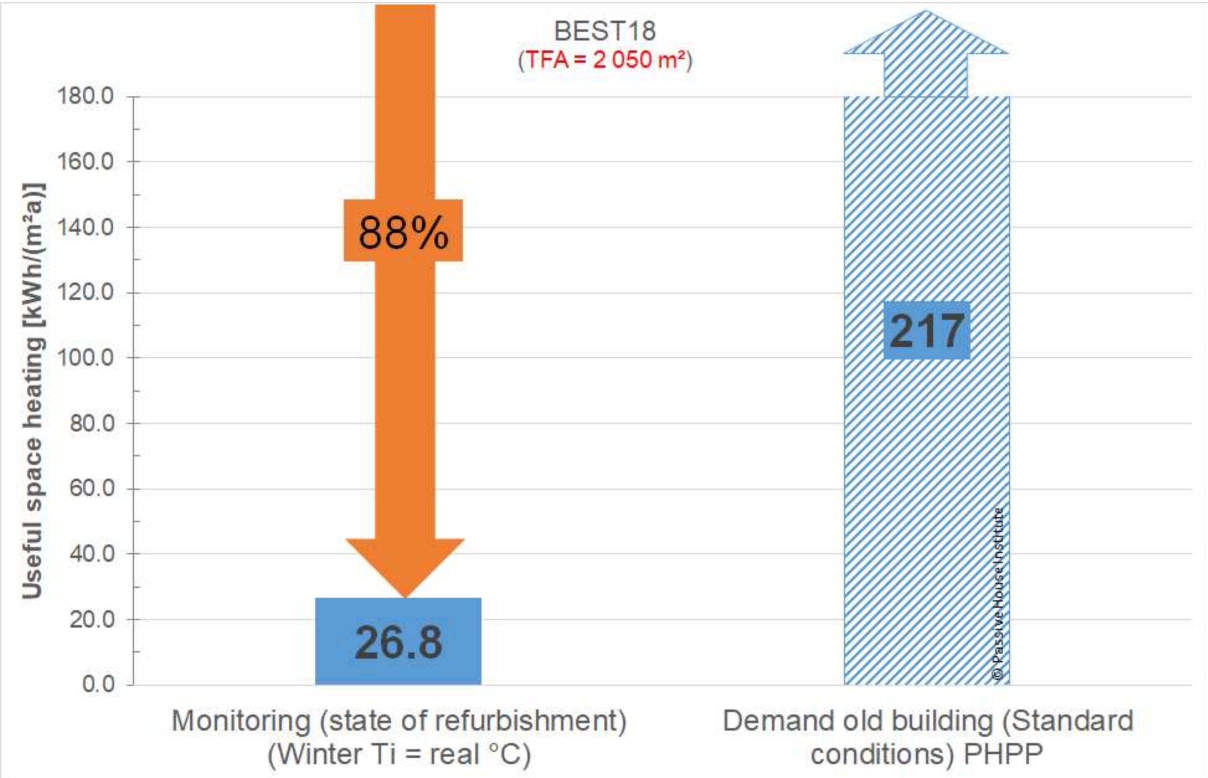

FIGURE 31: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST16 (PHPP).

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2.8 BUILDING BEST07

2.8.1 BRIEF INTRODUCTION OF THE BUILDING BEST07

FIGURE 32: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the building BEST07 can be found in the following table.

TABLE 7: INTRODUCTION OF THE BUILDING

	Subject area	**Specifications**
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	3 500 / 4 933
3	year of construction/ refurbishment	1963 / November 2017
4	number of apartments total/monitoring energy	49 / 49 (100% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (72%), airtightness upgraded, ventilation systems partly (22%)
6	Period Data analysis	May 2019 to April 2020
7	average indoor temperature (winter) of the measured apartments	21.1 °C

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2.8.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

The structure of the following graphic has already been explained in section 2.2.2. For the large multi-family building with 49 flats, the calculation method of the energy performance certificates results in a target value of 21.6 kWh/(m²a) for the heating requirement.

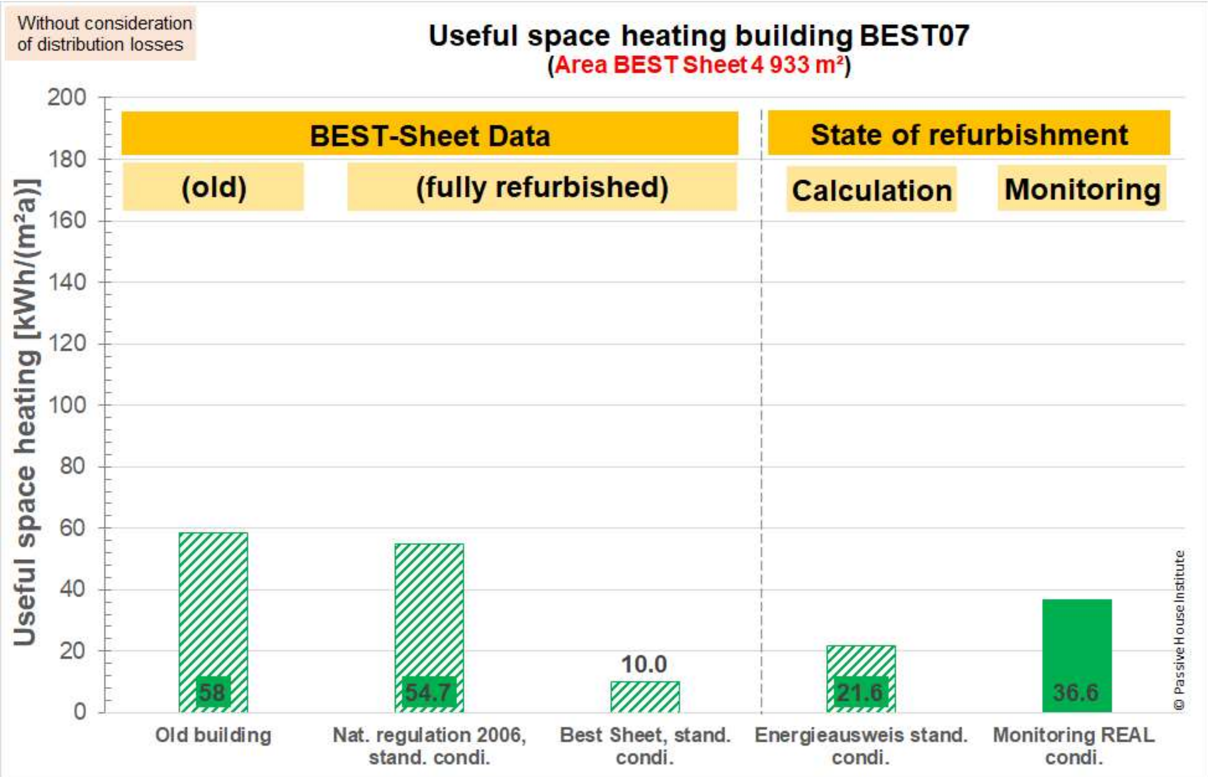

FIGURE 33: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO “ENERGIEAUSWEIS” (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

The special feature of the measurement data acquisition of the building lies in the evaluation of the central district heating meter for the entire building. No individual values of the apartments are recorded. When measuring the heat consumption of the entire building at the transfer station, all conversion, storage and distribution losses are included. Since statements on useful heat are to be made here, this amount of energy must be subtracted from the measured value. Since no measurement data are available for this, a proportional, flat-rate value is deducted. An average value of 17% was determined from detailed measurements of buildings [Peper 2012]. This proportion is subtracted from the measured value of the district heating to obtain an estimate of the useful heat.

The measured value for district heating includes not only the heat consumption of the apartments but also that of the unrefurbished shops on the ground floor. As no other measurement technology is available to differentiate the consumption areas, the heating cost settlement had to be used. The units of the billing service measured by means of digital heat cost allocators result in a share of 81.9% of total consumption for the apartments [Gspan 2020]. This division applies to the billing period of 2019 and not to the measuring period from May 2019 to April 2020. As no other information is available, the value for the measuring period is applied. The specific heating consumption of all 49 apartments determined in this way is thus estimated at 36.6 kWh/(m²a).

2.8.3 COMPARSION B: PHPP AND MONITORING

The structure of the graph and the corresponding explanation of the comparison of the PHPP calculations with the measured value has also been given above (Section 2.2.3). The potential to be expected with a complete remediation is 22.6 kWh/(m²a), the previous remediation step can be expected to be 43.1 kWh/(m²a) under standard conditions. Using the conditions in the measurement year (May 2019 to April 2020) with an average indoor temperature of 21.1°C and real weather data, a heating requirement of 40.2 kWh/(m²a) would be calculated. As described above (Section 2.8.2), the measurement result has been determined from the district heating consumption and is estimated at 51.6 kWh/(m²a). However, due to the large calculation uncertainty, the expected value is between 43 and 61 kWh/(m²a). Thus, the demand and consumption values also overlap here.

In the building, 35% of the windows still need to be renovated and 75% of the ventilation systems need to be retrofitted. The measured value of 51.6 kWh/(m²a) is therefore only the result of this partial renovation.

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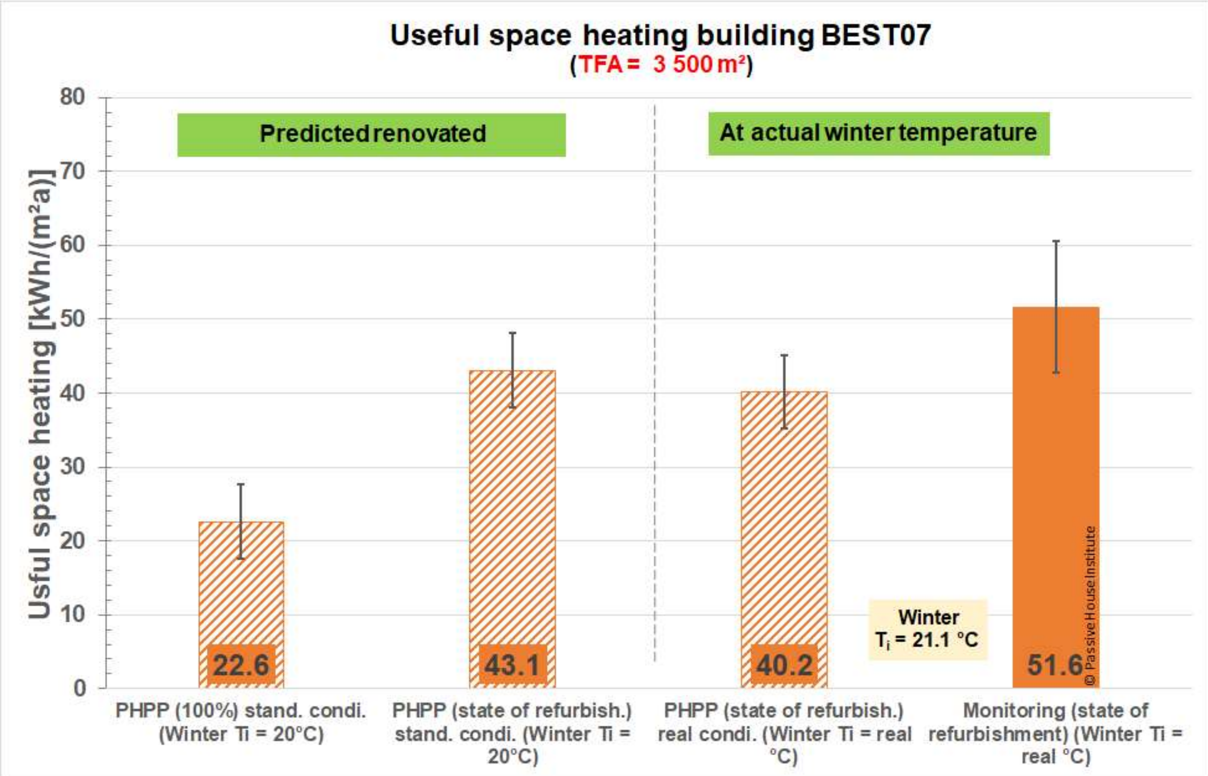

FIGURE 34: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

Due to the first stage of this step-by-step renovation (see above), the proven savings so far are 41% (comparison with the heating requirements of the old building situation (standard conditions, 20°C)). The initial condition of the old building is also already relatively low at 87 kWh/(m²a). If one considers the savings in absolute figures, it amounts over 120 000 kWh per year for the entire house (without shops). This clearly shows that significant savings have already been achieved in this building as well.

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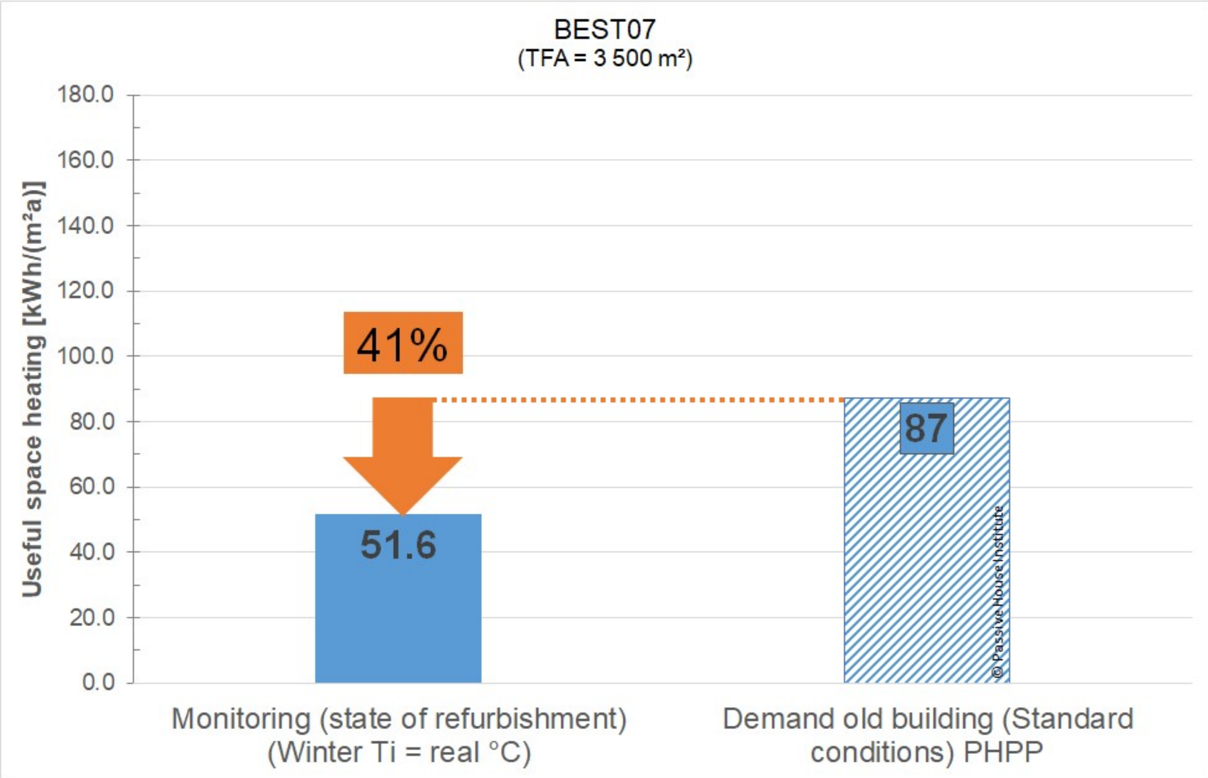

FIGURE 35: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST07 (PHPP).

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2.9 BUILDINGS BEST08

2.9.1 BRIEF INTRODUCTION OF THE BUILDINGS BEST08

FIGURE 36: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the BEST08 buildings can be found in the following table.

TABLE 8: INTRODUCTION OF THE BUILDING

	Subject area	Specifications
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	2 680 / 3 650
3	year of construction/ refurbishment	1953 / December 2019
4	number of apartments total	90
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (100%), airtightness upgraded, ventilation systems partly (10%)
6	Period Data analysis	not available
7	average indoor temperature (winter) of the measured apartments	not available

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2.9.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

For the large apartment building with nine staircases and 90 flats, the consumption in the unrefurbished state is given in the BEST-Sheets as 154 kWh/(m²a), with reference to the area according to the BEST Sheets of 3 650 m². After complete refurbishment, the calculated value is 24.5 kWh/(m²a). The value according to the calculation of the energy performance certificates is somewhat higher at 31.3 kWh/(m²a). The structure of the following graph has already been explained in detail in section 2.2.2.

The measurements of energy consumption in the building are taken separately for each staircase and not per flat. Due to a mixed supply structure, with electricity, gas and solid fuel, the heat consumption for space heating cannot be calculated from the measured values per staircase. Therefore, it is unfortunately not possible to provide information on the measured heating energy consumption here.

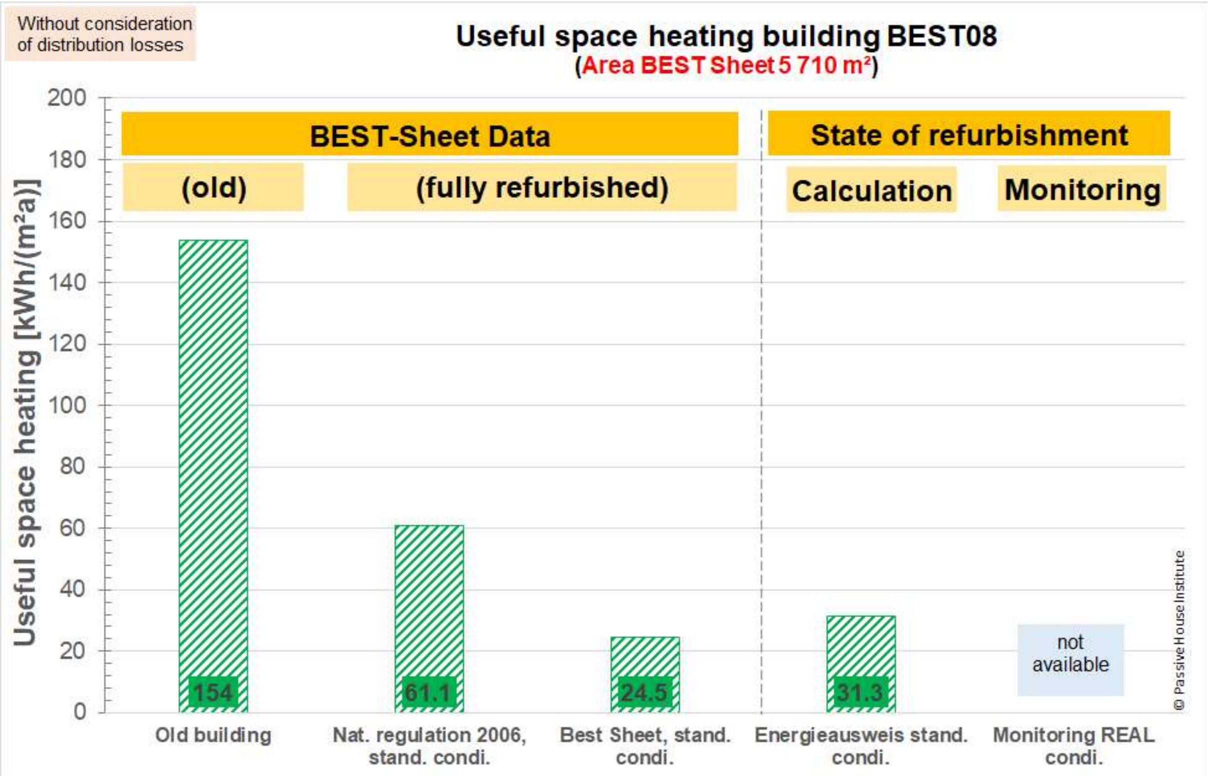

FIGURE 37: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS"(ENERGY CERTIFICATE) WITH THE BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS).

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2.9.3 COMPARSION B: PHPP

For the large and compact building, the energy balance calculations using PHPP result in an expected value of only 17.3 kWh/(m²a) for a complete refurbishment. The renovation of the ventilation system with heat recovery has only been carried out in 10% of the flats. All windows have been refurbished. Calculated for this state of refurbishment, a heating energy demand of 36.5 kWh/(m²a) results under standard weather conditions (Innsbruck) and at an indoor temperature of 20 °C. If the weather conditions of 2020 are taken as a basis and a typical, average indoor temperature of 21.5 °C is assumed [Peper 2012], the heating energy demand for this renovation state is only 25.3 kWh/(m²a). In deviation from the explanation of the diagram in Section 2.2.3, the measured value cannot be shown here.

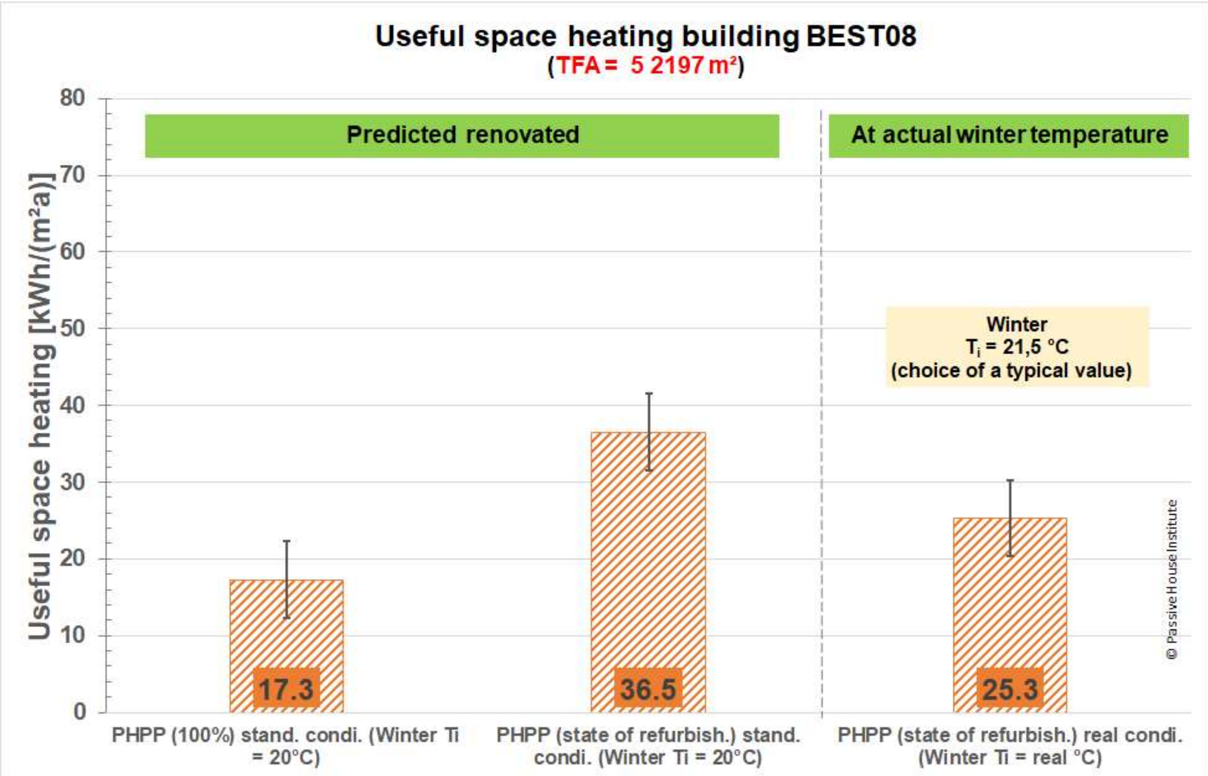

FIGURE 38: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS). FOR EXPLANATIONS SEE SECTION 2.2.3.

2.10 BUILDINGS BEST11

2.10.1 BRIEF INTRODUCTION OF THE BUILDINGS BEST11

FIGURE 39: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the buildings BEST11 can be found in the following table.

TABLE 9: INTRODUCTION OF THE BUILDING

	Subject area	Specifications
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	5 919 / 6 994
3	year of construction/ refurbishment	1958 / Sep. 2016
4	number of apartments total/monitoring energy	80 / 13 (16% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (60%), airtightness upgraded, ventilation systems partly (37%)
6	Period Data analysis	October 2019 to September 2020
7	average indoor temperature (winter) of the measured apartments	22.7 °C

2.10.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

The identical structure of the diagram already explained in section 2.2.2 is also used here. For the two multi-family buildings, the calculation method of the energy performance certificates results in a target

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value for the heating requirement of 28.8 kWh/(m²a). For these two buildings with a total of 80 apartments, consumption values from individual apartments are again evaluated. The measured specific heating consumption of the apartments in the BEST11 property is 39.4 kWh/(m²a).

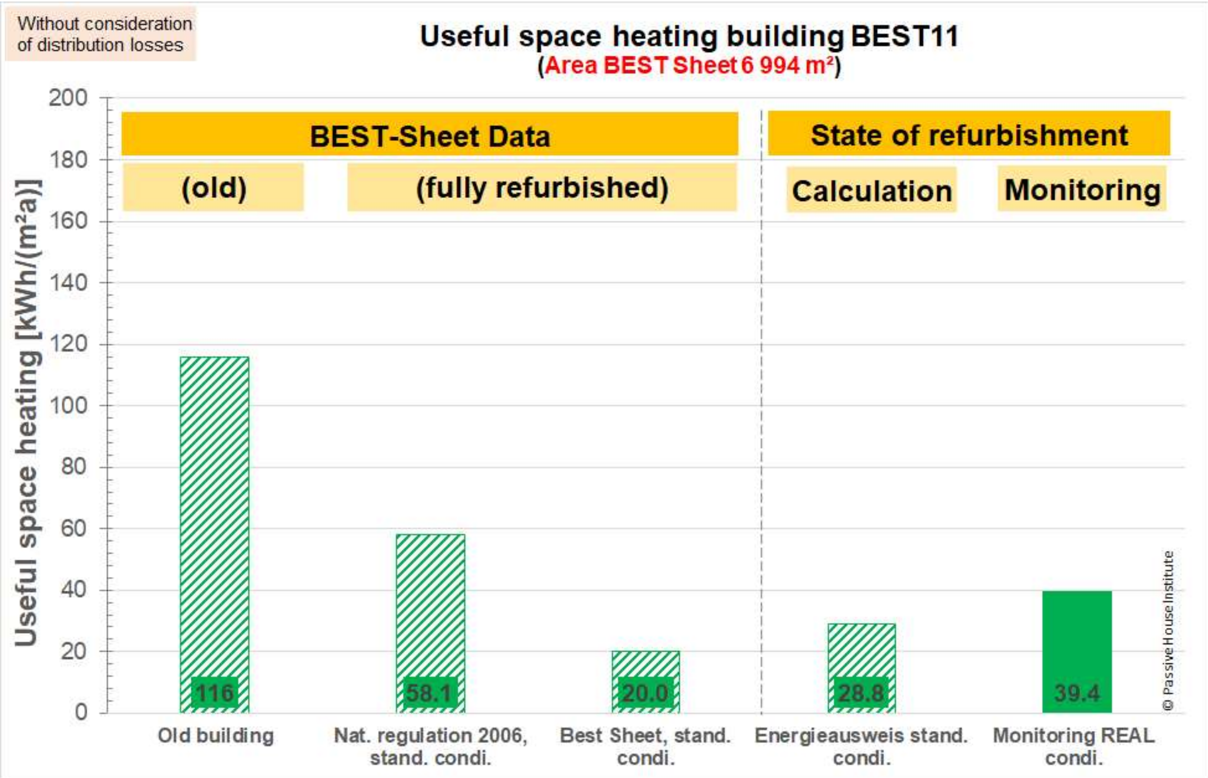

FIGURE 40: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS" (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

2.10.3 COMPARSION B: PHPP AND MONITORING

Completely refurbished, these two buildings are expected to have an average heating requirement of only 17.8 kWh/(m²a) under standard conditions (for diagram explanations, see Section 2.2.3). The refurbishment step carried out so far suggests an average of 40.7 kWh/(m²a) under standard conditions. In the measurement year (Oct. 2019 to Sep. 2020), the average indoor temperature during the heating period is 22.7°C, a relatively high value. Due to the mild weather conditions, however, this does not have such a strong effect on the overall result compared to standard use: The demand value when entering the real conditions during the 12 months (weather data, indoor temperature) decreases to an expected 28.8 kWh/(m²a). In contrast, the heating consumption is measured in 13 of the 80 apartments at 46.6 kWh/(m²a). It is thus higher than the balance calculation; taking into account the confidence interval and the balance accuracy (PHPP), this deviation can be explained. The reasons for the slightly higher deviation can be different, but cannot be explained within the scope of the depth of the investigation. It can be assumed that it could be an unfavourable sample of the measured values from the dwellings. Usually, very good agreement is achieved between a measurement and the balance calculation (see Figure 9). If, in the next step, the 40% of the windows in the two buildings are replaced and ventilation systems with highly efficient heat recovery are installed in 63% of the apartments, it can be expected that the consumption value will still decrease significantly.

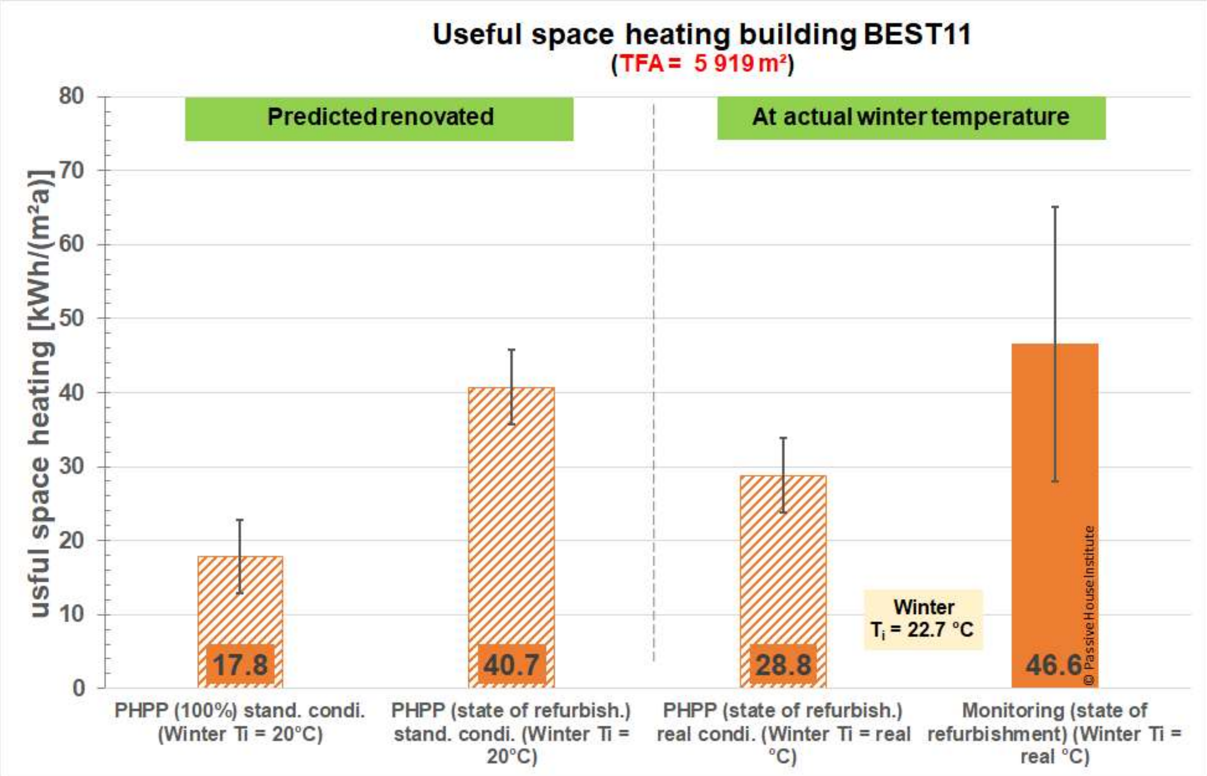

FIGURE 41: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

For these two buildings, too, a high average saving can be achieved compared to the old building situation (standard conditions). This results in a value of more than 58%, which means that the building refurbishment is considered successful for the first refurbishment step.

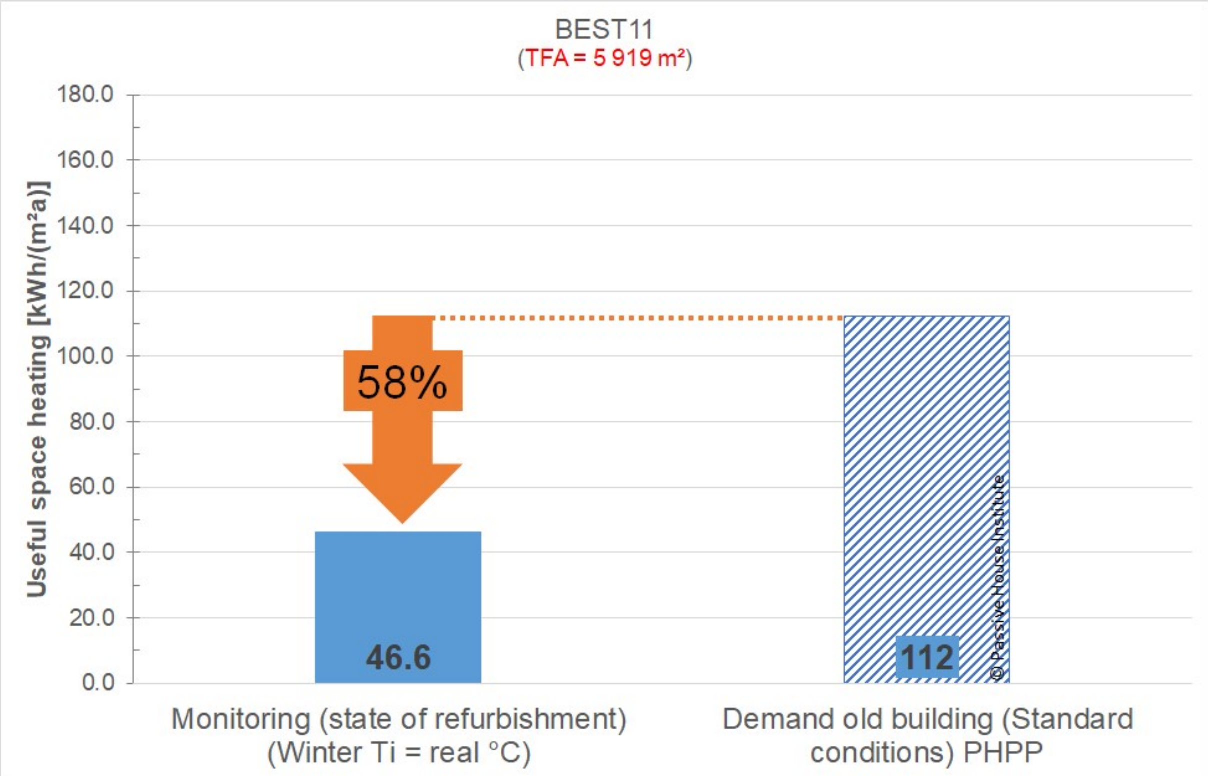

FIGURE 42: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST03 (PHPP).

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2.11 BUILDING BEST12

2.11.1 BRIEF INTRODUCTION OF THE BUILDING BEST12

FIGURE 43: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the six BEST12 apartment buildings can be found in the following table.

TABLE 10: INTRODUCTION OF THE BUILDING

	Subject area	**Specifications**
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	5 213 / 6 653
3	year of construction/ refurbishment	1958 / May. 2019
4	number of apartments total/monitoring energy	85 / 21 (25% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (100%), airtightness upgraded, ventilation systems partly (77%)
6	Period Data analysis	October 2019 to September 2020
7	average indoor temperature (winter) of the measured apartments	21.7°C

2.11.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

This project is a collection of six multi-family buildings of different sizes and orientations, which are grouped together in BEST12. The structure of the following diagram has already been explained in Section 2.2.2. The calculation of the Energieausweis gives an average value of 23.3 kWh/(m²a) for the standardised specifications. The value of the measured data evaluation of the 21 example apartments results in a consumption for heating of 20.7 kWh/(m²a). This means that the measured value is almost on a par with the value of the Energieausweis. Measured consumption values of two to eight apartments of each building are available.

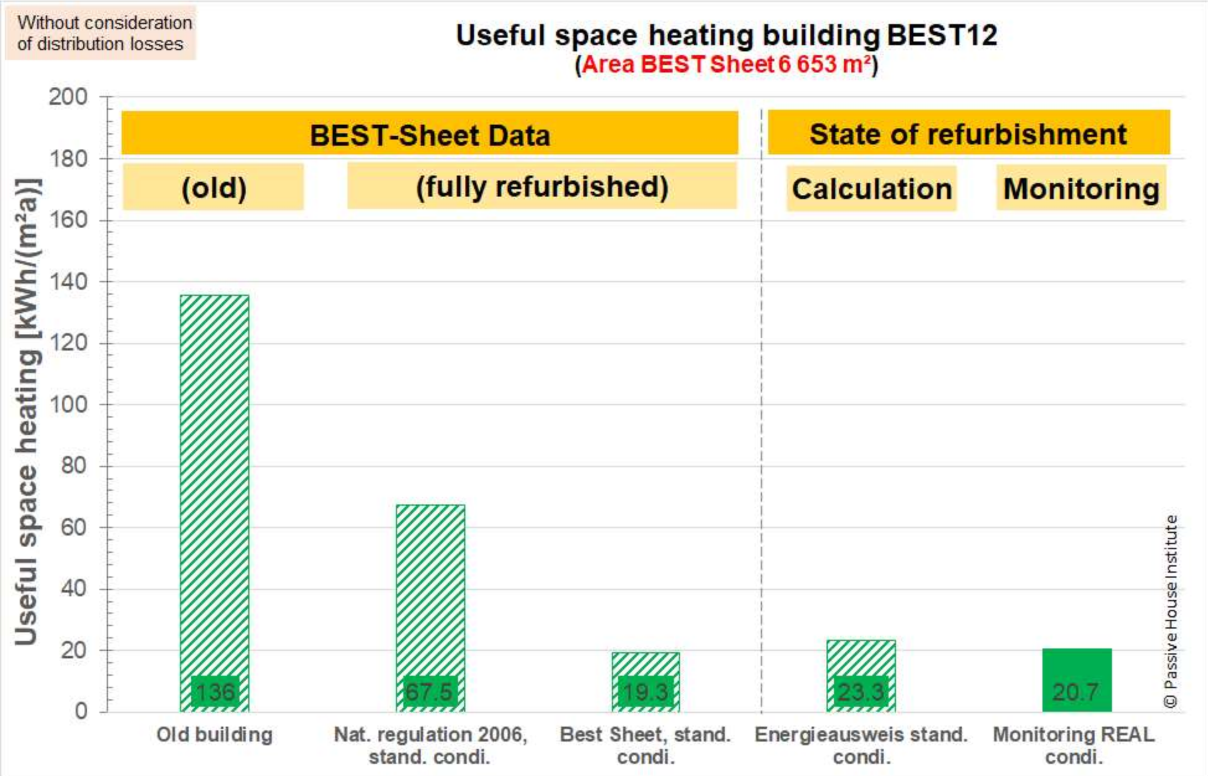

FIGURE 44: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS" (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

2.11.3 COMPARSION B: PHPP AND MONITORING

For each of the 6 buildings a separate PHPP has been created, as the buildings differ in e.g. size, orientation and shading. The measurement conditions (weather, indoor temperatures) have been entered in all PHPPs. The measured indoor temperatures of the winter months of the 6 buildings fluctuate between 19.7 and 22.9°C; the area-weighted average is 21.7°C. From the individual values of the PHPPs, area-weighted average values are calculated for all the variables required here. This results in a heating requirement for the ensemble of a very good 22.0 kWh/(m²a) for the standard case at 20°C and 27.2 kWh/(m²a) for the current state of refurbishment.

If the weather of the measuring period and the measured indoor temperatures are taken into account again, the demand drops to only 12.7 kWh/(m²a), which shows a clear influence of solar radiation on the buildings: The climate data set in the PHPP (Innsbruck site) for the winter months (October to April) is 2.3 K cooler than the measured values for the period under investigation. The radiation sum of the global radiation is 24% lower in the PHPP during the same period. In March the difference in global radiation is even 19%, in April 16%. The measurements of the 21 apartments show a heating consumption of 26.4 kWh/(m²a). This again results in a overlap between demand calculation and consumption value if the balance accuracy and the expected deviation of the mean value (confidence interval) are taken into account. It should be noted that the measured values are data from two different sources (electricity heating and gas heating). The evaluation is carried out in different ways and is subject to various uncertainties, as the hot water consumption must be separated from the heating consumption on a flat-rate basis. Thus, different uncertainties come together, which may possibly explain the higher deviation.

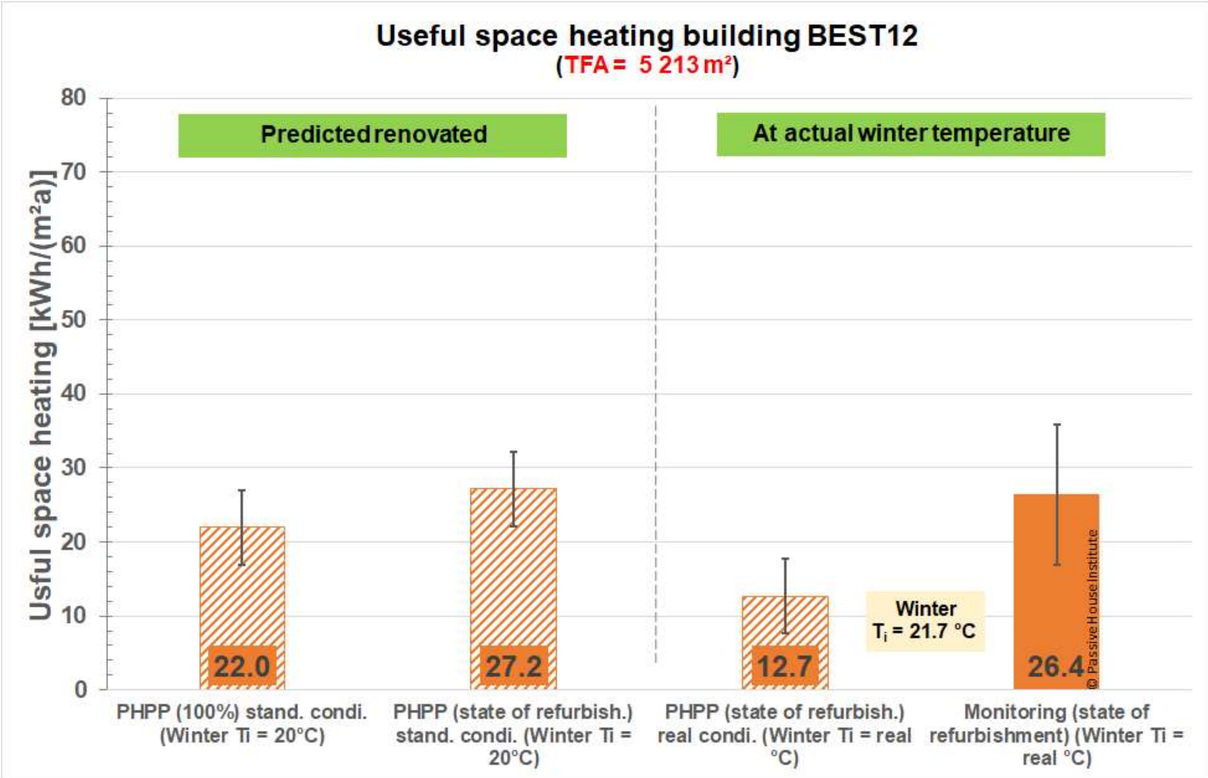

FIGURE 45: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

The measured values determined for the BEST12 project show a saving of an impressive over 80% compared to the old building situation under standard conditions (climate data set Innsbruck, interior temperature 20°C), which also shows the already great success of the efforts.

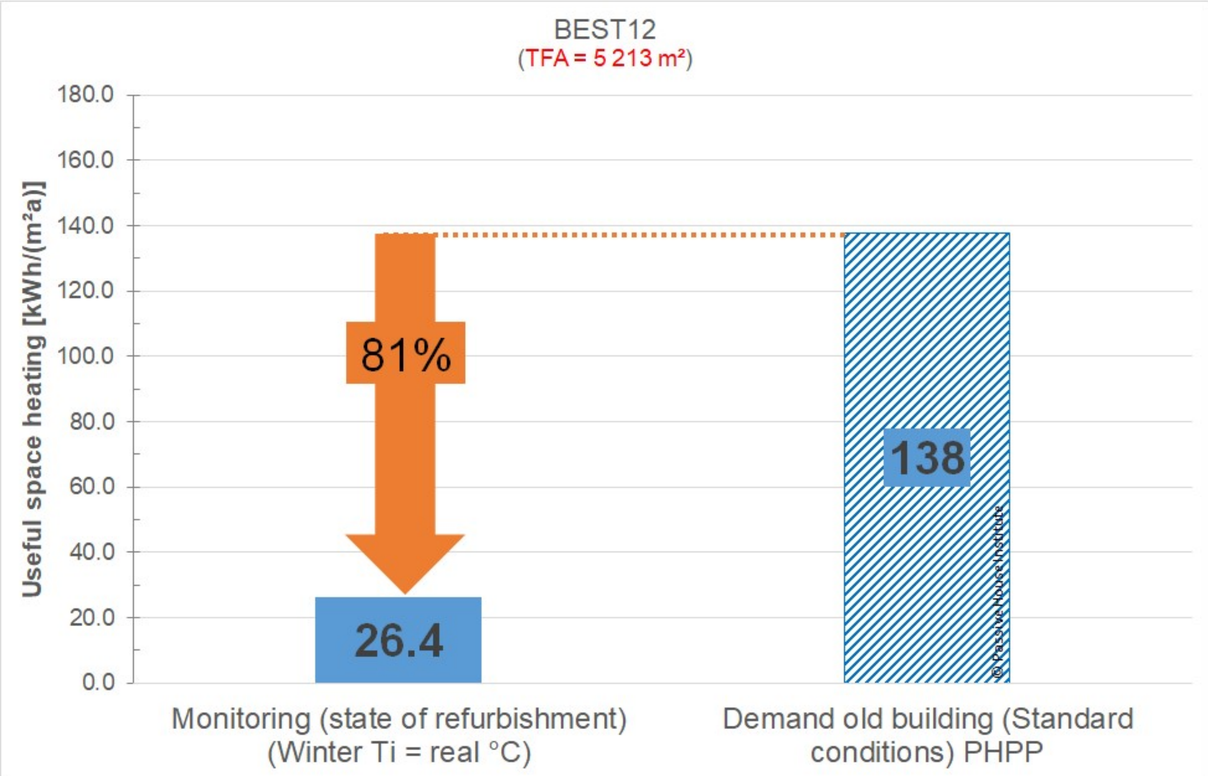

FIGURE 46: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST012 (PHPP).

2.12 BUILDING BEST13:

2.12.1 BRIEF INTRODUCTION OF THE BUILDING BEST13

FIGURE 47: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the building BEST13 can be found in the following table.

TABLE 11: INTRODUCTION OF THE BUILDING

	Subject area	Specifications
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	3 893 / 5 300
3	year of construction/ refurbishment	1965 / Nov. 2017
4	number of apartments total/monitoring energy	60 / 11 (19% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (100%), airtightness upgraded, ventilation systems partly (17%)
6	Period Data analysis	October 2019 to September 2020
7	average indoor temperature (winter) of the measured apartments	22.5 °C

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2.12.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

For this large apartment building with 60 apartments, the value calculated in the BEST-Sheet for the old building is only 66 kWh/(m²a). The Energieausweis calculates the required value after the first renovation step at only 24.6 kWh/(m²a). The measured value in relation to the area according to the BEST-Sheet is only 8.2 kWh/(m²a). The structure of the following diagram has already been explained in section 2.2.2.

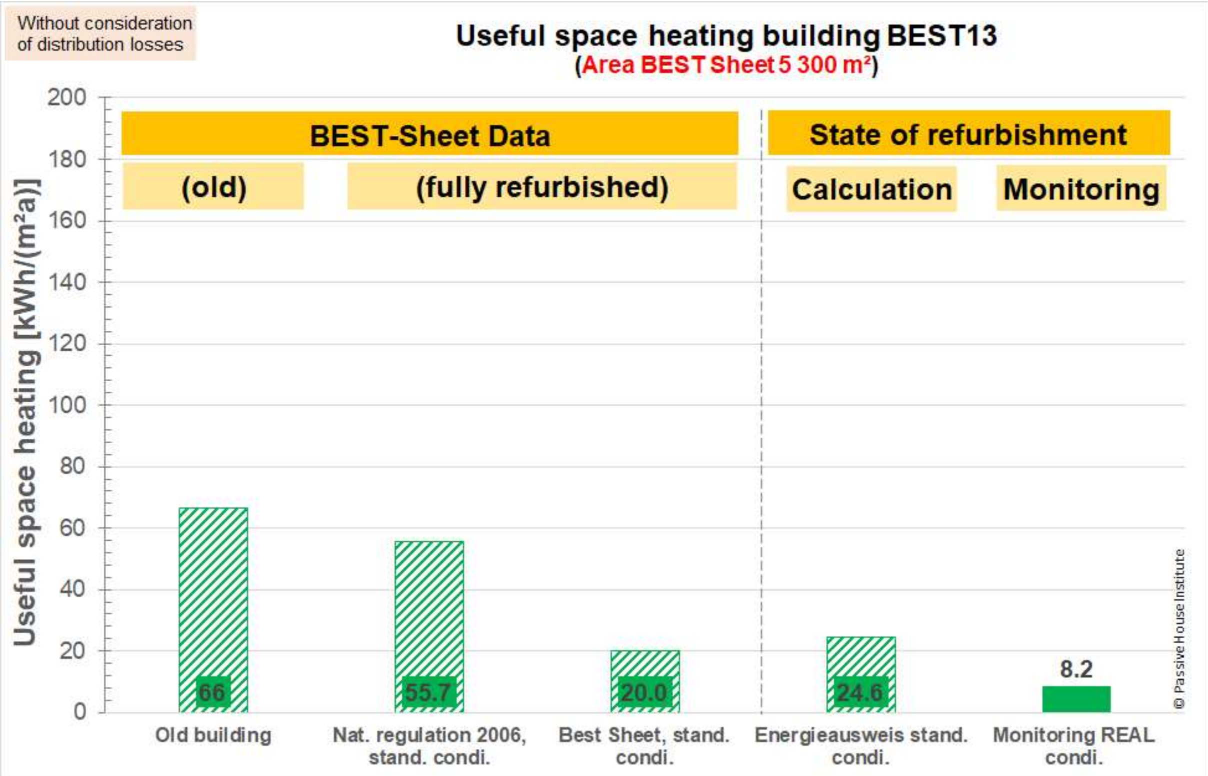

FIGURE 48: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIE-AUSWEIS" (ENERGY CERTIFICATE), BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

2.12.3 COMPARSION B: PHPP AND MONITORING

When the refurbishment of the building is fully completed, 25.3 kWh/(m²a) can be expected under standard conditions, and 44.5 kWh/(m²a) for the current interim status.

The measured values are one to four gas consumption values per house entrance. These partly include the consumption for hot water heating. By determining the summer consumption data for the hot

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water heating of these apartments, it was possible to simplify the calculation back to the pure heating consumption. This means that the determination of the measured value is subject to an additional uncertainty.

When examining this building, the first thing that stands out is that the measured value of the useful heat consumption is pleasingly low at only 11,2 kWh/(m²a) (see section 2.2.3 for the diagram of the explanations). Compared to the expected balance value for the measurement period (weather conditions, 22.5°C indoor temperature) of 31.8 kWh/(m²a), this is significantly lower than expected. The reason for the deviation is due to the fact that most of the measurements (63%) were carried out in apartments that already had a ventilation system with heat recovery. However, only 17% of the dwellings in the overall building were equipped with ventilation systems. This means that the PHPP must account for a significantly higher value, which illustrates the great influence of heat recovery. For this reason, an additional PHPP variant was created, in which 63% of the apartments are equipped with these systems. This results in an expected value for the heating requirement of 21.9 kWh/(m²a). Due to this realistic approach, the difference between calculation and measurement is significantly smaller.

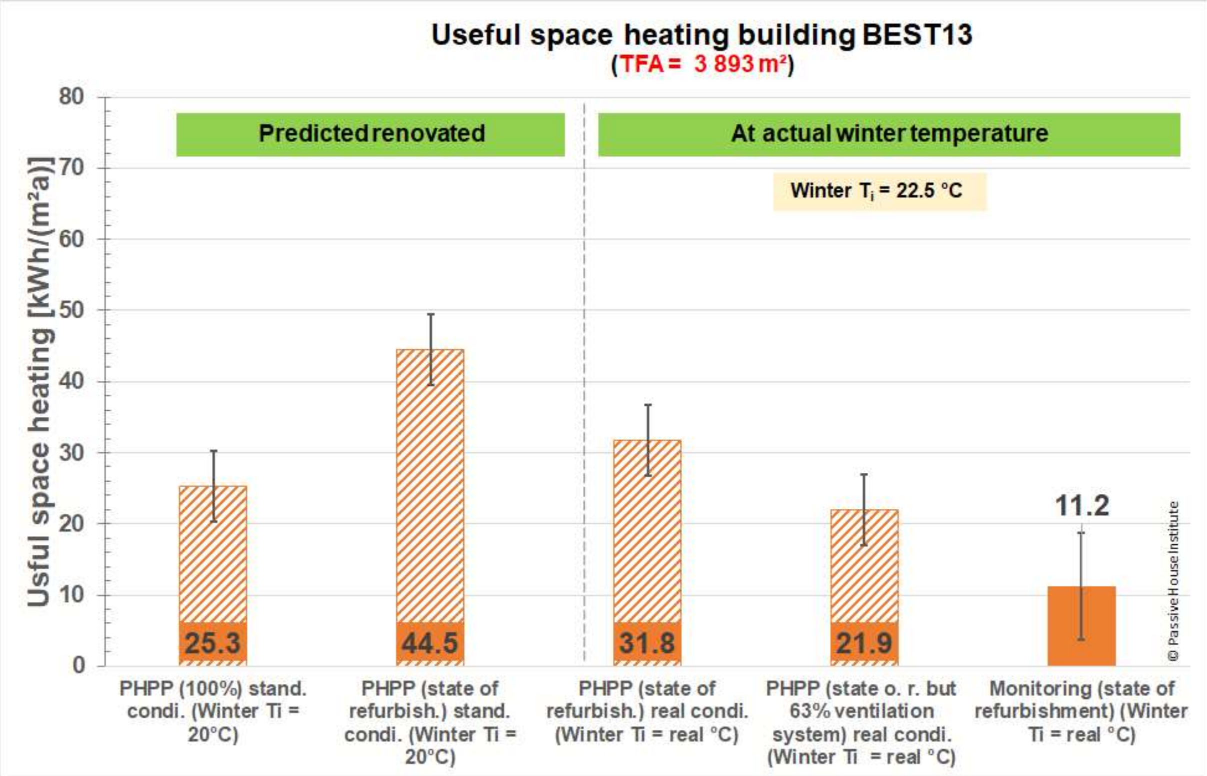

FIGURE 49: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES. FOR EXPLANATIONS SEE SECTION 2.2.3.

The achieved savings compared to the old building balance (standard conditions) amount to over 90%.

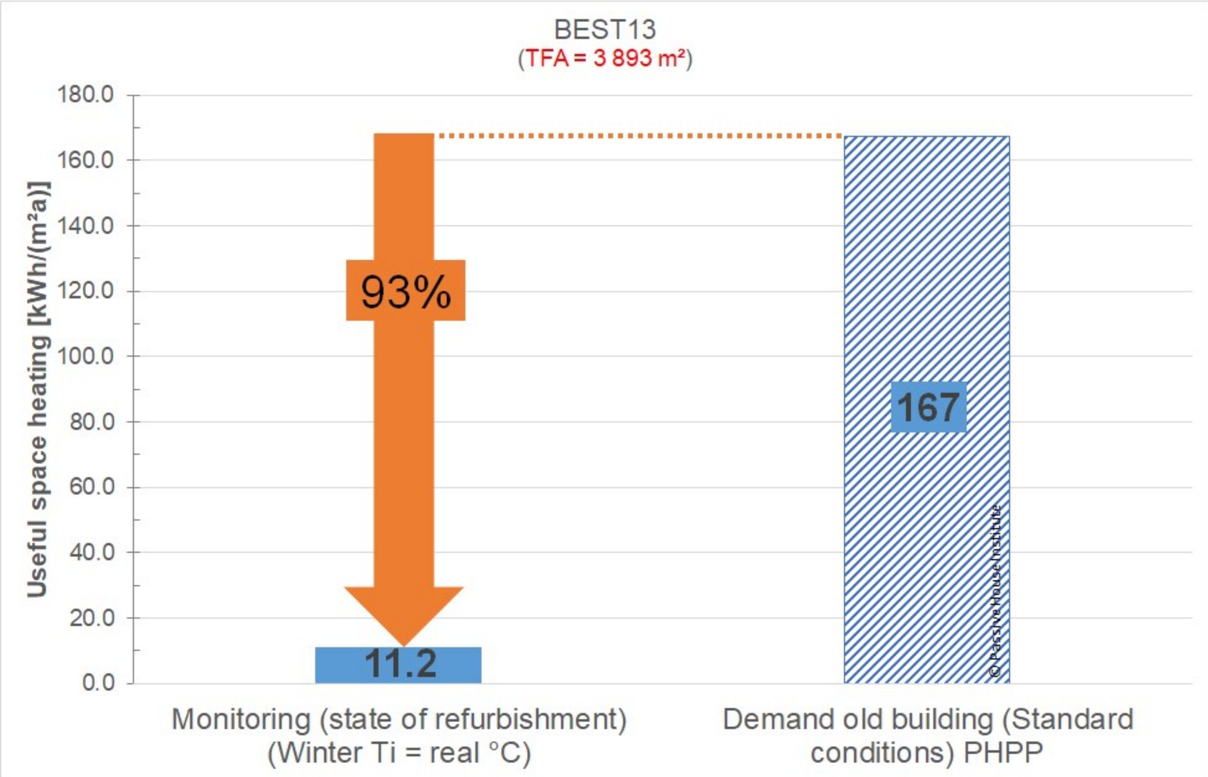

FIGURE 50: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST13 (PHPP).

2.13 BUILDING BEST19

2.13.1 BRIEF INTRODUCTION OF THE BUILDING BEST19

FIGURE 51: VIEW OF THE BUILDING AFTER THE RENOVATION (SOURCE: PHI)

An overview of the most important points concerning the BEST19 apartment buildings can be found in the following table.

TABLE 12: INTRODUCTION OF THE BUILDING

	Subject area	**Specifications**
1	position	Innsbruck
2	TFA / BEST-Sheet area [m²]	16 468 (536) / 24 010 (only one building of the ensemble)
3	year of construction/ refurbishment	1941 / Oct. 2018
4	number of apartments total/monitoring energy	269 / 17 (6% of the total area)
5	state of refurbishment	Refurbishment has been implemented in the first steps: Exterior insulation, new windows (100%), airtightness upgraded, ventilation systems partly (3%) (Building investigated by measurement: 0%)
6	Period Data analysis	June 2020 to April 2021
7	average indoor temperature of the measured apartments	21.5°C 20.4°C (examined building)

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2.13.2 COMPARISON A: OLD BUILDING, NATIONAL REGULATION, BEST-SHEET AND MONITORING

The project comprises 16 buildings with 269 flats and a total heated area of almost 16 500 m² (or 24 010 m² according to BEST-Sheet). The buildings have different sizes and orientations. The sample of flats that were measured is 17 with a total heated area of 1 008 m². The renovation of the building envelope and the windows has been completed. However, only 9 flats have been equipped with ventilation technology with heat recovery so far (corresponds to 3% of the number of flats).

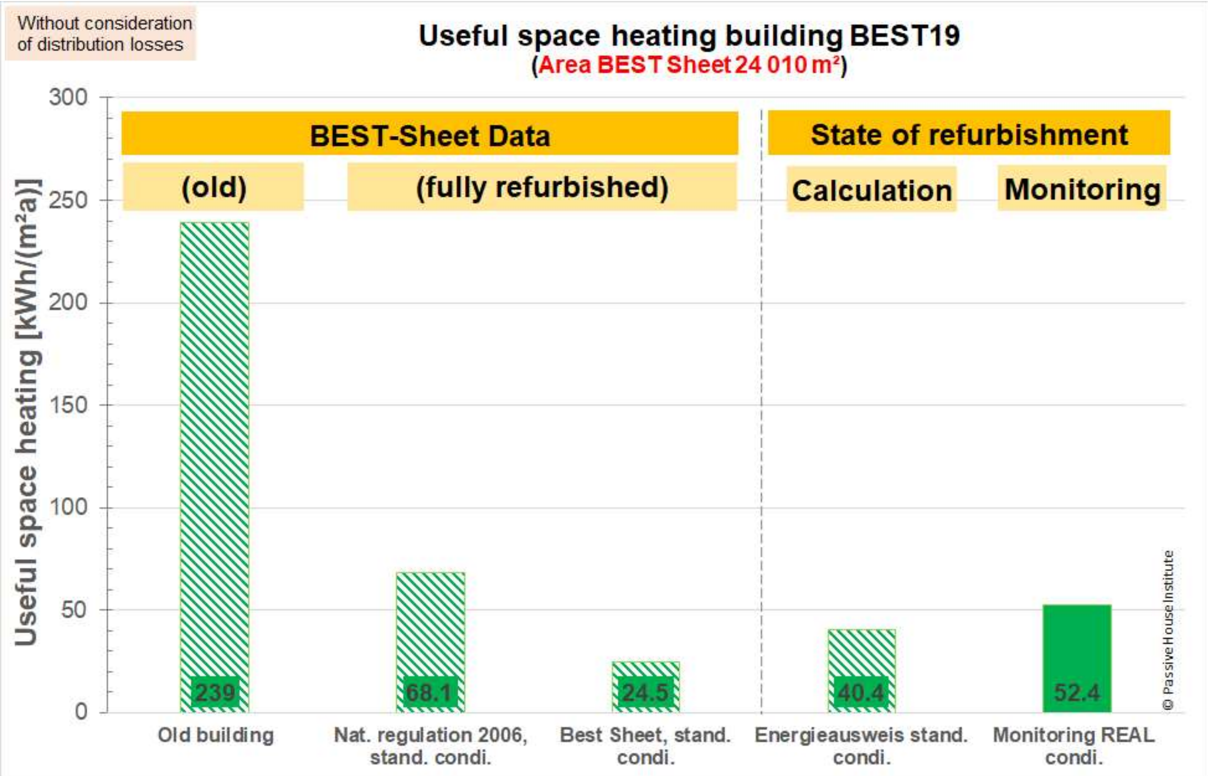

FIGURE 52: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) ACCORDING TO "ENERGIEAUSWEIS" (ENERGY CERTIFICATE) AND BEST-SHEETS (WITH DIFFERENT BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES.

The results of the summary of all energy performance certificates and BEST-Sheets are shown in Figure Figure 52. As usual, the diagram has the same structure as explained in section 2.2.2. The mean value of the heating demand according to the BEST-Sheets for the unrefurbished buildings is 239 kWh/(m²a), the complete refurbishment would be expected to result in 24.5 kWh/(m²a). For the refurbished condition, the energy performance certificates give the heating demand as 40.4 kWh/(m²a). The measured consumption value of the sample related to the BEST-sheet area is 52.4 kWh/(m²a). The missing consumption value for May 2021 (according to the PHPP calculation) was estimated and added with a marginal 0.9% of the annual total.

2.13.3 COMPARSION B: PHPP AND MONITORING

For the analysis of the project, a PHPP of one of the 16 buildings was created and is used here as an example. This building does not have mechanical ventilation technology after the refurbishment. The other buildings were not modelled. The other buildings on the BEST19 site are arranged in different cardinal directions and also differ greatly from one another, e.g. in terms of size and design. For these reasons, a projection is not possible and a comparison is not possible. Therefore, the one building is examined more closely. Here, two of the eight flats were measured and can be compared with the energy balance. The very small sample (2 units) leads to a correspondingly high confidence interval. For this comparison of the PHPP calculations with the measured value, the structure of the graph and the corresponding explanation have already been given above (section 2.2.3).

The calculations described above result in a target value of 27.5 kWh/(m²a) for complete refurbishment of the building (standard conditions, T_i = 20 °C). The current refurbishment level would be expected to be 51,2 kWh/ (m²a) under standard conditions. If the climate conditions of the measurement period and the average indoor temperature of the both measured units are used (20,4°C), the value decreases slightly to 50.9 kWh/(m²a). The measured value from the both flats is 57.5 kWh/(m²a). It should be noted that no ventilation technology has been realised so far. The potential of the ventilation systems with heat recovery is shown by the difference of the demand values of 51,2 and 27,5 kWh/(m²a) (heating demands of the achieved condition and the full refurbishment). Nevertheless, Figure 54 already shows the considerable savings of 68% that can be achieved compared to the condition of the old building.

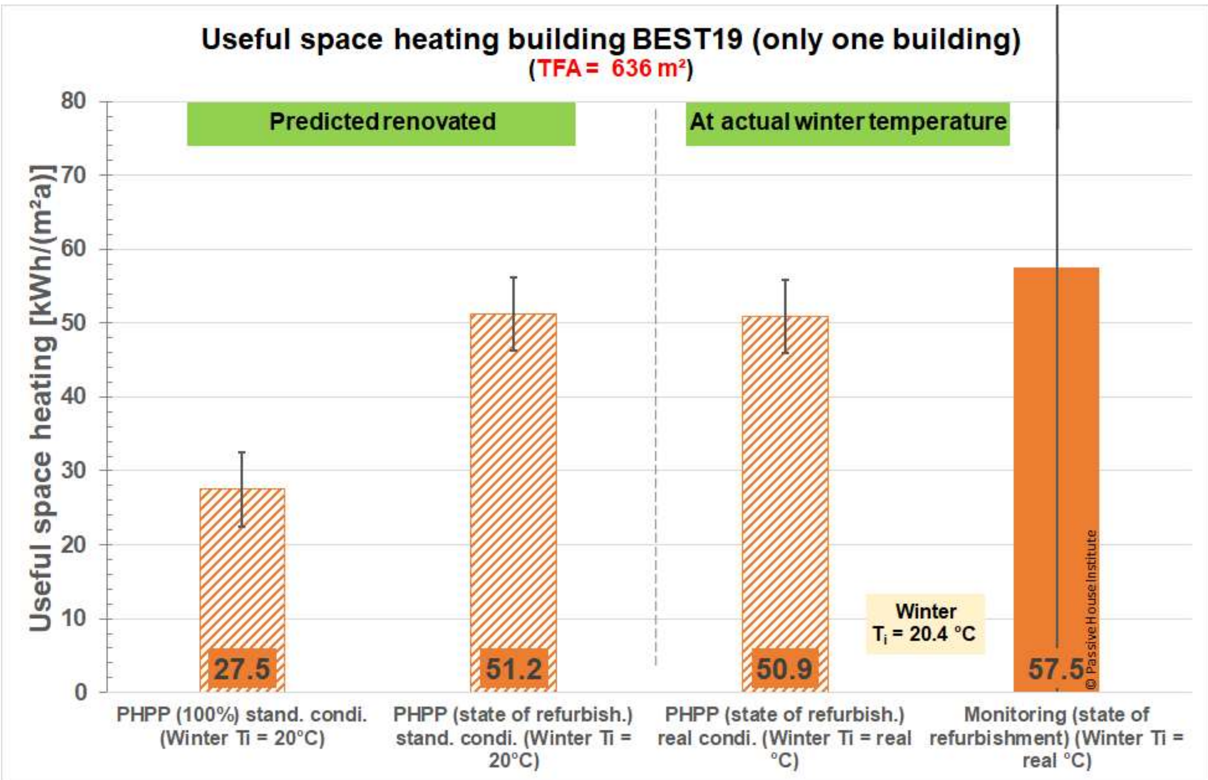

FIGURE 53: COMPARISON OF THE SPECIFIC ENERGY DEMAND (CALCULATION) WITH THE ENERGY BALANCE TOOL (PHPP) (COMPLETE RENOVATION, PARTIAL RENOVATION, PARTIAL RENOVATION WITH MEASURED BOUNDARY CONDITIONS) WITH THE MEASURED CONSUMPTION VALUES (KOFLERSTRASSE 13/15). FOR EXPLANATIONS SEE SECTION 2.2.3.

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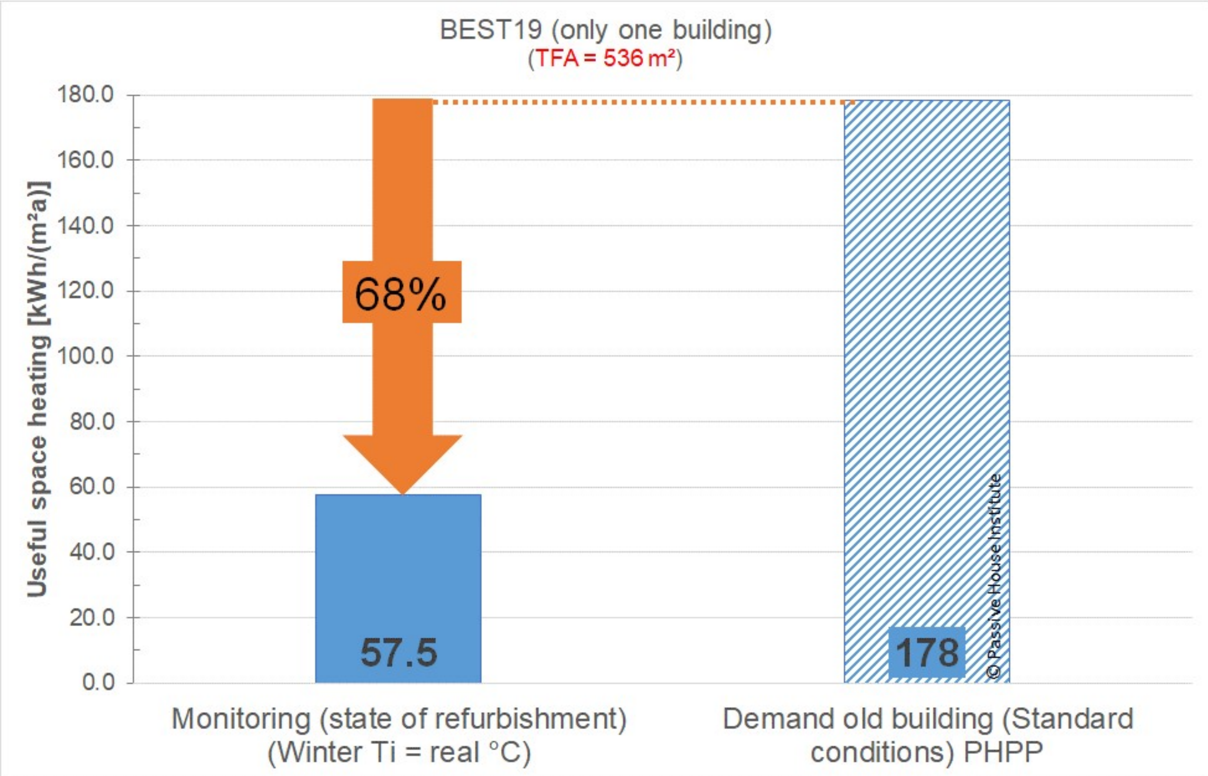

FIGURE 54: COMPARISON OF THE MEASURED CONSUMPTION VALUE WITH THE SPECIFIC ENERGY DEMAND (CALCULATION) OF THE OLD BUILDING BEST19, KOFLERSTRASSE 13/15 (PHPP).

3. COMPARISON TOOLS PROCASACLIMA – PHPP

The comparison between the energy balance tools Passive House Planning Package (PHPP) from Passive House Institute (PHI) and ProCasaClima from CasaClima Agency (CC) was carried out modelling the same building in both the Excel tools and then comparing the yearly energy consumption results. The buildings modelled in this study are the single-family house “Wooden House” from Atelier AIR – Arch. Roberto Iannetti in Costa Volpino (Bergamo) and the multi-family house “C0021” from IPES (Istituto per l'Edilizia Sociale) in Bolzano.

3.1 “WOODEN HOUSE” FROM ATELIER AIR

A comparison between the two systems and related tools is not a straightforward procedure because the different results are due to different reasons:

- calculation algorithm implemented in the tools
- entries in the tools according to the different requirements from PHI or CC for the energy balance calculation (e.g. data input of the shading, data input of thermal bridges)
- reference area
- For standard conditions with respect to the calculation of energy need in advance or for certification requirements, different boundary conditions are assumed (climate data, or user related internal conditions like internal temperature, internal heat gains).

For this project, the comparison is carried out in different steps to determine the influence of all the factors listed above on the results from the tools.

The single-family house was first modelled in ProCasaClima because of certification purposes. The building was then entered with the same geometry and components quality in PHPP.

In the first comparison, the same internal and external boundary conditions, as well as the same reference area, were set into the two tools, referring to CasaClima’s requirements. In this way, the difference between the results can be entirely attributed to the different calculation algorithm implemented in the two tools. The results of the annual heating demand per square meter in PHPP and ProCasaClima in the first comparison are the following:

TABLE 13.: RESULT COMPARIOSON OF THE TOOLS FOR "WOODEN HOUSE" (FIRST)

	ProCasaClima	PHPP
Heating demand [kWh/(m²a)]	8.1	8.5
Reference area [m2]	180	180

In the second comparison, the external boundary conditions are still the same, but PHPP's calculation is taking into account PHI's standard for internal boundary conditions, the building's reference net area and the data input are determined according to PHPP standard. In this way, the difference between the results can be attributed to the different calculation algorithm implemented in the two tools and the different ways of approaching data input in the tool. The results of the annual heating demand per square meter in PHPP and ProCasaClima in the second comparison are the following:

TABLE 14.: RESULT COMPARIOSON OF THE TOOLS FOR "WOODEN HOUSE" (SECOND)

	ProCasaClima	PHPP
Heating demand [kWh/(m²a)]	8.1	12.4
Reference area [m²]	180	175

3.2 "C0021" FROM IPES

For this project, the energy balance has been calculated from the Passive House Institute with the PHPP tool, supported by designPH for the shading calculation, and from CasaClima Agency with the ProCasaClima (last update in 2016). The boundary conditions, reference areas and climate data were entered in the tools according to the different calculation methods followed by PHI and CC and, therefore, different input are entered in the two tools. Please notice that, the energy demand calculated in ProCasaClima for this project is referring to a net area that is automatically calculated by the tool through the multiplication with a reduction factor, once the gross area is entered; on the other side, the PHPP calculation is referring to a net area of the building, coming from a detailed calculation according to PHI method. However, in general it is possible to enter the net area also in ProCasaClima. The results of the annual heating demand per square meter in PHPP and ProCasaClima are the following:

TABLE 15.: RESULT COMPARIOSON OF THE TOOLS FOR "COO21"

	ProCasaClima	PHPP
Heating demand [kWh/(m²a)]	18.0	16.2
Reference area [m²]	8 681	9 607

Notice that some assumptions have been made from PHI for the energy balance calculation with PHPP, because no sufficient data about the curtain wall installed at the five staircases was available (e.g. technical drawings from the manufacturer showing the frame profile). PHPP data with significant influence on the energy balance are sometimes not reported in CC when not relevant for funding. Despite the small percentage of thermal envelope area covered by the curtain wall, the final annual heating demand is remarkably influenced by its thermal properties.

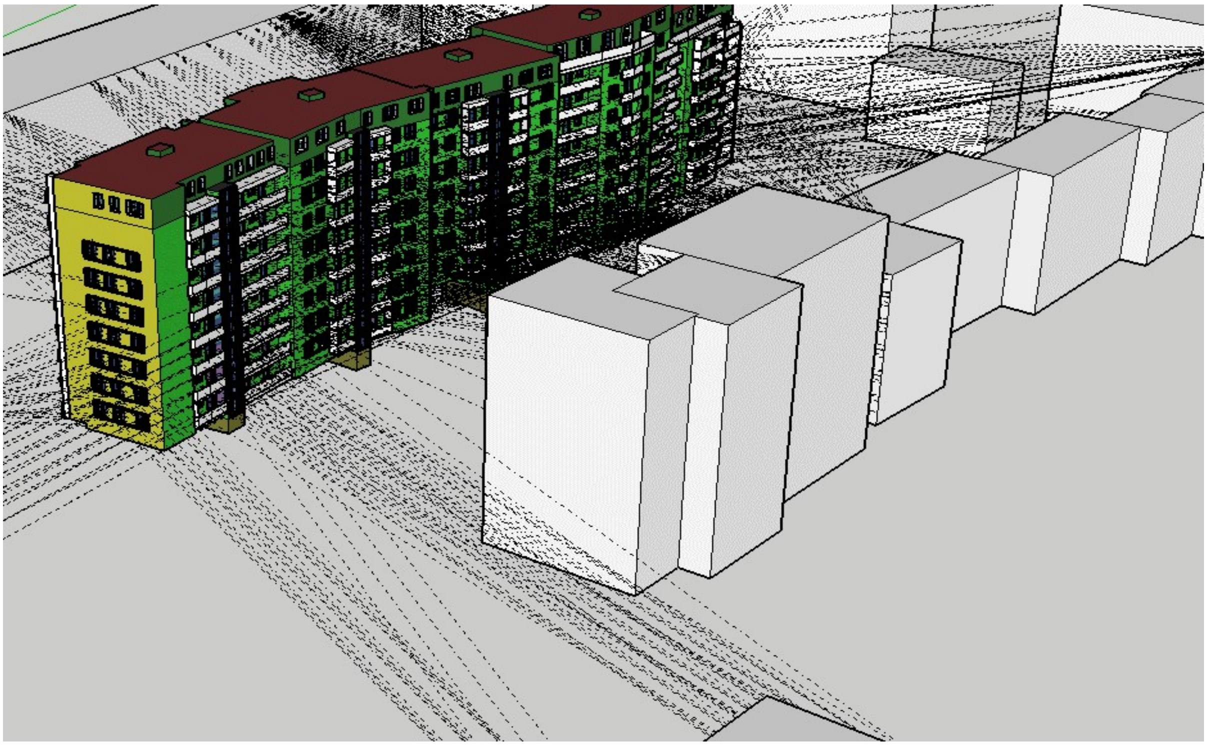

FIGURE 55: CALCULATION OF THE SHADING IN THE PROJECT "C0021" WITH THE DESIGNPH TOOL FROM PHI.

3.3 CONCLUSION COMPARISON

The comparison between the two tools showed that, under the same boundary conditions and with the same data input, the two energy balance calculations lead to comparable results. As soon as the approach established in the frame of building certification, either from PHI or CC, is applied, the difference between the two results increases. In particular, the difference in heating demand results to be higher for smaller building, due to the higher influence of shading and thermal bridges effect, which are investigated in more details according to the approach from PHI.

This comparison of the two calculation tools should help to better compare the results of the investigations of the buildings in the Sinfonia project.

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