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proKlima

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CEPHEUS
cost efficient passive houses as european standards

Climate Neutral Passive House Estate in Hannover-Kronsberg: Construction and Measurement Results

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CONTENTS

1 Foreword to the Kronsberg Passive House residential estate

The start of the 21st century brings with it new perspectives: a vastly improved efficiency of energy use can reduce the remaining energy demand so far that it is possible to meet this demand solely with renewable sources – not only technically, but also economically.

In the 32 terraced houses built in 1998 by the developer Rasch & Partner in cooperation with the Stadtwerke Hannover, for the first time a heating system using exclusively postheating of the fresh air necessary (due to indoor air quality reasons) was used; only the bathrooms have small radiators. This very simple and cost-efficient house technology concept is possible thanks to extremely high building envelope efficiency: very good insulation, thermal-bridge free construction, airtight building element junctions and windows of a quality not previously available. Together with the heat recovery system, this leads to a space heating requirement in the houses of less than 15 kWh/(m²a), a figure which is roughly a seventh of that used today in typical new (1999) German housing.

According to the available results, the improvement of the insulation quality leads not only to large energy savings, but also to a definite improvement in occupant comfort and guarantees condensation-free inner surfaces. The excellent insulation also prevents draughts and temperature stratification.

With an effectiveness ratio of roughly 80% under real working conditions, the heat exchangers used in the buildings fulfil the expectations; the electricity consumption for the ventilator's operation and control was actually less than estimated (250 kWh/a). This leads to an annual performance factor of over 11 (under living conditions) for the ventilation system. The reduced energy consumption is not the only advantage for the ventilation system: the detectable objective and subjective improvement in indoor air quality is decisive. Not without reason was the Passive House estate's ventilation system given the best notes by the occupants in the socio-scientific census.

The total remaining energy consumption of the Passive House estate is so marginal that it is equivalent to an electrical energy input of roughly 33 kWh/(m²a)*. That is approximately the amount used in typical German homes only for household electricity (32,8 kWh/(m²a)).

The primary energy savings compared to typical new buildings are therefore almost 66%. This includes all household uses together, such as space heating, hot water,

* The equivalent energy input leads, in the conventional supply, to the same primary energy input.

auxiliary electricity for the ventilator's operation and the complete electricity requirements for lighting, cooking, washing, refrigeration and anything else.

Under these conditions it is economically feasible to cover the remaining energy needs for an estate through renewable energy sources: with a 2,6 kW share of the Kronsberg's 1,5 MW wind power plant, each house in the Passive House estate has contributed roughly 35 kWh/(m²a) to an electricity supply from renewable energy. The costs for a single wind power share equalled 1.250 Euro per house.

The CEPHEUS demonstration estate on the Kronsberg has proven that:

- Passive Houses are comfortable, they have a high thermal comfort and a very good indoor air quality;
- Passive Houses are cost-efficient; the Kronsberg houses were not sold at higher prices than comparable objects in the same building area. The energy efficiency improvement measures proved themselves profitable under contemporary conditions;
- Passive Houses are environmentally friendly.

The Passive House estate in Hannover-Kronsberg shows for the first time in Europe that a fully renewable energy supply („climate neutrality") is not only technically feasible, but also economically justifiable when using the Passive House standard. The balance of the low remaining primary energy requirementss of the Passive Houses is made possible through the connection to the wind power plant on the Kronsberg. To verify the aims of the project, the estate was extensively equipped with measuring equipment.

The thermal quality in all houses proved to be excellent, with an average winter indoor temperature of 21,1°C: the temperatures are very stable, the inner surface temperatures hardly differ from the room's air temperatures. Summer time comfort is also excellent: despite rather high outdoor temperatures during the measuring period of summer 2000, the number of hours during which average room temperatures were above 25 °C accounted for less than 2,5 % of the total annual hours.

Except when otherwise stated, the measurement values refer to a full year of measurement (1.10.1999 to 30.9.2000). Possible heating during the summer is also included in the documented data. All the data about energy consumption or the full primary energy consumption also include all electricity needs, and not only auxiliary electricity for house technology (as in DIN 4701/Part 10), but also household electricity consumption (including lighting, refrigerating, washing, cooking etc.) and the full useful electricity consumption of the shared facilities.

We refer the measured consumption values strictly to the „treated floor area" TFA. This reference area is almost equal to the heated living area according to the 2nd

German calculation regulation (II. BV). This means that the herein documented energy consumption values (kWh/(m²a)) are directly comparable with the statistical surveying of the heating cost bill. The "useful building area A_N" used to calculate the specific heating demand according to the German Insulation Regulation or the German Energy Saving Regulation is, in contrast, 32% bigger (see Table 1).

Living area of the reference house in the Passive House estate	Area according to CEPHEUS agreement TFA m²	Heated living area according to §44 Paragraph 1 II.BV m²	Useful building area A_N according to Insulation Regulation M²
	111,7 used here	111,1	147,5

Table 1: Living area comparison using the estate's reference House as an example

The measured annual energy consumption for heating of the permanently occupied 22 terraced houses in the Passive House estate, including summer time demands, equalled 16 kWh/(m²a); calculating the consumption using the Insulation Regulation's "useful building area" A_N would give a value of 12,1 kWh/(m²a). The savings in comparison to the typical German building stock are over 90% and even in comparison to new terraced housing are still over 85%. This means:

The improved insulation with an average U-value of 0,11 W/(m²K) for opaque building parts is fully effective. The thermal-bridge-free construction principle and the airtightness concept have proven themselves. This was also independently confirmed through a thermo-graphical analysis [Peper 2001a] and air tightness measurements [Peper 1999a].

The radically improved windows with U-values of 0,83 W/(m²K) and high g-values of 60% contribute substantially to the arrived-at energy balance: their inner surface temperatures are on average above 17°C during severe cold periods and, even in deepest winter, more solar energy is provided passively than heat energy lost through the windows.

The high-efficiency ventilation system with its measured efficiency ratio of 78% shows only minimal electricity consumption (less than 2,3 kWh/(m²a)). The heat recovery is fully effective in practice and was not counteracted by occupant behaviour.

The heating demand measurement results show clearly that the impact of additional window opening by the occupants during the heating period was very limited. In the Passive House estate, each room has a window or French door with open-tilt mountings. The occupants also use these windows in the transition seasons and especially in the summer.

The Kronsberg Passive Houses represent the first estate in which only the fresh air heating system is used to heat the living spaces. The functionality of this concept was first tested in the CEPHEUS research project with a thermal building simulation [Schnieders 1998]. Using solely the fresh air heating system, a maximum of roughly 10 watts heating output per square meter living area is available for the estate's houses; the bathroom radiator allows for a slight increase. The measurement results for the real heating load necessary in the winters of 1999/2000 and 2000/2001 prove the theory: maximum average heating loads of 8,8 and 7,0 W/m² were measured.

The fact that the heating output was always sufficient is also proven by the fact that the indoor temperatures are practically independent of the outside temperatures during the winter: even on the coldest day, the average temperature in the occupied houses attained 20,9°C.

The final energy consumption from the district heating system for space heating and hot water heating together were measured in the first year at 34,6 kWh/(m²a), this signifies savings of 75% compared to average new houses.

When one calculates the specific primary energy value not according to the living area, but based on the useful building area A_N and uses primary energy factors in accordance with DIN 4701/10 (district heating CHP 0,7, electricity 3,0) and includes the measured auxiliary electricity consumption, the result is a measured annual primary energy consumption of 26,1 kWh/(m²a) (heating, ventilation and hot water heating). This allows for a comparison with the German EnEV-requirements: the representative terrace house has a surface to volume (A/V) ratio of 0,61 m^{-1}. Hence one arrives at a required value for Q_p" of 106,9 kWh/(m²a). The average primary energy consumption for the estate lies therefore more than a factor 4 below the required value in the regulation. One must also keep in mind that the calculated values according to the 4108/6 and 4701/10 standards will be lower than the actual consumption values [Eschenfelder 1999].

The consumption of electrical energy in the household is now dominant. All the electrical energy used in the house will finally be converted to heat and this forms a part of the available internal heat sources: during the heating period this electrical heat covers a significant share of the heating losses (ca. 7,6 kWh/(m²a)) – this contribution is almost as high as the calculated heating consumption. In the summer this electrical heat constitutes an additional heat load, which can influence comfort under certain conditions. This is also a reason why high efficiency electrical appliances are important in Passive Houses.

The electrical efficiency of the household appliances in the Kronsberg Passive House estate was successfully and considerably increased in comparison to those found in typical German households. With a combination of advice and financial incentives it was possible to convince 18 households to equip their houses with particularly efficient electrical appliances. The resultant household electricity savings average 45% for these 18 households.

The total primary energy balance also includes the primary energy input for household electricity; this value of 49,4 kWh/(m²a) actually dominates the balance. Together with the primary energy for district heating, ventilation and auxiliary electricity, the total primary energy consumption for all energy sources used in the estate equals 82,6 kWh/(m²a). This value is about 66% less than the reference primary energy consumption of similar new houses in Germany.

The *average value* of the measured final energy consumption in the Passive House estate (58,0 kWh/(m²a)) has standard deviation (of the average value) of only ±2,5kWh/(m²a), despite the range of occupant behaviour. In a reference estate published by Lundström, the average final energy consumption is 203 kWh/(m²a), with an standard deviation of ±3,1 kWh/(m²a). This shows that Passive Houses can be just as reliably projected with regards to occupant behaviour as conventional buildings. Misgivings expressed previously, that specifications of building physics and of the heating demand of very well insulated buildings could no longer be determined, have therefore proven to be mistaken. Large variations due to the ventilation behaviour in the Passive Houses are also not discernible.

The total energy consumption of the Passive House estate is so low that it is technically and financially feasible to substitute this demand through renewable energy sources: with a share of the Kronsberg wind power plant worth Euro 1.250 per house included in the sales price, it is possible to produce electricity with a primary energy value of 89 kWh/(m²a) – that is more than the total consumption in the estate. High-efficiency technology has proven itself in this case to be a decisive prerequisite and opportunity for a long-term sustainable energy supply.

2 Outline Maps

Figure 1: Map of Germany and the location of Hannover (in the state of Lower Saxony)

The city of Hannover is the capital city of the German state of Lower Saxony. It has a population of 510.000. The Passive House estate lies in the „Kronsberg“ district, southeast of the city centre. It is a part of the newly developed Kronsberg residential estate, built within the framework of the EXPO 2000 world exhibition and currently providing 3000 homes. The estate is on land that rises gradually from west to east, thus leading to a height difference of 25 cm between each house. The estate’s four rows of housing are aligned almost to the south with a deviation of 15° to the west. A shared building services house supplies two rows of housing respectively, containing the district heating transmission station, all electrical meters and the main water connection.

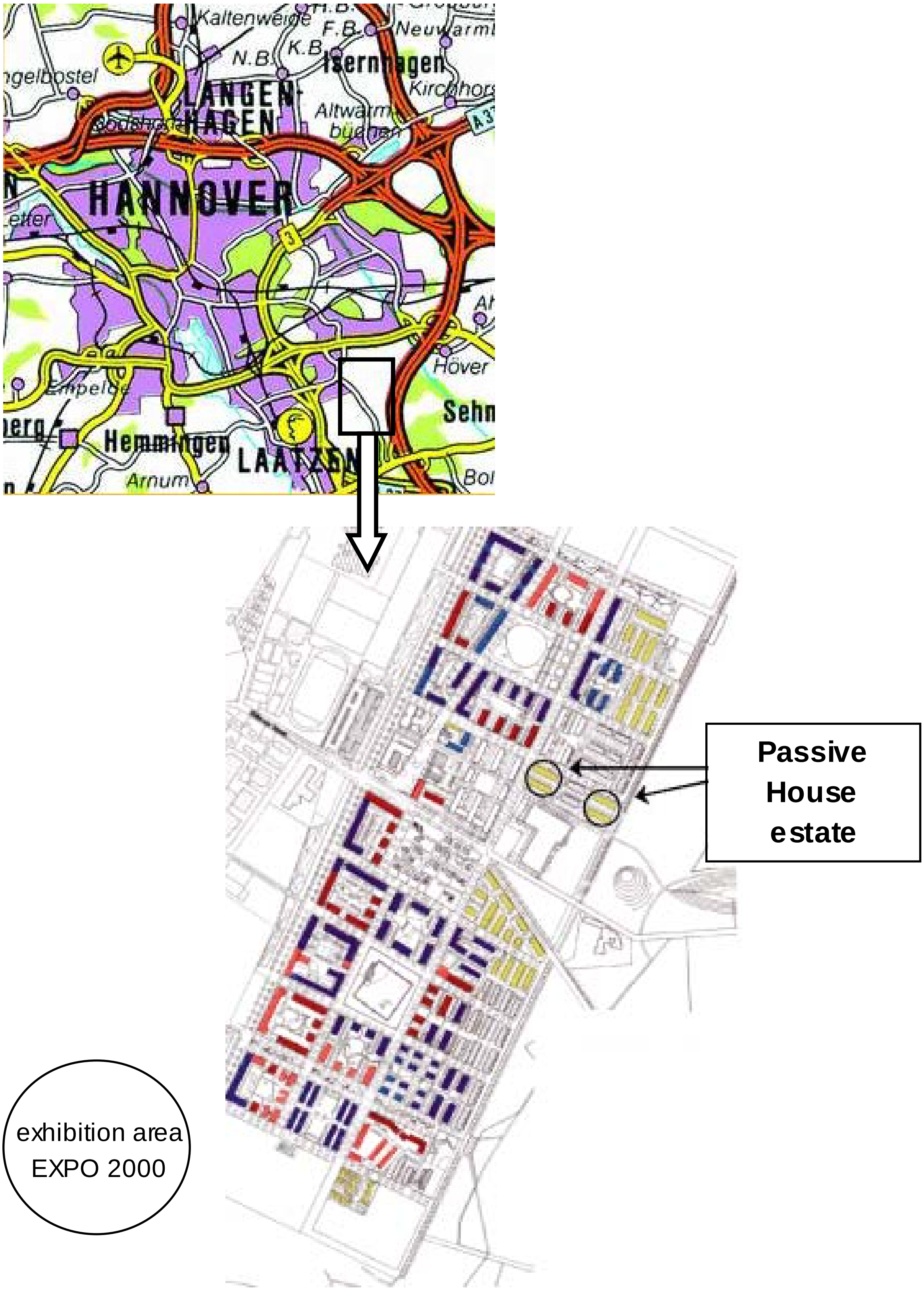


Figure 2: **Map of Hannover with the location of the Passive House estate in the Kronsberg district [Hannover], [Eckert 2000].**

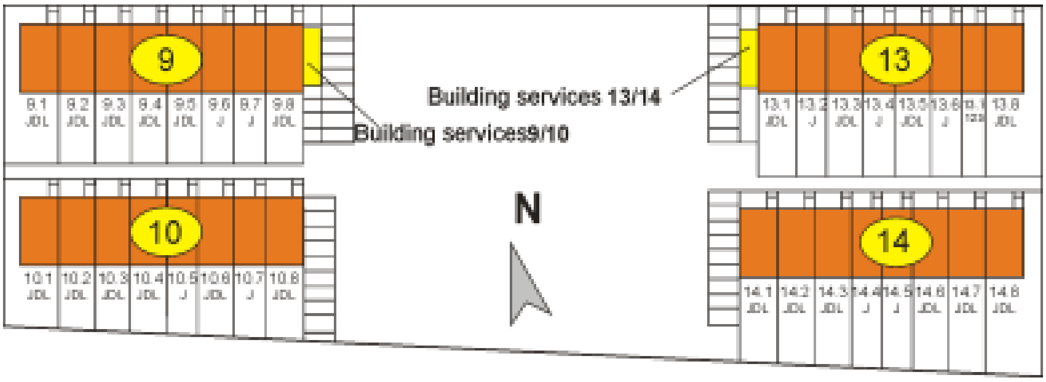


Figure 3: **Site plan of the Kronsberg Passive House estate (Sticksfeld Nr. 30 to 124). The numbers reflect those used during construction and in this report.**

Location: Longitude: 9° 44' Latitude: 52° 22' 90
Min. outdoor temperature winter: -13,4 °C
Max outdoor temperature summer: 31,2 °C

Month / Year	**Daily average outdoor temperature**			**Heating degree days (re. 18 °C)*** $\sum_{T_m \le 15°C}(18°C - T_m)$	**Cooling degree days (re. 24 °C)*** $\sum_{T_m \ge 24°C}(T_m - 24°C)$	**Monthly average solar radiation values**	**Monthly average relative humidity**
	min	**avg.**	**max**				
	[°C]			**[Kd]**	**[Kd]**	**[kWh/m² d]**	**[%]**
Jan.	-13,4	0,0	6,7	559,2	0,00	0,62	87,7
Feb.	-12	0,8	8,2	481,9	0,00	1,26	85,3
March	-3,6	3,8	13,3	440,8	0,00	1,71	79,8
Apr.	-2,7	7,5	19,9	315,2	0,00	3,13	75,9
May	1,6	12,3	24,4	167,5	0,00	4,49	70,9
June	5,3	15,0	25,2	61,2	0,00	4,88	75,2
July	7,6	17,1	30,8	32,5	0,00	5,01	75,3
Aug.	7	17,1	31,2	19,7	0,00	3,83	74,0
Sept.	2,6	14,2	28,9	110,1	0,00	2,80	81,1
Oct.	-0,9	9,1	20,2	277,1	0,00	1,44	85,4
Nov.	-6,8	4,9	17,7	391,9	0,00	0,75	85,5
Dec.	-9,9	1,1	12	522,7	0,00	0,51	87,9
Year	**-13,4**	**8,6**	**31,2**	**3379,8**	**0,00**	**0,71**	**80,3**

Table 2: **Climate conditions in Hannover (according to the climate data used in the simulations [Schnieders 1998])**

* Calculated with average daily values

3 Description of the Construction

3.1 Floor Plans, Building Sections and Views

The non-basement terraced houses with gabled roofs and external storage rooms are built using a mixed modular system: ceilings, partition walls between homes, gable walls and remaining load-bearing structures consist of prefabricated reinforced-concrete slabs; the highly insulated facade and roof are lightweight prefabricated wood elements. In addition, triple-glazed windows with specially insulated window frames as well as a home ventilation system with a high efficiency heat exchanger were installed.

Figure 4 shows the south and north views of the houses with the large window surfaces opening to the garden side patio and the storage rooms on the north side.

Figure 4: South and North views of the Passive House rows in Hannover-Kronsberg

Three house sizes were built in Kronsberg:

House type „JDL: Jangster de Lüx",

the widest house with an inner dimension of 6 m and a "Treated Floor Area" of 119,5 m² according to CEPHEUS-rules; a total of 22 houses, of which 8 are end houses.

House type „J: Jangster"

with an inner dimension of 5 m and a Treated Floor Area of 97,3 m² according to CEPHEUS-rules. 9 houses of this type were built.

House type „123"

with an inner dimension of only 3,80 m and a Treated Floor Area of 75,1 m² according to CEPHEUS-rules; only one house of this type was built.

The longitudinal section (Figure 5) shows the important characteristics of the Passive House standard:

- A thick insulation layer surrounds the entire building.
- The triple-glazed low-emissivity windows are integrated into the insulated wood-facade elements in a thermally optimal fashion.
- Only the exhaust and intake ducts in the gable area and the drainage pipe through the base plate penetrate the thermal envelope.
- The ventilation system and the supply pipes run to the building services container in the gable area of the houses.

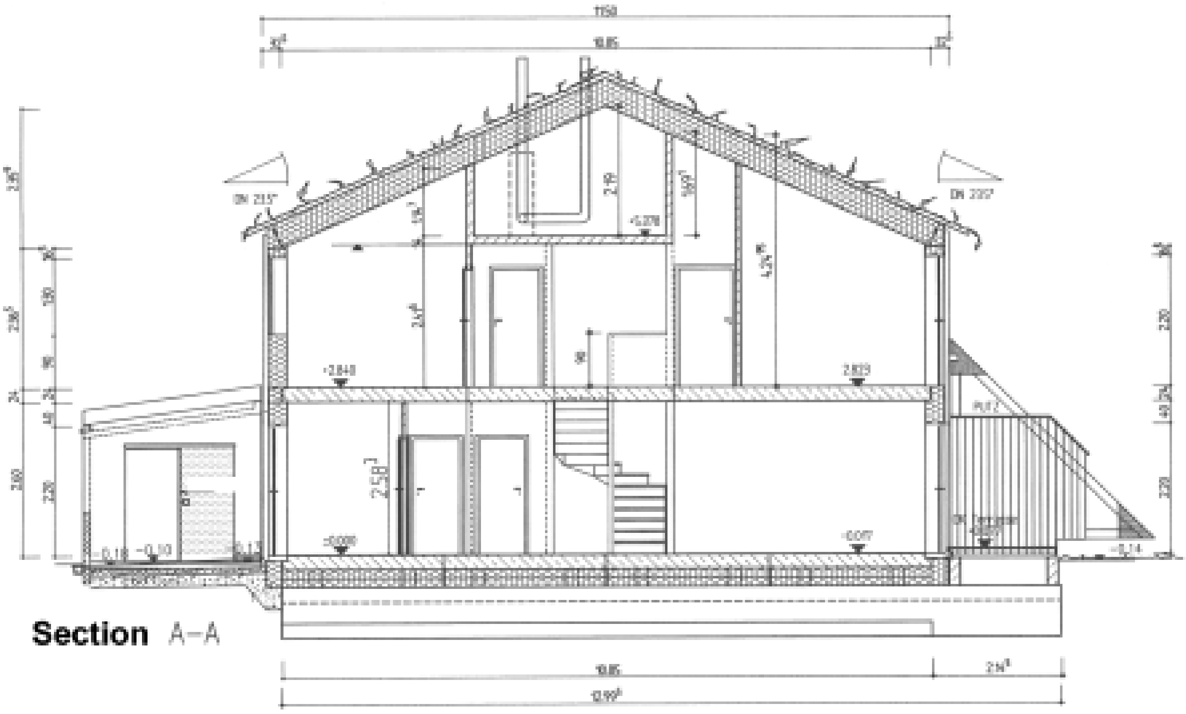


Figure 5: Longitudinal section through a Kronsberg terraced Passive House

Figure 6 shows the floor plans for house type „Jangster de Lüx“. One gains entry into the ground floor through a windscreen on the north side; to the east is a storage room and the guest toilet, to the west is the dining room with its own entry to a free space on the north side.

In the middle of the ground floor are the functional rooms: to the east a hallway and the staircase, to the west the kitchen. The south side opens onto a large living room with a door to the patio.

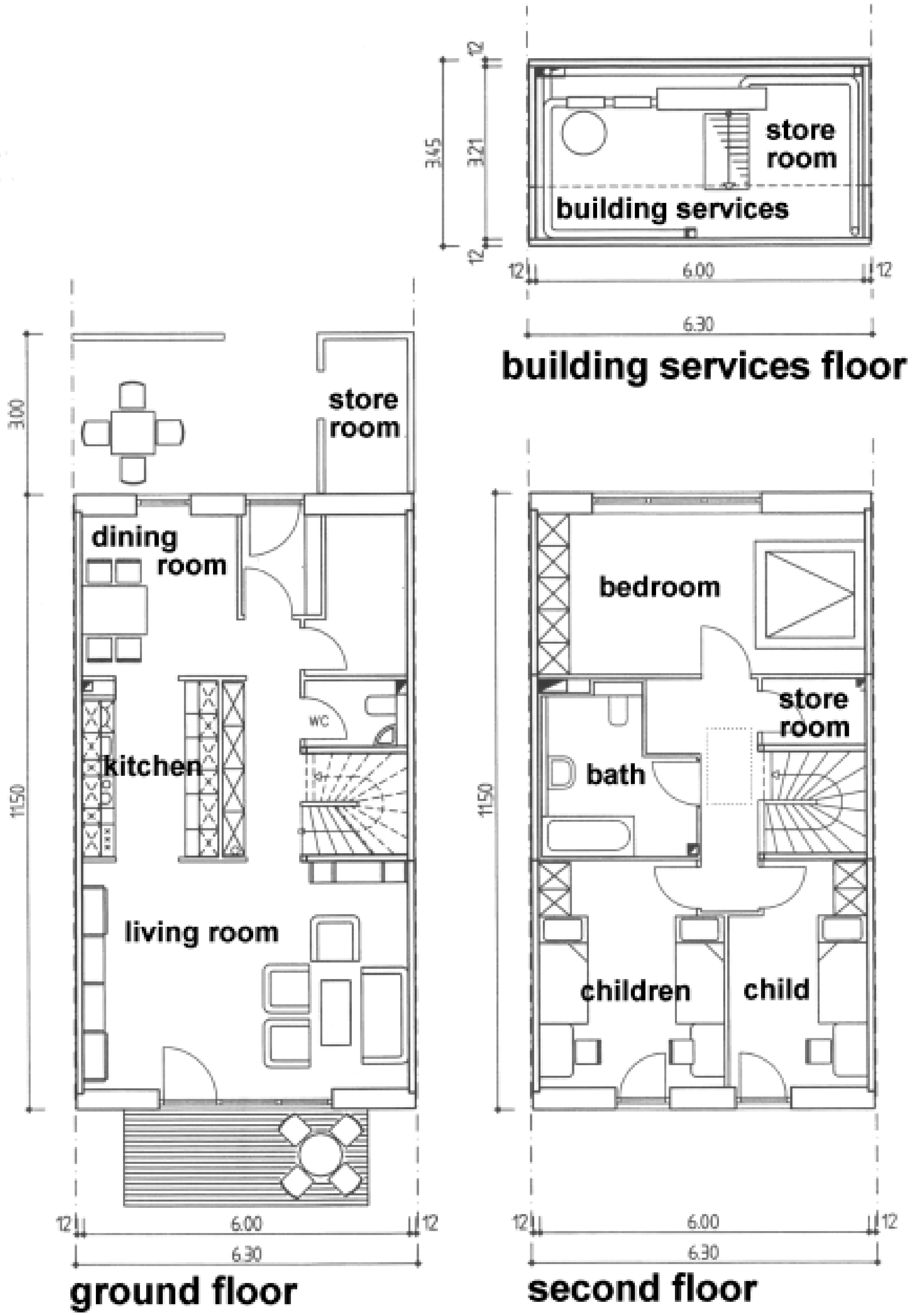


Figure 6: Floor plans for the house type Jangster de Lüx (Kronsberg Passive Houses)

3.2 Details about Treated Floor Area for the Kronsberg Passive Houses

Object	Heated living surface according to German II. BVO	Treated floor area TFA according to the EU-accepted calculation mode	Reference floor area according to the 1995 German Insulation regulation and EnEV
Jangster de Lüx MH	118,3	119,5	153,3
Jangster de Lüx EH	118,3	119,5	164,3
Jangster	97,3	96,8	128,7
„123“	79,0	75,1	99,2

3.3 Standard cross section of the external components

Figure 7 shows the standard details of the highly insulated building envelope:

- The roof is built from prefabricated lightweight wood elements with 400 mm high **I** beams, which span from one partition wall to the next. An internal polyethylene foil forms the airtight layer.
- The outer wall elements for the north and south facades are also built using prefabricated lightweight wood elements. So-called half box beams are used as shafts. An internal polyethylene foil forms the airtight layer.
- The outer wall of the gable sides is, like the house partition walls, built from load-carrying reinforced-concrete slabs. This is protected on the outside against heating losses by a 400 mm polystyrene external thermal insulation compound system. The concrete itself forms the airtight layer for the gable wall.
- The floor slab consists of 240 mm prefabricated steel-reinforced slabs, which is insulated underneath by factory-made 300 mm polystyrene external thermal insulation (420 mm for the end-of-terrace houses) . The concrete floor itself also forms the airtight layer.

To achieve the Passive House standard it is not only necessary to have good standard insulation for the building envelope surfaces, but most importantly a thermal-bridge free and airtight connection between the building elements. All connections were analysed for their thermal bridge effect with multi-dimensional heat flow calculations; the calculations have already been published elsewhere [Baffia 1999], only the results are cited here.

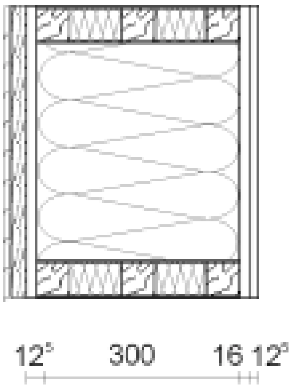
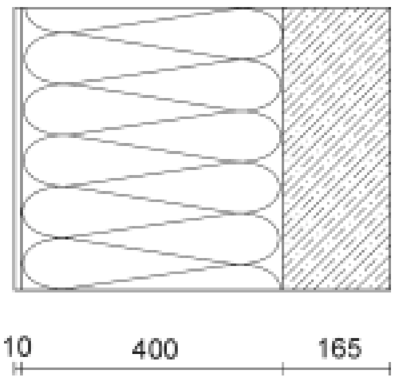
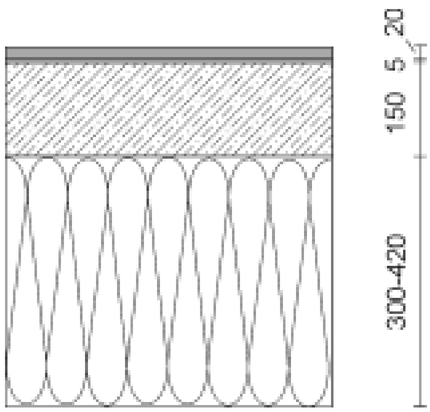
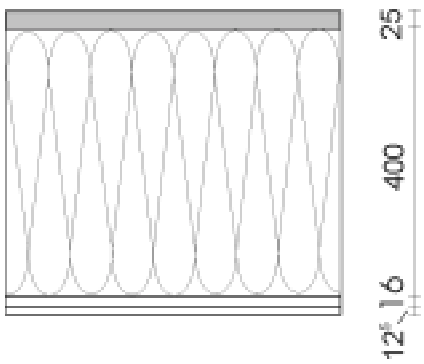
	**Outer wall (south and north facade)** Prefabricated lightweight wood element Plaster board Particleboard Mineral wool insulation/box beam truss Particleboard ventilated board casing U = 0,126 W/(m²K)
	**Outer wall (gable side)** Prefabricated concrete element (165 mm) with thermal insulation compound system (400 mm) out of polystyrene hard foam EPS, plastered on the outside U=0,097 W/(m²K)
	**Floor slab** Wood flooring Tread absorbing insulation (5 mm PE-foam) Concrete slab (150 mm) Insulation (300 mm/420 mm Final houses) U=0,125 W/(m²K) (Middle houses) U=0,091 W/(m²K) (End of row)
	**Roof system** Plaster board 12,5 mm Particle board 19 mm Mineral wool 400 mm/**I** truss Particle board 25 mm Roof sealing Green roof system U=0,095 W/(m²K)

Figure 7: The standard details of the Hanover-Kronsberg Passive Houses' building envelope

3.4 Presentation of junction details: air-tightness and thermal-bridge-free construction

Figure 8 shows the junction of two offset flat roof elements above the house partition walls; the prefabricated wood elements form closed plates, which are each closed with a particleboard. The interstice is filled with 60 mm mineral wool. In order to achieve an insulated thermal-bridge-free envelope, an insulated box is placed on the lower roof element.

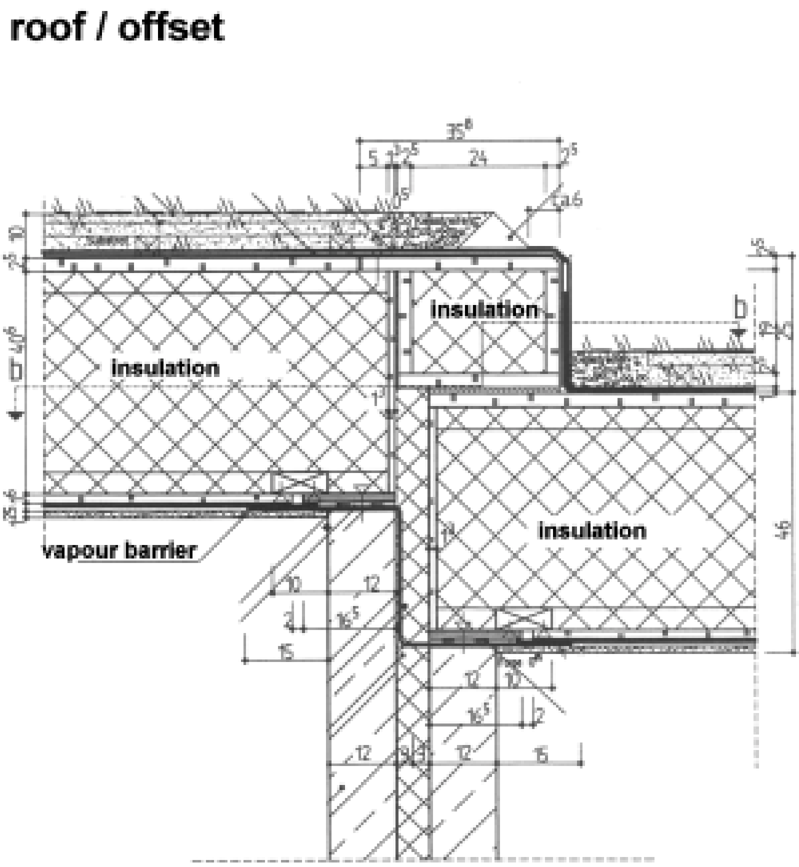


Figure 8: Thermal-bridge-free junction of two offset roof elements

The thermal-bridge-loss coefficient Ψ of this junction detail equals -0,002 W/(mK) for the upper and +0,007 W/(mK) for the lower house. The airtightness is arrived at using polyethylene (PE) foils. A foil strip was laid over the two concrete partition slabs before the installation of the roof elements. The integrated PE foil in each roof element is then joined to the foil strip to form a permanent airtight seal.

Figure 9 shows the junction of the end-of-terrace house roof element and the gable wall with its thermal compound insulation system. The roof element, in this case, extends 345 mm across the concrete wall. A thermal-bridge-free junction, with a Ψ-value of -0,055 W/(mK), is also achieved here.

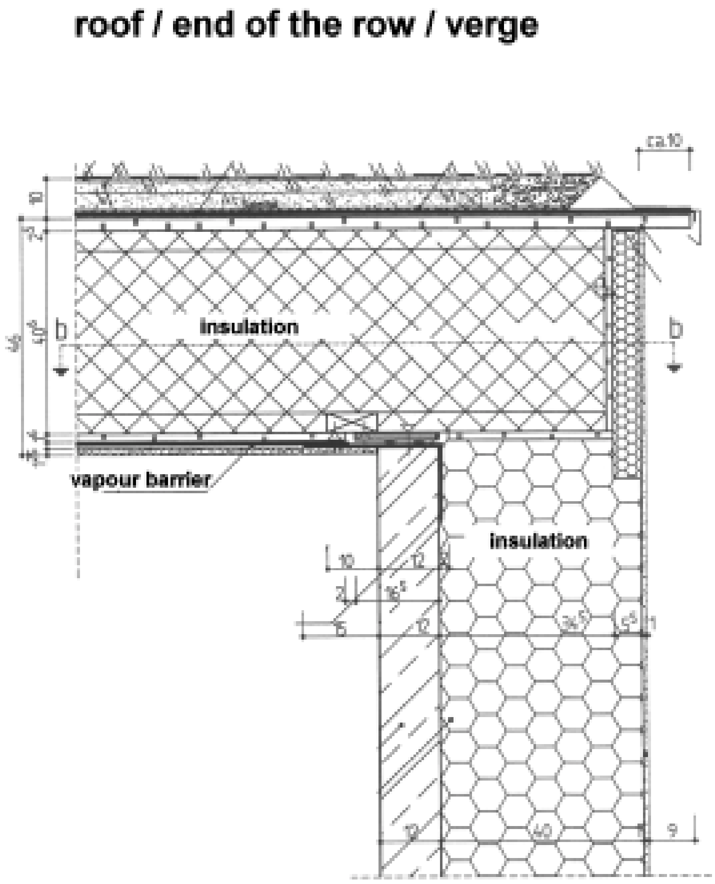


Figure 9: Thermal-bridge-free junction with the gable wall's thermal compound insulation system against the lightweight roof element

The airtight layer was formed in the same fashion as with the partition wall above.

Figure 10 shows the junction of two roof elements in the ridge area. The two foils integrated in the roof elements are permanently sealed. The upper 100 mm plaster board strips are added once the work is done. A Ψ-value of -0,014 W/(mK) was calculated for this junction.

The junction of the roof element and the facade wall element is shown in Figure 11. A gap-less insulation envelope was achieved (the Ψ-value for this junction is -0,052 W/(mK)). The airtightness is also achieved here through the sealing of both airtight foils; to achieve that, the plasterboard strip is built into the wall element after the sealing work done.

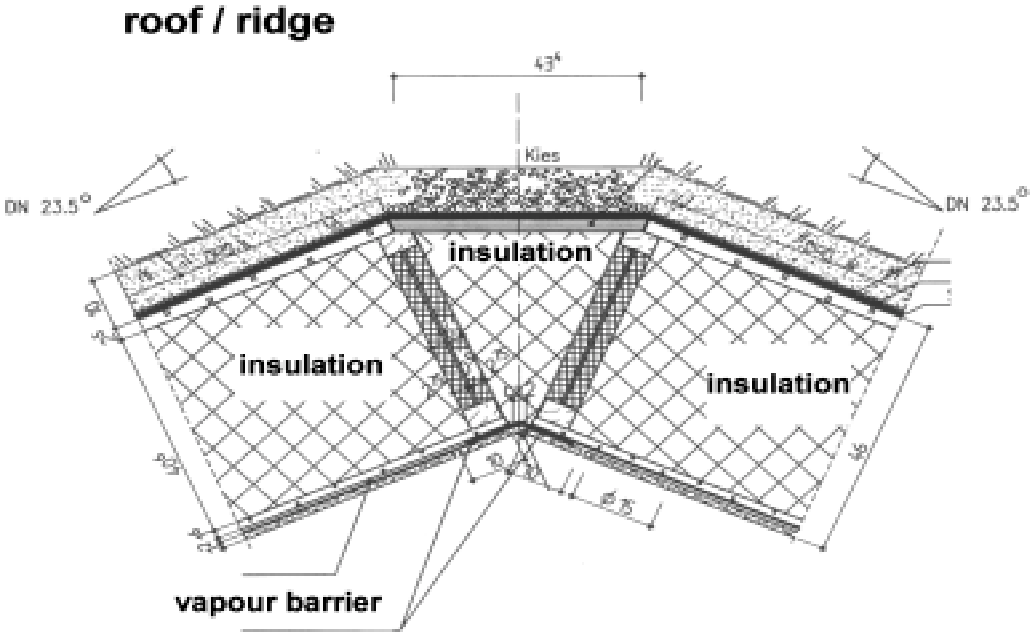


Figure 10: Thermal-bridge-free ridge junction

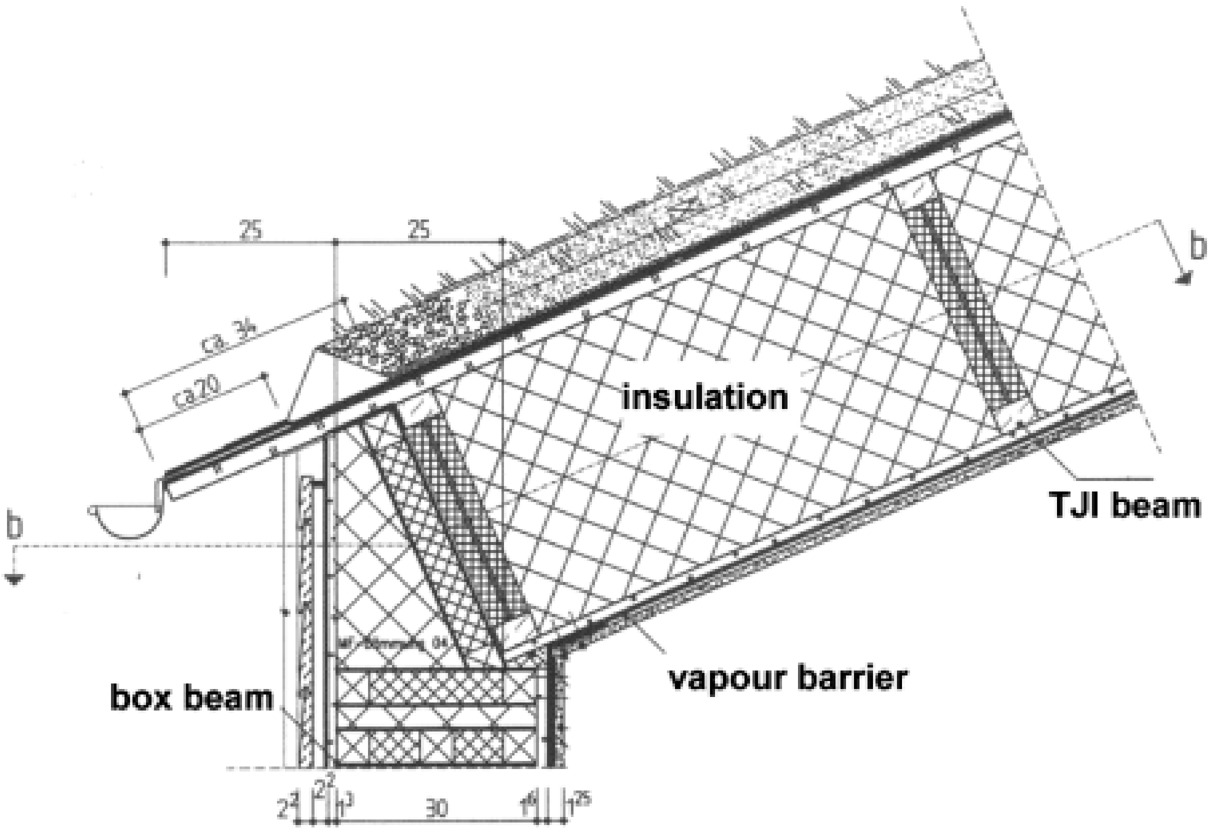


Figure 11: Thermal-bridge-free eaves junction of the roof element to the facade element

Figure 12 shows the junction of the ground floor and first floor facade elements at the concrete floor level. The ground floor ceiling protrudes roughly 50 mm into the insulation level of the lightweight wood elements. This leads to a certain thermal-bridge effect with a Ψ-value of 0,015 W/(mK); the aim of a „thermal-bridge-free“ effect is technically not achieved here; the impact, however, is overcompensated by the negative Ψ-value of the ridge and eave.

The junction of the facade elements to the gable wall, with its thermal compound insulation system, is shown in Figure 13. With a Ψ-value of -0,054 W/(mK), the junction is thermal-bridge-free.

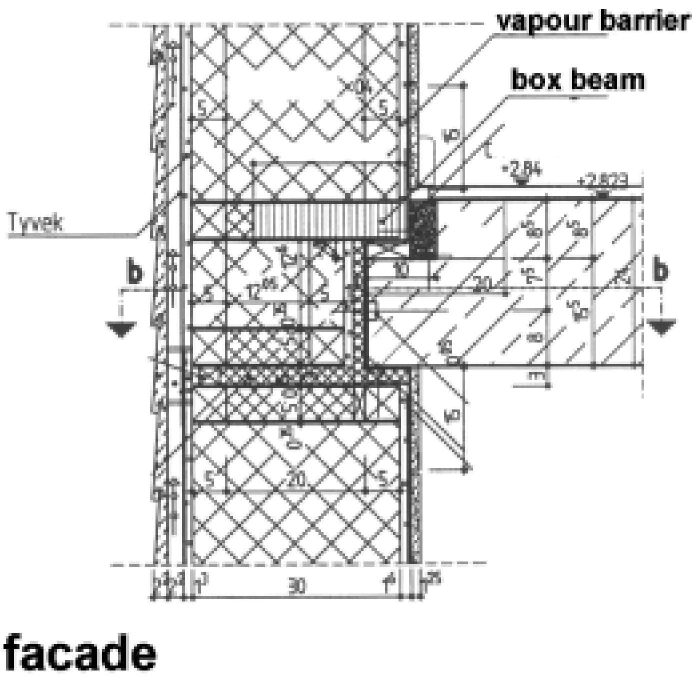


Figure 12: Concrete floor level between the ground floor and first floor (north side)

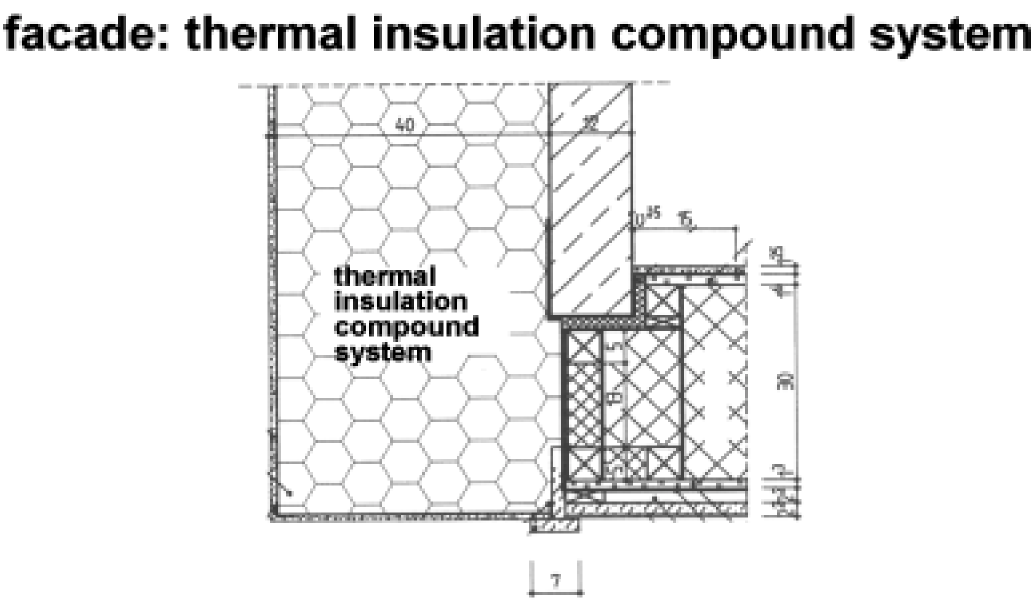


Figure 13: Junction of the facade element and the gable wall

Figure 14 shows the junction of the rising facade element to the floor slab. Several separated foundation blocks support the floor slab. The load-carrying concrete consoles are only sporadically present.

The window is integrated into the facade in a way that attachment through blocking onto the laminated wood is possible. The window-frame insulation merges without a gap into the insulation between the box truss' spars. The insulation on the front end of the floor slab is mounted on the construction side.

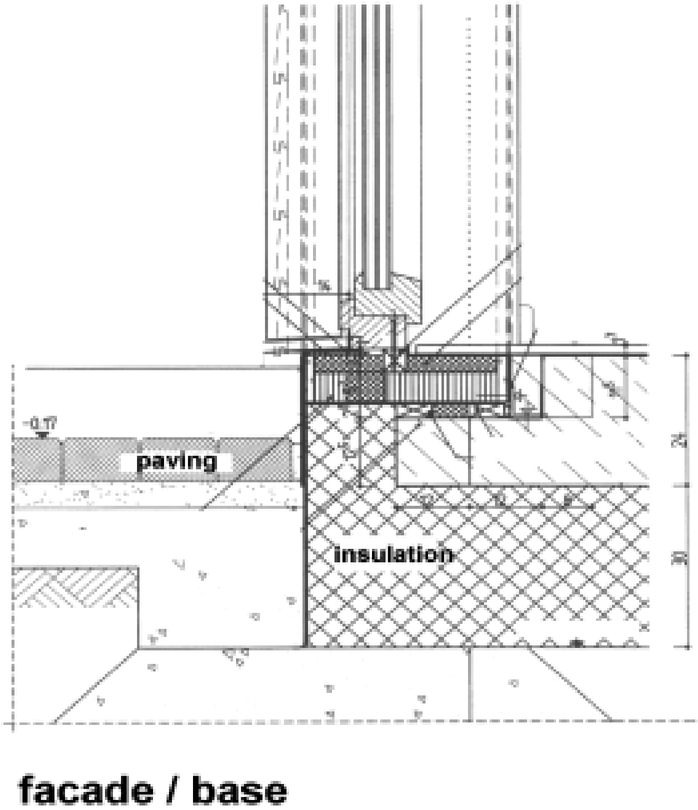


Figure 14: Junction of the facade elements with the floor slab

Figure 15 shows the triple-glazed low-emissivity windows that were installed for the first time in the estate (2 * 15 mm pane separation, argon gas filling). The glazing's U-value was set at 0,75 W/(m²K), the g-value equals 60%. The frame's U-value equals U_f = 0,57 W/(m²K), the Ψ-value of the glass edge is 0,03 W/(mK) (a thermal insulating spacer was used) and the junction Ψ-value is 0,03 W/(mK). This results in an average effective window U-value of U_W = 0,83 W/(m²K) in the Jangster de Lüx house.

To install the window into the lightweight wood elements, a new, particularly thermal-bridge reducing solution was developed: a continuous insulation layer exists between the insulation of the window frame and the prefabricated wall element; the thermal-bridge loss coefficient is therefore clearly reduced and the Ψ-value is just 0,026 W/(mK).

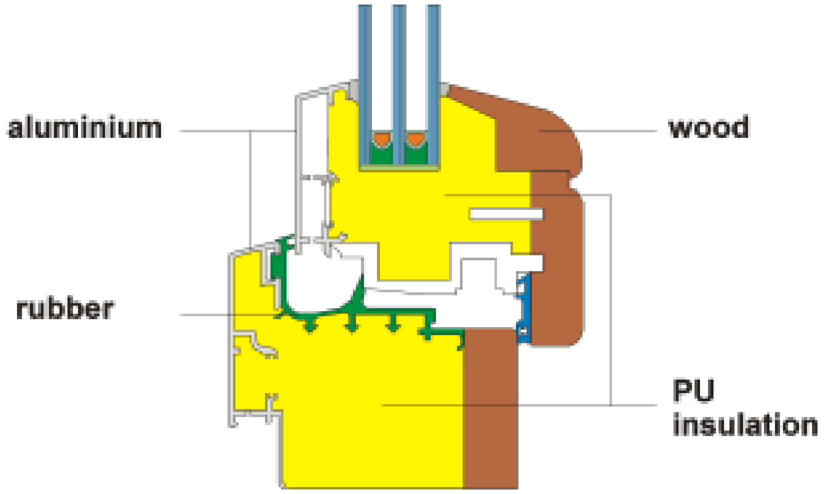


Figure 15: The windows in the Kronsberg Passive House estate

The concrete bearers, integrated in the concrete elements of the ground floor slab for structural reasons, also have an impact on the thermal losses in the estate (Figure 16). The extra thermal losses are considerable (Ψ=0,022 W/(mK)) despite the extra insulation and actually worse in the less insulated middle houses (Ψ=0,032 W/(mK)).

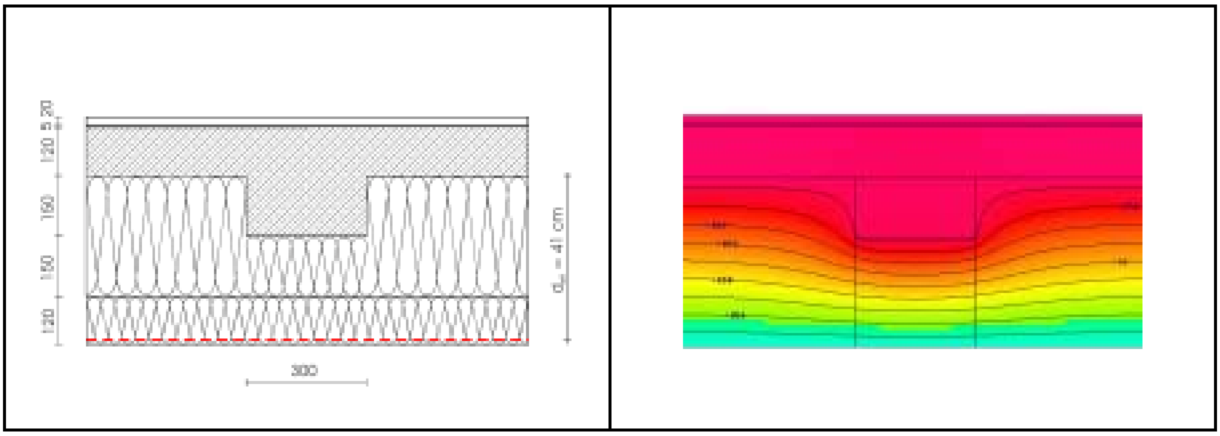


Figure 16: Concrete bearer in the insulation of the floor slab (Final house)

In order to avoid further thermal-bridge effects in the concrete walls, the houses' girders were placed in punctiform fashion on a total of 16 „bumps“ on the strip foundations. The punctiform thermal-bridge effect is substantial (due to the steel-reinforced concrete); when one divides the extra heating losses across the entire length of the strip foundations, the result is an effective Ψ-value of 0,09 W/(mK). Whilst this value does not fulfil the thermal-bridge-free condition, the result is altogether satisfactory for the Passive Houses.

4 Ventilation concept

Each of the 32 Passive houses has its own independent ventilation system with built-in heat exchanger to recover heat, which can be operated by the occupants. The system is located in the building services room under the roof; supply and exhaust air are aspirated or blown out directly above the roof. The ventilator control is clearly located in the windscreen area of each house.

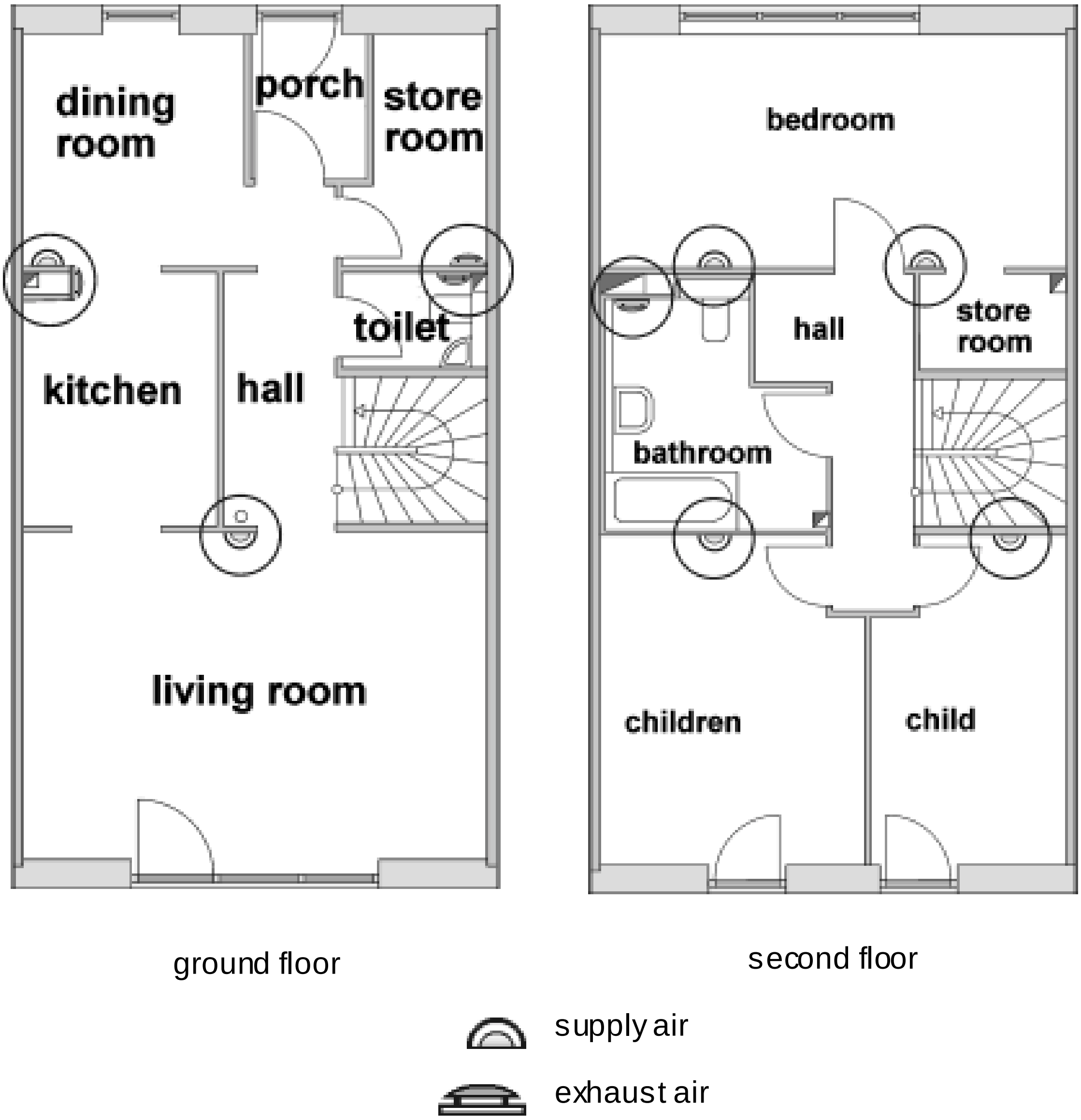


Figure 17: Position of the supply and exhaust air outlets and respective nozzles on both floors

4.1 Ventilation zones

There is no room, which is not clearly integrated into the ventilation concept. The supply air is shared and it is guaranteed that no „dead zones“ with stagnant air exist. Figure 17 shows the locations of the supply and exhaust air outlets in the „Jangster de Lüx" house type. All living and sleeping rooms are planned as supply air zones, the exhaust air rooms are the kitchen, storeroom, toilet and bathroom. The hallway and staircase act as overflow zones.

The duct network for air distribution is made up of folded spiral-seam pipe and sound absorbers, and was arranged as compactly as possible to minimise pressure losses. The physical distribution of air to the three vertical shafts takes place in the services floor. A shaft with the exhaust duct passes on the north side along the bathroom/partition wall corner to the kitchen on the ground floor. The second shaft goes down along the south side into the bathroom and leads the supply duct through the penetration into the living/dining room. The third shaft with a folded spiral-seam pipe goes through the north side of the first floor storage room along the partition wall and then aspirates the exhaust air in the ground floor from the toilet and storage room.

The supply nozzles in the sleeping and children's rooms in the first floor are serviced directly from the services floor.

4.2 Technical parameters of housing ventilation

The complete building services technology was planned by the inPlan engineering office, the following technical parameter details were taken from [Stärz 1998].

4.2.1 Ventilation duct network

An optimum between large nominal diameters and justifiable investment costs was aimed at for the duct network. The air flow velocity is set at a maximum of 3 m/s. Due to the central location of the wet rooms (exhaust) and the use of wide casting nozzles, a duct network with very low pressure losses was realized.

The fresh air and exhaust ducts were built with very short extensions out of the thermal envelope and through the roof. A folded spiral-seam pipe with a 160 nominal diameter and 90mm aluminium-clad mineral wool insulation was used. Both pipelines have permanently installed differential pressure sensors from the Westaflex company („dynamic pressure measuring device" model, Halton system, DN 160), so as to allow for system balance calibration. The fresh air duct also has an electrical frost protection heating system with temperature sensors, in order to avoid freezing of the heat exchanger. Both ducts are located on the north side of the roofs. In order to avoid a short-circuit of the airflows, the ducts are situated with the largest possible separation distance (ca. 3 m) on the roof. The ducts end in a 90-degree bend with weather protection and built-in coarse grid protector (bent outlet with grid, Lindab company).

Inside the thermal envelope and from the heat recovery system onwards, the supply and extract ducts are carried out in nominal diameters of 100 and 125 mm respectively. The supply ducts are insulated with 30 mm aluminium-clad mineral wool from the air-heating-element (postheater) onwards. The extract ducts are carried out without insulation.

The duct network plan in Figure 18 shows the ventilation system for the house type „Jangster de Lüx". The other house types are only slightly different.

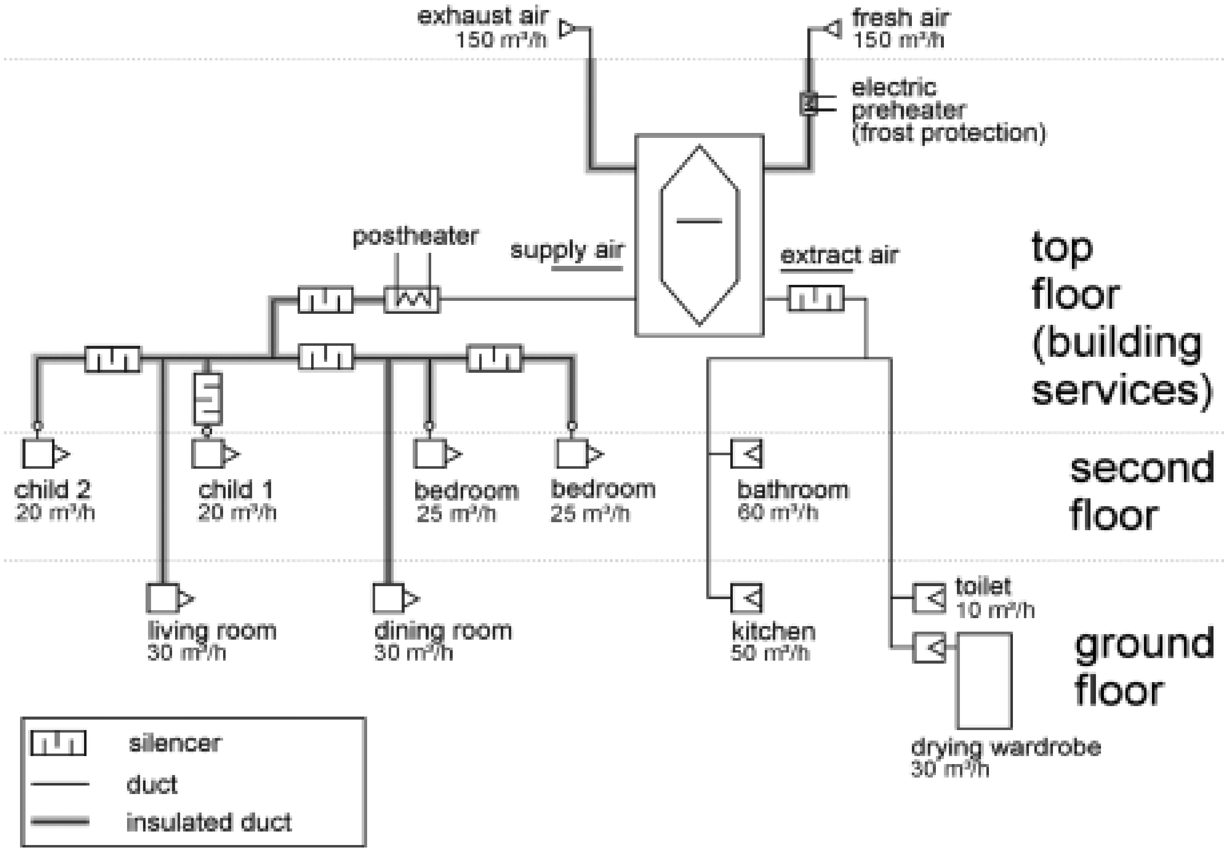


Figure 18: Ventilation system duct network plan for Passive House type „Jangster de Lüx" with the design layout flow volumes

A noise pressure level of 25 dB(A) was aimed for, which is clearly below the limit of 30 dB(A) for so-called "rooms requiring protection". The **silencers** are flexible pieces from the „Aerotechnik Sigwart" company, made up of a perforated aluminium inner pipe, mineral fibre packaging and aluminium outer pipe. On the exhaust side, there is a common silencer (nominal diameter 160, packaging thickness 25 mm, length 1000 mm) before the ventilation system.

4.2.2 Design layout flow volumes

On the supply side, the per-person flow volumes are set at 30 m³/h. That means 90 m³/h for 3 people („123"), 120 m³/h for 4 people („Jangster") and 150 m³/h for 5 people („Jangster de Lüx"). On the exhaust side, there are flow volumes set for the kitchen (40-50 m³/h), the ground floor toilet (10 m³/h) and the bathroom (40 m³/h). This set-up leads to the following flow volumes:

House type		„123“	„Jangster“	„Jangster de Lüx“
		[m³/h]	[m³/h]	[m³/h]
Supply air room	Dining room ground floor	20	30	40
	Living ground floor	25	30	40
	Sleeping first floor	25	30	40
	Child 1 first floor	20	15	15
	Child 2 first floor	-	15	15
Total		**90**	**120**	**150**
Exhaust air room	Dry storage cabinet	-	30	30
	Kitchen ground floor	50	40	50
	Toilet ground floor	-	10	10
	Bathroom first floor	40	40	60
Total		**90**	**120**	**150**

Table 3: Design layout flow volumes for the three house types (m^3/h)

In order to be able to react to the different occupancy levels and uses of the houses, the ventilation system can be set at three levels. In addition to normal ventilation, the occupants can choose „basic ventilation“ for a reduced airflow (75%) or “maximum ventilation” for an increased airflow if necessary (150%).

4.2.3 Pressure losses

An overview of the magnitude of the pressure losses of the entire system under the different operation levels is shown in the following Table:

	Post-heater	In- & outflow elements	Filter	duct network	**Total**
	[Pa]	[Pa]	[Pa]	[Pa]	**[Pa]**
Basic ventilation 90 m³/h	10	10	15	25	**60**
Normal ventilation 120 m³/h	15	30	20	40	**105**
Max ventilation 180 m³/h	35	50	30	60	**175**

Table 4: Projected ventilation system pressure losses for the three different operational levels

4.2.4 Inflow vents

The inflow elements used in living and sleeping rooms are solely of the wide-casting nozzle type (ceiling and wall versions) from the manufacturer ABB („CTVB“ and „CTVK“ models).

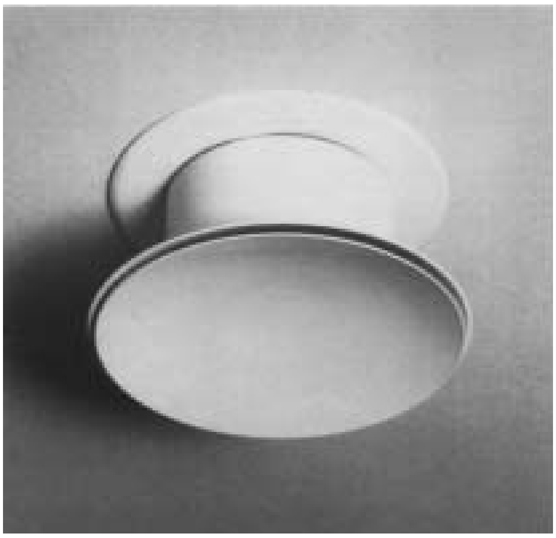


Figure 19: Inflow elements as wide-casting nozzles, both ceiling and wall versions (Photos: Manufacturer)

4.2.5 Outflow vents

The outflow rooms are equipped with exhaust elements from the manufacturer Exhausto. Plate vents (VTU model) are used in the bathroom, toilet and ground floor storage room, whereas the kitchen has a filter brace (FA 100 PB model) with removable aluminium filter (EU3 / G85) and an exhaust vent (URH model) behind it.

4.2.6 Overflow elements

Overflow openings are necessary to guarantee directional airflows in the building when doors are closed between the zones. The overflow openings in the 32 houses are integrated above the door frames (see Figure 20). The bathroom door is an exception, being equipped with a traditional grid in the upper part of the door; here as well, the PHI recommends the solution shown in Figure 20, which has proven itself very effective.

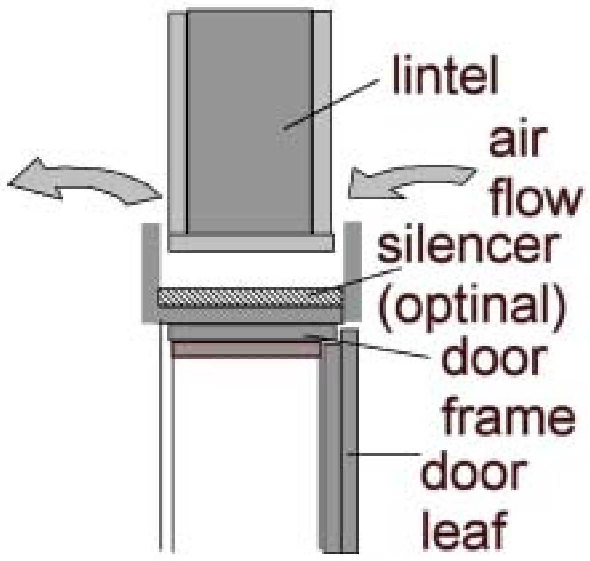


Figure 20: Overflow openings between the lintel and the door frame (source ebök)

4.3 Central ventilation system with heat exchanger

The ventilation units are made up of a counterflow heat exchanger, the supply-, and exhaust ventilators, two integrated filters and a control to set the flow volumes. The installed central ventilation units with counterflow heat exchangers are from the Paul Company („Thermos 201 DC" model). The system's two ventilators are maintenance-free 24 V direct current (ecm) ventilators (radial ventilators with reverse bend blades). Each ventilation system is equipped with an electrical „defrost heater" in the fresh air flow, which prevents the heat exchanger from freezing.

<u>Technical details of the ventilation system (manufacturer's specifications):</u>

Dimensions:	1010x1300x450mm (WxHxD)
Duct material:	plastic
Duct connectors:	DN 160
Ventilators:	2 radial ventilators, 24 V
Volume airflow:	75 to 230 m³/h
Power consumption (entire system):	36 to 88 W
Filter form (In- & outflow filter):	Z-Filter
Filter class (In- & outflow filter):	G4

Figure 21: Ventilation unit with heat exchanger in the building services floor of a Hannover-Kronsberg Passive House. In the background is the fresh air duct with defrost heater and in the foreground is the exhaust air pipe (both insulated with mineral wool, aluminium laminated)

The units are all equipped with a by-pass slide, which can be manually operated. If the heat exchanger is no longer needed in the transition season, this part of the system can be by-passed by pulling the slide. On the reverse side of the unit is a condensation drainpipe to drain the condensed water, which forms in the heat exchanger.

4.4 Control possibilities

Through the use of an operating unit clearly positioned in the windscreen area, the ventilation system can be switched to the different operation levels. The choice can be made between basic ventilation (75%), normal ventilation (100%) and maximum ventilation (150%). In addition, the „summer ventilation“ button can be pushed, so that only the exhaust ventilator is used when the outdoor air comes through opened windows and the inlying bathroom needs to be vented. The fifth button, „off“, shuts the ventilation system down. The respective operating level is indicated on the display. Furthermore, the „filter change“ display appears each time after an operating period of three months. The chosen operating level remain in operation until another setting is chosen (also maximum ventilation). Automatic timing is not available with this design.

5 Space heating supply concept

5.1 Heating distribution

A combined building services container with an integrated district heating transfer station is in place for each set of two housing rows (each row having eight terraced houses). The building services container is located directly along the gable wall of each northern housing row. The supply and return pipe lead under the gable wall insulation to the building services floor of the end of terrace house. The two pipes then lead from there through the eight building services floors. The other row is connected to the building services container with two underground pipes. The pipeline runs otherwise identically to the other row.

Due to the low heating losses, a separate heating distribution system within the houses is no longer necessary. The heating distribution now takes place through the supply air flows (necessary for indoor air quality reasons). An exception is the bathroom, in which a higher temperature (24 °C) is sometimes necessary for a short period. The only heating radiator in each house is located here.

5.2 Heating supply

5.2.1 District heating supply

The district heating supply for the Kronsberg new housing estate, with its 2.700 homes and roughly 240.000 m² of heated floor area, is ensured by a central energy station with a combined heat and power plant located at the southern end of the estate.

5.2.2 House heating supply

The heating supply for the hot water and space heating consumption of the four terraced housing rows takes place through the district heating transfer station in the two building services containers (each with 40 kW power) as well as the flat solar collector systems for hot water on the house roofs. The hot supply water directly supplies each house's central postheater element (to warm the supply air), the bathroom radiator and the hot water tank.

The central direct air/water postheater elements are located on the building services floor and heat up the supply air after the ventilation unit, when necessary. The element used is a „hot water postheater radiator WHR 125“ from the Helios Company, designed to be built directly into the ventilation duct and with an output of 1100 Watt (specifications at 0 °C supply air temperature, supply/return water temperatures of 60/40 °C). The system is designed so that the maximum air temperature at the postheater does not exceed 55 °C, in order to avoid dust pyrolysis.

The distribution of the postheated air occurs as described in Chapter 3 „Ventilation concept“. The necessary heat thus is brought along with the fresh air into the inflow rooms.

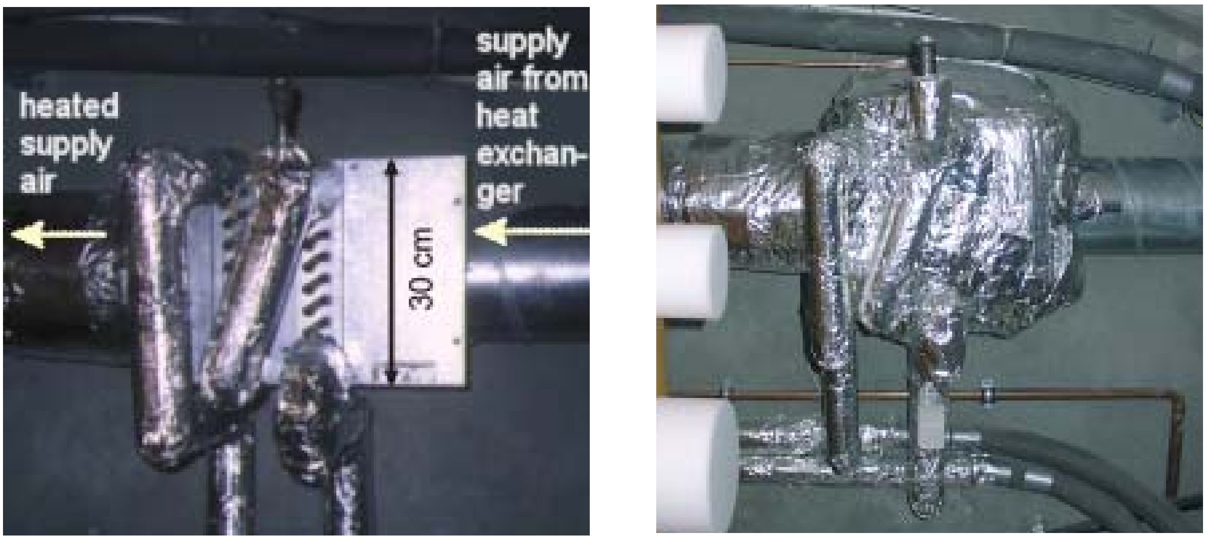


Figure 22: Postheater in the inflow pipeline (before and after the addition of insulation)

The control for the postheater occurs over a vent with battery operated drive mechanism. A central room thermostat, located on the ground floor, controls the motorised vent. The room thermostat controls the room temperature centrally for the entire house (one zone). A temperature reduction overnight does not make sense any more, due to the excellent building insulation and the resulting long time constants.

The bathroom radiator (Brötche Company, „towel warmer radiator“, rating: 205 Watt) has its own control thermostat vent and can thus be used independently from the central heating system.

6 Domestic hot water supply concept

6.1 Production, storage and distribution details

On the one hand, the domestic hot water supply for all houses is also provided by the two district heating connections and the distribution system described above. On the other hand, each house has a solar thermal system. These two heating sources each supply a 300-litre water storage tank on the building services floor. The storage tanks are heated in the upper third to roughly 45 °C, according to the setting. This takes place over a thermostatic control.

As is usual for every centrally supplied residential building, the domestic hot water distribution comes prior to the space heating distribution. At the storage tank exit, the hot water pipe has a built-in thermostatic water mixer as a scald protector. This mixes cold water into the pipe should the temperature get too high, in order to avoid dangerously high tap temperatures.

During the summer months, the heating supply pipes form the building services containers are only used for domestic hot water preparation. It is therefore only necessary to supplement the energy, which is not delivered by the solar thermal system. In order to avoid unnecessary circulation losses in the supply pipes during this period, an additional clock timer was installed on each pipe at the recommendation of the Passive House Institute. This results in the hot water pump being in operation for only a few hours per day during the non-heating period. During this time, the supply pipes are used to load up the house's hot water storage tank. In this manner, the circulation losses can be dramatically reduced.

6.2 Design data

The hot water consumption is largely dependent on the number of people living in the house and their behaviour. The seasonal swings are relatively minor. In the design for the hot water supply, a base consumption of 40-litres at 45 °C per person and day was set. An average power demand of ca. 270 Watt was assumed for a 4-person household. To determine the size of the storage tank, a minimum of a full bathtub should be accounted for. The upper part of the storage tank must suffice for this, since only this part is continuously heated by district heating.

6.3 Solar thermal system

The solar thermal system (Wagner & Co Company) consists of a ca. 4 m² flat collector field on the southern roof, a control unit, the expansion vessel as well as the heat exchanger in the lower part of the hot water tank. It functions as an independent system with an anti-freeze liquid filled closed circuit. Under sufficient solar radiation, the control unit activates the pump. Due to the placement of the heat exchanger in the lower part of the water tank, it can be completely heated from below (300-litres). The storage tank temperature sensor is mounted in the area of the solar heat exchanger. The second temperature sensor is located in the collector on the roof.

The temperature in the storage tank can be heated up to roughly 85 °C by solar energy. The above mentioned water mixer makes sure, through the mixing of cold water, that no scalding occurs at the taps.

7 Configuration of large household appliances and lighting

The developer tested a new concept for the Hannover Kronsberg Passive House estate, which was aimed at increasing the adoption of energy efficient household appliances:

- The sales price of the houses was increased by 1000 Euro per home.
- Each purchasing household was offered the possibility of determining the electrical efficiency through the use of the Passive House Institute's „Projected electricity consumption" software, and of receiving advice with regards to purchasing new, particularly efficient appliances.
- If the „Projected electricity consumption" software determined an electricity requirement of less than 18 kWh/(m²a) and a primary energy requirement for electricity of less than 55 kWh/(m²a), the 1000 Euro from the sales price would be returned.
- As a special feature, all the homes in the Passive House estate were equipped by the developer with optimised clothes dryers (see CEPHEUS-report Nr. 4 and [Feist 2000]), which use only a seventh of the electricity requirement under air-vented operation compared to typical air-vented or condensation dryers.

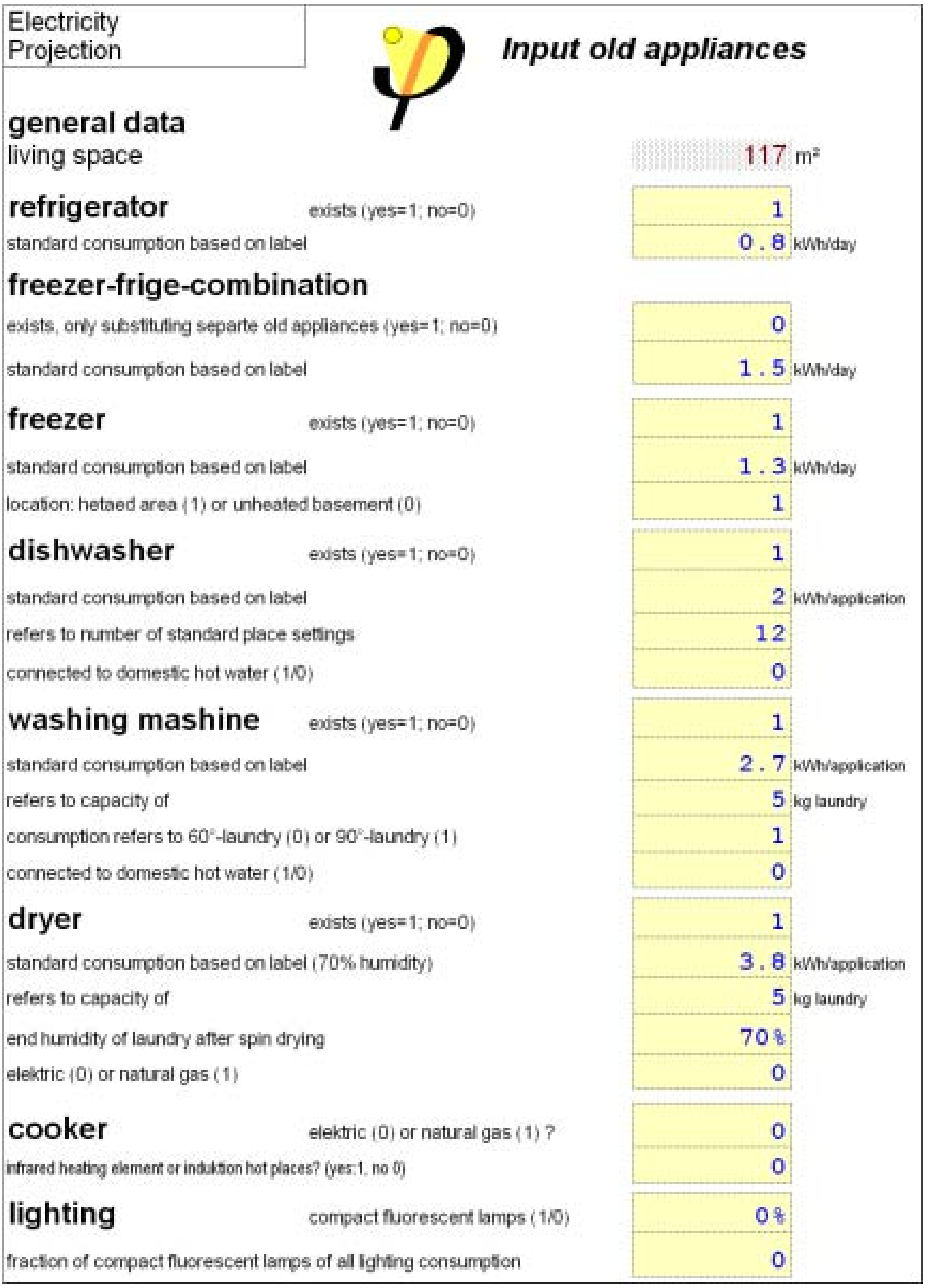
With the data of the old and new appliances as well as the purchase costs of the new appliances, one could determine:

- the annual electricity consumption of a combination of old and new appliances,
- the total investment for the purchase of the new appliances in this combination,
- the energy cost savings and the cost effectiveness of the new purchases.

The cost effectiveness was determined on the basis of net present values: the energy savings were capitalised with the real interest rates over the useful life of the appliances (e.g. washing machine 12 years).

In this way, it was possible to reach a mix of relatively efficient old appliances and a few new high-efficiency replacement appliances, which both achieve the requirements (electricity demand less than 18 kWh/(m²a)) and are cost effective.

With this instrument, a total of 18 buyers were advised by the developer's Hannover outer office. The consultations were all successful, in the sense that the calculated compliance with the CEPHEUS project's „electrical efficiency criteria compliance" (electricity demand ≤ 18 kWh/(m²a)) requirements was proven in 14 out of 18 cases.



Electricity Projection

Input old appliances

general data			
living space		117	m²
refrigerator	exists (yes=1; no=0)	1	
standard consumption based on label		0.8	kWh/day
freezer-frige-combination			
exists, only substituting separte old appliances (yes=1; no=0)		0	
standard consumption based on label		1.5	kWh/day
freezer	exists (yes=1; no=0)	1	
standard consumption based on label		1.3	kWh/day
location: hetaed area (1) or unheated basement (0)		1	
dishwasher	exists (yes=1; no=0)	1	
standard consumption based on label		2	kWh/application
refers to number of standard place settings		12	
connected to domestic hot water (1/0)		0	
washing mashine	exists (yes=1; no=0)	1	
standard consumption based on label		2.7	kWh/application
refers to capacity of		5	kg laundry
consumption refers to 60°-laundry (0) or 90°-laundry (1)		1	
connected to domestic hot water (1/0)		0	
dryer	exists (yes=1; no=0)	1	
standard consumption based on label (70% humidity)		3.8	kWh/application
refers to capacity of		5	kg laundry
end humidity of laundry after spin drying		70%	
elektric (0) or natural gas (1)		0	
cooker	elektric (0) or natural gas (1) ?	0	
infrared heating element or induktion hot places? (yes:1, no 0)		0	
lighting	compact fluorescent lamps (1/0)	0%	
fraction of compact fluorescent lamps of all lighting consumption		0	

Figure 23: Input form for old electrical appliances for the electrical efficiency consultation at the Hannover Kronsberg Passive House estate

Electricity Projection		Input new appliances	
general data			
living space		117	m²
refrigerator	exists (yes=1; no=0)	1	
standard consumption based on label		0.28	kWh/day
freezer-frige-combination			
exists, only substituting separte old appliances (yes=1; no=0)		0	
standard consumption based on label		0.7	kWh/day
freezer	exists (yes=1; no=0)	1	
standard consumption based on label		0.5	kWh/day
location: hetaed area (1) or unheated basement (0)		1	
dishwasher	exists (yes=1; no=0)	1	
standard consumption based on label		1.2	kWh/application
refers to number of standard place settings		12	
connected to domestic hot water (1/0)		1	
washing mashine	exists (yes=1; no=0)	1	
standard consumption based on label		1	kWh/application
refers to capacity of		5	kg laundry
consumption refers to 60°-laundry (0) or 90°-laundry (1)		0	
connected to domestic hot water (1/0)		0	
dryer	exists (yes=1; no=0)	1	
standard consumption based on label (70% humidity)		0.4	kWh/application
refers to capacity of		4	kg laundry
end humidity of laundry after spin drying		50%	
elektric (0) or natural gas (1)		0	
cooker	elektric (0) or natural gas (1) ?	0	
infrared heating element or induktion hot places? (yes:1, no 0)		0	
lighting	compact fluorescent lamps (1/0)	1	
fraction of compact fluorescent lamps of all lighting consumption		90%	

Figure 24: Input form for new, energy-efficient appliances (electrical efficiency consultation)

economical analysis

results

living space 117 m²

application	energy costs saved	capital costs added	costs saved (Euro)
dishwasher	459	479	
washing mashine	227	764	
dryer	699	390	
refrigerator	305	316	
freezer	469	413	
or combination	-	-	
cooker	-	714	
lighting	675	196	
		-	
grant		1023	
		=	
total	2833 -	2250 =	583

Figure 25: Results sheet for projection of electrical efficiency; in this case: cost effectiveness (example)

8 Costs, extra costs and cost effectiveness

8.1 Extra capital investments for Passive Houses

The statement of costs accounts for all investment costs from cost types 3 and 4 (according to the German standard), each without value added tax, but including all the extra work such as side connections, plugging of holes, etc. The following building components are relevant:

- Improvement of the insulation in the lightweight outer wall elements

  According to the 1995 German insulation ordinance, a U-value of 0,5 W/(m²K) for a respective insulation thickness of 80 mm would be sufficient here. The specific extra costs for the Passive House wall construction with a total insulation thickness of 300 mm were quoted by the developer as being

  outer wall lightweight construction extra costs: 17,90 Euro/m²

  The total costs for the lightweight facade were 240,31 Euro/m².

- Improvement of the gable wall insulation with a thermal insulation compound system

  A U-value of 0,5 W/(m²K) for this part would also be sufficient according to the 1995 insulation ordinance. The insulation thickness was increased from 70 mm to 400 mm; for this, the developer quotes extra costs of 25,56 Euro/m². The total costs for this building component were quoted at 145,72 Euro/m².

- Improvement of the roof insulation

  An insulation thickness of 150 mm in the rafter roof would have sufficed to reach the 1995 insulation ordinance's U-value of 0,29 W/(m²K). An insulation thickness of 400 mm was chosen for the Passive house. The component costs were quoted as follows

  roof construction Passive House roof at 102,26 Euro/m²

  and the

  extra investment costs for the Passive House roof at 10,23 Euro/m².

- Improvement of the ground insulation

  In the ground floor slab, an insulation thickness of 50 mm would have been sufficient for the insulation ordinance (U-value 0,6 W/(m²K)). The average thickness, for all house types, of the direct concrete-covered polystyrene insulation for the prefabricated slab is 326 mm; the construction costs were

  slab construction Passive House 102,26 Euro/m²

  The extra investment costs for the Passive House slab were 15,34 Euro/m².

- Windows with triple glazing and insulated frames

  Typical double-glazed insulation windows with a standard frame would have had a thermal conductivity coefficient of roughly 1,9 W/(m²K). In this case, a U_W-value of 0,83 W/(m²K) was achieved. The total costs of the

  Passive House windows were quoted at 341,54 Euro/m².

  According to the developer, these windows cost 111,46 Euro/m² more than typical windows with U_W=1,9 W/(m²K). The relative extra costs of 48% above the standard windows are high; thanks to increased numbers of production, we expect a further reduction in the extra costs for this type of window in the future.

- Ventilation system

  The current regulations in Germany do not require ventilation systems in residential buildings. Although we are of the opinion that a continuous ventilation of residential buildings is an essential requirement for a healthy living environment in all conventional new buildings, we wish to comply with the current practices and thus apply the total

  investment costs for the residential ventilation system of 4601,63 Euro

  on each of the 32 Passive Houses.

  A simple residential ventilation system based on an exhaust ventilation system with decentralised inflow through outdoor air vents would have been possible in these houses for investment costs of ca. 1300 Euro. We do not calculate these costs against the Passive House standard.

- Heating distribution

  The hydraulic heating distribution (pipe network, gates, bathroom radiator) necessary for this project is very simple and only cost

  903,58 Euro (heating distribution)

  per house [Stärz 1999]. The cost reductions against standard costs for

  typical heating distribution and disposal of 2828,27 Euro

  per house are a result of two contributions:

  a) The reduction of the maximum heating load of a Passive House compared with a typical insulation ordinance house from roughly 6 kW to only 2,5 kW installed output saves about 1400 Euro (400 Euro per Kilowatt).

  b) The supply air ducts also provide the heating distribution for the living, eating, children and bedrooms, so that only a very small radiator in the bathroom is necessary. This results in a further reduction in the investment costs for radiators and pipes of roughly 1525 Euro.

- Pressurisation test

  According to current German regulations, an air-tightness check is not absolutely necessary for new buildings. Such a check was performed on each Kronsberg Passive House, with investment costs of

  153,39 Euro

  per object. These costs were added to the extra costs for the Passive Houses in the statement of costs account, although they should actually belong to a professional quality assurance for each new building and were also demanded by the city of Hannover for the Kronsberg standard.

- Solar thermal system

  A solar thermal system was required for the CEPHEUS-project, although these do not belong absolutely to the Passive House standard. These systems resulted in extra investment costs:

for collectors incl. assembly, adjustment, heat exchanger	2273,71 Euro
for a larger and solar capable hot water tank	766,94 Euro.

  The sum of the extra investment costs for the hot water system in comparison to a conventional system were thus 3.040,65 Euro or roughly 800 Euro per square meter collector surface area (system costs).

To determine the total extra investment costs for the individual house types of the **Passive House estate**, the surface area data must be used. These were based on the final invoice statements between the developer Rasch & Partner and their subcontractors.

With the specific extra costs and the surface areas, the resulting extra costs for the heating savings of the four house types (each without value added tax) are:

House type „Jangster de Lüx end of terrace“	10258,37 Euro
House type „Jangster de Lüx middle house“	8172,30 Euro
House type „Jangster middle house“	7518,87 Euro
House type „123“	6808,17 Euro.

For the energy savings with regards to the domestic hot water preparation, the solar thermal system and associated larger hot water storage tank add equal costs for each house of 3.040,65 Euro.

The total construction costs per m² living area for this project, for the cost groups 300 and 400 according to the German standard, were:

House type „Jangster de Lüx final house“	951,02 Euro/m²
House type „Jangster de Lüx middle house“	885,48 Euro/m²
House type „Jangster middle house“	987,94 Euro/m²
House type „123“	1089,91 Euro./m²

The construction costs were thus in the lower half of the typical construction costs for similar terraced houses at the construction site.

The proportionate extra costs in comparison with a building built according to the insulation ordinance were between 11,6% and 13,7% of the pure construction costs, including the extra costs for the solar thermal collectors; were one to consider only the costs for the Passive House, they would be between 8 and 9% of the construction costs.

For presentation clarity, it does not make sense to discuss the cost effectiveness of the measures using all four building types; due to the relatively low differences in the percentage costs, this is also not worth a detailed calculation. Therefore, a

representative house

was defined for the next step, with which the following analysis will be conducted:

The „representative house“ is defined as a thirtysecondth (1/32) of all 4 combined terraced housing rows. This allows the use of the respective values for all extensive parts (such as for example envelope surface areas, air volumes, energy consumption values, construction costs, etc.) for the representative house to be given as a weighted average value for the respective parts of the four house types:

$$X_{repr} = (n_{JDF}X_{JDF} + n_{JDM}X_{JDM} + n_{JAM}X_{JAM} + n_{123}X_{123}).$$

The estate has the following numbers of each house type

$$n_{JDF} = 8$$
$$n_{JDM} = 14$$
$$n_{JAM} = 9$$
$$n_{123} = 1$$

With this definition, it is possible to set up a PHPP-calculation sheet for the representative house. The resulting extra costs for the Passive House standard according to the representative house are

Insulation and ventilation system	8467,41 Euro (9,1%)
Solar thermal system	3040,65 Euro (3,3%)

This results in a total extra cost of 12,4% of the investment costs for an otherwise similar building built according to the 1995 insulation ordinance.

8.2 From the 1995 Insulation Regulation house to the Passive House

8.2.1 Cost effectiveness considerations

First of all, a decision was taken about which construction parts and components would have been used, if one had been required to build according to the 1995 insulation ordinance:

- The U-values of the outer walls can be increased to roughly 0,5 W/(m²K).
- The insulation in the roof is reduced to the point where U_D = 0,29 W/(m²K).
- The ground floor slab insulation is reduced to U_G = 0,61 W/(m²K). Typical window frames and glazing with U_g = 1,2 W/(m²K) and g = 62% are installed. This results in U_w = 1,9 W/(m²K).
- A ventilation system is no longer needed, however
- heating radiators with a total output of 6 kW must be installed against the outer facades.

The assumptions in the calculation method for the insulation ordinance lead to an alleged low consumption value. Therefore, the energy balance was calculated once more with the PHPP process using the envelope surface areas described above. It was assumed that the air-tightness would not change and that the average air change rate would stay at the Passive House level. The thermal-bridge-free construction was also assumed, although any further careful insulation in the area of the house height offset was not assumed.

Passive House Planning

SPECIFIC ANNUAL HEAT REQUIREMENT

Climate:	Standard	Interior Temperature:	20.0 °C
Building:	Terraced Passive House	Building Type/Use:	Terrace House / Dwellings
Location:	Hannover Kronsberg	Treated Floor Area (TFA):	111.7 m²
		Standard Occupancy:	4.0 Pers

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Temp. factor f_t		G_t kKh/a		kWh/a	per m² Treated Floor Area
1	Exterior Wall - Ambient Ai	A	53.6	*	0.126	*	1.00	*	84.0	=	567	
2	Exterior Wall - Ground	B		*		*	0.50	*		=		
3	Roof/Ceiling - Exterior Ai	D	77.8	*	0.097	*	1.00	*	84.0	=	636	
4	Floor Slab	B	70.8	*	0.117	*	0.50	*	84.0	=	347	
5	Exterior Wall Masonry	A	20.8	*	0.097	*	1.00	*	84.0	=	170	
6		A		*		*	1.00	*		=		
7		X		*		*	0.75	*		=		
8	Windows	A	19.6	*	0.830	*	1.00	*	84.0	=	1364	
9	Exterior Door	A		*		*	1.00	*		=		
10	Exterior Thermal Bridge (l	A	72.3	*	-0.013	*	1.00	*	84.0	=	-79	
11	Perimeter Thermal Bridge (	P		*		*	0.50	*		=		
12	Ground Thermal Bridge (len	B	47.7	*	0.033	*	0.50	*	84.0	=	66	
	Total of all building envelope areas		242.6									kWh/(m²a)
	Transmission Heat Losses Q_T									Total	3072	27.5

Ventilation System:

			A_{TFA} m²		Room Height m		m³		
Effective Air Volume V_{RAX}			111.7	*	2.50	=	279.3		
Actual Efficiency of Heat Recovery	η_{eff}	80%							
Efficiency of Subsoil Heat Exchanger	η_{SHX}	0%							
			$n_{V,system}$ 1/h		Φ_{HR}		$n_{V,Res}$ 1/h		1/h
Energetically Effective Air Exchange n_V			0.430	(1	0.80	) +	0.024	=	0.110

	V_V m³		n_V 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	279	*	0.110	*	0.33	*	84.0	=	849	7.6

		Q_T kWh/a		Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	3072	+	849	)	1.0	=	3921	35.1

	Orientation of the Area	Reduction Factor see Windows		g-Value (perp. radiation)		Area m²		Global Radiation Heating Period kWh/(m²a)		kWh/a	kWh/(m²a)
1	East	0.40	*	0.00	*	0.00	*	220	=	0	
2	South	0.49	*	0.60	*	11.25	*	364	=	1193	
3	West	0.40	*	0.00	*	0.00	*	230	=	0	
4	North	0.42	*	0.60	*	8.31	*	142	=	299	
5	Horizontal	0.40	*	0.00	*	0.00	*	360	=	0	
	Gross Solar Heat Gains Q_S								Total	1492	13.4

	kh/d		Heating Period d/a		Spec. Power q_i W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Sources Q_I	0.024	*	225	*	2.10	*	111.7	=	1267	11.3

			kWh/a	kWh/(m²a)
Free Heat Q_F	Q_S + Q_I	=	2759	24.7
Ratio of Free Heat to Losses	Q_F / Q_L	=	0.70	
Utilization Factor Heat Gains η_G	$(1 - (Q_F/Q_L)^5) / (1 - (Q_F/Q_L)^6)$	=	94%	
Heat Gains Q_G	η_G * Q_F	=	2598	23.3
Annual Heat Requirement Q_H	Q_L - Q_G	=	1322	**11.8**

Table 5: **Documentation of the Passive House design package (PHPP) calculation of the annual heating requirement for the representative house in Hannover-Kronsberg.**

Passive Houses - Investment Costs (01-Germany, Hannover-Kronsberg)

Spezific Investment costs EUR

climatic data:	Germany	Building Type:	terraced houses
building:	averaged representative passive house	Building Site:	Hannover Kronsberg

Space Heating:

	component	amount	unit	total cost for component PH	specific extra investment costs compared to WSVO ordinance
1.	facade, timber construction	64.77 m²	EUR/m²	240.31	17.90
2.	Fassade WDVS	20.00 m²	EUR/m²	145.72	25.56
3.	roof	73.54 m²	EUR/m²	102.26	10.23
4.	ground	67.45 m²	EUR/m²	102.26	15.34
5.	windows	19.56 m²	EUR/m²	341.54	111.46
6.	ventilation	1	EUR	4 601.63	4 601.63
7.	heat distribution	1	EUR	903.58	-1 924.69
8.	pressurisation test	1	EUR	153.39	153.39
	total investment costs space heating		EUR	45 234.80	8 467.41

domestic hot water

	component	amount	unit	component total costs PH	specific extra investment costs compared to WSVO ordinance
1.	dhw distribution	36.50 m	EUR/m	20.38	0.00
2.	dhw storage	1	EUR	1 542.69	766.94
3.	thermal solar collectors	1	EUR	2 273.71	2 273.71
	total investment costs domestic hot water		EUR	4 560.36	3 040.65
	total investment costs heating and dhw		EUR	49 795.16	11 508.07

electricity efficiency:

	component	amount	unit	value
1.	extra investment efficient appliances	1	EUR	1 022.58
	extra investment efficient appliances			1 022.58
	total costs of construction EUR			104 168.51
	total costs of construction per m² living area 119.53 m²		EUR/m²	871.52
	extra investment / total investment			12.4%

Table 6: Investment costs for energy efficiency measures for the representative house

The calculated heating requirement according to PHPP of a terraced house that just fulfils the legal insulation ordinance is 11420 kWh/a. The fact that the area-specific heating consumption of 102 kWh/(m²a) clearly lies above the 71 kWh/(m²a) calculated according to the insulation ordinance, is largely due to the much larger reference area used in the latter calculation.

The supply of the terraced house is assumed to be the same connection to the district heating network as in the actual estate; only the connected load increases from 2,5 kW to 6 kW. Including the pipeline network losses and the heat transfer losses, the annual utilization ratio for the distribution system and the connection according to the insulation ordinance is 91%. The district heating consumption for heating is then 12600 kWh/a.

In the following steps, the impact of the progressive improvement of the building standard, starting with the reference object and ending with the actually constructed Passive House, will be viewed: the heating energy requirements and the respective energy savings due to the individual steps are shown in Figure 26. Figure 27 shows the extra investment costs for the respective steps. Finally, Figure 28 documents the net-equivalent price for a kilowatt-hour of heating energy, according to how it is produced by the energy efficiency measures.

This „saved kilowatt-hour price“ is a result of the apportioning of the extra investments into annual costs (real costs, i.e. adjusted for inflation) on the cost basis of the year 2000/2001:

$$P_{save} = (a \cdot I_{extra} + Z) / E_{save},$$

where **a** is the annuity, I_{extra} is the extra investment, Z are the additional yearly costs (e.g. service) and E_{save} are the respective energy savings [Feist 1998a].

To calculate the annuity a, a real interest rate of 4%/a was set. This is about the long-term average real interest rate for a mortgage loan in Germany and is quite near to the current conditions (with roughly 6,5%/a effective interest rate and 2,4%/a inflation rate). The useful lifetime for the construction measures and the ventilation system were set at 25 years, for the solar thermal system at 20 years. This results in annuities of 6,4%/a (real) for the construction measures and 7,4%/a for the solar thermal system. For the pure construction measures there are no service or other additional costs: costs for the care and adjustment of the windows are not higher in a Passive House than in a typical building. The yearly additional costs for the building services systems will be discussed in the appropriate place.

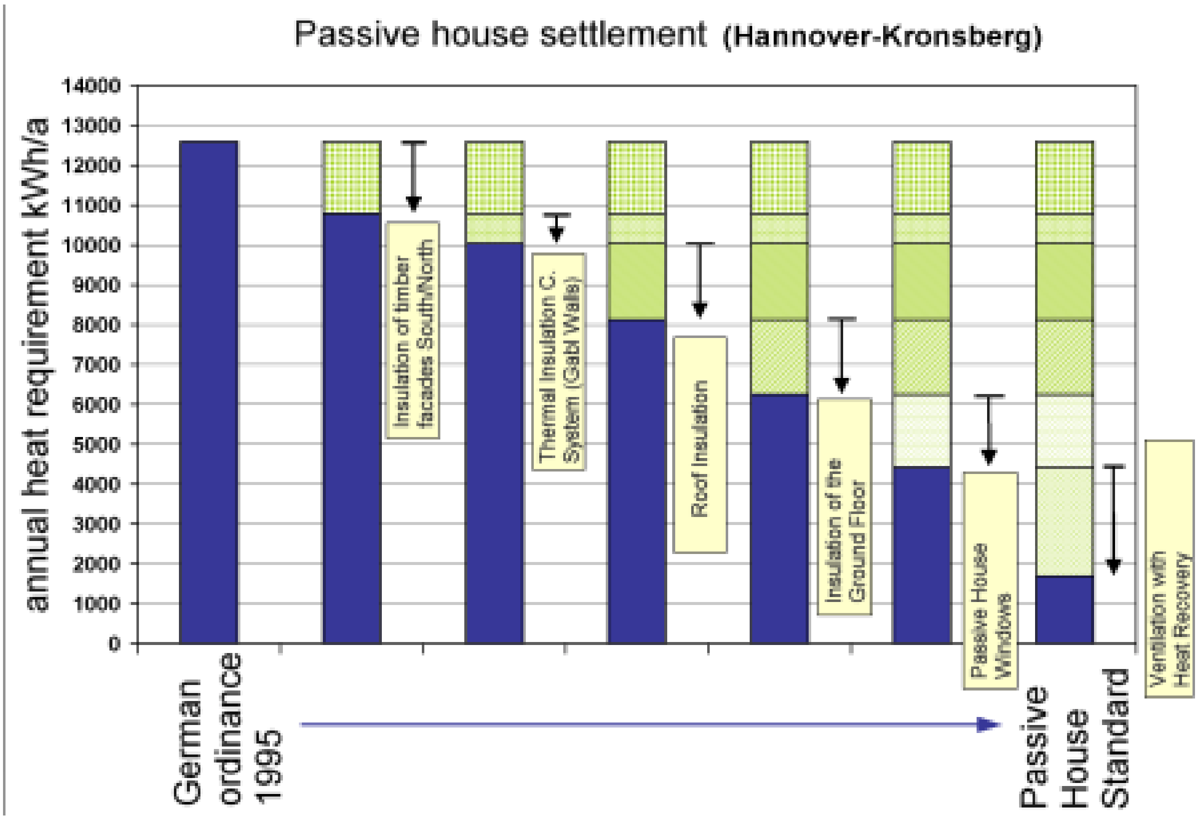


Figure 26: **Six steps from the insulation ordinance standard to the Passive House: Through the energy efficiency measures described in the text, the yearly heating energy requirement (incl. building services losses) is reduced by more than 80%. The Passive House standard on the far right was realised in the Kronsberg built estate.**

The “costs for the saved kilowatt-hour” calculated by dynamic cost effectiveness analysis, allow for a transparent comparison of the efficiency measures taken in the Passive House estate to other possibilities for energy production. Figure 28 shows such comparison values:

On the one hand, the actual heating price for the district heating supply on the Kronsberg, which, according to the bill, lies at 13,72 DPfg/kWh including value added tax. This gives a

Kronsberg district heating price without VAT (2001) of 6,05 Eurocent/kWh.

As a further comparison value, the average price for heating oil in Germany in the period 6/2000 to 5/2001 was determined at 0,71 DM/litre (without value added tax). Due to the large swings in the oil price, we set a

final energy price for heating oil without VAT (2001) of 3,66±0,44 Eurocent/kWh.
(Note: in 2005 this price was 4.1 Eurocent/kWh)

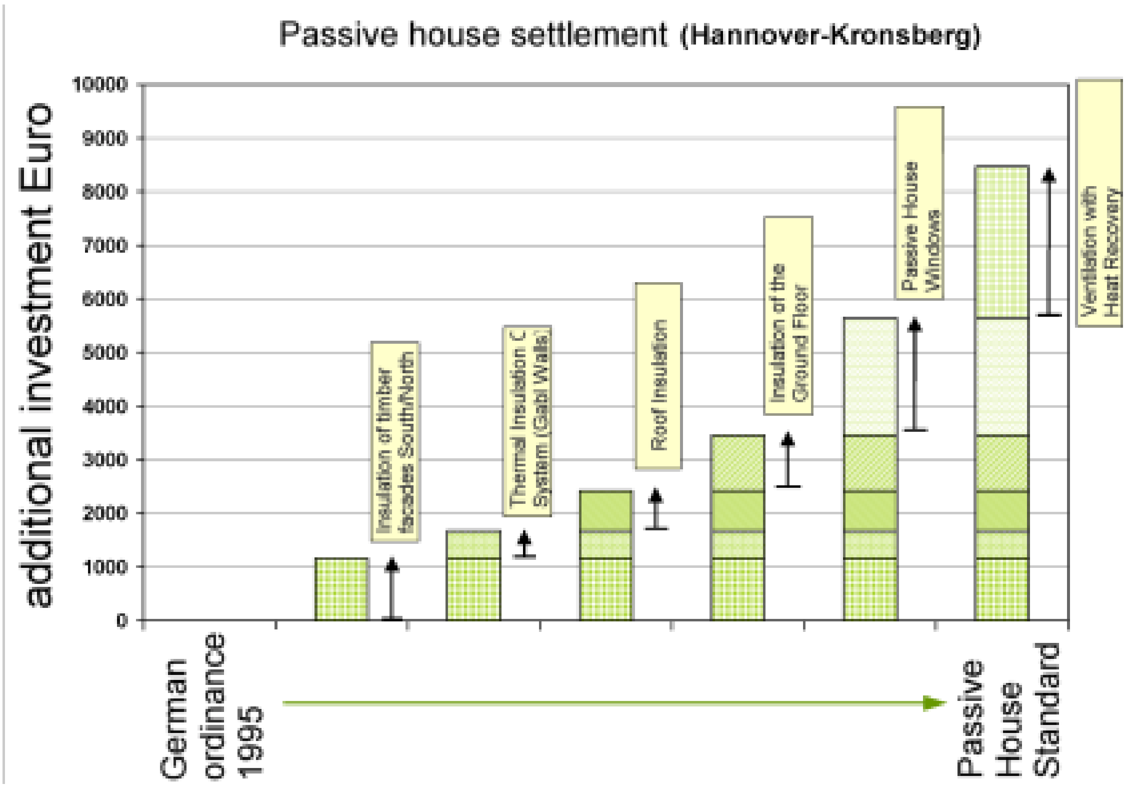


Figure 27: Required extra investments for the efficiency measures in Figure 26.

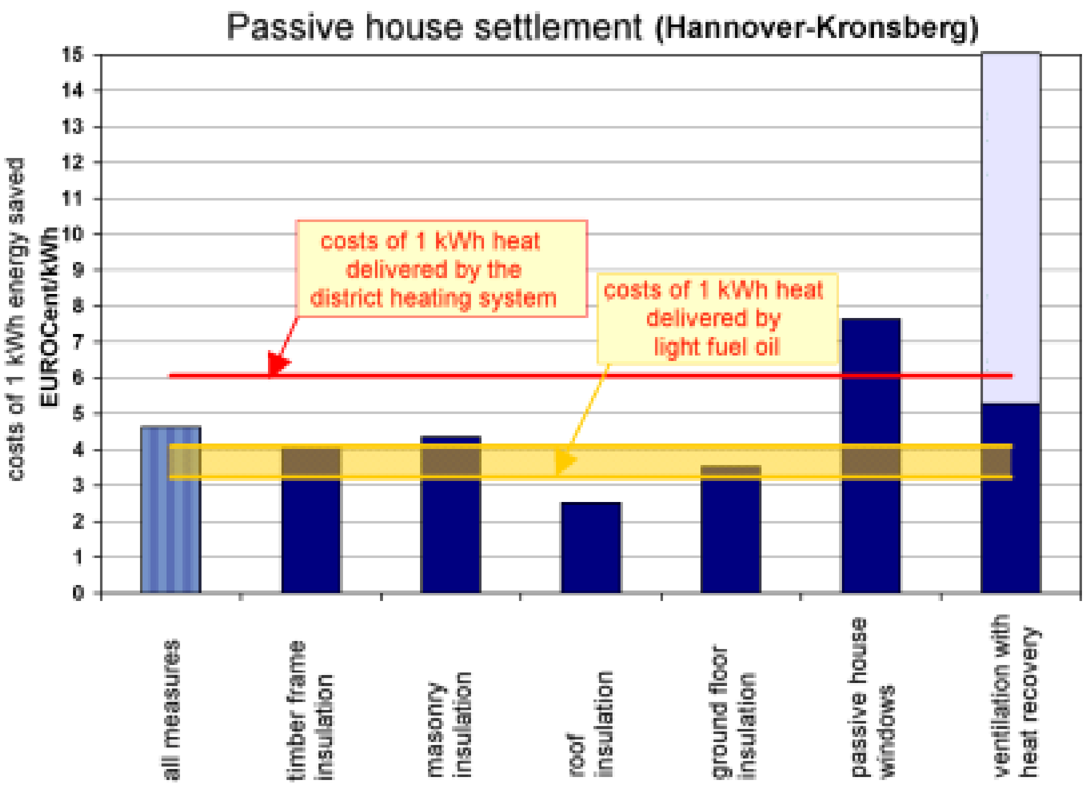


Figure 28: Costs for the „saved kilowatt-hour“ due to the efficiency measures in comparison to the district heating supply and the end energy price for heating oil in Germany. The left column is the sum of all measures (WSVO-standard → Passive House standard), the rest for the respective additional measures of the individual steps.

8.2.2 Step I: Passive House insulation of the lightweight facades

Due to the increased insulation on the north and south facades, heating energy savings of 14% compared with the heating energy requirement of the insulation ordinance reference case are achieved. The extra investments, for 64,8 m² of construction element surface area, are 1159 Euro. Costs for the kilowatt-hour of saved energy equal 4,1 Eurocent/kWh. This on-site measure is thus individually cost effective.

8.2.3 Step II: Insulation of the gable walls with thermal insulation compound system

This measure affects mostly the end of terrace houses; allocated to the middle representative house, the resulting energy savings are some 6%. The extra investments, for 20 m² in the representative house, are about 511 Euro. The annuity costs for the kilowatt-hour of saved energy equal 4,6 Eurocent/kWh. This Passive House insulation measure is thus also individually cost effective today.

8.2.4 Step III: Roof insulation increase

The final energy savings achieved in the representative house are about 15% of the heating energy demand for the insulation ordinance standard. The extra investments, for 73,5 m² of construction element surface area, are about 1471 Euro. The price for the roof insulation's saved kilowatt-hour is 2,4 Eurocent/kWh. This is a lot cheaper than the current district heating price and also the current heating oil price.

8.2.5 Step IV: Ground floor slab insulation

The insulation of the slab was realised in the prefabricated structure through a concrete covered polystyrene insulation board. The resulting energy savings are about 15% of the insulation ordinance demand. The extra investments, for 67,5 m² of construction element surface area, are about 1035 Euro. The annuity costs for the kilowatt-hour of saved energy equal 3,5 Eurocent/kWh. This is also very low compared to the district heating supply, and individually cost effective in comparison to the current oil prices.

With step IV, all measures to do with the opaque envelope have been addressed. The heating energy consumption after this fourth step is now equal to only 56 kWh/(m²a) („6-liter-house") or 50 % of the value that could be reached by an insulation ordinance-standard house. The steps presented show that all the measures discussed to improve the opaque insulation are individually cost effective.

8.2.6 Step V: Addition of Passive House windows

Through the use of Passive House windows, a further energy saving of 15% in comparison to the WSVO (insulation ordinance) standard is achieved. The extra investments, for 19,6 m² of billed window surface area, are about 2180 Euro. This leads to a price for the saved kilowatt-hour of 7,6 Eurocent/kWh; these costs are slightly higher than the district heating costs. However, the Passive House windows used allow for a simpler heating system installation: heating radiators must no longer be placed along the facade under the windows, since the average internal surface temperatures are above 17°C (see also [Peper/Feist 2001]). The savings for the conventional heating technology are not dealt with here, but further on.

With the use of the Passive House windows, the current practical limits of the energy savings to be achieved solely with construction measures has been reached; the representative house now has a heating energy consumption of about 40 kWh/m² (4-liter-house). Further efficiency improvements now also require a reduction of the proportionately high ventilation heat losses: it now equals 53% of the total heating losses, which are covered by solar gains (23%) and internal heat sources (19%).

8.2.7 Step VI: High-efficiency heat recovery

A reduction of the fresh air amounts to minimise the ventilation heating losses is impossible for indoor air quality reasons: on the contrary, a good solution for home ventilation will actually improve the rate of air replacement in the buildings.

A high-efficiency heat recovery system with an effectiveness ratio of about 80% was used in the Kronsberg Passive Houses. This system is operated with an average fresh air volume flow of 120 m³/h. The experience with occupied houses shows that a very good indoor air quality is thus achieved – in very cold winter phases, the air volume could actually be reduced a bit more, in order to achieve a higher relative air humidity in the inflow rooms. The heating energy savings achieved with heat recovery equal 22% of the heating energy demands of the WSVO-standard. With step VI, the standard of the actually built Passive Houses has been achieved: the remaining heating energy requirement at a normal operational level is 15 kWh/(m²a).

The costs for the ventilation system including all the components with installation, ductwork, filter, control system and central unit totalled 4602 Euro. These investment costs must however be contrasted with the cost savings of no longer requiring the traditional building services. According to Table 7, solely reducing the heating output of the heating distribution and heating supply in the Passive House saves 1395 Euro (7 instead of 8 heating radiators, output reduced from 6 to 2,5 kW, heating radiators located on the inner walls instead of the outer walls). Using the supply air postheater instead of 6 normal heating radiators leads to a further savings of 529 Euro [Stärz 1999].

Case		investment costs without VAT		source
		DM	Euro	
Case 0: WSVO ordinance	conventional heat distribution; max. load 6 kW; 8 radiators in total below windows, incl. Distribution and thermostatic valves and all components needed	5531.61	2828.27	[Feist 1998], "Heating systems in low energy houses"
Passive house, but using radiators	heat distribution; max. load 2.5 kW, 7 radiators in total placed at inside walls, incl. smaller distribution net and thermostatic valves and all components needed	2801.72	1432.50	[Starz 1999] (AK 17)
Case PH: Passive house radiator only in bathroom +supply air post heater	only one radiator in the bathroom; supply air postheater; incl. all components needed; max. total load 1.3 kW	1767.24	903.58	[Starz 1999] (AK 17)
reduction of investment costs: Case 0 - Case PH		3764.37	1924.69	

Table 7: **Through the large reduction of the maximum heating load, costs for the heating distribution and supply network are saved. In the Kronsberg Passive Houses, only a ventilation postheater and one radiator in the bathroom are necessary.**

The total investment cost reduction resulting from the exclusion of the conventional technology is about 1924 Euro. In actual fact, the ventilation and heating technology used in the Kronsberg Passive Houses is about 2678 Euro more expensive than a conventional heating distribution system in a WSVO-standard house.

The costs of 153 Euro for the pressurisation tests are placed for clarity under ventilation system costs. In order to determine the annuity costs for the Passive House ventilation system, the yearly additional costs have been compiled:

a) Capital cost savings due to a simplified

Heating system (from -1924 Euro, in annuity terms) - 113,38 Euro/a

b) Load reduction price savings district heating 3,5 kW - 101,20 Euro/a

c) Capital costs pressurisation test

(from 153 Euro, in annuity terms) 9,82 Euro/a

d) Filter costs for the ventilation system 35,26 Euro/a

e) The service costs for the ventilation system are not more expensive than the service costs for an alternative heating system. No additional costs.

f) Electricity costs for the ventilation system:

252,6 kWh/a with a net electricity tariff of 11,5 Eurocent/kWh 29,06 Euro/a

The resulting total additional annual costs Z for the ventilation system equal -150,26 Euro/a. The ventilation system annuity costs for the saving of one kilowatt-hour of thermal heat are therefore

$P_{Esave, vent.}$ = (6,4%/a · 4602 Euro - 150,26 Euro/a) / 2736 kWh/a = 5,27 Eurocent/kWh.

If one includes only the capital and operational costs (electricity and filter) for the building's ventilation system and ignores the costs saved for the heating system, the resulting annuity costs for this object are then 15 Eurocent/kWh. Thanks to this comparison, it is clear how important the use of the Passive House standard's cost advantages are for the cost effective operation of the home's ventilation system [Feist 1999].

In comparison to the district heating used (6,05 Eurocent/kWh), the operation of the home ventilation system is individually cost effective; in comparison with the 2001 oil prices, however, the saved kilowatt-hours costs are higher. Future real energy prices should, however, lie at around 5 Eurocent / kWh (Note added in 2005: this proves to be true now).

Taking the total Passive House measures together, the result is a total extra investment (without value added tax) of 8467 Euro for the representative house. Including the ventilation system's additional costs b) d) e) and f) results in a total annuity cost of saved kWh's for the Passive House of

P_{Esave} = 4,6 Eurocent/kWh

These costs for the saved kilowatt-hour are clearly less than the district heating price and only slightly above the oil price for 2001. When one assumes a medium-term comparative price of 5 Eurocent/kWh, the measures for the Passive House described here are then individually cost effective without any government support.

7.3 Cost effectiveness consideration for the solar hot water preparation

The investment costs for the solar thermal system including extra storage tank costs were set at 3040,65 Euro. With a useful life of 20 years (7,4% annuity) and electricity costs of 3,45 Euro/a (20 kWh at 11,5 Eurocent/kWh), the resulting costs for the kilowatt-hour of delivered solar heat are

P_{Solar} = 13,8 Eurocent/kWh

These actual production costs are higher than those for district heating and much higher than the energy saving costs for the efficiency measures. The extra investment in the Passive House standard is, according to this result, more cost effective than a conventional solar thermal collector. Hot water solar systems are considered to be a sensible investment for climate protection; we share this view because the actual production costs are justifiable in relationship to the expected future energy costs. The investment in the Passive House standard when building a new house is, in comparison to a solar thermal system, actually even more cost effective.

9 Description of the Construction Process

9.1 Period of construction

The design phase for the terraced housing estate began in 1998, construction began on the 01.09.1998. The topping-out ceremony took place in November 1998. The houses were completed in December 1998, the first occupants began moving in during the month of December 1998.

9.2 Participants and organisation of the construction process

Developer	Rasch and Partner GmbH
Architects	Petra Grenz, Folkmer Rasch
Building services	InPlan GmbH Company, Pfungstadt
Site manager	Petra Grenz, Rasch and Partner
Quality assurance	Passive House Institute under contract of Rasch&Partner

Table 8: Design participants and developers for the Hannover-Kronsberg Passive House estate

9.3 Instruction, Qualification and Quality assurance

The developer Rasch and Partner contracted the Passive House Institute on the 03.09.1998 to perform the quality assurance with regards to the Passive House standard. The foundations for quality control during the construction phase were the dimensioned implementation plans and the detail drawings of the designed standard assembly and construction element connections as well as the thermal characteristics for the construction materials, insulation and fasteners. In addition to this, the airtight concept was discussed with the developer beforehand using detail drawings.

The quality assurance was performed with on-site visits during the prefabrication, construction site inspections, photo documentation, pressurisation tests (blower door method) and thermograph pictures.

9.3.1 Building Envelope

9.3.1.1 Quality assurance in concrete works/pre-assembly of building services

The building services rooms in the peaked attic of the houses were premanufactured as far as possible at the prefab-concrete element manufacturer (concrete factory Müller-Gönnern). The ventilation and water installations including armatures were premounted there.

9.3.1.2 Prefabrication of the lightweight wood elements in the wood construction factory and insulation

The developer Rasch&Partner contracted the prefab-wood element manufacturer „Lehner Holzbau GmbH". The building of the elements in the wood construction factory was checked on-site by the PHI on 03.09.1998. The check comprised:

- Integrity and quality of the prefabricated box beam insulation.
- the quality of the implemented insulation materials (generally thermal conductivity group 040 for all wall and roof elements);
- the correct cutout for the insulation as well as the exact insertion of the mineral wool insulation in the lightweight elements. The insulation must completely fill the element, it must not be compressed too much such that deformations occur, but it must be inflated by about 5 to 10 mm so that the closing particle board lightly compresses the insulation along the entire surface area (Figure 29).

Figure 29: The insulation must lie loose and slightly inflated within the element, so that no cavities are formed later

- The use of proper materials to form the airtight layer on the lightweight wood element: only heat and UV-stabilised polyethylene foils can be used [Carlsson/Elmroth 1980].

- The attachment of the foil according to plan, so that an airtight connection from element to element is possible later.

Figure 30 (left): Facade element window opening. The airtight foil joints are carefully glued, the overhanging foil is there to allow for an airtight seal with the next elements

Figure 31 (right): The finished elements, prepared for transport to the construction site. Clearly visible are the overhanging foils for the airtight connection.

9.3.2 Windows

9.3.2.1 Glazing selection

The PHI recommended the use of glazing with larger pane separation (2*16 mm) and argon gas filling due to cost considerations. This glazing offers virtually the same U-values as the previously used krypton-filled glazing and is thus appropriate for the Passive House. Thanks to this development, a cost-increase for the construction of the Passive Houses could be avoided. It was important for this project that a glazing with a high g-value could be chosen (Vegla “Climatop solar”, g=60%, was chosen).

9.3.3 Air-tightness

9.3.3.1 Connections between the elements

The foils extend sufficiently past the element frames for the connections to be made. It was foreseen to unhurriedly unfold the overhanging foil pieces from the inside after the mounting of the elements and the sealing of the entire house, and to glue the foil pieces of the respective neighbouring elements or the previously laid foil pieces in an air-tight fashion over the home partition elements or storey ceiling. On-site visits determined that this work was generally completed in a professional manner. However, there were individual cases were the lower foil pieces had been stepped on by workers with heavy shoes, which lead to soiling and sometimes the damaging of the foils.

9.3.3.2 Roof penetrations of the ventilation ducts

The locations where the ventilation ducts penetrate the roof require special care during design and construction to guarantee air-tightness. It was already noticed during the design phase that a mineral wool strip covered with a polyethylene foil would make sense here. A corresponding prefabricated product from the Gullfiber (Sweden, 260 50 Billesholm) Company is available under the name „Tätfiber 1011“.

Instead of a prefabricated product, the seal can simply be made out of a strip of mineral wool and polyethylene foil pieces. The foil is folded along its length for this purpose, so that a strip roughly 15 cm high forms a (V-form) „pocket“ (Figure 32). This piece must be so long that both ends overlap by at least 10 cm when they are wrapped around the inner duct in the cylinder cut to be sealed. The foil pocket is placed in the seam with the opening pointing downwards and then filled out with mineral wool or foamed polyethylene foil afterwards.

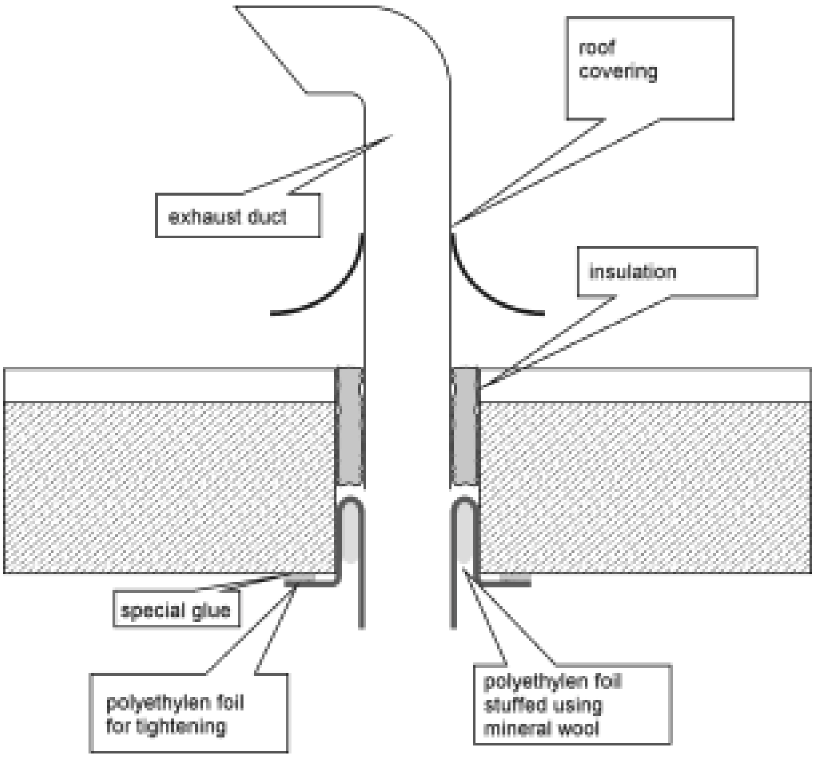


Figure 32: Airtight ventilation duct penetration in the roof area.

9.4 Air-tightness tests

Between the 8th of December 1998 and the 12th of February 1999, the airtightness of all 32 Passive Houses was checked as part of the quality assurance contracted by the developer Rasch & Partner and with the support of the city of Hannover. The measurements were carried out by the Bau + Energie + Umwelt engineering community together with the Passive House Institute. The most important results are briefly documented here (see [Peper 1999a]).

The pressure test measurements were carried out with a Blower Door (Minneapolis Company, Model 4). The building envelopes were closed on the dates of measurement (all doors and windows had been built in). Each house was accordingly prepared before the actual measurements, in that the lead-throughs for the ventilation pipes and solar thermal system lines as well as all the water/drainage pipes were sealed. The Blower Door was placed in the opened patio doors. Under a constant negative pressure of 50 Pa, any remaining leakages in the connections and lead-throughs in the entire building were found and, if possible, improved. The air speeds of the main leakages were quantified with the help of a thermoanemometer.

Main leakages found:

1. Connection of outer wall elements to the concrete pieces
2. Support caulking in the gabled walls on the ground floor and first floor plates
3. Seals and connections of house doors and windows
4. Cable lead-throughs through the base plate and through the walls of the building services room
5. Concrete cracks
6. Sanitary pipes and water lines
7. Roof lead-throughs

The remaining leakages were almost always small defects. The adjustment of windows and doors was found to be particularly important.

9.4.1 Quantitative measurement results

For the actual measurements, the Blower Door was used to create various pressure differences (ca. 20 to 60 Pa, both positive and negative pressure) between the house and the environment, and the respective volume flows were recorded by the measurement system thanks to an electronic evaluation system. An average volume flow at a pressure difference of 50 Pa was determined and put in relationship to the building volume. This results in an air-tightness comparison value, independent of the house volume, with the designation n_{50} and the unit [h^{-1}].

Through the use of a **guard-zone measurement**, it is possible to determine the size of the leakages between a house and the neighbouring zone, in this case between a single terraced house and its neighbouring houses. These guard-zone leakage flows to the respective neighbouring houses are subtracted from the volume flows of the actual airtightness measurements, in order to determine the relevant airtightness value (against outer air) of the house.

9.4.2 Pressurisation test measurement results

The measurement values of the air-tightness tests produce, despite small defects, optimal results of **n_{50} = 0,17 to 0,4 h^{-1}**, the average value for all houses produces the exceptionally low value of **$n_{50\ Avg.}$ = 0,29 h^{-1}**. The limit for Passive Houses of **n_{50} = 0,6 h^{-1}** is thus clearly above the maximum measurement values. The estate can in this regard be considered exemplary, when one compares the relationship to current typical construction practice. Figure 33 shows the final results in graphical form:

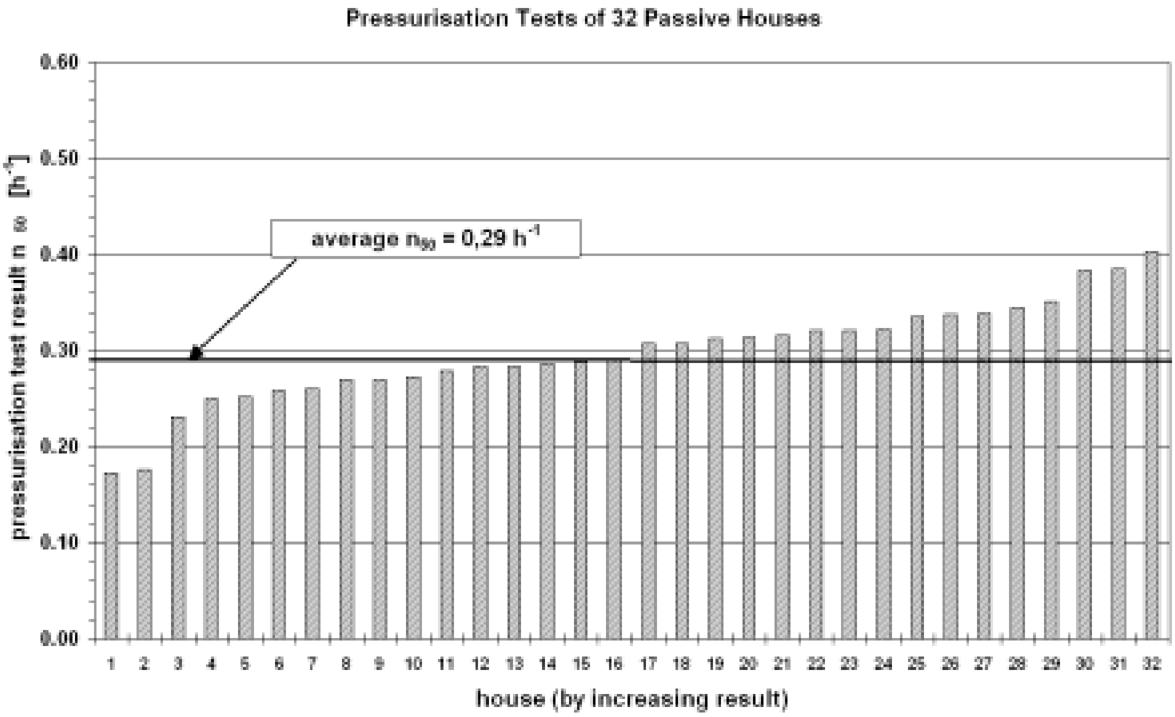


Figure 33: Final pressurisation test results for the 32 Passive Houses sorted in ascending order

Such incredible values are only guaranteed by a combination of careful design and planning, good construction and quality assurance through the use of pressurisation test measurements. The houses in Hannover showed that, in terms of air-tightness, a consequent design in the early stages can lead to the realisation of reproducible high quality at a low cost. The measured guard-zone volume flows were between 5 and 37 m³/h, on average around 14 m³/h.

9.5 Results of the thermograph analysis

Infrared thermograph pictures were taken in the Passive House estate under contract from the Stadtwerke Hannover on 15.02.2001. Involved were professors W. Zapke and A. Bethe (both from the Hannover technical college / Dept. of civil engineering) as well as Søren Peper from the Passive House Institute. The documentation and scientific evaluation of the pictures are published in a separate report [Peper 2001a]. A few key results of the thermograph analysis are presented here.

- Thanks to simultaneous precision measurements of representative surface temperatures, it was possible to make a quantitative evaluation both inside and outside.

- The majority of the regular surfaces (windows, outdoor walls, roofs) show in thermograph pictures, qualitatively and quantitatively, the surface temperatures expected in theory. The thermographs therefore confirm the high quality insulation of the envelope construction elements of the Passive House estate.

- The outer surface temperatures were, except for parts of the main door and window frames and the frame areas of the window panes (as well as a few convective thermal bridges), under the outer air temperature. This proves once again the large impact of long-wave radiation into the cold night sky (whose equivalent temperatures during the pictures reached -13,5 °C; in comparison: the outer temperatures were between -1,5 and -3,7 °C).

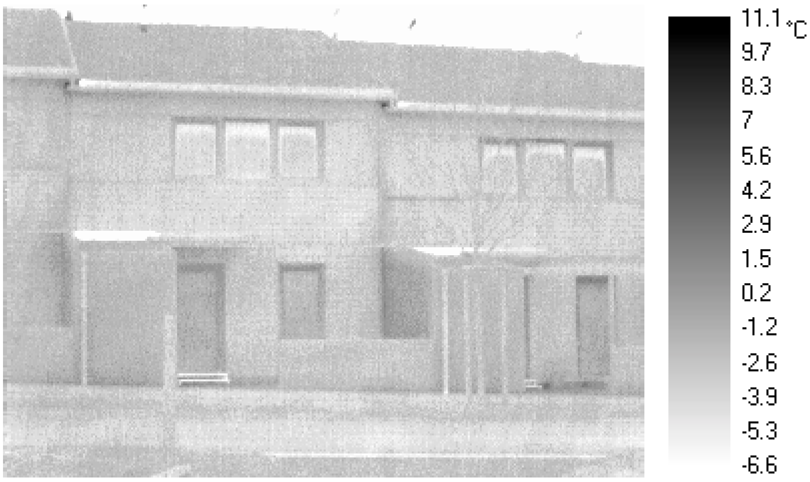


Figure 34: Outdoor thermograph of a section of the houses in row 9 (north side). The area under the roof overhand and under the canopy over the main door seem warmer, since these areas are „covered“ from radiation into the cold night sky. Otherwise, the facades show continuous low temperature of around -4 °C.

- One must be careful when analysing thermograph pictures taken from directly reflecting surfaces: with the building tested here, these surfaces are for example the metallic rainwater drains and the glazed surfaces. Due to an important contribution from the reflex radiation, the thermographic picture should not be interpreted as the surface temperature of the respective construction element. Particularly good examples are the IR-pictures of the windows in the first floor. The glazing in the central area is covered in dew ($\varepsilon \approx 0{,}95$, hardly any reflection and whatever there is, is diffuse: the thermograph picture therefore actually shows roughly the surface temperature). The surface temperatures rise nearer to the frame because of the thermal bridges in the edge seal – the glazing is therefore <u>not</u> covered in dew there. Due to the direct reflection of the cold night sky, however, one can see the “colder” area in the thermograph picture in the form of an “upside-down U“.

- The Hannover-Kronsberg Passive House estate is also not free from weak areas visible in the thermograph pictures. However, as far as can currently be assessed, the weak areas found (especially the convective thermal bridges) are neither critical for the building’s substance nor do they have an important impact on the heating balance.

- Small weak areas are indirectly to be assumed as being due to the warm air currents exciting above the rear-ventilated facades. On the other hand, the high quality of the outer facades is clear when one sees the surface temperatures in the area of the thermal insulation compound system (south side ground floor) and the rear-ventilated facade (south side first floor): There is **no measurable temperature difference** on these two surfaces!

- The inner thermograph of one of the unoccupied but heated houses showed continuously high surface temperatures on all wall surfaces. The high surface temperatures show the success of the high quality insulation and show that no condensation water problems are to be expected in the entire house. In a few cases, the surface temperatures in the area of constructive thermal bridges (two bedroom edges on the first floor) were under the expected values. Also in these areas, there is no condensation water danger. These areas lead only to a minimal increase in the heating energy consumption. With surface temperatures of 16,9 °C, one can certainly not talk of weak areas.

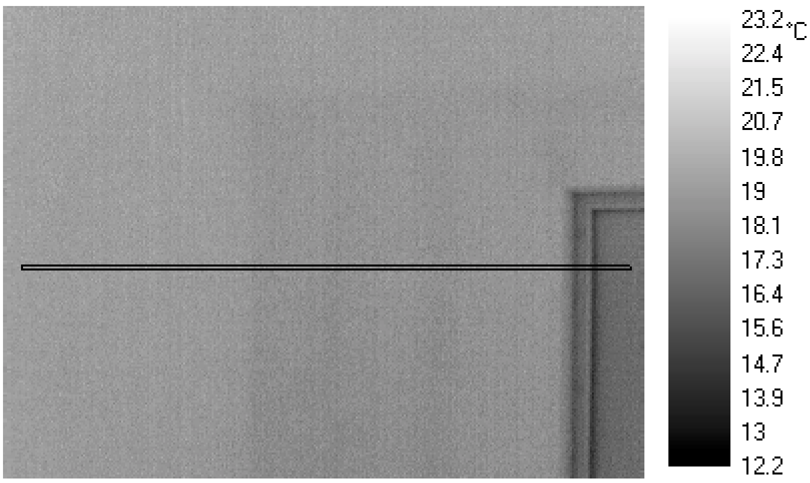


Figure 35: Thermograph picture of the left living room edge (house partition and outer wall, with a part of the window). Temperature differences between the walls are practically not identifiable.

- The main door already showed noticeable leakages in the lower area during the measurement without negative pressure in the house (Blower Door test). The outdoor thermographs also showed such weak areas at two other main doors. These lead to higher energy losses than projected. All the main doors were strengthened in the seal area in March 2001 (after the IR-test) and adjusted. It can thus be assumed, that these weak areas were improved.

- During the testing of the building under negative pressure conditions (Blower Door use in the patio door), only 5 cases were found with measurable differences from the comparison pictures without negative pressure. Due to the high air-tightness of the house, these areas were even under this „artificial“ building condition not critical.

Altogether, the results of the thermographical evaluation of the Hannover-Kronsberg Passive House estate consistently confirm the high quality of the insulation of the total building envelope.

9.6 Balance calibration of the ventilation systems

During checks in the intensively measured house, deviations in the ventilation system from the ventilator output values set by the house technician were discovered. With the change in ventilator output, the system was no longer calibrated. A continuous misbalance was present, which, based on the setting used, led to forced in- or exfiltration due to leakages. This defect has a clear impact on the energy consumption of a house, since these air currents are not led through the high-efficiency heat exchanger.

Figure 36: Measurement technology set-up for the balance calibration of the heat recovery system in the building services floor of one of the Passive Houses. With the use of pressure measurement, the volume flows at the differential pressure sensors in the in- (right) and outflow (left) ducts were determined and evaluated. The outputs of both ventilators were individually set-up with the manufacturer’s operating device.

In order to check, and adjust if necessary, the settings of the remaining Passive Houses, all 32 houses were tested by two Passive House employees between the 24th and the 26th of October 2000. With differential pressure measurement systems and a service device to adjust the ventilation systems, all the systems were tested and adjusted according to the differential pressure sensors installed in the in- and outflow air flows. Numerous clear discrepancies from the preset values or misbalances occurring with correctly adjusted values were determined. All the systems were adjusted again and the changed values were later handed over to the occupants on set-up protocols. The reason for the deviances found could never be explained.

The results of the adjustment are ventilation systems in all 32 houses being as optimally balanced as possible.

9.7 User manual

Under contract of the Stadtwerke Hannover, the Passive House estate occupants were provided with user manuals from the Passive House Institute [Peper 2000a]. It is meant to explain the technical particularities of a Passive House and should ease the familiarisation and operation of the new standard. For reasons of completeness and clarity, all the other occupant relevant technical components and their operation were also described in detail.

Since the user manual is, with about 60 pages and included „technical manufacturer manuals“, relatively bulky, a short list of user instructions (Living in the Passive House – at a glance) was produced, laminated and added to the long version. In this way, the occupants have the most important user details quickly at hand (and can hang them up in an appropriate location).

Living in the Passive House – At a glance

What you should do on a regular basis:

- The windows should be closed from November to the end of March (according to the weather), and the ventilation system should be operated with the Bypass-gate set.
- Normal window ventilation during the summer and venting of the bathroom and toilet by switching to "summer ventilation". During the warm summer period, take out the Bypass-gate and place it on the system, so that it is easy to find again.
- Filter change: Inspection of the ventilation system every 3 months (both filters), inspection of the kitchen filter every 3 month.
- Monthly visual inspection of the building services and solar thermal system.
- To avoid over-heating during the summer: use night ventilation and shades, use the most energy efficient household equipment possible.

What you should regularly do over longer periods of time:

- Wash the ventilation system's heat exchanger every two years.
- Adjust the windows, check the seals and grease the fittings.

What you should be aware of:

- Even during long periods of absence during the winter, do **not** turn off the heating system, e.g. set the thermostat at 18°C.
- Only open windows during the heating period if absolutely necessary (ventilation system failure, party, etc), close entrance doors and balcony doors after use as quickly and snuggly as possible! The main door only closes air-tight when the key is turned fully twice.
- Avoid placing indoor items and bright or reflective surfaces in front of the window (minimum distance 20 cm), local heating could lead to the breaking of glass.
- Puncturing of the air-tight envelope due to dowels, nails, screws, etc.: After removal, carefully spackle the remaining holes in the plaster with caulking mortar!
- Always keep inflow, overflow and outflow openings free and do not change the settings!
- Do not use exhaust-air drying machines to dry clothes (mold formation due to too much condensed water)!
- Empty the garden water pipe before the first frost.
- If possible, avoid shading the windows during the cold season (solar gains).

How you can save energy:

- Avoid window ventilation during the hot season.
- Set the room temperature only as high as necessary (don't overheat rooms!)
- As a rule, keep the bathroom heater switched-off, or at least avoid using it to heat continuously.
- To dry clothes, use an airing cupboard **without** an electrical heater or dry the clothes on a clotheshorse in the hallway or the bathroom, so that the humidity can better dissipate.
- Use high-efficiency household equipment and energy-saving (CFL) lightbulbs, turn off systems with stand-by functions completely when not in use.

Figure 37: Short introduction to the user's manual

10 Measurement concept

The aim of the measurements is to provide evidence of the energy consumption, the comfort and the occupant behaviour in all 32 Passive Houses. Particularly the climate neutrality of the estate is also to be checked through measurements [Peper 2001].

The measurement program is made up of a so-called „standard measurement“, which is present in all 32 houses, and a so-called “intensive measurement” which is made up of additional measurement sensors only installed in one house. In addition, there are a few further measurement points to determine the total and the common consumption as well as special measurements.

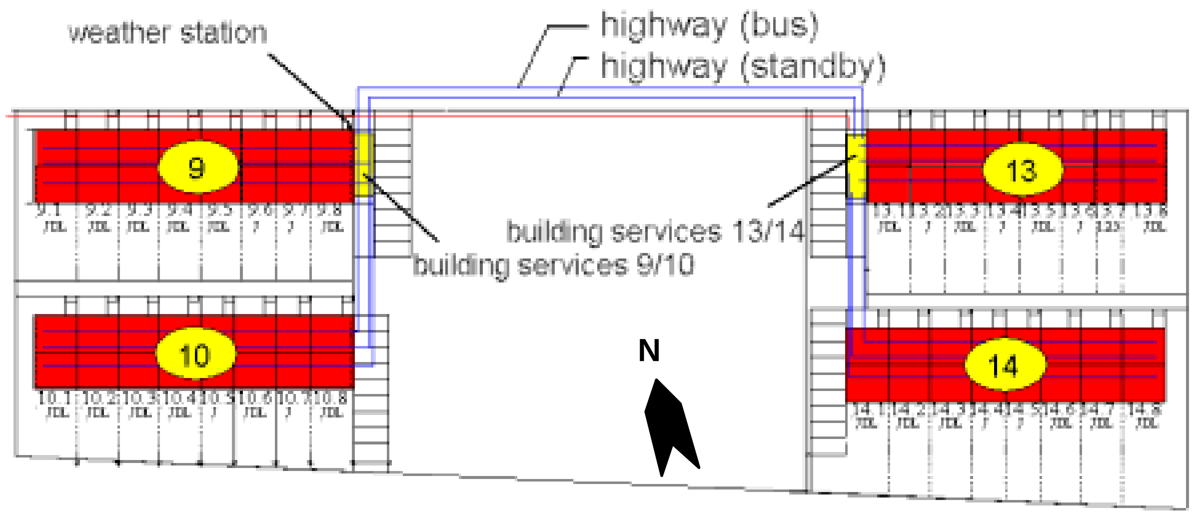


Figure 38: Location drawing of the Hannover-Kronsberg Passive House estate with measurements lines and weather station. The four house rows are numbered in the respective circles.

A central data system is installed in the Passive House estate for continuous measurement data gathering. All measurement sensors are connected through M-Bus or field-bus wires and sub modules with the switching cabinet in each second house. Data monitoring and data analysis is possible through a modem connection.

10.1 Measurement sensors

Seven measurement sensors are placed in each house for the standard measurement. The following parameters are continuously measured and recorded:

1. Total hea quantity (Q_{total})
2. Hot water hea quantity (Q_{HW})
3. Cold water volume (V_{CW})
4. Hot water volume (V_{HW})

5. Electrical Energy
6. Room temperature ground floor living room / south side
7. Room temperature first floor bedroom / north side

The location of the measurement sensor in the individual Passive Houses (standard measurement) can be seen in Figure 39. The two heat quantity and the two water meters are all located in the building services floor of the houses.

Figure 39: Cut-away section through a terraced Passive House with drawn-in location of the measurement points for the standard measurement (according to [Pfluger 2000]).

The building services floor of the respective buildings is, as shown above, equipped with four measurement sensors. In Figure 40, the additional measurement sensors for the intensive measurement in one of the houses are presented.

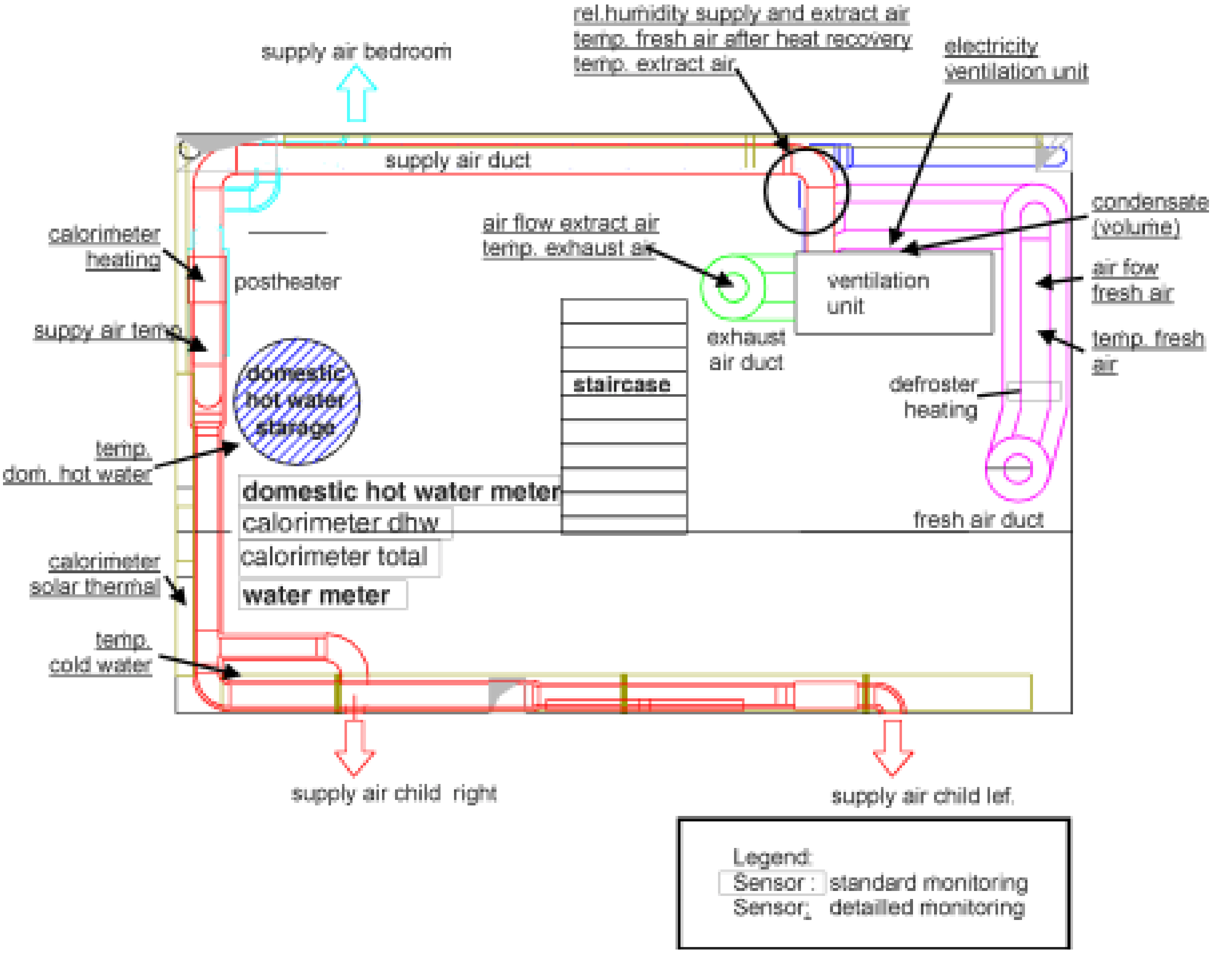


Figure 40: Position of the measurement sensors for the standard and intensive measurement in the building services floor.

10.2 Heating quantity meters (HQM)

10.2.1 House systems

Two heat quantity meters (Techem Company, type Delta Tech Compact II, volume measurement with electronically scanned wheel, calculator, temperature measurement Pt 500, M-Bus connector, construction size Q_n = 0,6) are installed in each house. One meter measures the total heating supply of the house (HQM_{total}) and the second is a sub meter used to measure the part of the hot water heating taken from district heating (HQM_{HW}).

Figure 41: Installation wall on the building services floor with water storage tank. The two heat quantity meters are marked with arrows.

Figure 42: Total heat quantity meter on the installation wall of the building services floor. The cable leads to the temperature sensor (Pt 500) in the supply pipe.

The heating consumption of a house, due to the existing heat quantity meter set-up, is determined from the difference between the total heat quantity meter and the hot water heat meter:

$$Q_{Heating} = Q_{total} - Q_{HW}$$

10.2.2 Intensive measurement-HQM

Two further HQM of the same type are built into the intensively measured house. One measures the consumption of the postheater in the supply air duct, whilst the other measures the yield of the solar thermal system, which is fed into the domestic hot water storage tank. In addition, all four supply temperatures and volumes of the HQM as well as the return temperatures of the solar thermal system HQM are recorded in this house.

10.2.3 Main-HQM for the house rows

Two further HQMs, type Techem / Delta Tech Compact II/ Q_n = 1,5, were built into the estate to record the total heat consumption within the framework of the measurement project. These measure the total heat quantity supplying the two sets of sixteen houses after the district heating transfer station and the buffer storage tank on the building services floor.

10.3 Main and domestic hot water meter

In each of the 32 houses there is a main water meter and a sub-meter for domestic hot water quantity (in the cold line, before the hot water storage tank).

10.4 Room air temperatures

Room temperature sensors from the K & P Company / model TRD 2 were installed in each of the 32 Passive Houses in the ground floor south room (living room) on the wall to the staircase and in the first floor north room (normally the bedroom) near the bedroom door (in the finery). The sensors were installed in the ground floor ca. 1,5 meters and in the first floor about 1,4 meters above the floor. Three additional room air temperature sensors of the same model were installed in the kitchen and the two child rooms for the intensive measurements in order to give evidence on all the living and lounging rooms. A ± 0,1 K calibrated thermometer (Ahlborn Company / model PK 06, 1/10 DIN) was used by the PHI to re-calibrate the room air temperature sensors at the 67 measurement points and then adjusted by K & P per offset entry.

10.5 Electricity meter

The electricity meters of all the houses are centrally located in both building services containers. They are typical alternating current electricity meters (DZG Oranienburg Company / model DV 620 UF2 / electricity class 2) equipped with an impulse outlet. In addition to the 32 single house meters, there is one more meter per container for the common electricity consumption (pumps, common lighting and parking spots). A further electricity meter for the intensive measurement gauges the electrical energy needed to supply the ventilation system with integrated heat exchanger.

10.6 Intensive measurement

In addition to the measurement sensors listed so far for the intensive measurement, there are the following measurement points in the intensively measured house.

10.6.1 Water temperatures

The cold and hot water temperature are measured on the building services floor through sensors (K&P Company / model TAVD with an active measurement element KP10) and relayed directly to the DDC-central station.

10.6.2 Air duct temperatures and humidity

In order to give more precise evidence about the behaviour and output capacity of the air-to-air heat exchanger and the postheater in the supply air duct, five more air temperature measurements were planned for the air ducts:

1. Outdoor air before heat exchanger (after frost protection heater)
2. Outdoor air after air-to-air heat exchanger
3. Inflow air (after postheater)
4. Outflow (extract) air
5. Exhaust air

The relative air humidity of the supply- and extract air in the air ducts is measured with duct humidity sensors, model HR250D (K&P Company).

10.6.3 Volume flows

The measurement of the volume flows from the outdoor and exhaust air is done through pressure difference measurements at the two differential pressure sensors in the relatively short outdoor and exhaust air pipes with pressure difference sensors (Huba Company / fine pressure transmitter model 694). There are two DN 100 differential pressure sensors built into this house – in contrast to the estate's other Passive Houses - for permanent measurement (Westaflex comp. / model MSD 100).

10.6.4 Condensation

Water condensation can occur in the ventilation unit exhaust ducts under cold outdoor temperatures. A measurement of the mass of the condensed water was therefore necessary.

10.7 Weather station

To record the local climate data, a weather station was built onto a telescope tower (Figure 43). It is equipped with two radiation measuring devices (Kipp & Zonen comp., pyranometer model CM 11, with and without shadow ring) to measure the total horizontal radiation and the diffuse horizontal radiation, a radiation protected outdoor temperature and humidity sensor (Kipp & Zonen comp., hydro-thermo-transmitter-compact), a wind direction measurement device (Kipp & Zonen comp., wind direction-compact model) and a wind speed gauge device (Kipp & Zonen comp., wind speed gauge-compact).


Figure 43 and Figure 44: Weather station in the Passive House estate. Left: Telescope pole with the sensors. Right: Radiation measurement units with and without shadow ring on the ridge.

11 Data evaluation

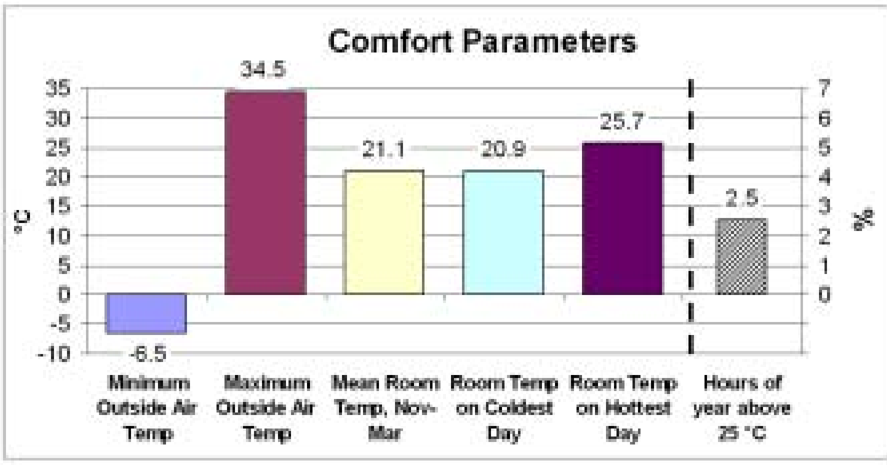
Data from the first complete heating period (01.10.1999 to 30.09.2000) and the following heating period (01.10.2000 to 30.04.2001) were evaluated. This allows for direct comparisons between the first and the second heating periods (both: 1.10. to 30.4.).

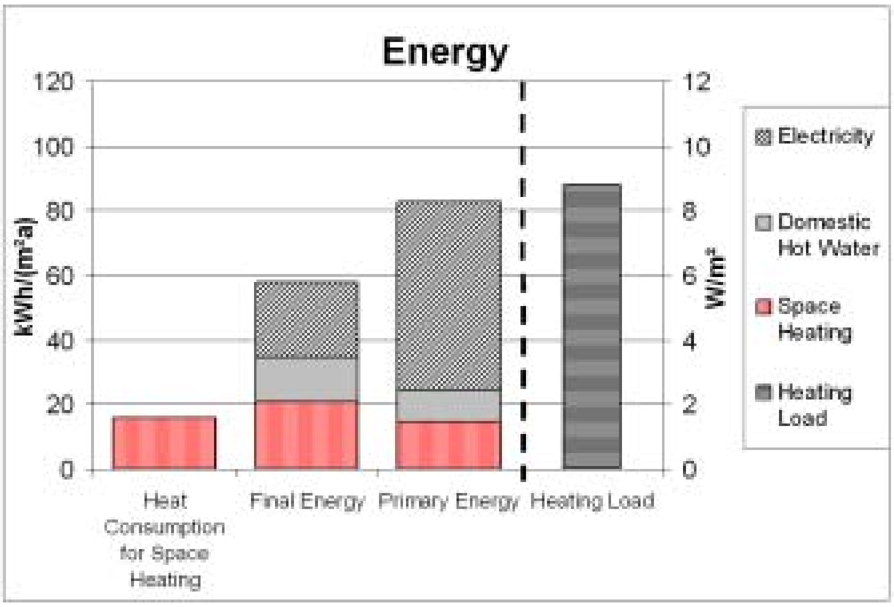
Time period		Number of permanently occupied houses
1	01.10.1999 - 30.09.2000	22
2	01.10.2000 - 30.04.2001	25

Table 9: Number of permanently occupied houses in both research periods

Since all the houses are permanently heated during the heating periods under consideration, the heating consumption for all the houses are evaluated and presented as an average. The presentation of data from unoccupied houses is marked. These houses experience a large reduction in the amount of heat coming from indoor heat sources, since nobody is present and the electrical energy is used solely for the ventilation system. That normally leads to higher heating energy consumption than in an occupied house. With such parameters as water and electricity consumption being heavily dependent on demand, only those houses that were permanently occupied are presented.

12 Overview of the measurement results





Climate		
Minimum Outside Air Temp	-6.5	°C
Maximum Outside Air Temp	34.5	°C
Heating Degree Days	2762	Kd
Global Solar (Nov - Mar)	153	kWh/m²
Comfort		
Mean Room Temp, Nov-Mar	21.1	°C
Room Temp on Coldest Day	20.9	°C
Room Temp on Hottest Day	25.7	°C
Hours of year above 25 °C	2.5	%

Energy		
Heat Consumption for Space Heating	16	kWh/(m²a)
Maximum Daily Mean Heating Load	8.8	W/m²
First day of Heating Period	08.11.1999	
Last day of Heating Period	18.04.2000	
Final Energy for Space Heating	20.9	kWh/(m²a)
Final Energy for DHW	13.7	kWh/(m²a)
Final Energy for Electricity	23.3	kWh/(m²a)
Total Final Energy	58.0	kWh/(m²a)
Primary Energy for Space Heating	14.7	kWh/(m²a)
Primary Energy for DHW	9.6	kWh/(m²a)
Primary Energy for Electricity	58.4	kWh/(m²a)
Total Primary Energy	82.6	kWh/(m²a)

The measurement overview shows the data from the first year of measurement (1.10.99 to 30.9.2000). The comfort parameters and the heating energy consumption are based on the permanently occupied houses (average values).

12.1 Comfort parameters

The room temperatures of the permanently occupied terraced houses are right in the middle of the comfort range, with an average 21,1°C in the middle of winter; the very slight deviation (20,9°C) on the coldest day shows that comfort is guaranteed, independent of the climate conditions. The value of the average temperature lies clearly above the typical target temperature of 20°C. The calculated extra heating consumption for a representative terraced house in Hannover, for an increase in the room temperature from 20°C to 21°C, is 1,7 kWh/(m²a) or 15% [PHPP].

The summer-time room temperatures lie, except for a few hours, under 25°C and thus even without an air conditioning system in the comfort range. Even on the hottest day of the measurement year, the average temperature of all occupied houses was only at 25,7°C.

12.2 Heating load

Particularly important for the functioning of the Passive Houses is the maximum required heating load; if this lies under 10 W/m², it is then possible to heat the homes solely over the fresh air (required air change for indoor air quality) from the ventilation system. The Hannover measurements during the first heating period show that the maximum daily value of 8,8 W/m² was already underneath this limit; the maximum value is in this case a clear exception (see Figure 62). The maximum heating output of 7,0 W/m² in the second heating period is even lower and is below the calculated value (7,1 W/m², see Figure 63). The Kronsberg Passive Houses thus prove under practical circumstances, that the concept of fresh air heating in Passive House quality buildings functions. The theoretical proof was already provided in CEPHEUS-Project Information Nr. 5 [Schnieders 1998].

12.3 Heating consumption

The annual heating consumption in the first year, including summer consumption, was 16,0 kWh/(m²a). When one removes the not really necessary summer consumption, a value of 14,9 kWh/(m²a) remains (01.10.99 to 30.04.00). In the second winter period (01.10.00 to 30.4.01) the measured heating consumption was only 13,3 kWh/(m²a). The average calculated heating consumption for a target temperature of 20 °C for all houses is about 11,8 kWh/(m²a), according to PHPP; even an increase in the average room temperatures to 21 °C, as mentioned above, leads to a calculated heating consumption of 13,6 kWh/(m²a). The measured values of the Passive House estate are thus in the first year only slightly above the calculated consumption (about +10 %) and in the first year actually slightly below (-2 %). The heating consumption measured here means a saving of:

- more than 90% compared to the average building stock in Germany,
- more than 85% compared to the average new terraced houses in Germany.

12.4 Final energy consumption

The heating distribution and heating transfer losses were also held extremely low in the Passive Houses. Including the (partly useable) heating transfer of the distribution networks in the houses, these losses for heating and hot water preparation equalled about 9 kWh/(m²a). This is equivalent to the previously calculated projected value; however, in percent terms of the total final energy consumption from district heating, this equals 27%, and is thus not to be ignored. It therefore seems worthwhile to intensify research and development to achieve a further reduction of these losses.

According to the measurements, the final energy consumption for heating in the first year of operation was 20,9 kWh/(m²a), whilst the required demand for hot water postheating was 13,7 kWh/(m²a) (both measured at the district heating transfer station and both including all distribution and transfer losses). The hot water preparation in the individual houses is largely done by the on-site solar thermal systems; their energy deposit is not included in the values documented here. The final energy consumption for heating and hot water preparation at 34,6 kWh/(m²a) of district heating is, already in the first year of operation, only slightly above the projected calculated value of 33,1 kWh/(m²a). In comparison to the current average new building stock, the final energy savings for heating and hot water are over 75%. It is important to note that the reduction in final energy demand is not due to a substitution through an exergetically higher value energy supply – the heating supply is based as before on district heating.

The first year's (1.10.1999 to 30.9.2000) measured final energy consumption in terms of electricity for the permanently occupied terraced houses equalled 23,3 kWh/(m²a), which includes

- the total household electricity consumption of the 22 households (such as: lighting, cooling and freezing appliances, washing machines, dryers, dish washing machines, cooking and any other uses) (House hold electricity: 19,8 kWh/m²a)),
- the total auxiliary electricity consumption of the house ventilation systems (such as: control, ventilation operation, and frost protection radiator) (electricity for the ventilation systems 2,2 kWh/(m²a)),
- the total auxiliary electricity consumption of the heating distribution of the central control systems and the remaining common electricity demand (common electricity demand: 1,4 kWh/(m²a)).

The total electricity consumption is therefore much lower in this estate than the reference value of the average household electricity demand in Germany of 32,8 kWh/(m²a), this despite the fact that all households in the estate are better equipped than average with electrical appliances and both the ventilation system and the solar thermal hot water preparation require additional electricity in comparison to the reference case. A more exact analysis (see Chapter) shows that the success of final energy savings in the area of electricity is due to the use of particularly energy efficient household appliances. Through a consultation concept, combined with a financial incentive, it was possible to convince 18 households in the estate to equip their homes with modern appliances with very high energy efficiency. The household electricity savings (without ventilation and common electricity) of these 18 households was 45% in comparison with the reference case.

The total final energy consumption from district heating and electricity of the permanently occupied Passive Houses in this estate equals 58,0 kWh/(m²a) and is thus **about 67%** below the demand of a new reference building. Due to the very high heating savings, the electricity consumption is now dominant – despite the efficiency improvements there. The further improvement of electricity efficiency is therefore one of the most important aims for future research and development.

12.5 Primary energy consumption

To determine the primary energy consumption out of the measured final energy consumption values, the primary energy factors decided upon internationally by CEPHEUS for the European Union are used (2,5 [kWh/kWh] for electricity, 1,15 for natural gas, 0,7 for district heating from combined heat and power as well as 0,1 for wood pellets; renewable energy sources such as solar thermal energy, wind and solar electricity are set at 0 [kWh/kWh]).

Since district heating from a combined heat and power plant supplies the estate, the primary energy consumption for heating and hot water preparation is reduced in comparison to the final energy consumption to a total of 24,2 kWh/(m²a). This means a reduction of 85% in comparison to the reference case.

Due to the high losses experienced by the currently prevailing form of electricity production, the primary energy consumption for electricity is particularly conspicuous. Although the total electricity consumption is roughly 30% less than in the reference case, the electricity production for this estate makes up about $^{3}/_{5}$ of the primary energy consumption. This underlines the task described in the previous chapter, to improve particularly electricity efficiency in the future.

Overall, the total primary energy consumption of the estate in the first year is 82,6 kWh/(m²a), and is only a third of the demand in a conventional new housing estate. This extremely low demand can be substituted by the purchasing of production capacity from the wind power generator on the Kronsberg, and this to economically effective costs: with a share of Euro 1.250 per terraced house, an electricity production of ca. 35,5 kWh/(m²a) is substituted; this is equivalent, using the appropriate primary energy factors, to a primary energy input of ca. 89 kWh/(m²a) and more than covers the estate's demands.

The high efficiency of the energy consumption in the Passive House estate thus makes it possible to provide the majority of the energy supply from a sustainable basis; the determining factor is that, only once the demand has been reduced enough by such efficiency measures as found in the estate, is it possible to find enough sites for renewable energy production located close enough to the customer.

13 Measurement results in detail

13.1.1 Useful energy consumption

The presentation of the Passive Houses' energy quality in the form of an annual heating energy balance is shown in Figure 45. It was drawn up based on the measurement values for solar radiation, outer temperature and heating demand. The heat transmission losses to the environment and the ground, the ventilation losses as well as the solar gains were calculated with the help of the measured data according to the EN 832-monthly method.

According to the measurements, the annual heating consumption for the whole year for all 32 terraced houses is 16,0 kWh/(m²a). Since electricity and hot water consumption values are incorporated in the monthly depiction, it only makes sense to present permanently occupied Passive Houses. To the measured household electricity consumption of each house was added the respective share of the common electricity consumption (for pumps and lighting of the common used areas without the share of the measurement technology electricity). The electrical energy consumption for the ventilation system was determined with the help of data from the intensively measured house. These monthly amounts are presented separately in the diagram.

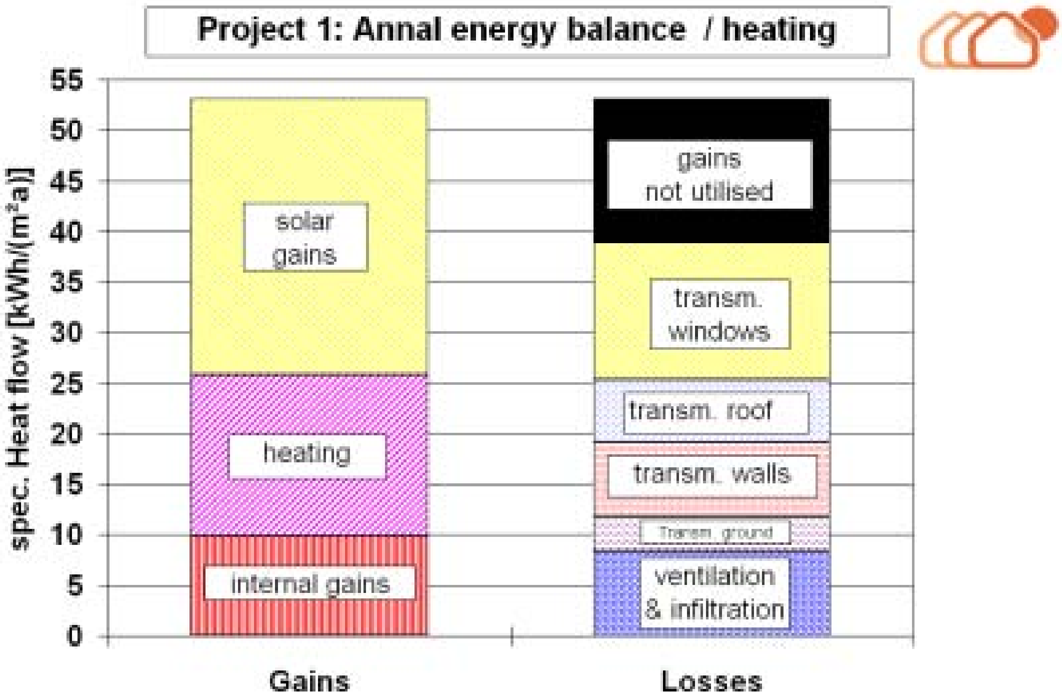


Figure 45: Annual heating energy balance in the first measurement year (01.10.1999 to 30.09.2000).

The measured energy consumption is presented in Figure 46 as monthly values. Figure 47 shows the daily consumption of the permanently occupied houses for heating and domestic hot water preparation from district heating as well as the consumption for electrical energy. The electrical energy contains the common shares (without measurement technology) and the ventilation systems' consumption.

What becomes particularly clear here is the impact of the solar hot water heating when one sees the heavy increase in the share of district heating for domestic hot water preparation in the darker seasons. The electricity consumption is relatively constant over the whole year, with a slight increase in the winter months, probably due to the increased lighting needs and a small "vacation dip" in July.

Figure 48 shows the heating consumption for the full first measurement year of each house in increasing order. The average value for the 32 Passive Houses in this analysis is **q_{Heiz} = 16,0 kWh/(m²a)**. This figure is slightly above the heating demand value calculated for all houses by the PHPP-balancing [PHPP 1999] program of $q_{Heat\ theo}$ = 11,8 kWh/(m²a). The reasons for this have largely to do with summer heating and somewhat higher indoor air temperatures. The average value in the actual heating period from 1.10.1999 till 30.04.2000 is **q_{Heat} = 14,9 kWh/m²**.

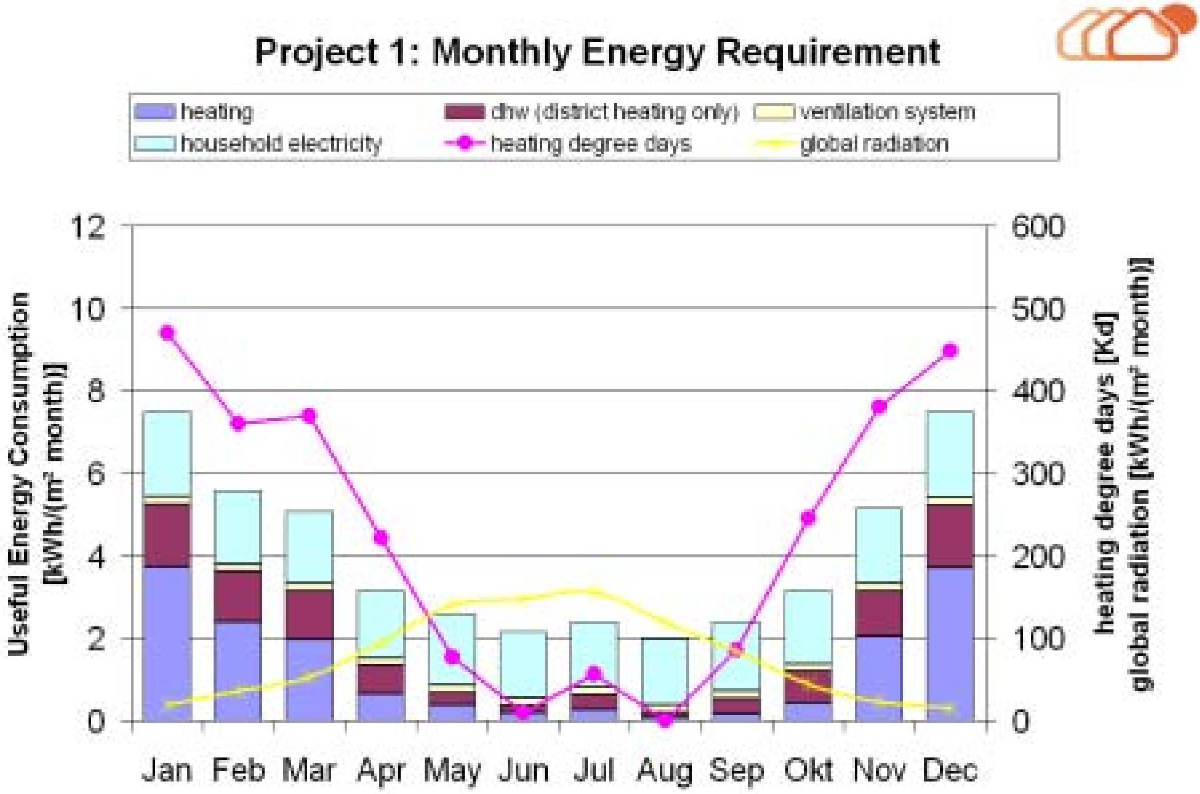


Figure 46: Monthly energy requirement for the permanently occupied Passive houses in the first measurement year (01.10.1999 to 30.09.2000).

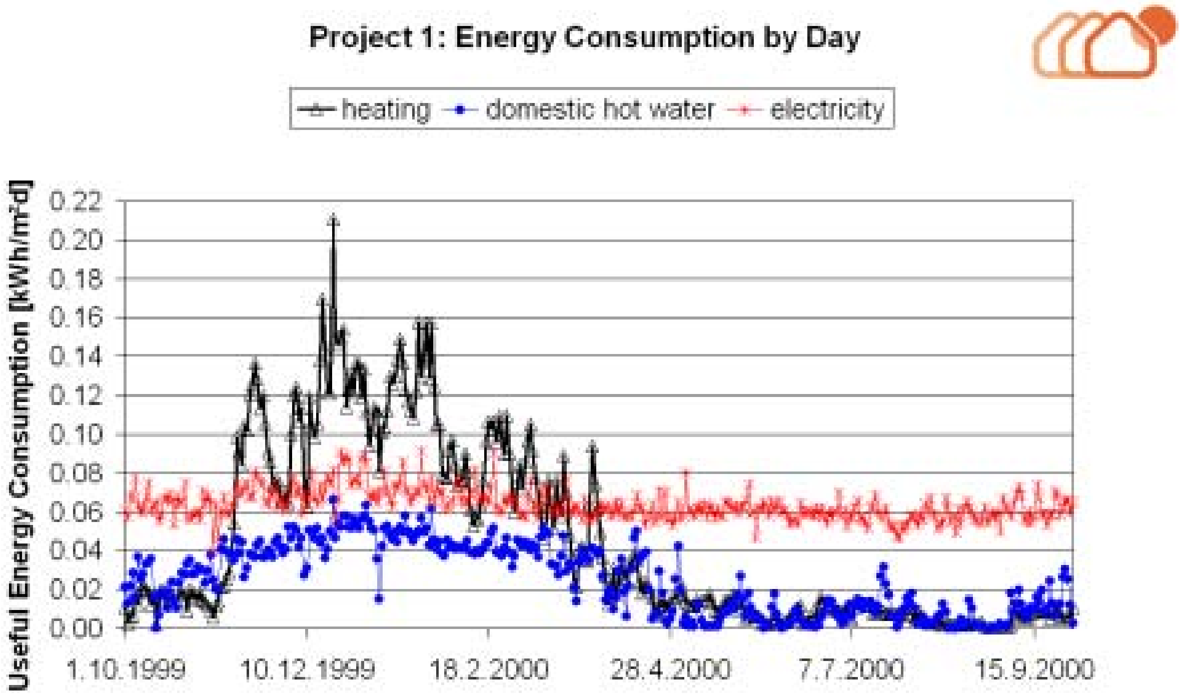


Figure 47: Energy consumption per day in the permanently occupied houses in the first measurement year

Due to the high insulation standard of the Passive Houses, it is normally not necessary to heat even during the transition period. The average summer consumption of 1,1 kWh/m² are largely due to seven houses, which had appreciable demands in summer 2000, whereby one house with a value of 9,6 kWh/m² is to be seen as an exception. This house's heating system was in use when the daily average room temperature was over 24 °C! The system was even operating for short periods of time during outdoor air temperatures of 28 °C. When the high outdoor temperatures started to drop, the heating system turned on permanently again, even though the indoor temperature in the ground floor equalled 28°C. This extreme case makes it clear that this is an **unwanted heating**. It is likely that, as in other houses in the estate, there was a defect in the functioning or interaction of the room thermostat, motor-driven valve or postheater.

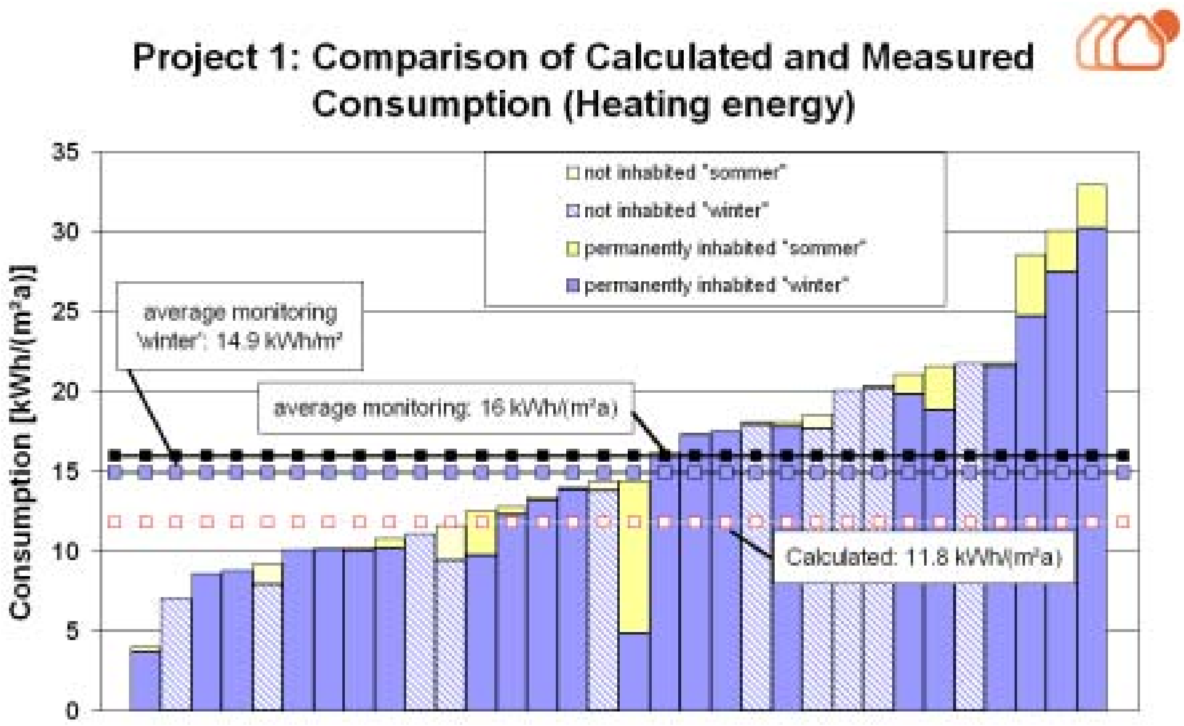


Figure 48: Comparison of the measured heating consumption and the projected (calculated) heating consumption values in the first year of measurement (1.10.1999 to 30.9.2000).

The wide range of consumption values is a surprise at first. As we know from other research in other estates and other objects, this range is due to occupant behaviour and fully normal: such ranges are also to be seen in old buildings in the building stock and in Low Energy Houses, except the ranges there are much larger. [Schnieders 2001] shows that the measured demands closely follow the normal distribution (Gauss' integral). Their average values correspond to the average demand values of the respective construction/technical building standards, the standard deviations are a gauge for the swings due to the occupiers. In the two totalities documented here, the respective values are documented in Table 10. In the third column, an estimate s is stated for the standard deviation σ of the individual consumption values. The measurement results for the 88 low energy houses are actually further spread out (±65 % of the average) than those of the Passive Houses (±42 % of the average value). In contrast to the often-voiced fear, the individual range does not increase in any decisive manner when the energy efficiency is improved.

One should consider that the average consumption value is more precisely determined in both cases, and in fact, through $C{\cdot}s/n^{1/2}$ for the 95% confidence interval, whereby C is determined using the t-distribution with n-1 degrees of freedom to the level of significance α = 95%; n is in this case already so large, that $C \approx 2$ lies close to the value for the normal distribution. The 95% confidence interval outcome for the expected value of the 88 low energy houses (see Chapter 13.1.3) occurs to 64,8 ± 9,0 kWh/(m²a) and for the 32 Passive Houses to 16,0 ± 2,4 kWh/(m²a), each including summer consumption. The savings resulting from the construction/technical energy saving measures are thus statistically assured.

Project (data including summer heating)	Estimate for the expected value μ: Average heating consumption (complete year) in kWh/(m²a))	Estimate for the standard deviation σ of the associated distribution: gauge for the range of individual values conditional on the occupants in kWh/(m²a)
Low Energy Houses Kronsberg, 1999/2000	64,8	±42,5 (65%)
Passive Houses Hannover-Kronsberg 1999/2000	16,0	±6,7 (42%)

Table 10: Average values and standard deviations of the different construction standards

The following hypotheses based on the Kronsberg Low Energy Houses are drawn up in [Wolff 2000] for the reasons behind the range of values:

- **air change rates/ventilation behaviour**
  The air change in the heating period is said to vary between 0,3 and 1,2 air changes per hour, according to different ventilation behaviour. The result would be a range from +20 to +100 kWh/(m²a) solely due to the ventilation behaviour.

This hypothesis is refuted by the measured results from the Passive House estate: the maximum heating consumption deviation upwards is only 17 kWh/(m²a) in this case. The assumed high variation due to ventilation behaviour is definitely not present with Passive Houses. In addition, this hypothesis does not explain downwards demand variations.

- **Room temperature level**
  A room temperature increase of 1 K means an extra consumption of ca. 7-11 kWh/(m²a) in the Low Energy House (11 to 17%).

The impact of room temperatures is also very high in the Passive House. The absolute values are in actual fact “only” 1,7 kWh/(m²a) per Kelvin, but this means almost 15 %/K under such low consumption levels. With a spectrum of average winter indoor temperatures between 19 und 23 °C, the resulting consumption variations are ±3,4 kWh/(m²a). However, this alone does not fully explain the variations at hand.

- **„Heat theft (?)“**.
  The heat flows between individual housing units become more important, when these units are heated to different temperatures.

According to the analysis conducted, for example in the CEPHEUS-Project "Passive House multiple storey housing/Kassel Marbachshöhe", this is actually the most important reason for the consumption variation [Pfluger 2001]. This effect strengthens the consumption differences due to indoor temperature between two neighbouring houses: let’s consider that neighbour A has set his room temperature at 23°, whereas neighbour B has set his at 19°C. The resulting heat flow through the partition wall from A to B in a Passive House standard terraced house is almost 900 kWh/a. House B’s heating consumption is thus reduced by about 7,6 kWh/(m²a), whilst house A’s consumption is increased by the same amount. For the estate’s overall heating consumption, this effect is a zero sum game – the heat has not been lost, it is just in the neighbour’s house. The absolute level of this effect is not dramatic; the effect is economically compensated due to the only partially consumption-dependent billing.

When one combines the impact of these cross currents and the actual extra losses at higher room temperatures, the result is a consumption variation of ±11 kWh/(m²a) for the Passive House estate for the measured differences in temperature levels. Values of 16±11 range from between 5 to 27 kWh/(m²a); that is nearly the observed range in the first year of operation.

Since different average room temperatures were actually measured in the interval from 19 to 23 °C, a resulting range of consumption values has to be expected on this account.

These variations due to the occupants are still, however, covered by a range of influences, which are typical for the „first year" of an occupied new house: adjustment problems, remaining work by tradesmen, drying phase, occupant familiarisation, etc. This can be seen in the fact that the average heating demand is slightly higher in comparison to the theoretical calculation.
In the second heating period a further reduction of the heating demand was established (Figure 49).

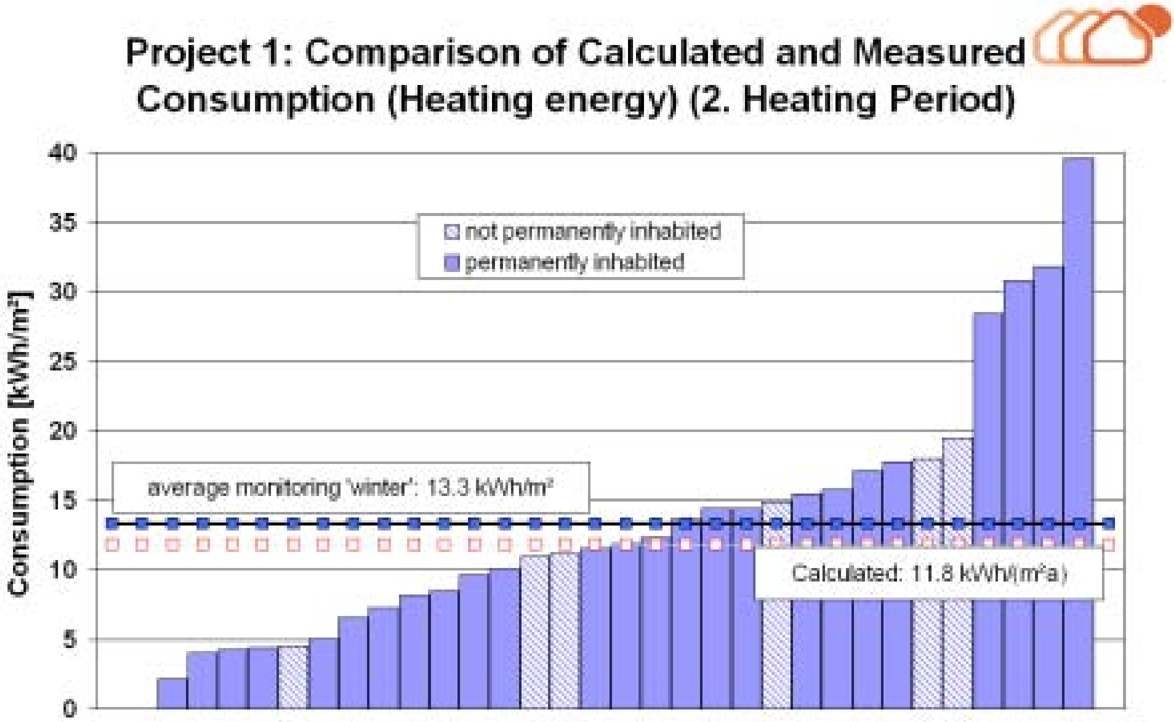


Figure 49: Comparison of the measured heating consumption and the projected heating requirement values (calculated) in the second heating period (1.10.2000 to 30.4.2001).

The average value of $\mathbf{Q_{Heiz}}$ **= 13,3 kWh/m²** confirms the assumed improvements in the second heating period, as is known from other analysed objects.

A degree day-weighting (weather adjusted consumption data) of the measured period in comparison to the long-term average does not make sense with Passive Houses, since there would not be any appreciable differences.

In addition to the measured useful energy demand, a part of the pipe network's heating losses in the houses during the heating period (dealt with in the next section) is useful. The reason is that the inflow and outflow pipes run through the building services floors. There, heat radiation is to a large extent „useful" to each house. This useful share is determined in section 14.3.3. It lies at 3,9 (± 1,5) kWh/m². The value for the first heating period is 14,9 + 3,9 = **18,8 (± 2,5) kWh/m²** and 13,3 + 3,9 = **17,2 (± 2,5) kWh/m²** for the second heating period.

13.1.2 Final energy consumption

We describe the non-renewable energy flows delivered through the building envelopes into the estate as final energy consumption. These are presented here as house-related measurement data for the first complete measurement year (1.10.1999 to 30.9.2000).

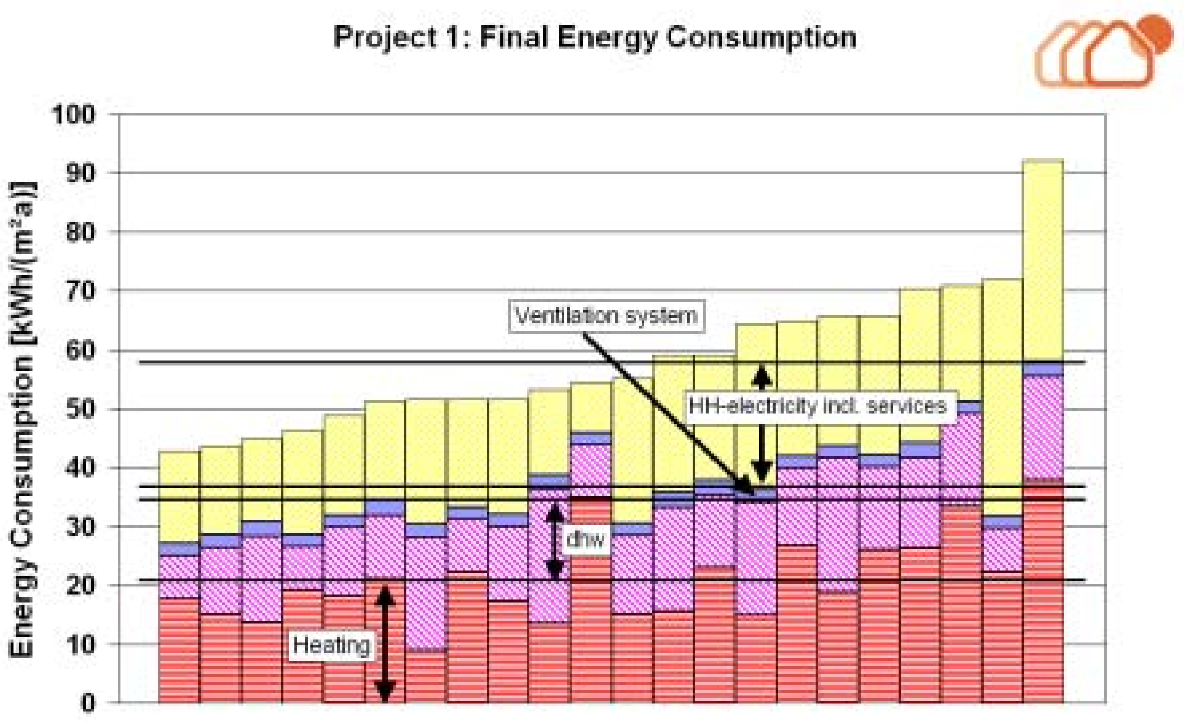


Figure 50: House-related final energy consumption of the first complete measurement year (1.10.1999 to 30.9.2000) of the 22 permanently occupied Passive Houses.

For this presentation, the following data were used: the district heating consumption for heating and domestic hot water preparation, the ventilation electricity consumption and the remaining household electricity consumption. The electricity consumption is determined as described in Figure 46. The losses of all household technical installations, including the district heating transfer station, are accounted for in the final energy consumption values. These were added respectively to each house, and weighted according to heating and hot water district heating supply. The average heating value is $\mathbf{q_{HeatFinal} = 20{,}9\ kWh/(m^2a)}$, the average for the final energy (district heating) required for hot water preparation is $\mathbf{q_{HW\ Final} = 13{,}7\ kWh/(m^2a)}$. The electrical energy supply values do not change under these considerations. The average household electricity value including the common share is $\mathbf{q_{HousElec} = 21{,}1\ kWh/(m^2a)}$, the value for the ventilation system including control and frost protection is $\mathbf{q_{VCFElec} = 2{,}2\ kWh/(m^2a)}$.

The average final energy characteristic value for all 22 permanently occupied Passive Houses is **q_{Final} = 58,0 kWh/(m²a)** (including household electricity).

In comparison to the projections (51,9 kWh/(m²a), the measured consumption is 6,1 kWh/(m²a) higher. In view of the effectively **achieved final energy savings of 67 %** in comparison to the average new house, the result is to be judged as a great success. For the comparison with the average new house, the estate's houses were remodelled and recalculated according to [WSVO 95]. The reference case's resulting final energy demand was 173,8 kWh/(m²a).

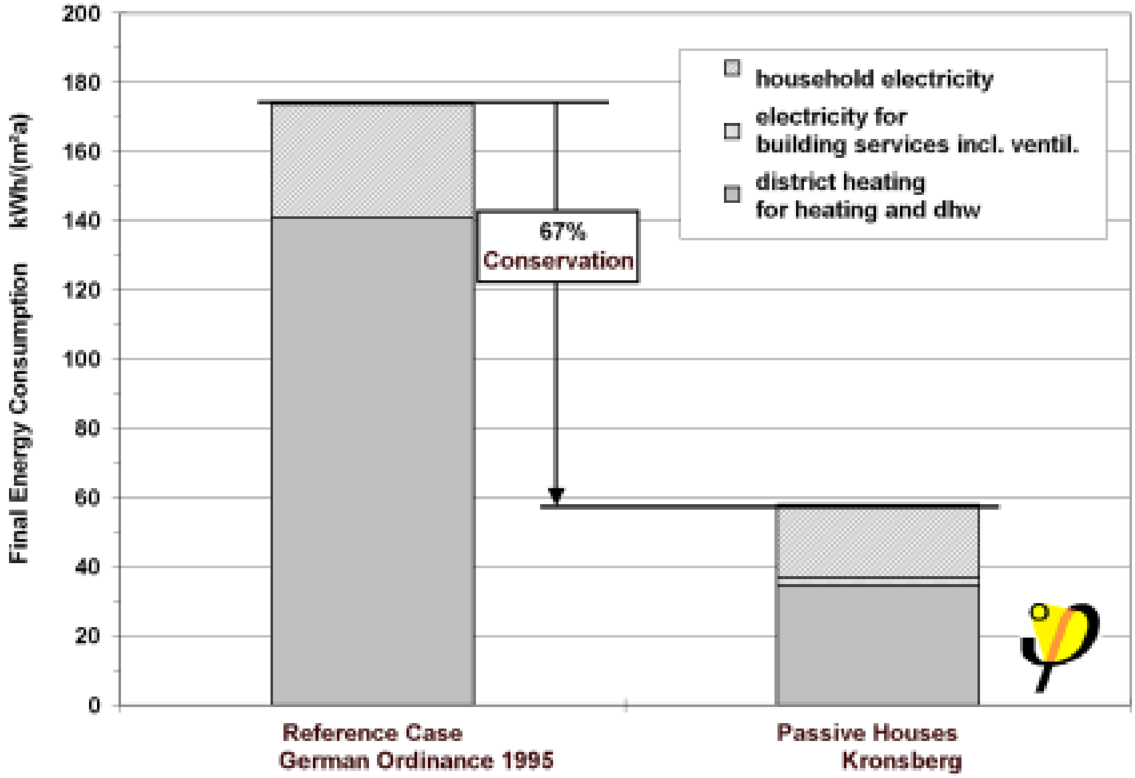


Figure 51: Total final energy consumption (district heating and electricity including household electricity) for a reference estate with the current average standard in Germany (left) and according to the measurement values in the Kronsberg Passive House estate (22 permanently occupied houses in the measurement cycle 4.10.1999 to 3.10.2000).

13.1.3 Final energy comparison with Low Energy Houses (LEH)

All the buildings in the new Hannover-Kronsberg housing estate had to be built at least to Low Energy House (LEH) standards according to the city of Hannover guidelines. Defined as the „Kronsberg-Standard", these guidelines are more strenuous than the requirements of the 2000 German Energy Saving ordinance: proven verification of the standards was required by the city of Hannover for all buildings, and a comprehensive quality assurance was supported. The Stadtwerke Hannover has made available for comparison the heating cost bills of five larger multi-family houses with a total of 88 Kronsberg-standard homes. The measured demand data from the objects include the pipe network distribution losses in the houses. It is therefore necessary to refer to the final energy demands for a comparison with the 32 Passive Houses.

The data compared refer to almost the same annual period: the LEH consumption was recorded from 15.10.1999 to 16.10.2000, those for the Passive Houses in the first measurement year from 01.10.1999 to 30.09.2000.

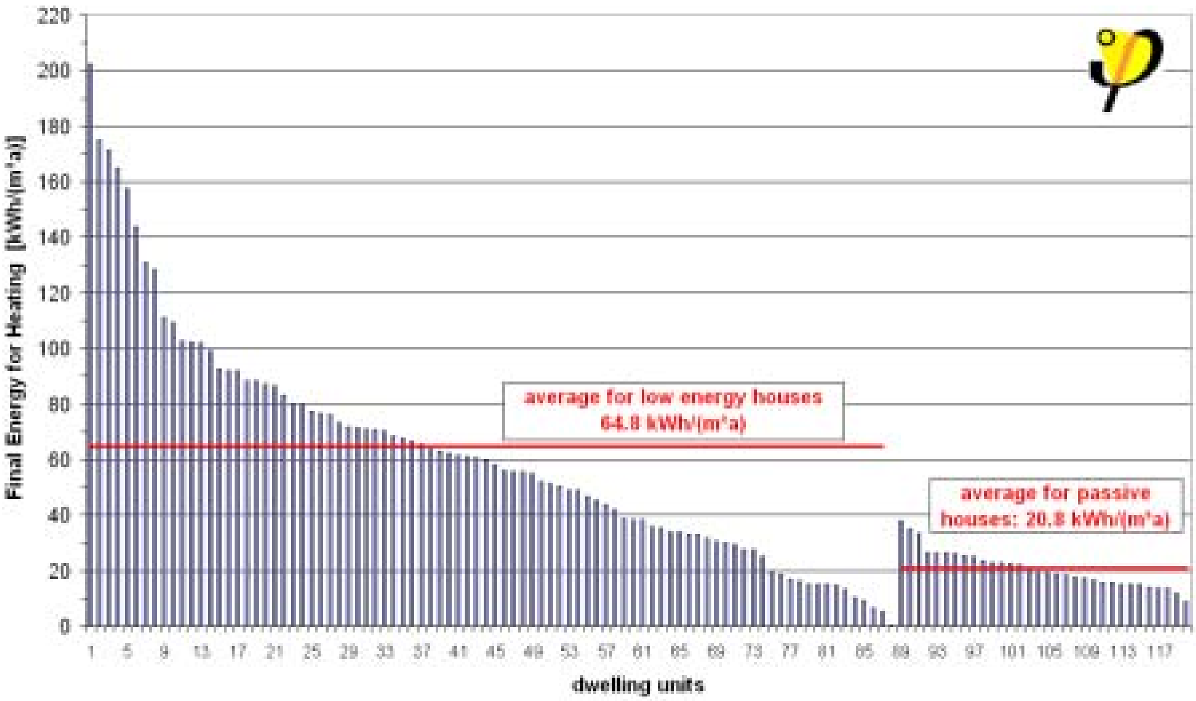


Figure 52: Comparison of the final energy demands for heating of five Kronsberg multi-family houses built to the Low Energy standard (according to the heating bill) and of the 32 Passive Houses. The comparable annual periods of one year are presented (LEH: 15.10.1999 to 16.10.2000, PH: 01.10.1999 to 30.09.2001). The average of the measured values clearly shows the difference between the two standards.

Figure 52 shows the impressive difference between the two standards, with average final energy values for heating of **64,8 kWh/(m²a)** for the LEH and **20,8 kWh/(m²a)** for the Passive Houses. It is likely that a few of the LEH homes were unoccupied and unheated at times. With regards to the values, it must be noted that we are dealing here with LEH standard new buildings that are already optimised for energy use and have been quality controlled. Their demands are about 40% less than conventional new buildings. The heating energy demands of the Passive Houses are, in comparison to the LEH houses, reduced by a factor 3 and thus so low that the heating is practically negligible on economic terms.

13.1.4 Occupant range and consumption level in comparison

Erik Lundström published (1986) an important evaluation of the impact of occupant behaviour on the energy demand in single-family homes in Sweden [Lundström 1986]. Lundström measured the total energy consumption of 77 equally constructed single-family homes in Stockholm. The freestanding single-family homes that were analysed have a comparatively good insulation (U_{Floor} = 0,25; U_{Wall} = 0,38, U_{Window} = 2,79 und U_{Roof} = 0,23 W/(m²K)) and are solely supplied with electrical energy – that means that heating and hot water preparation are done with electricity. Only the total electricity consumption was measured: heating, domestic hot water preparation and household electricity together.

The final energy consumption of the 77 Stockholm houses is presented in Figure 53 in increasing order. The average of the final energy consumption equals 203 kWh/(m²a) and the estimated standard deviation is s = 27,4 kWh/(m²a). Lundström made the following hypotheses based on the range of consumption values:

- The energy demands of equally built houses swung considerably depending on the occupant behaviour (ratio to 1:2).
- Occupant behaviour has the dominating effect on energy consumption.
- The impact of building quality and technology on consumption is exaggerated.
- Saving measures due to changes in behaviour are better and more cost-effective than technical and construction improvements.

Lundström therefore advises in his work to defer the efforts to improve technical efficiency and rather to place more emphasis on programs about energy saving occupant behaviour.

It is possible to test the hypotheses of this historic report with the results of our measurements in the Hannover Kronsberg Passive House estate. Using the same benchmark, we have included both sets (the 77 Stockholm houses and the 22 Passive Houses) of measured final energy consumption for heating, domestic hot water preparation and household electricity in Figure 53: the qualitative statistical variation is similar in both surveys. Both sets can be viewed as being normally spread.

The average final energy consumption of the Kronsberg Passive Houses, however, is only 58 kWh/(m²a), which is only 29% of the average value of Lundström's Stockholm houses. The final energy savings achieved between the Stockholm houses and the Hannover Passive Houses is thus over 70%.

The impact of occupant behaviour seen in the Stockholm houses is also present in the Hannover Passive Houses. The standard deviation in the Passive Houses, however, is only s = 11,8 kWh/(m²a), the absolute size of the consumption variations has therefore decreased with improved technical efficiency.

It is therefore possible to counter Lundström hypotheses with the results of the research performed here:

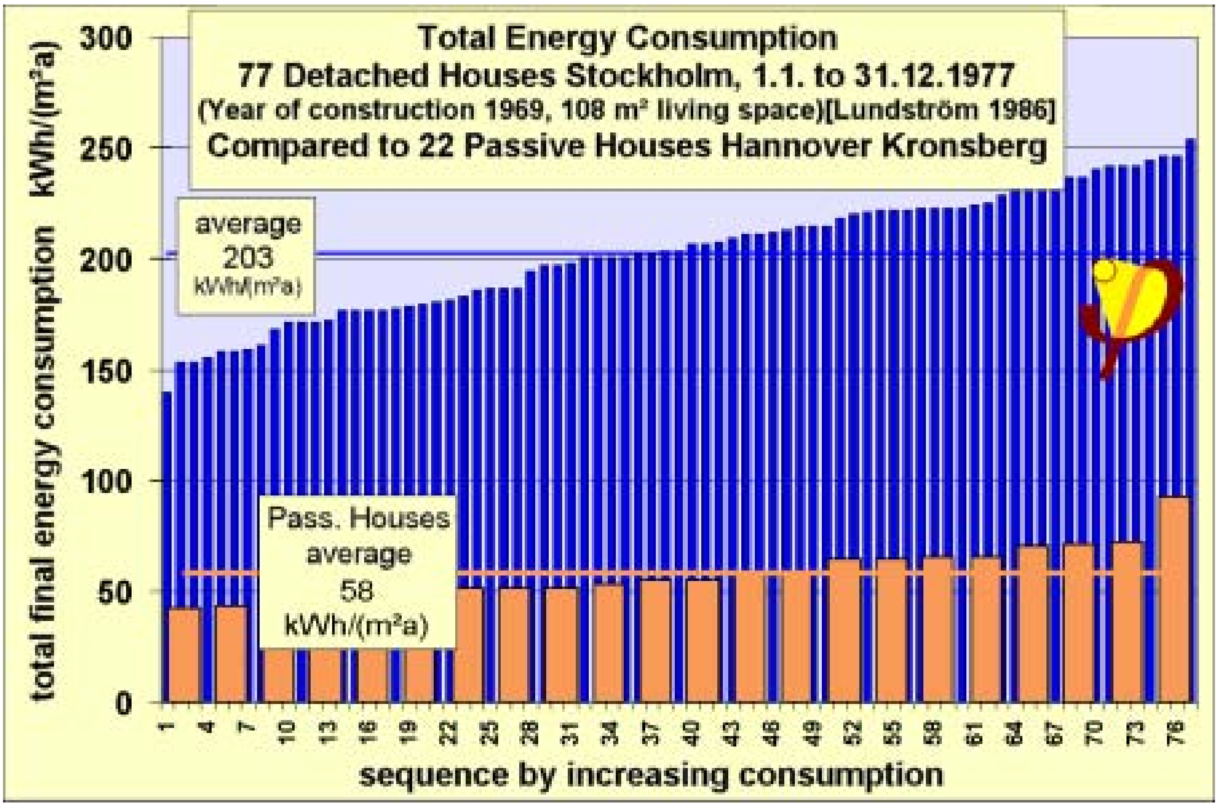


Figure 53: Comparison of the final energy consumption for heating, hot water and household electricity in the 22 permanently occupied Passive Houses with the 77 Stockholm houses according to [Lundström 1986].

- The final energy demands of houses with (largely) similar construction and technology vary independently from the respective standard in a ratio of roughly 1:2 between minimal and maximum consumption. With respect to this question there is practically no difference between poorly insulated houses and well-insulated ones.
- It is not occupant behaviour which has the dominating effect on the energy demand, but rather the construction/technical standard: solely through the improvement in technical efficiency has it been possible to reduce the average energy consumption by more than a factor 3 in the Kronsberg Passive Houses.
- The impact of building quality and technical efficiency on consumption seen in the average representative values is clearly reproduced by the calculated demand values. The potential of technical efficiency improvements is therefore not exagerated.

- Savings measures through construction/technology efficiency improvements are in many ways more effective than attempts to change occupant behaviour:
  - they lead to similar high relative savings, whether the occupant is frugal or wasteful.
  - as the Hannover Passive House project has shown, they are cost-effective to implement and hold their effect over the useful life of the building.
  - they do not patronise nor point with the raised finger.
  - they allow each occupant to have the thermal comfort level he/she wishes.

The CEPHEUS research was able to affirm and render more precise [Lundgren 1989]'s continuing studies: our research in CEPHEUS show (for the separated effect of the occupants) that more than half of the variations can be explained by different indoor temperatures chosen by the occupants (certainty measure ≈ 50 %). These differing occupant desires with respect to room climate are clearly present in all researched projects. The improvement in construction/technical efficiency allows considerable energy savings to be securely achieved without having to change the value judgements and needs of the occupant. The CEPHEUS results show that this is sufficient to achieve a sustainable energy supply situation in households. The efforts to improve technological efficiency should therefore be further intensified, and in two directions:

- First of all, through the use of the currently available high-efficiency technology in a wider practical implementation; in this case, the Passive House components have especially proven themselves – they can be used in a wide spectrum to improve existing houses.
- Secondly, through the continuation of research and development in the direction of even more efficient technology. Especially those technologies that improve electricity efficiency provide an important opportunity in this case.

13.1.5 Primary energy consumption

The primary energy demand differs from the final energy demand in that the additional losses of the complete preliminary energy production chain are included. The following primary energy factors for the preliminary chain were used pursuant to the CEPHEUS agreement

- district heating from CHP units: 0,7 $kWh_{Primary}/kWh_{Final}$
- average European electricity mix: 2,5 $kWh_{Primary}/kWh_{Final}$.

All renewable energy sources are valued at 0 $kWh_{Primary}/kWh_{Final}$, since they do not contribute to global warming.

According to the measurement results of the first year, the resulting average primary energy value in the Passive House estate's 22 permanently occupied houses is 82,6 kWh/(m²a). The reference case according to WSVO 95 was calculated at 244,2 kWh/(m²a). The primary energy savings achieved thus equal **66 %**.

Since the heating supply (heating 14,7 kWh/(m²a)) and the non-renewable energy consumption for hot water preparation (9,6 kWh/(m²a)) run completely on district heating, the absolute values for those become smaller. With a 29,4% share of the primary energy consumption, they are very small. On the other hand, the importance of the household electricity consumption (52,7 kWh/(m²a)), with a 63,8% share of the total primary energy demand, is clear.

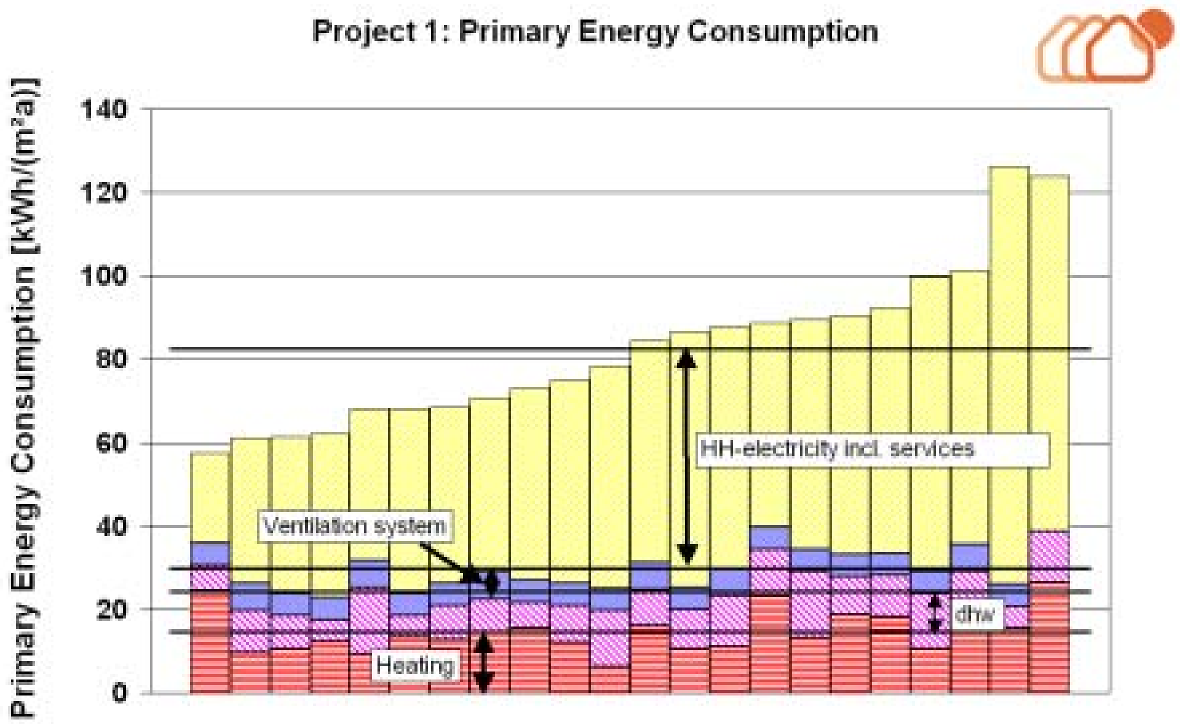


Figure 54: Primary energy consumption during the first full measurement year (1.10.1999 to 30.9.2000) for the 22 permanently occupied Passive Houses.

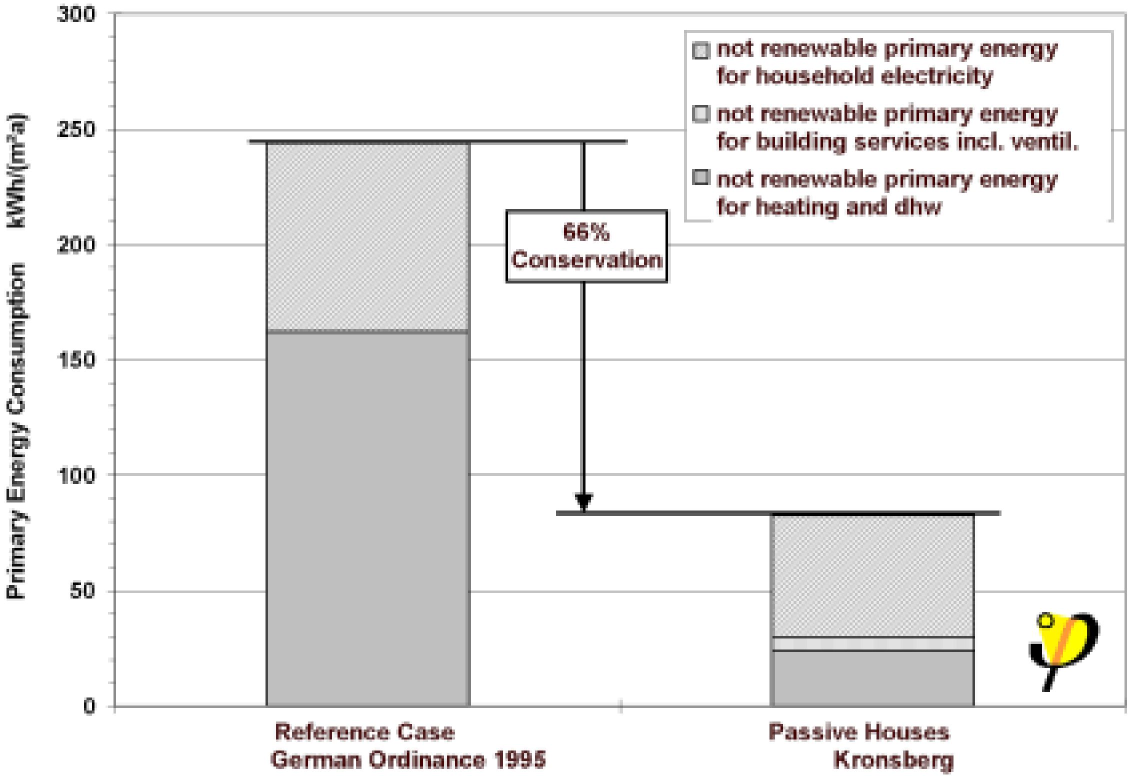


Figure 55: Total primary energy consumption for a reference case built to the current average new construction standard and according to the measurement values in the Passive House estate.

The primary energy consumption achieved lies clearly below the target value for new Passive Houses in Germany (120 kWh/(m²a)).

The result show that the thermal optimisation of the Kronsberg Passive Houses leads to very good specific values in practice. Whereas the efficient use of electricity is becoming more and more important: household electricity, with a formidable share of 65% of the primary energy consumption, has a major role, even though electricity improvement of about 38% have already been achieved here (see section 14.4.1).

13.2 Thermal Comfort

The progression of the measured room temperatures in the permanently occupied Passive Houses together with the area-weighted average value and the outdoor temperature are presented in Figure 56 as average daily values.

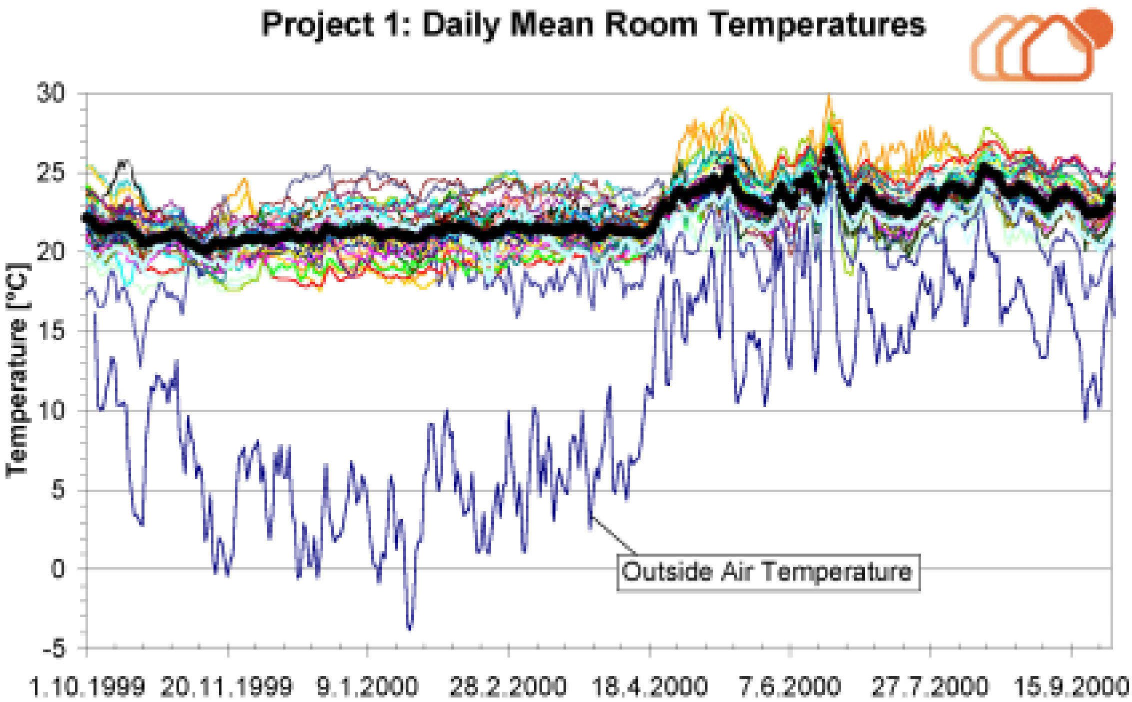


Figure 56: Average daily room air temperatures of the 22 permanently occupied houses in the first measurement year (1.10.1999 to 30.9.2000).

The spread of room temperatures range from ca. 12,7 to 29,9 °C. It should be noted, however, that the temperature of 12,7 °C was an exception lasting from the 18th to the 22nd of October 1999, and refers to the first floor of a house. As the graph shows, the outdoor temperature also fell sharply at the same time. This probably means that the bedroom window was open during this time. Except during the coldest winter period, the temperature in this first floor is, compared to the other houses, almost always very low. This likely means that the bedroom window was almost always open, except during the key heating period.

The thermal comfort during the summer, with average interior temperatures rarely – and when, only briefly - over 25 °C, was very good. The evaluation of the hourly values shows an overstepping of 25 °C in the occupied houses for only 2,5% of the total annual hours.

Under closer analysis of the occupied houses, the average summer daily temperatures in all four Passive Houses rows were found to lie between +22,3 and +26,4°C (1.6. to 30.09.2000). Daily average temperatures above +26°C (summer time comfort limit) occurred solely for a maximum of one day on the ground floor, and at most 1 to 4 days on the first floor. This means that the frequency $h_{\vartheta>26°C}$ in the Passive House estate appears to be at **maximum** of **1,1%** of the time in summer 2000. This can be considered a very comfortable indoor climate during the summer. The result fits well with the Passive House summer climate report [Feist 1998b].

On viewing the correlation between the inner daily temperatures of the occupied houses and the external temperature, one can see the clear difference between the winter and summer period (Figure 57).

The linear fitted curve for the external temperatures area to a maximum +10 °C shows an almost horizontal path (0,02 K temperature rise per Kelvin temperature increase in the external air temperature). This means that low external air temperatures only had a very slight impact on the interior air temperatures, which is largely due to the active control effect of the inflow air heating system.

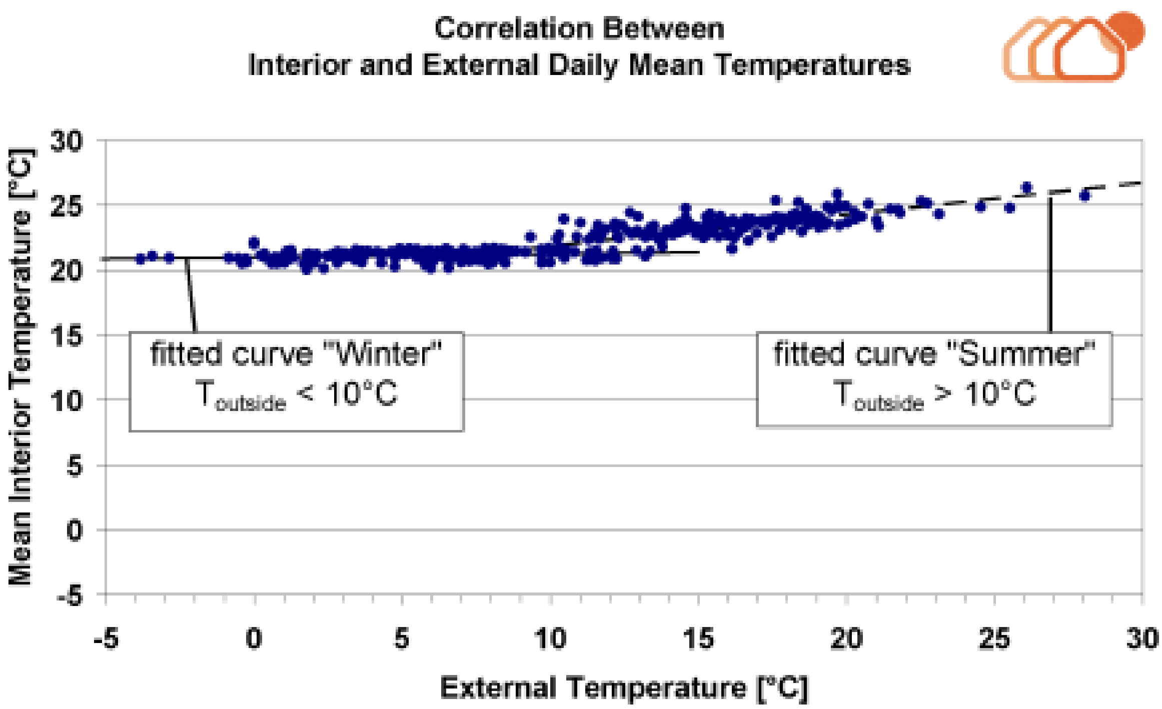


Figure 57: Correlation between external and interior daily mean temperatures in the first measurement year.

The higher outdoor temperatures (above 10 °C outdoor daily mean temperature) are presented in Figure 57 with a separate linear fitted curve ("Summer"). This linear curve shows that the relationship in the summer is completely different: since the houses do not have any sort of active cooling, the rooms act largely thermally passive; but thanks to the storage bulk and occupant behaviour such as window opening, there is a certain dampening of the variations in outdoor temperature: during the summer period (1.6.2000 to 30.9.2000) the $\Delta\vartheta_a$ of the daily average external temperature is 18,8 K (9,3 to 28,1°C). Inside, the temperatures only range between 22,3 and 26,4 °C; therefore, the $\Delta\vartheta_i$ equals 4,1 K. Were one to define a temperature amplitude ratio for the whole house, it would be about 22% in summer 2000. The houses are therefore passively compensational for the interior climate.

13.2.1 Typical winter weeks

In the following section we discuss the measurements in one of the 32 houses: During a typical cold and sunny winter week (20.1.2000 to 27.1.2000, see Figure 58) the outdoor temperatures were between -6,5 °C and +4,9 °C. The indoor temperatures during this week in this house were between 20,2 and 22,8 °C. This reflects the fact that the solar radiation only has a measurable impact on the indoor temperature above outputs of 150 W/m² - and then only on the ground floor (23. to 25.1.2000).

The high time constant is also visible when analysing the highest heating outputs, which occur on the 21st and 22nd of January 2000 (15,8 and 16,5 W/m²): the heating outputs on these two days are **not** a result of the decrease in outdoor temperatures from 5 to 0 °C, they are due to the occupant setting a higher target temperature on the thermostat. The high heating outputs produce an indoor temperature increase in the first floor of about 0,4 to 1,2 K. In the ground floor on the 21.1.2000, a temperature increase of 0,4 K is visible. A more precise analysis of these effects is to be found in a separate published report [Kaufmann 2001].

For a typical cloudy winter week, the period from 12.1. to 19.1.2000 was chosen and presented in Figure 59. The indoor temperatures lie between 19,8 and 22,4 °C. The solar radiation, on three continuous days, is always under 50 W/m². The heating output during these days in this house increases to values above 15 W/m². The indoor temperature, especially in the first floor, rises about 2,6 K, to a maximum of 22,4 °C.

It is clear in the discussion regarding Figure 58 and Figure 59, that the determinant heating load period for Passive Houses is **not** necessarily the cold, clear winter day, but rather more likely the cloudy days with outdoor temperatures around zero degrees. On cold clear days in the Central European climate, there is a large solar radiation supply due to the low cloudiness. This results in an increase in passive energy supply, which thus reduces the heating output. These results substantiate the analysis given in [Bisanz 1999].

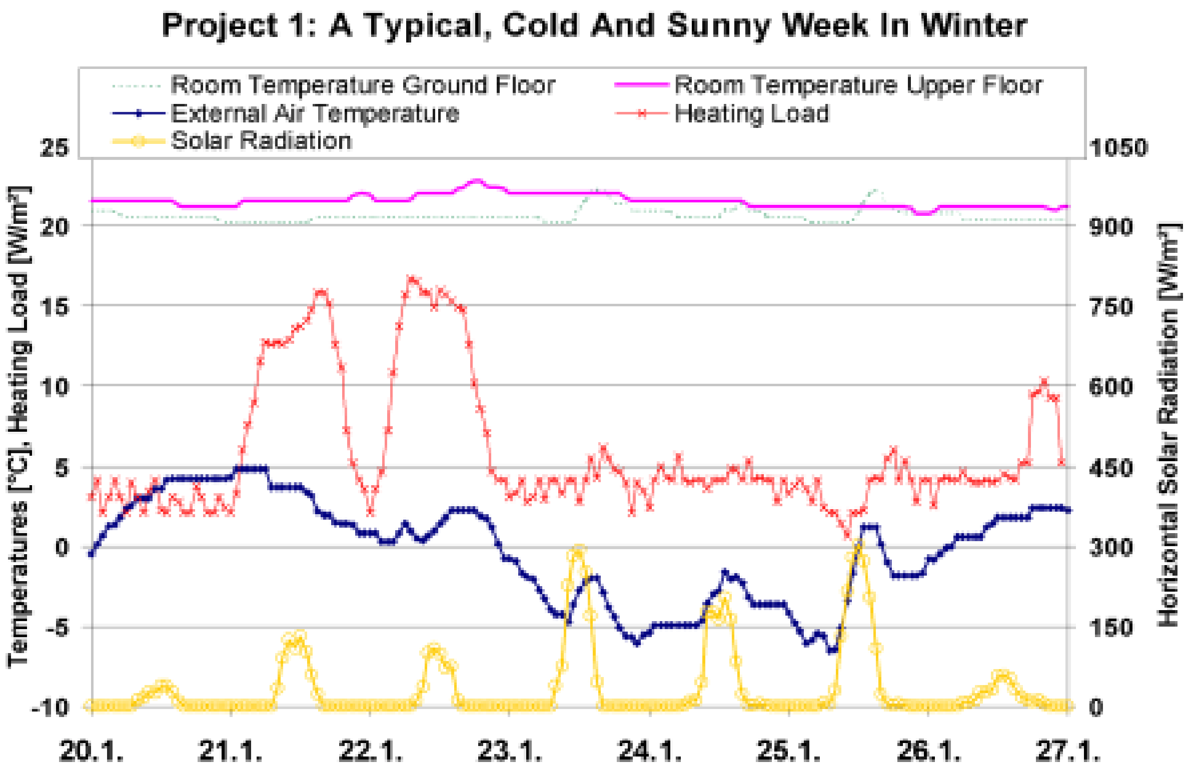


Figure 58: A typical cold and sunny week in winter, during the first heating period 1999/2000

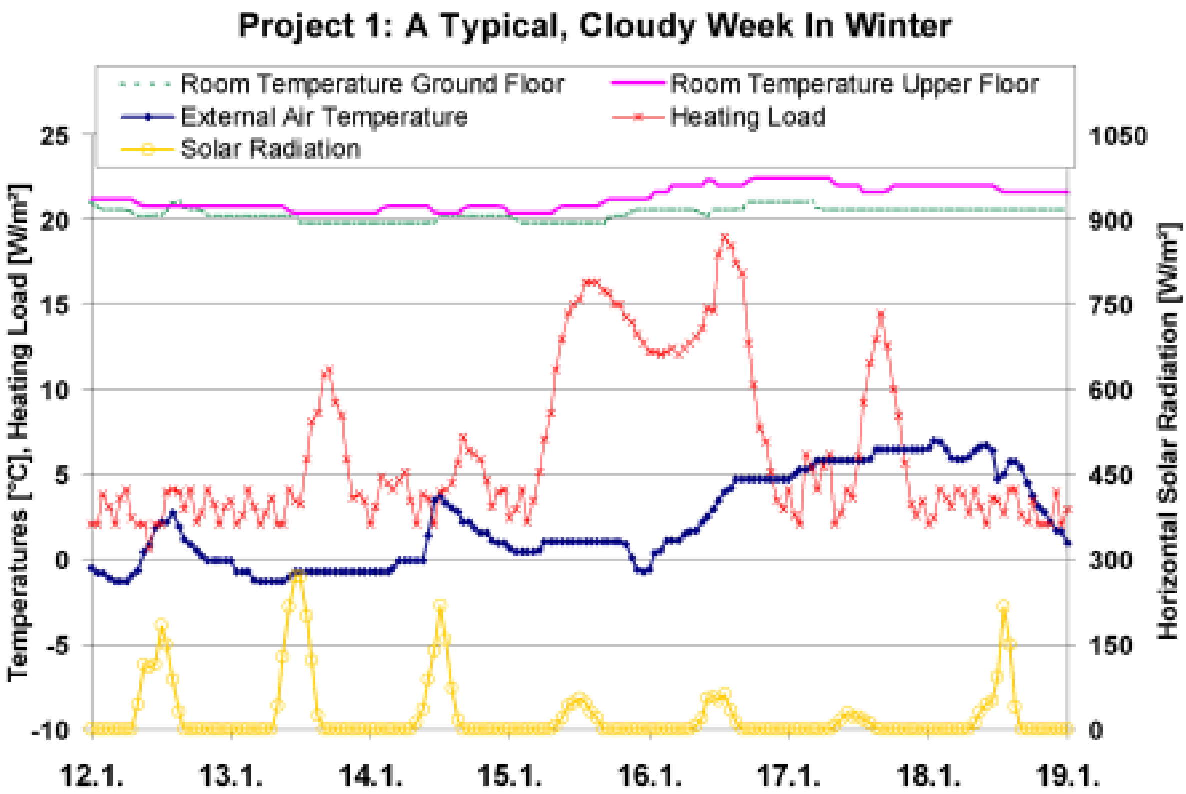


Figure 59: A typical moderately cloudy week in winter, during the first heating period 1999/2000

13.2.2 Typical summer weeks

To analyse a typical summer week the same house was chosen. The typical summer week (Figure 60) shows outdoor temperatures in a range between 13,2 and 27,7 °C with typical midday peaks and nighttime dips. The indoor temperatures in the ground and first floors vary between 23,1 and 25,1 °C. With regards to solar radiation, there are one rather overcast low-radiation day with a maximum of only 265 W/m² and six high radiation days with peak values up to 770 W/m². The outdoor temperature peaks and the radiation peaks at midday are reflected by much lower indoor temperature increases (up to 1,3 K).

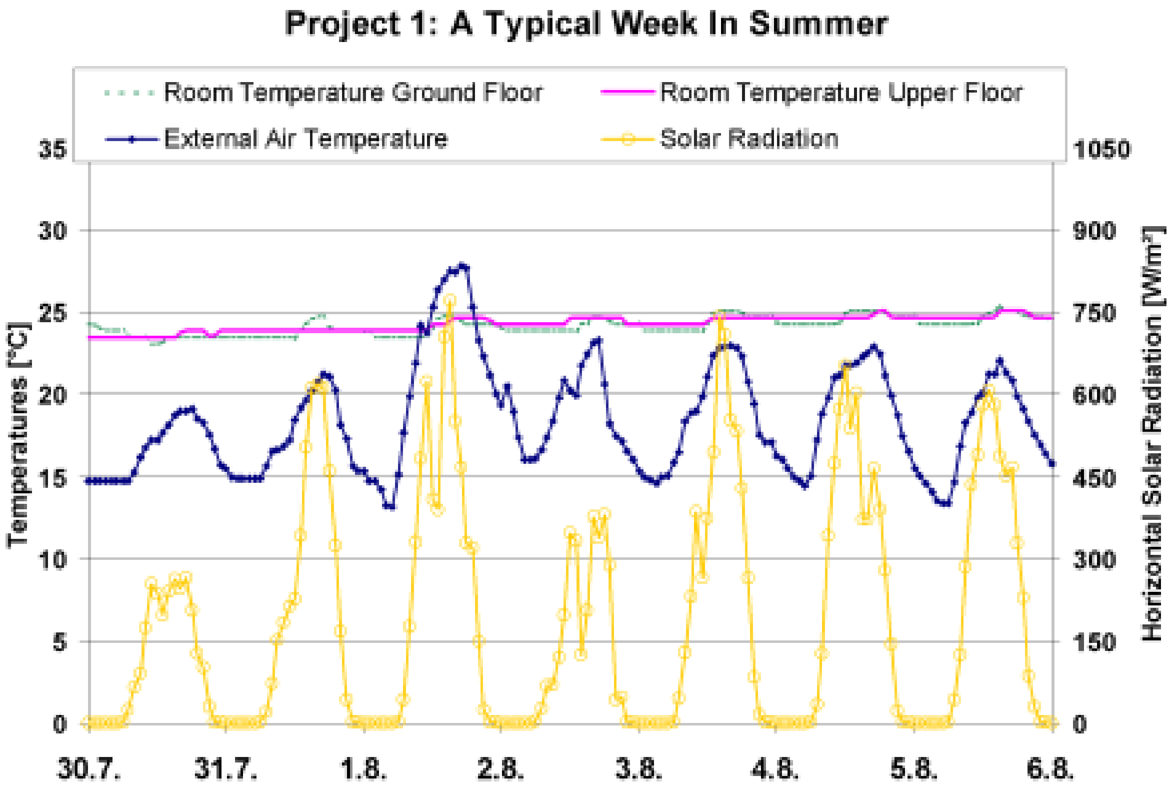


Figure 60: A typical week in summer 2000 in one of the 32 Passive Houses.

It is instructive, in terms of summer time indoor climates, to analyse the time period of a hot wave. The highest outdoor temperatures in the measurement period occurred from the 17th of June to the 23rd of June 2000. The temperature and radiation progressions experienced by the house under analysis during this very radiation-rich time are shown in Figure 61.

The outdoor temperature gradient shows the typical progression of a mid-European summer time heating period. The daily outdoor temperature maximums between the 18th and 20th of June 2000 are 27,9 °C, 33,2 °C and 34,5 °C.

The strong daily outdoor temperature swings are practically unnoticeable in the house. The very small daily temperature swing in the houses is due to radiation and occupant activities. What is typical for the temperature gradient in Passive Houses in the summer is the gradual increase in indoor temperature during the hot wave over the four days. The indoor temperature on the first floor increased by almost 3 Kelvin (from 24,3 to 27,1 °C) within the 3 days.

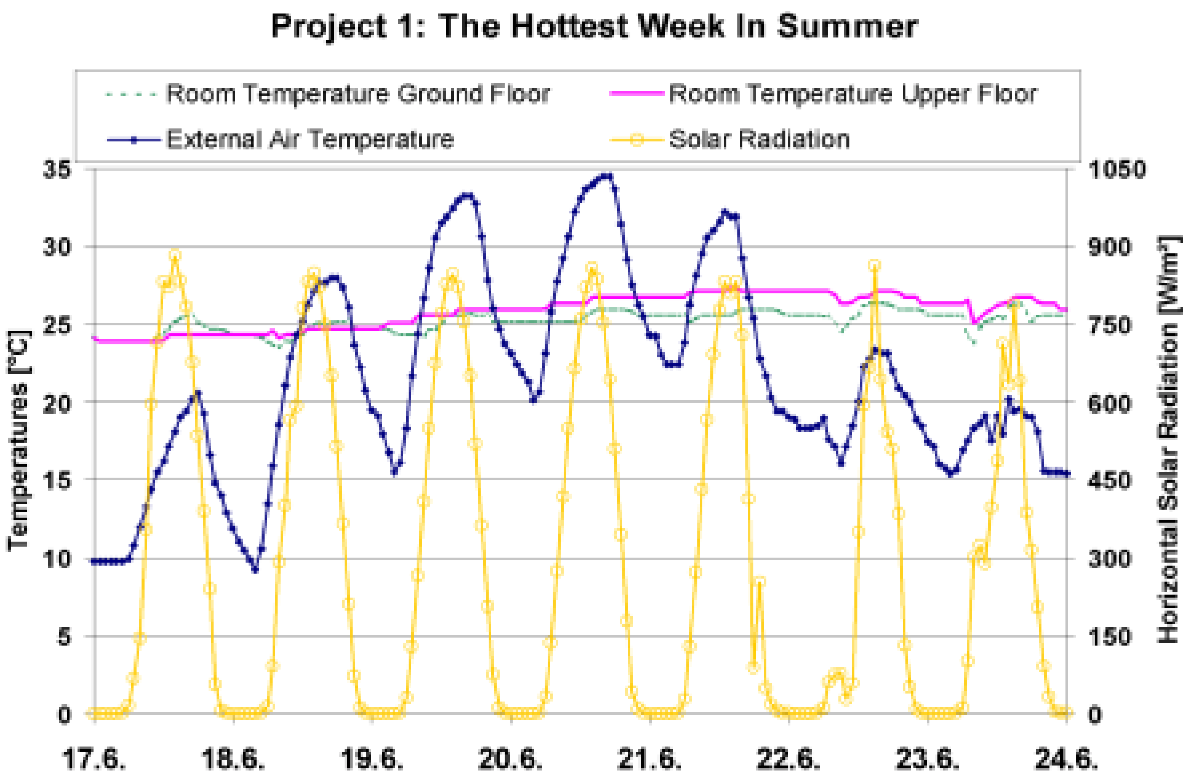


Figure 61: The hottest week in summer 2000 (heating period) in one of the 32 Passive Houses.

After the hot wave's peak, the indoor temperatures reached their maximum of 27,1 (first floor) and 25,5 °C (ground floor) respectively.

It was determined that the temperatures in the „coolest house" during the hot wave were between 2 to 4 Kelvin under those of the „hottest house" (only occupied houses are observed here). The research made clear that this difference is due solely to occupant behaviour. This has to do with the activities already described, night ventilation and shading the rooms through the use of blinds. To reach low temperatures during a hot wave, it is advisable to keep the windows closed during the day.

13.3 Heating load

To classify the heating outputs, it is helpful to determine the theoretical straight line of heat losses for the Passive Houses in the designed insulation standard. The straight line shows the dependence of the heating output on the outdoor temperature, which should occur with the projected standard. Without solar radiation, all heating outputs lie **theoretically exactly on this line**. Due to the heating gains of the passively used solar radiation, the measured heating output values should then be regularly below this line.

The inclination of such a straight line of heat losses is determined by the insulation standard and the preset indoor temperature, the axis intercept by the internal gains (2,1 W/m²). The measured values of all permanently occupied Passive Houses in the period from 8.11.1999 to 18.4.2000 are used here. The **average indoor temperature** in these houses was **21,1 °C**.

The straight line of heat losses in Figure 62 shows a heating temperature limit of ca. 16 °C for the houses (extension of the straight line right to the heating output „0“ W/m², in other words right through the axis of abscissas). The measurement points (the daily average heating outputs of the permanently occupied houses) however, show that no heating takes place above temperatures of 11,5 °C. The measurement points show that the real maximum heating output is 8,8 W/m². This value, however, is to be viewed as an outlier. The average daily heating outputs are regularly well under 7 W/m². The PHPP-heat load calculation sheet came to a maximum heat heat load for the estate’s representative house of 7,1 W/m².

In the figure it becomes clear also that the highest heating outputs do not occur on the coldest days.

In the second evaluated heating period 2000/2001, there is not a single case of the calculated heat load upper limit of 7,1 W/m² being exceeded (Figure 63). There are also less daily average heating outputs above the theoretical heating curve as in the first heating period.

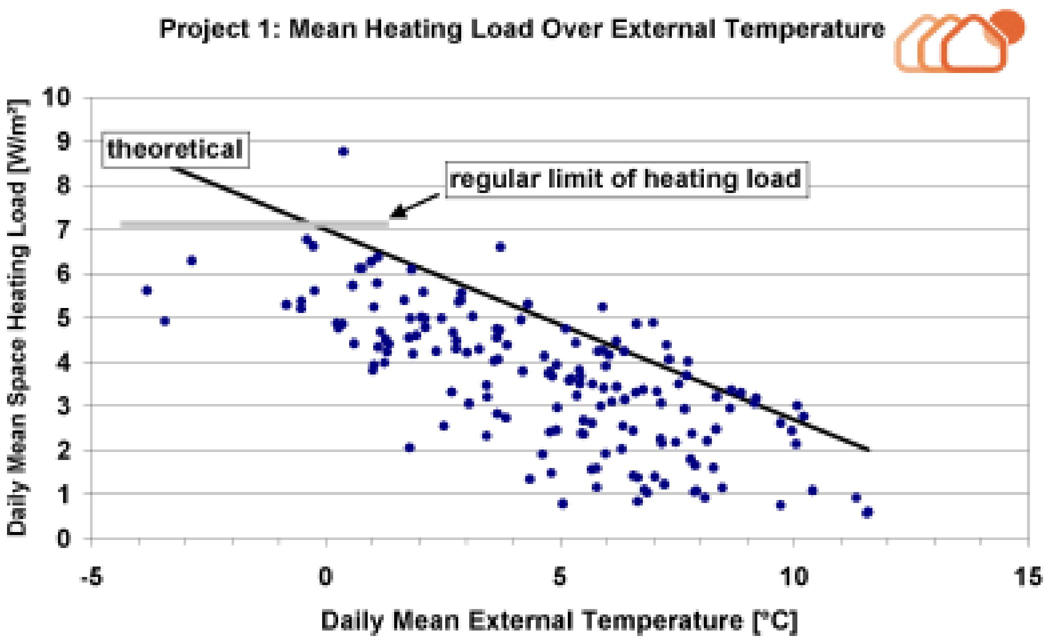


Figure 62: Theoretical heating load straight line and daily average heating output in comparison with the daily average outdoor temperatures (all permanently occupied houses) in the first heating period (08.11.1999 to 18.04.2000). The calculated heating load according to PHPP for the representative house is 7,1 W/m².

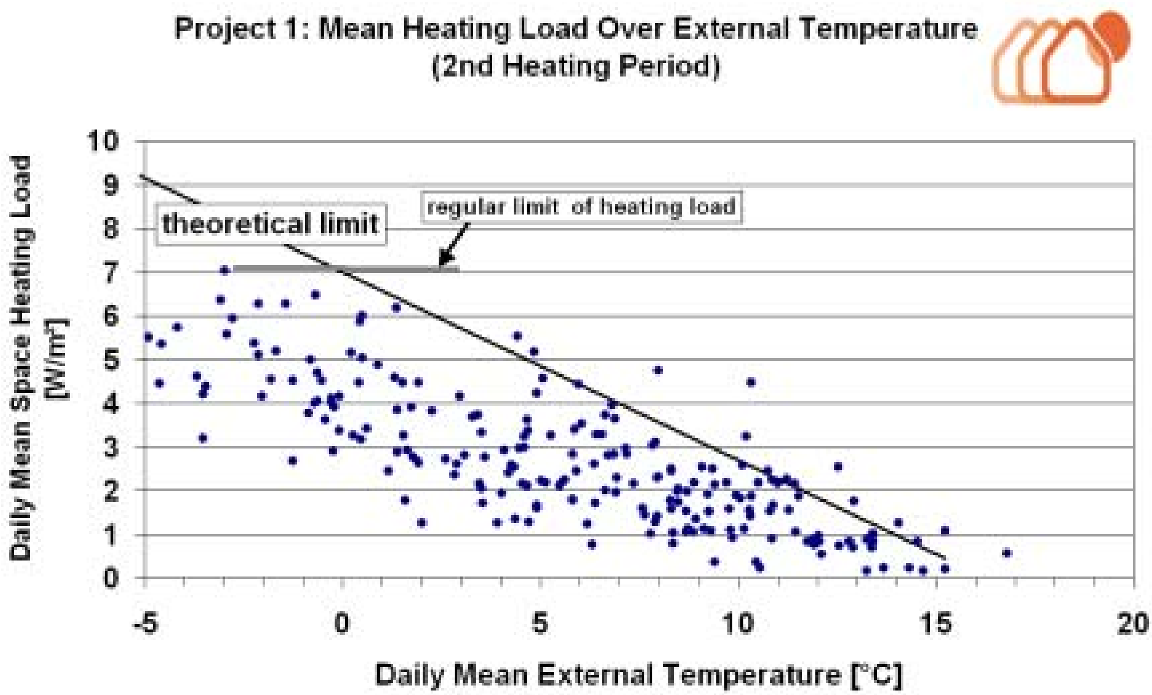


Figure 63: Theoretical heating load straight line and daily average heating output in comparison to the daily average outdoor temperatures (all permanently occupied houses) in the second heating period (01.10.2000 to 30.04.2001). The calculated heating load according to PHPP for the representative house is 7,1 W/m² and was not exceeded.

14 Project specific measurement data evaluation

14.1 Climate data comparison

To assess the climate conditions in the first measurement year (1999/2000), the measured climate data were compared with reference data. The reference data are used as a basis for the simulation of the Hannover-Kronsberg buildings [Schnieders 1998]. They represent the typical Hannover climate.

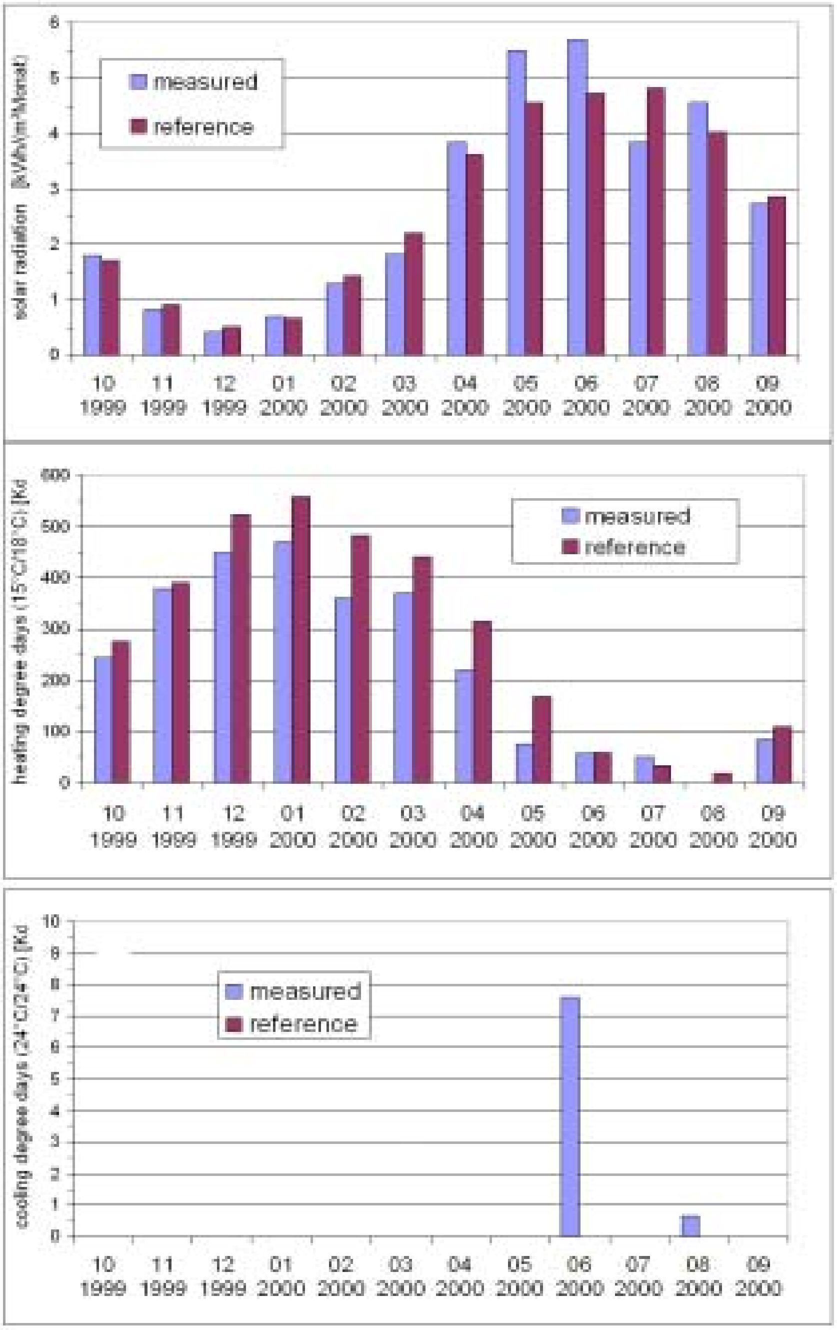


Figure 64: Comparison of the first year measurement data and the reference data, which are the basis for the simulation [Schnieders 98]. Above: solar radiation, middle: heating degree days (HDD), below: cooling degree days (CDD) (HDD: heating temperature limit 15 °C, indoor temperature 18 °C, CDD: cooling temperature limit 24 °C, indoor temperature 24 °C).

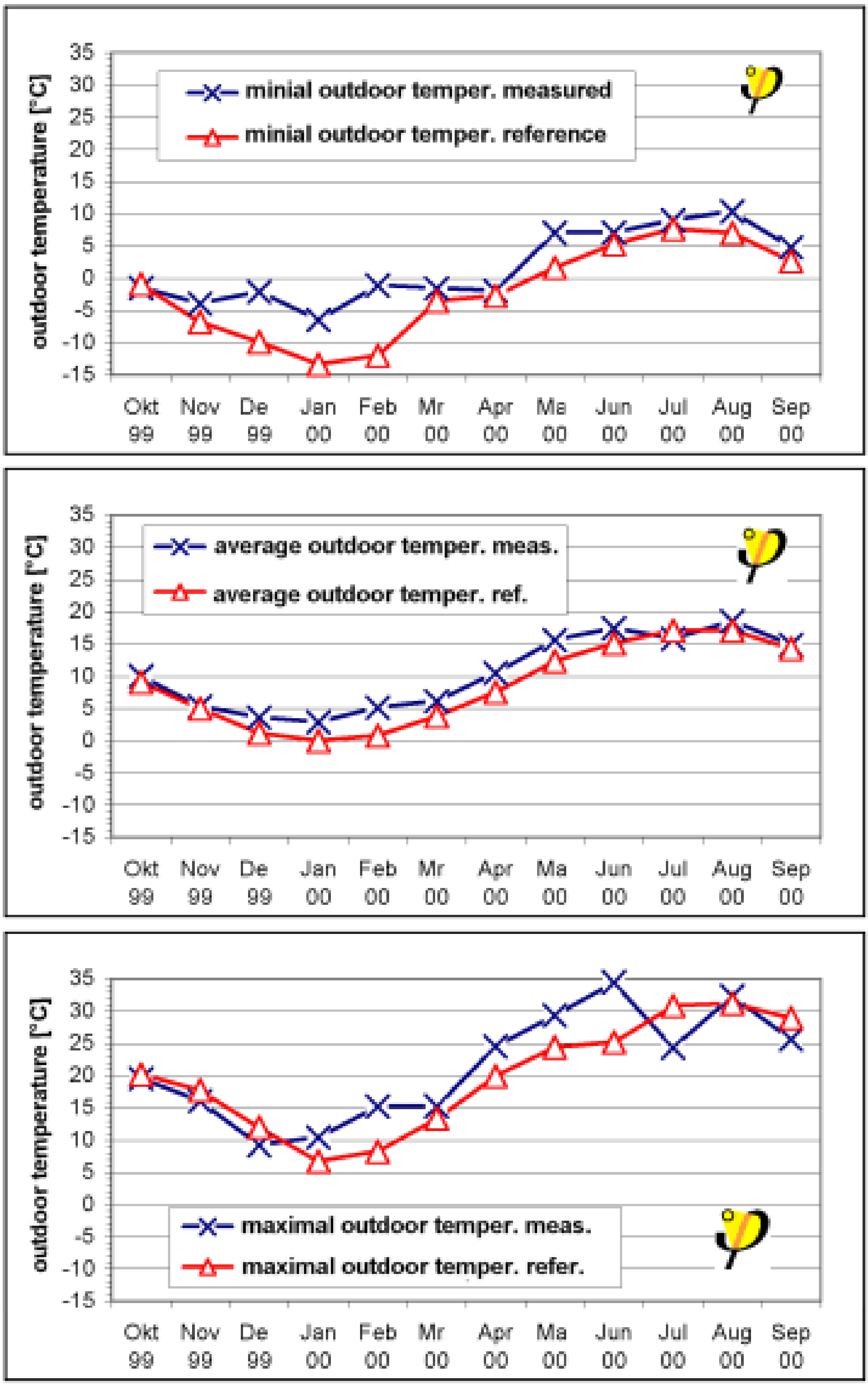


Figure 65: First measurement year climate data comparison of the minimal, average and maximum temperatures (monthly values from hourly data) between the measurement data and the reference data, which are used for the simulation [Schnieders 98].

14.2 Cold water consumption

The total water consumption of each house is measured with a respective water meter. The cold-water amounts are calculated from these total water amounts by subtracting the respective hot water amounts (sub meter). Figure 66 shows the evaluation of the first full measurement year's consumption in the 22 permanently occupied houses.

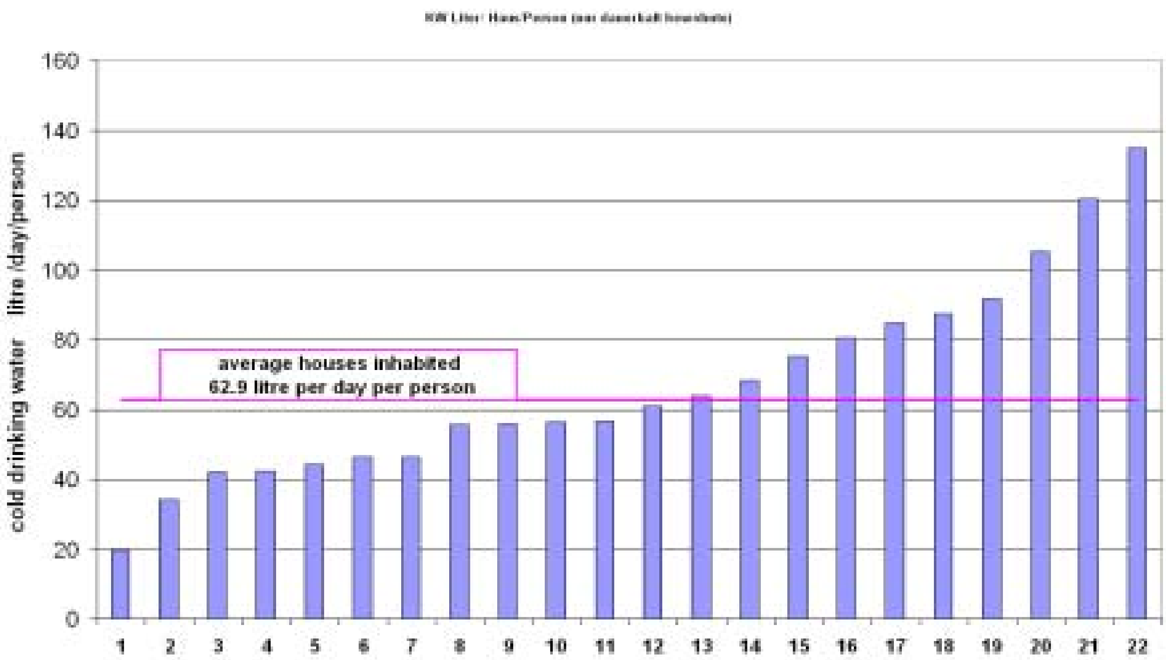


Figure 66: Average cold water consumption amount per day and person in litres from 01. October 1999 to 30. September 2000 for the 22 permanently occupied houses.

The **average daily value** for the permanently occupied houses is **62,9 litres per person**, with a range of values from 20 to 135 litres/day and person. The cold water consumption per house during the same period is 200,6 litres per house and day.

14.3 Hot water

For domestic hot water, this section has to differentiate between the hot water consumption amount and the district heating demand. Figure 46 already presented graphically the monthly totals of the district heating supply for hot water. Here they are presented for each house.

14.3.1 Hot water consumption

The hot water consumption is measured independently from the energy source used (district heating or solar thermal system) with separate water meters. The evaluation of the first measurement year (1.10.1999 to 30.09.2000) resulted in a daily average consumption of 31,6 litres per person (only permanently occupied houses). Each permanently occupied house had an average daily consumption of 100,5 litres.

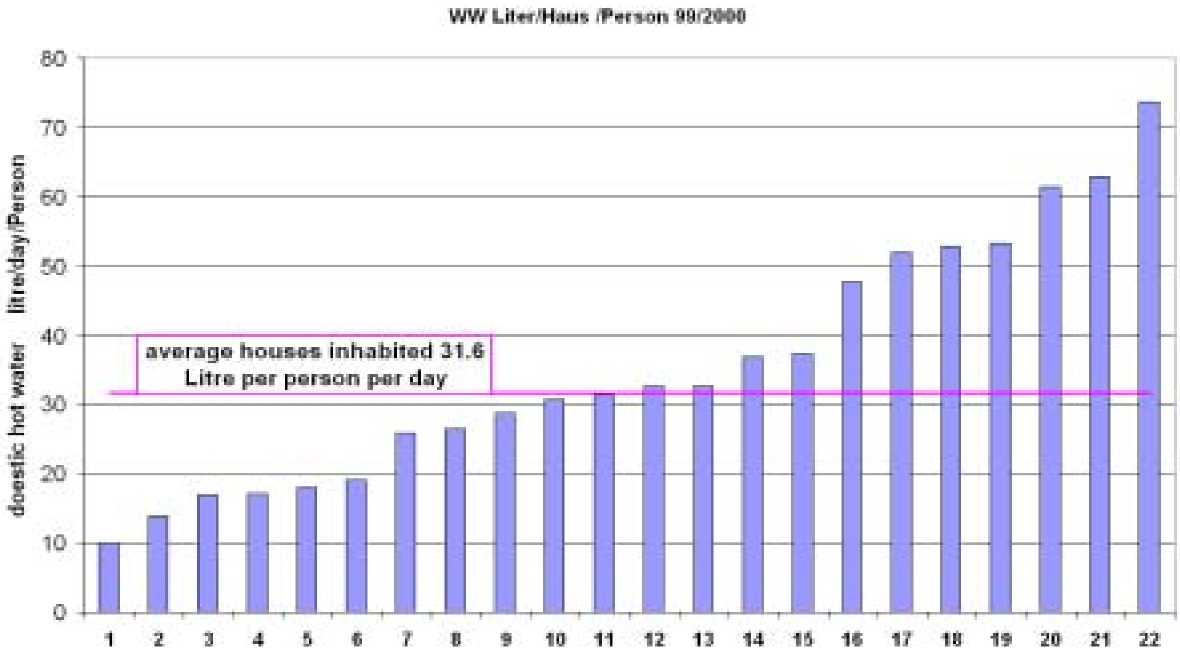


Figure 67: Average hot water consumption per day in litres per person from 1. October 1999 to 30. September 2000 in the 22 permanently occupied houses.

Figure 67 clearly shows the wide range in consumption in the permanently occupied houses, from 10 to 74 litres per day and person.

The evaluation of the temperature measurement after the cold water mixer in the intensively measured house provided an average hot water temperature of about 46 °C (full year). This value, however, can be individually set in the houses. The average tap temperature in all the houses is therefore not known.

A hot water consumption average of 25 litres per day and per person at a water temperature of 60 °C is set for the PHPP calculation program. When we use the temperature measurement value from the intensively measured house for all occupied houses, the resulting consumption at a tap temperature of 46 °C means an average consumption at 60 °C of about 22,8 litres per person and day. The average measured consumption values for hot water in the Passive House estate is roughly 9 % less than the projected value.

14.3.2 District heating for the hot water supply

The Hannover-Kronsberg Passive Houses are supplied through district heating with energy for space heating and domestic hot water preparation. One of the two HQM (heat quantity meters) in each house counts solely the heat consumption for the domestic hot water preparation from the district heating supply. However, this does not include the entire energy amount for hot water preparation, since each house has its own solar thermal system.

The presentation of the individual specific district heating consumption for hot water preparation in the permanently occupied houses in the first measurement year shows, as expected, a wide spread (Figure 68). The annual average equals 9,2 kWh/(m²a).

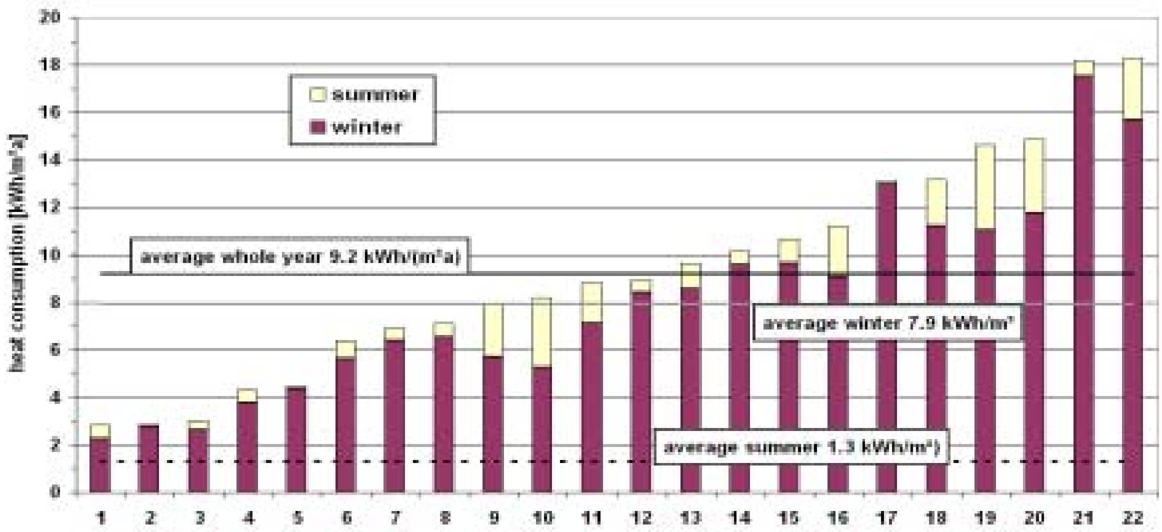


Figure 68: Specific district heating consumption for domestic hot water preparation during the first measurement year (01.10.1999 to 30.09.2000) for the 22 permanently occupied Passive Houses divided in winter (01.10.1999 to 30.04.2000) and summer period (01.05.2000 to 30.09.2000).

A few houses completely cease their district heating supply over a long period of time during the summer. This results in the hot water preparation being heated solely by the solar thermal system during this time, as can be clearly seen in the diagram.

14.3.3 Distribution network heat emission: partial use in the winter

The individual house total-HQM only count the individual heat consumption. These HQM's are placed directly at the exit of each home's internal district heating distribution in the attic. These meters ***do not*** count the heat consumption for the internal district heating distribution or the heat transfer, nor the buffer storage in the heating containers or the losses of the distribution networks laid in the ground.

In contrast, the two central heat quantity meters placed at the respective Stadtwerke Hannover transfer stations in the heating containers (in row 9/10 and row 13/14) count the total heat taken from the district heating network, including the above mentioned heating emission from the pipeline network and the storage tanks. The following values for the period from the 04.10.1999 to 04.10.2000 were reached:

- total district heating consumption rows 9+10: 61.430 kWh
- total district heating consumption rows 13+14: 56.311 kWh.

Using these figures, one can determine an average allocated district heating consumption per house of 3680 kWh/a or, based on the surface area:

32,9 kWh/(m²a) district heating consumption 1999/2000.

From this consumption value, one can then subtract the consumption for heating and domestic hot water using the individual house heat quantity meters:

- HQM heating winter and summer, all houses 16,0 kWh/(m²a)
- HQM hot water for the whole year, all houses 7,7 kWh/(m²a).

With regards to the values of the central meter that lie above the sum of these two individual demands (23,7 kWh/(m²a)), they represent:

- on the one hand, the heat dissipation from the distribution network and the building services technology in the building services containers and
- on the other hand, a possible error of measurement, which can result from the starting limits of the individual meters.

As we will see in the following analysis, the error of measurements just mentioned in the second point are evidently small; the differences between the individual meters and the exact value of both central meters can be fully explained by the distribution network's heat dissipation, and there is no reason to think that the distribution network would dissipate significantly less heat than calculated.

Even the distribution network's heat dissipation is not to be viewed fully as heat losses. The latter is only the case when

- the technical systems are located outside the heated building envelopes (for example, this is the case for the connections to the heating containers placed in the ground for house rows 10 and 14) and
- when the heat dissipation within the heated building envelope is not usable.

When the pipelines are within the heated building envelope, the dissipated heat then helps the inner heat sources and is at least partly usable.

a) Losses from the earth-laid pipelines

With a length-based heat loss coefficient for the earth-laid pipes of 0,16 W/(mK) and a total pipe length of 122 m, the calculated total heat loss to the ground is 6900 kWh/a or, based on the living area, 1,9 (±0,3) kWh/(m²a).

b) Losses from both buffer storage tanks

With a heat loss coefficient for the 500 litre storage tanks installed in the heating containers of 10 W/K, the resulting storage tank heat loss equals 3680 kWh/a or 1,0 (±0,2) kWh/(m²a) based on the living area.

c) Heat dissipation of the centrally laid pipe networks in the houses (attic)

With a length-based heat loss coefficient for the attic pipe networks of 0,15 W/(mK) and a total pipe length of 416 m, the calculated total heat dissipation in the attic is 19.800 kWh/a or, based on the living area, 5,5 (±1,2) kWh/(m²a).

Sum of the calculated heat dissipation of the technical systems

The sum of the three calculated expected heat losses from a) to c) equals 8,5 (±1,4) kWh/(m²a). The difference between the central meters and the sum of the individual meters, however, equals 9,3 (±1) kWh/(m²a). The calculated value and the difference value from the measurements do agree within the framework of the accuracy possible in this case. For the following presentation of the data, we start with the calculated values according to a) and b) and then use, for the heat losses of the network in the houses, the difference value of the measured technical losses minus the amounts of a) and b); this results, within the measurement accuracy, in a network heat dissipation in the houses of 6,4 (±1,5) kWh/(m²a). Most of this heat dissipation occurs in the period from the 1st of October 1999 to the 1st of May 2000, the rest during the summer.

Useful heating emission of the internal central network (attic)

The central network's heat dissipation during the main heating period dealt with in the last section is at least partly usable as a contribution to the inner heating sources. We determined the useful share of this heat dissipation by using the EN 832 calculation method, by at first calculating without the heat dissipation (base case) and then with the heat dissipation as an internal heat source. The result is a marginal utilisation rate for the network heat dissipation of 72 %. That means that during the period from 1. October to 1. May the average dissipated heat amount coming from the attic pipelines and being added to the overall heating was 3,9 (±1,5) kWh/(m²a). The resulting consumption for the 32 Kronsberg Passive Houses, including the determined useful heat dissipation from the pipelines, equals 19,9 (±2.5) kWh/(m²a).

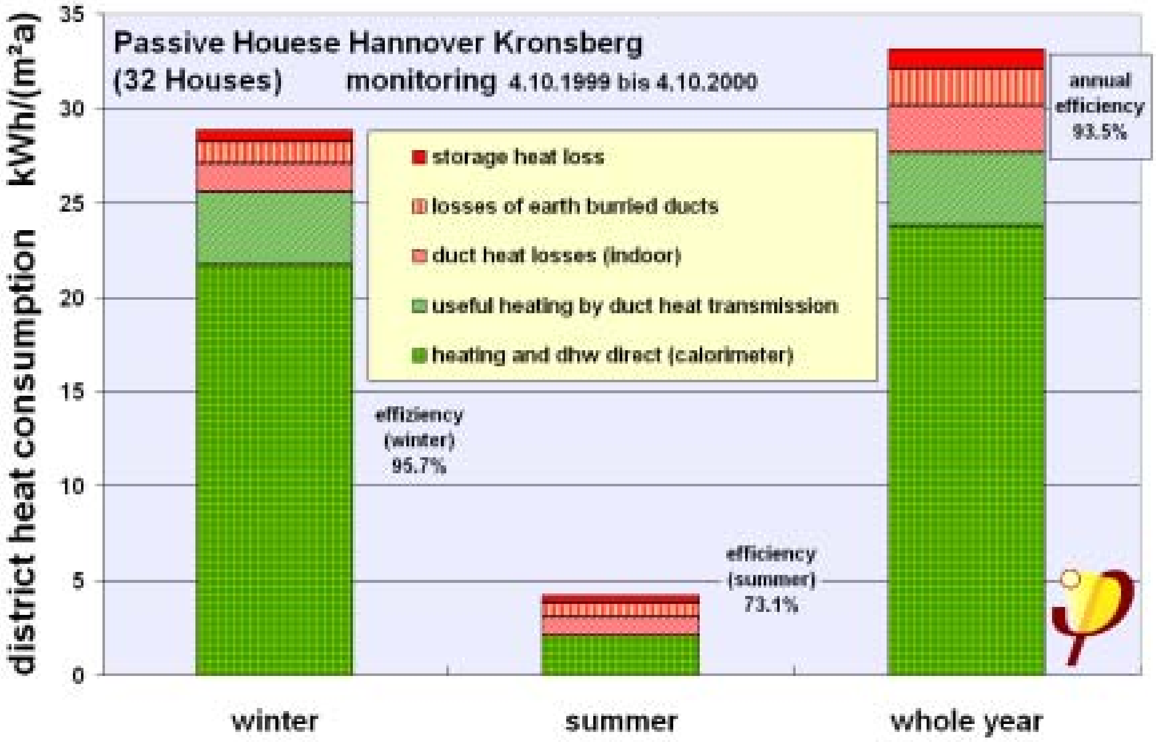


Figure 69: **The division of the total district heating consumption into useful heat (below), useful heat dissipation from the heating ducts and duct heat losses as well as storage heat losses (upper three columns) for all 32 Passive Houses (measurement cycle 4.10.1999 to 4.10.2000**).

The total final energy consumption from district heating in the first year for all houses was 32,9 kWh/(m²a), or 34,6 kWh/(m²a) for the 22 permanently occupied houses (the projected value equals 32,9 kWh/(m²a)). The reduced district heating consumption for domestic hot water therefore balances out the slightly higher values for the annual heating consumption.

14.4 Electricity consumption

Household and common electricity are separately evaluated.

14.4.1 Household electricity efficiency

To achieve the Passive House standard, it is not only necessary to have a highly insulated, thermal-bridge-free and airtight building envelope, but also to use all energy sources efficiently. This not only includes heating energy (district heating in this case) but also household electricity. This is the most valuable energy form, it has a particularly high primary energy demand and should therefore be used particularly efficiently.

Rasch & Partner therefore offered a special electricity saving consultation within the CEPHEUS framework to the Passive House buyers. This consultation was connected with a calculation of the expected electricity consumption of the old household appliances, a calculation of the cost effectiveness of purchasing new high-efficiency appliances and a precalculation of the expected electricity consumption with the new appliances. The aim was to reach an annual electricity consumption below the targeted Passive House characteristic value of 18 kWh/(m²a). Torsten Schwarz, an employee of Rasch & Partner, performed the consultations with the calculation method created by the Passive House Institute. The results of this precalculation are documented in [Feist 2001] and, shortly, in chapter 7 of this report.

As an incentive for the purchasers, a refund of Euro 1.000,- on the sales price of the house was offered towards the purchase of new high-efficiency household electrical appliances for those whose projected savings were successful.

A total of 18 electricity efficiency consultations were performed with the methods described. On average, a projected annual electricity consumption of 1901 kWh/(m²a) was calculated during the consultations. These calculated values are described here as "a priori-calculations". On the basis of the additional information now available about the equipment in the consulted households and the auxiliary electricity demand, which was only estimated during the consultations, an "ex posteriori-calculation“ was done by the PHI according to the same methods for the 18 households. The following were changed:

- A standard person occupancy of 35 m² living area per person was set for the electricity efficiency consultation. This should guarantee that the efficiency of the equipment is evaluated truly independently of the coincidental utilisation conditions. The actual electricity consumption is naturally heavily dependent on the number of people living in the house. After the household sizes were known, these values could then be used in the calculation methods. The largest share of the differences between a priori- and ex posteriori calculations is due to this difference between standard and real person occupancy.
- The auxiliary electricity consumption estimated in the efficiency consultations was adapted, a few clearly implausible cases were corrected and the living areas were adapted to the European wide CEPHEUS guidelines for “treated floor area”.
- A questionnaire was sent to the Passive House occupants concerning equipment and utilisation characteristics that have an important impact on the electricity demand. Using these data, it was possible to correct and complement the information from the electricity consultation. Following differences were noted:
  - There were a few cases where the details regarding the use of cold and hot water connections for clothes washing and dish washing machines were

the later details correctly mirrored the real utilisation conditions.
different. Since the consultation took place before moving in, we assumed that the later details correctly mirrored the real utilisation conditions.

- Almost all the consultations assumed that clothes would be dried in unheated airing cupboards. However, the questionnaire made clear that families were currently either drying clothes on the line or using an electrical clothes dryer. The details from the questionnaire were used.

Figure 70 shows the comparison between the a-priori und the ex-posteriori calculations for electricity demand. The average value for the ex-posteriori-calculation, at 1963 kWh/a, lies roughly 3% above the a-priori-calculation.

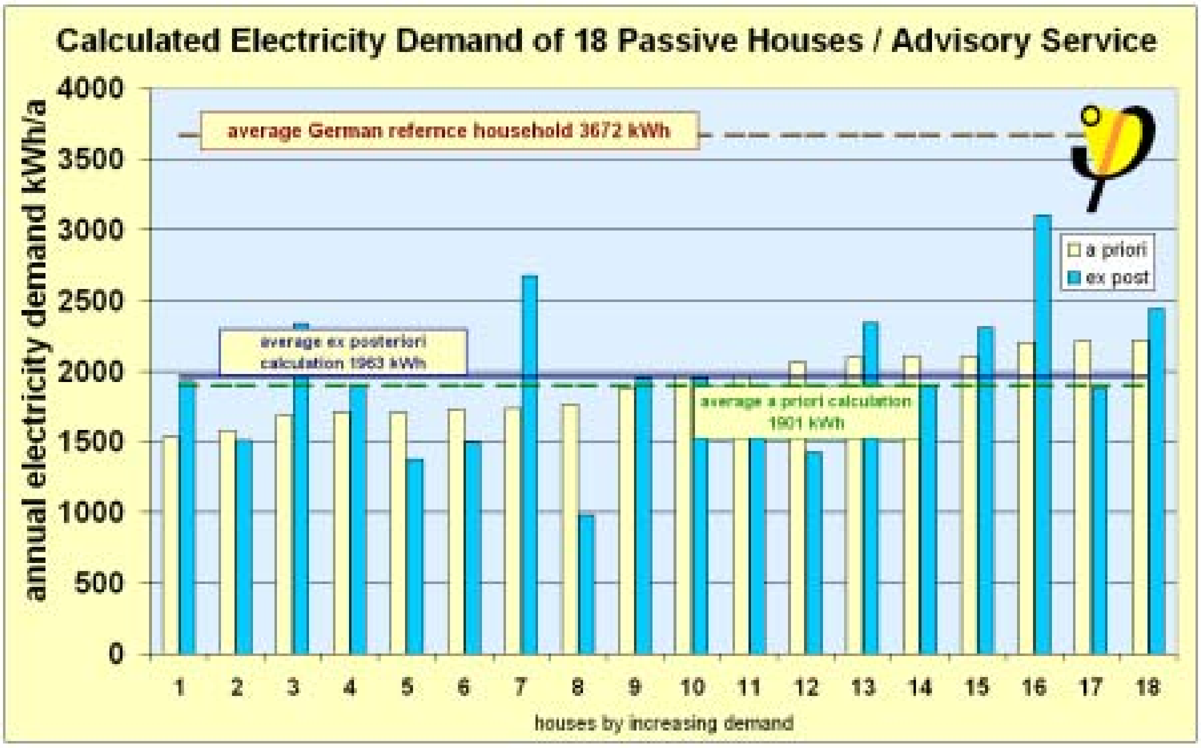


Figure 70: Comparison of a-priori and ex-posteriori calculations of the annual electricity demand for 18 households in the Hannover Passive House estate

Even after these additions it is likely that not all electricity consumption relevant equipment characteristics have been fully documented. It is particularly not known if appliances were exchanged (and thus have different standard consumptions) after moving in, or if additional appliances were purchased. In addition to the occupant-relevant variations, these effects are partly responsible for the differences between the calculated demand and measured electricity consumption.

Rasch&Partner stopped the electricity consultations after the 18 cases documented here. As will be shown below, the remaining households did achieve a certain level of electricity savings, but they used 50% more electricity than the consulted households. For the evaluation, the measurement results were divided in

- 18 consulted households and
- 4 households without electricity efficiency consultation.

The household electricity meter readings during the period 1.10.1999 to 30.09.2000 of the 22 permanently occupied houses were evaluated.

These household electricity meters count the total household electricity consumption as well as the auxiliary electricity for the technical systems (pumps for the solar thermal system, control) in each house. This also includes the ventilation systems, with which all the houses are equipped.

Not included in the household electricity meters is the so-called common electricity for the shared outdoor lighting and the consumption in both building services containers (lighting, pumps for heating distribution, building control technology, etc.).

Figure 71 presents the annual consumption data for the 22 Passive Houses; the 4 cases without consultation are formatted separately.

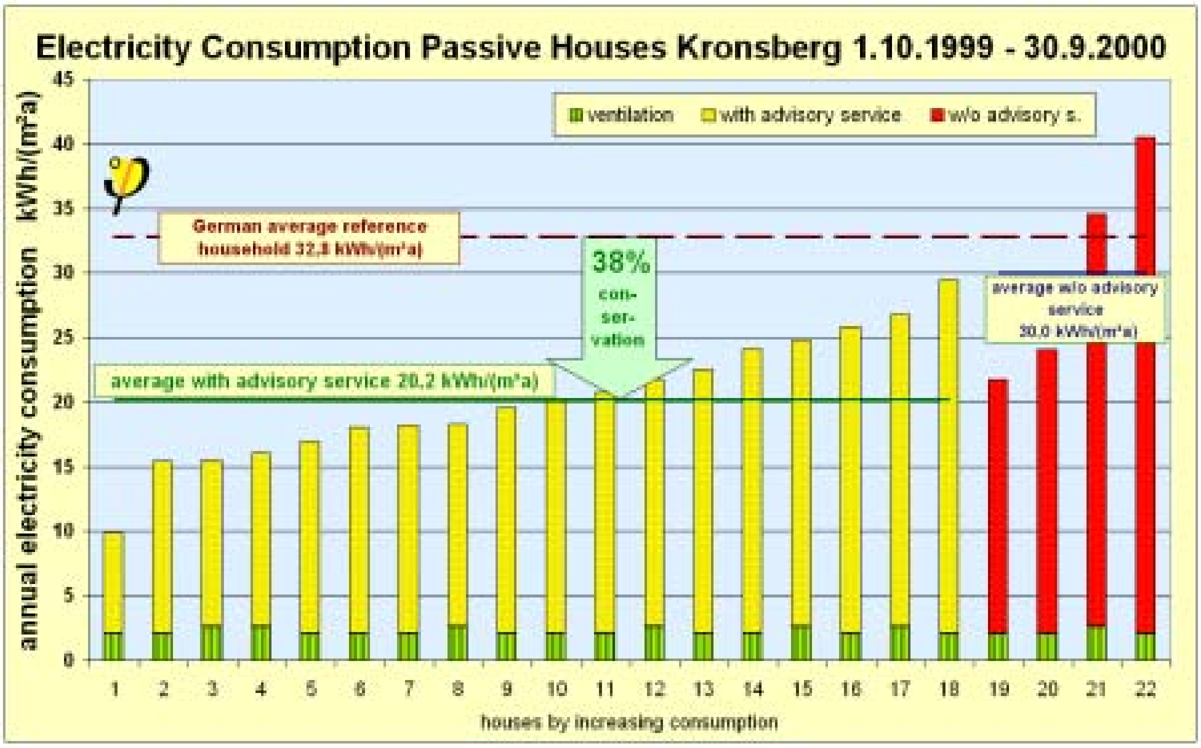


Figure 71: Measured annual electricity consumption of the 22 Passive Houses (permanently occupied in 1999/2000) from 1.10.1999 to 30.09.2000 (household, auxiliary and ventilation electricity, but without common electricity).

Figure 72 shows the correlation analysis between the measured annual electricity consumption and the calculated ex-posteriori annual electricity demand. The separation is clear between

- the 18 consulted houses with an average measured electricity consumption of 20,2 kWh/(m²a) and
- the 4 houses without consultation, with a measured value of 30 kWh/(m²a).

Between the calculated ex posteriori demand values and the measured consumption values lies a significant correlation with a correlation coefficient of 41%. The variation of consumption values, however, is rather high; this is due largely to occupant behaviour.

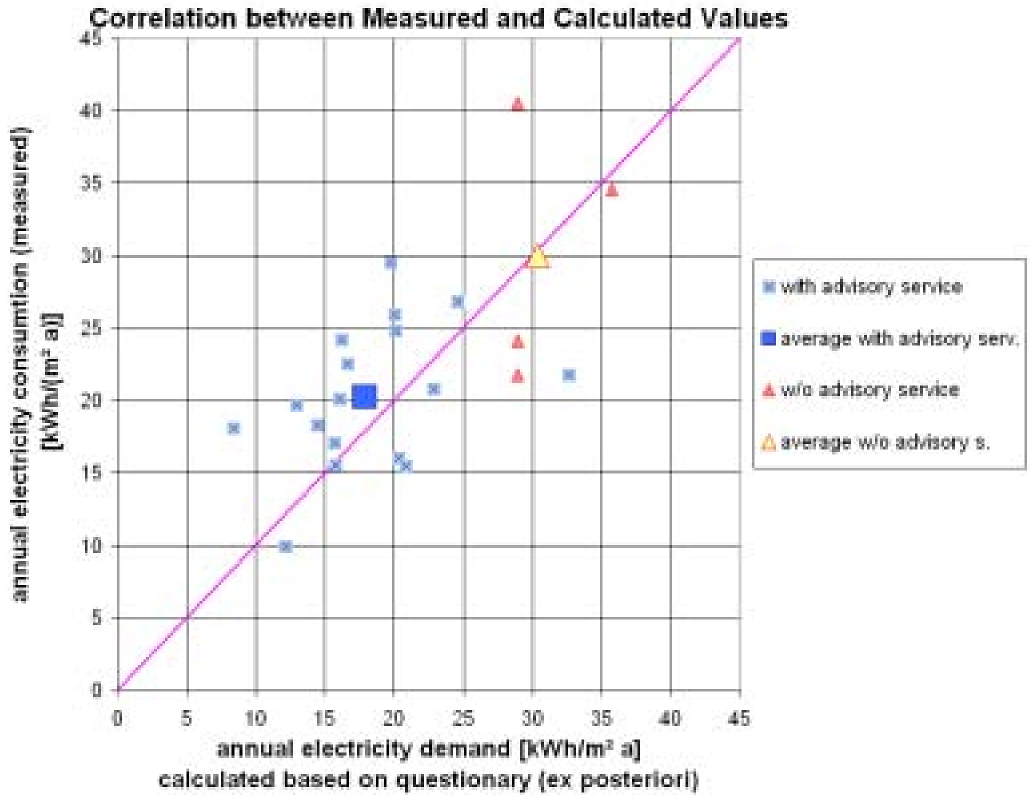


Figure 72: Correlation analysis between calculated annual electricity demand (ex posteriori) and measured annual electricity consumption in the 18 Kronsberg Passive Houses. Also presented are the 4 households which did not receive a consultation; their average consumption of 30 kWh/(m²a) is on the one hand 50% above the consumption of the consulted households, but on the other hand close to the expected value of a typical household electricity consumption in Germany.

The analysis of the average values shows that the calculated value of 17,5 kWh/(m²a) underestimates the measurement value of 20,2 kWh/(m²a) by an average of 13%. That is a very viable result to determine the expected electricity consumption under average utilisation conditions.

The measured values of the 4 cases without consultation, at 30 kWh/(m²a), are almost at the level of the statistically determined average for typical households in

Germany (32,8 kWh/(m²a) without off-peak storage heating and without electrical hot water preparation).

If one sets this nationwide average value as a comparison benchmark, the **electricity savings** for the households with electricity consultations and the purchase of new energy efficient appliances equals **38%**.

In the reference value of 32,8 kWh/(m²a) there is no electricity consumption included for the ventilation system, although this is definitely part of the measured average value of 20,2 kWh/(m²a) for the occupied houses. The average electricity consumption for the ventilation systems, according to the detailed measurements carried out, equals about 2,3 kWh/(m²a); without this necessary extra consumption for Passive Houses, the household electricity consumption would equal 17,9 kWh/(m²a) and be thus **45% under the statistical average value**.

The instrument used here, „detailed consultation and financial incentive for the purchaser“, requires a rather high effort. Both the consultation and the provision of an incentive lead to extra costs. The questionnaires show, in light of the good results, that this effort is certainly justifiable. At least for demonstration projects such as the Passive House estate realised here, it is not possible in Germany to achieve the electricity efficiency improvements seen here with less consultation effort. The problem is due to the fact that even today appliances with very poor electricity efficiency are still being offered on the market. If one wants to convince the consumer to choose more efficient appliances, this is only possible with an appropriate consultation and a financial incentive. A much better solution would be to make sure that high efficiency appliances are offered and that those appliances with clearly poor performance are taken out of the range of products. However, there is still a relatively long transfer period, which is roughly equal to the lifetime cycles of the appliances (10 to 15 years). For demonstration projects such as CEPHEUS, therefore, more wide-reaching instruments must be used.

14.4.2 Common electricity consumption

The two electricity meters in the building services containers measure the estate's common electricity consumption. They include the energy for the pumps of the warm-water heating and outdoor lighting for the shared areas (parking and garbage spots as well as building services containers). The electricity consumption of the measuring devices are measured separately and already subtracted. The monthly evolution of the specific consumptions is seen in Figure 73.

The consumption graph clearly shows the season-dependent variations. As a comparison, the average values of both comparative periods (each October to April) are presented. A reduction of 36% between the two average values can be ascertained. A larger savings for the summer period is to be expected, since two clock timers (set by the occupatns) control the heating circulation pumps. The clock timers make sure that the pumps only operated a few hours per day. This operational mode is sufficient in the summer for the hot water supply, since the energy supply is provided largely by the solar thermal systems on each house. The clock timers were first installed or activated in July and September 2000. During the winter the clock timers are placed on continuous operation. To determine the average value the lowest consumption during one complete year was used. The average for the period from May 2000 to April 2001 equals 0,08 kWh/(m² month), and therefore for the whole year a total of 0,98 kWh/(m²a).

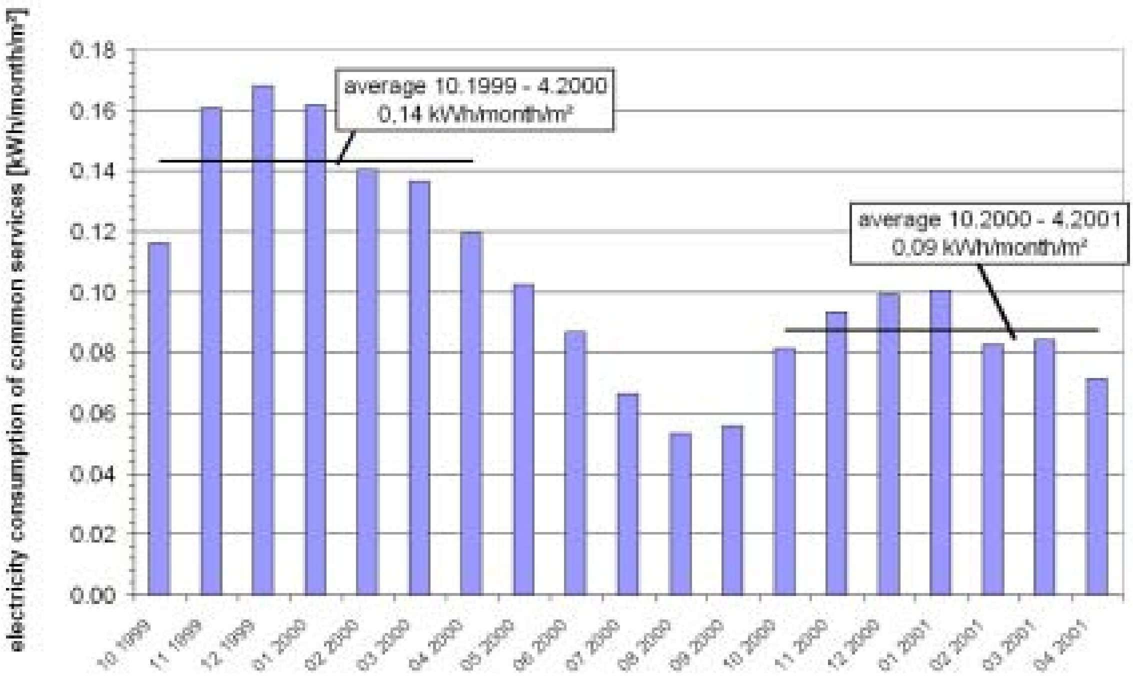


Figure 73: Specific common electricity consumption of the 32 Passive Houses without electricity used for the measurements from October 1999 to April 2001. The common electricity consumption includes the energy for the heat circulation pumps in the building services containers and the outdoor lighting for the common areas (parking and garbage places). The columns clearly show the seasonal variations. As a comparison, the respective average values for the time period October to April are presented.

14.5 Heat recovery system

The operational perfomance of the heat recovery system was closely analysed within the framework of the measurement concept. First, a period was chosen during which the electrical frost-protection heater to protect the heat recovery system was not active. Figure 74 shows the measured evolution of the supply, exhaust, extract and outdoor air temperatures from 09.02. to 31.03.2001.

The heat recovery efficiency rate (see Figure 75) calculated with the measurement data (temperatures, humidity, volume currents and electricity consumption) takes into account transmission heat current losses and leakage flow losses, as well as the forced exfiltration caused by the supply air excess. Despite great care taken during the setting of the balance, misbalances of over 10% occur under operation, which have a significant impact on the ventilation heat losses. In total, the average heat recovery efficiency was determined to be **78 %**.

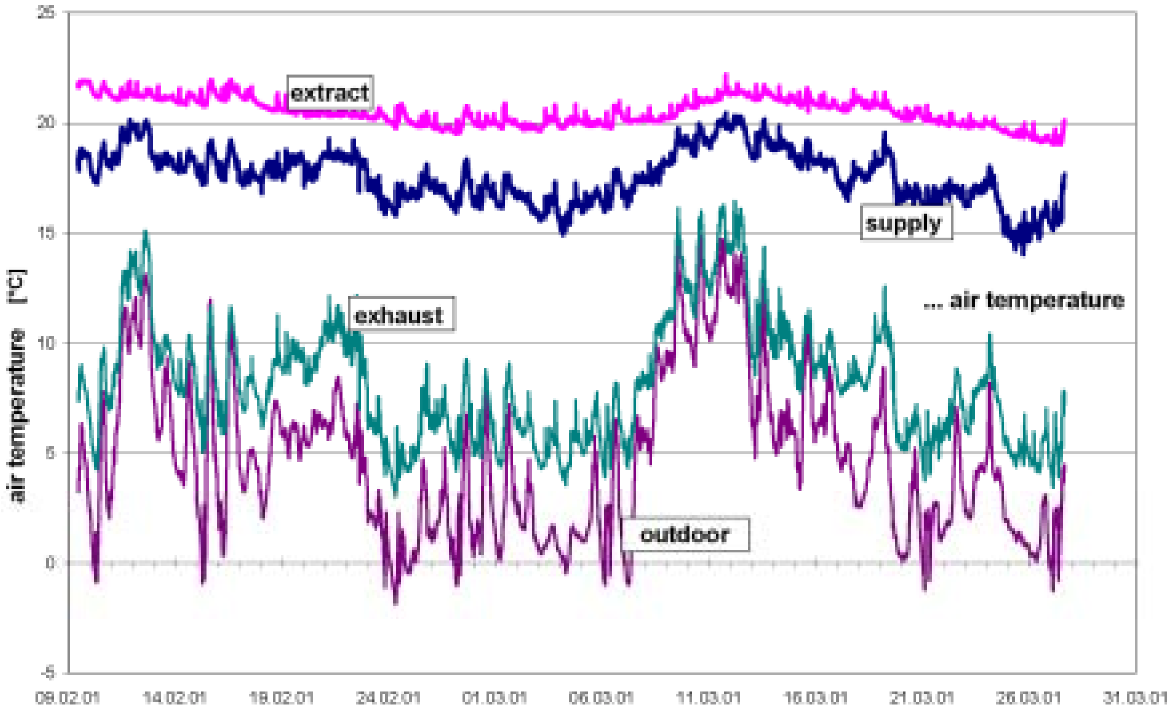


Figure 74: Measured evolution of the supply, exhaust, extract and outdoor air temperatures in the ventilation system with heat recovery (average hourly values).

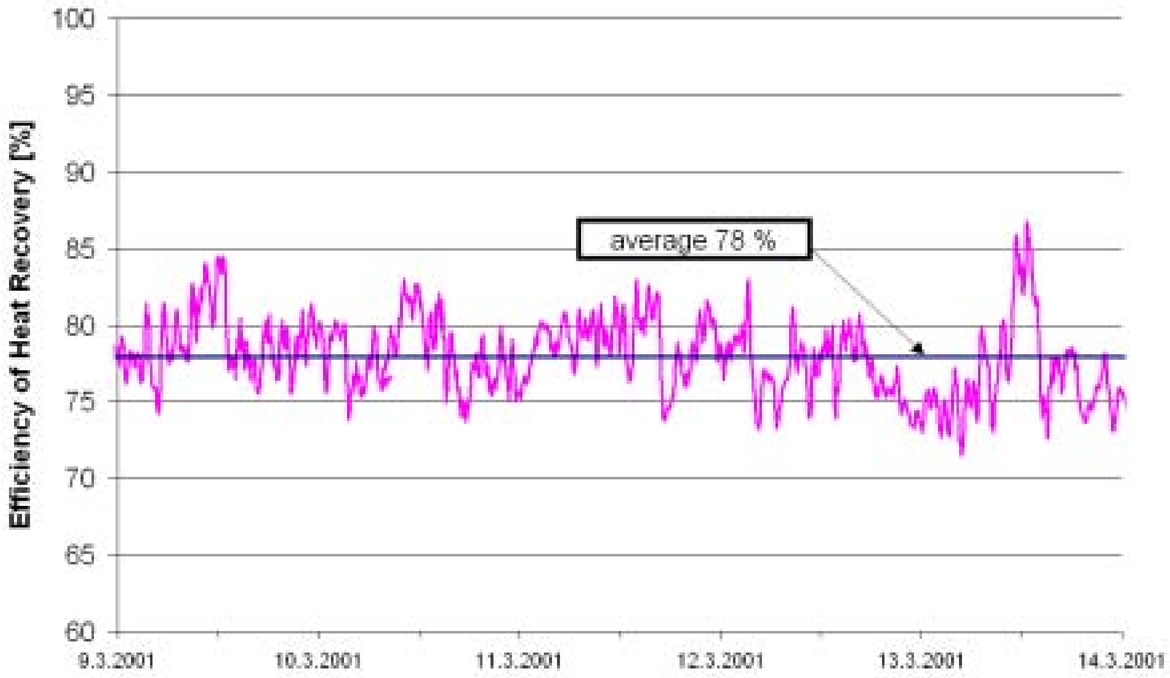


Figure 75: Evolution of the heat recovery efficiency of the ventilation system with heat exchanger.

The evolution of the resulting condensate volume in comparison to the outdoor air temperature (Figure 76) shows that, (according to the respective air humidity) below an outdoor air temperature of ca. 5 °C, a measurable amount of condensation forms.

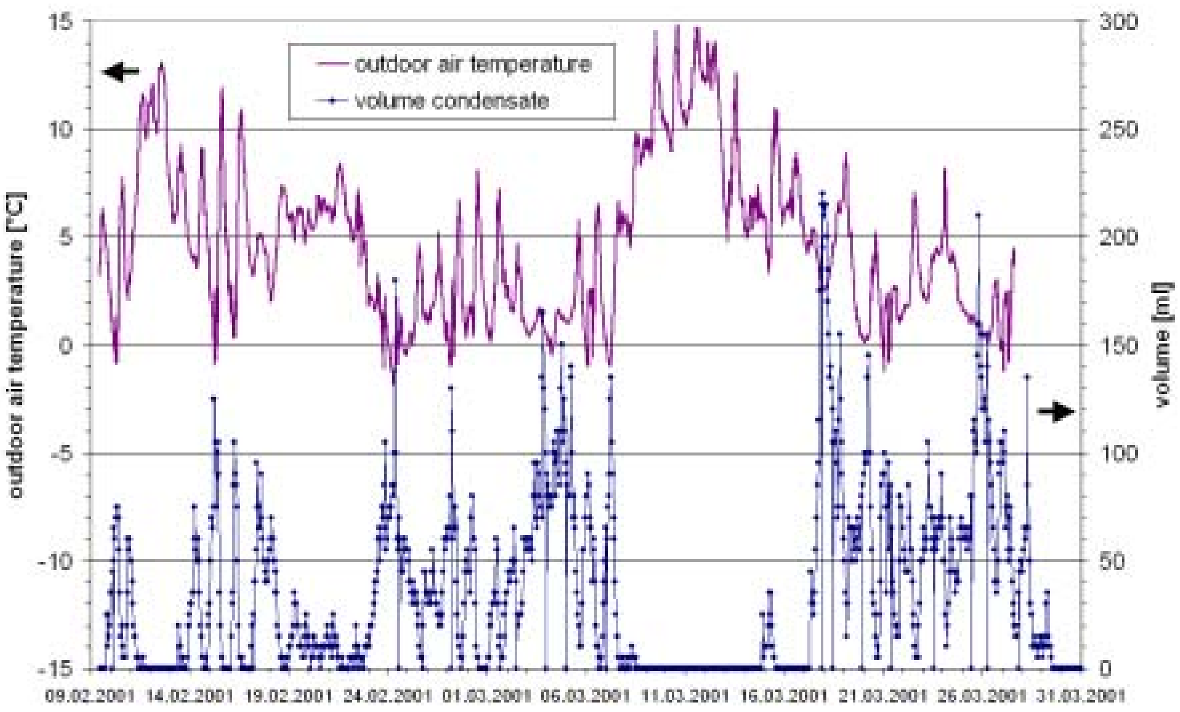


Figure 76: Condensate volume in the heat recovery system in comparison to the outdoor air temperature (temperature: hourly average, condensate: hourly sums).

Up to 220 ml of water condensates in an hour. During the presented period of 50 days (09.02. to 31.03.2001) a total of 41,86 litres of condensed water are removed. Using the evaporation enthalpy lead to condensation output peaks of over 100 Watts. The average condensation output over the entire 50 days is about 22 Watts. However, this output is not significant when calculating the heat recovery efficiency (improvements in the area of less than 1 %).

The electrical frost protection device (also „defroster heater“) in front of the heat exchanger protects it from freezing. According to the manufacturer, the heater has a 500-Watt output and operates by setting its output according to the outdoor air temperature. The on and off temperature settings are set in the factory and cannot be changed by the user. The manufacturer sets the activation temperature at $\vartheta_{outdoor} < -4$ and the turning off temperature behind the heater at 0 °C. Figure 77 presents the measured outdoor temperatures and the fresh air temperatures after the defroster as well as its output from January 16th to January 21st of 2001. This shows the on and off points of the defroster and thus its operation times.

The defroster switches on when the outdoor air temperature goes below -2,8 °C and turns off when the air temperature after the radiator passes +1,4 °C (both are average values of the on and off temperatures shown below). The electrical heating of the air after the radiator (before the heat exchanger) to about +1,4 °C is relatively high. It would be better if the hysterisis were clearly lower than it is. That would lead to a further optimisation of the system’s already low electrical consumption. The defroster’s total electrical consumption in the heating period 2000/2001 is **36 kWh**. That equals an energy input of 0,3 kWh/m² for the house during this heating period.

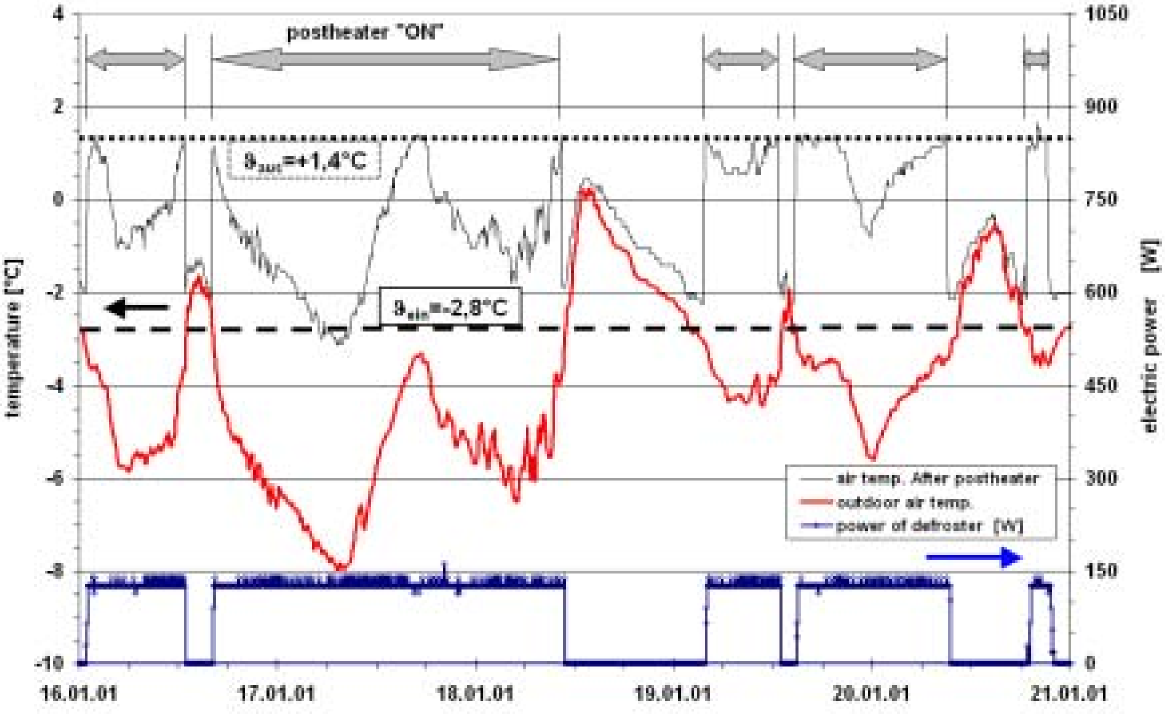


Figure 77: Operation times of the electrical frost-protection device (on and off temperatures), which is placed in front of the ventilation system's heat exchanger. Data from the 16th to the 21st of January 2001 is shown. The electrical output of the heater defines the operation times. The turning on temperature equals an outdoor temperature of -2,8 °C, the switching off temperature equals a temperature of +1,4 °C behind the device.

One can also see that, during the analysed period, the air temperature after the defroster clearly sinks when the outdoor temperature decreases and reaches values of -3 °C. At this point, the outdoor temperatures were briefly at -8 °C. This is a sign of the limited heat output of the heater.

14.6 Air humidity

The relative supply and exhaust air humidity in the intensively measured house were continuously recorded by the data recording system. The measurement occurs in the air flows in the ducts after or in front of the ventilation unit. Thus the measurement value of the exhaust air humidity does not represent the relative air humidity in the room of a house, but rather the average value of the air humidity from air that is removed from the exhaust air rooms. The room air humidity of a single room was measured in the ground floor living room of another Passive House with the help of stand alone data loggers (testo Company).

Abb. 78 shows the evolution of the relative room air humidity and room temperature in the living room of this house, as well as the outdoor air temperature. The data logger recorded the temperature and humidity data in 2-hour intervals. The floating averages over four data points are presented in the graph. The measured relative room air humidity was between 26 and 49% in the period presented (19.11.1999 to 20.03.2000), the average around 38 %. The relative humidity was below 30 % for only short periods of time. It is clear that the humidity variations are not due to a change in the room air temperature, since these are quite constant in the core period of winter.

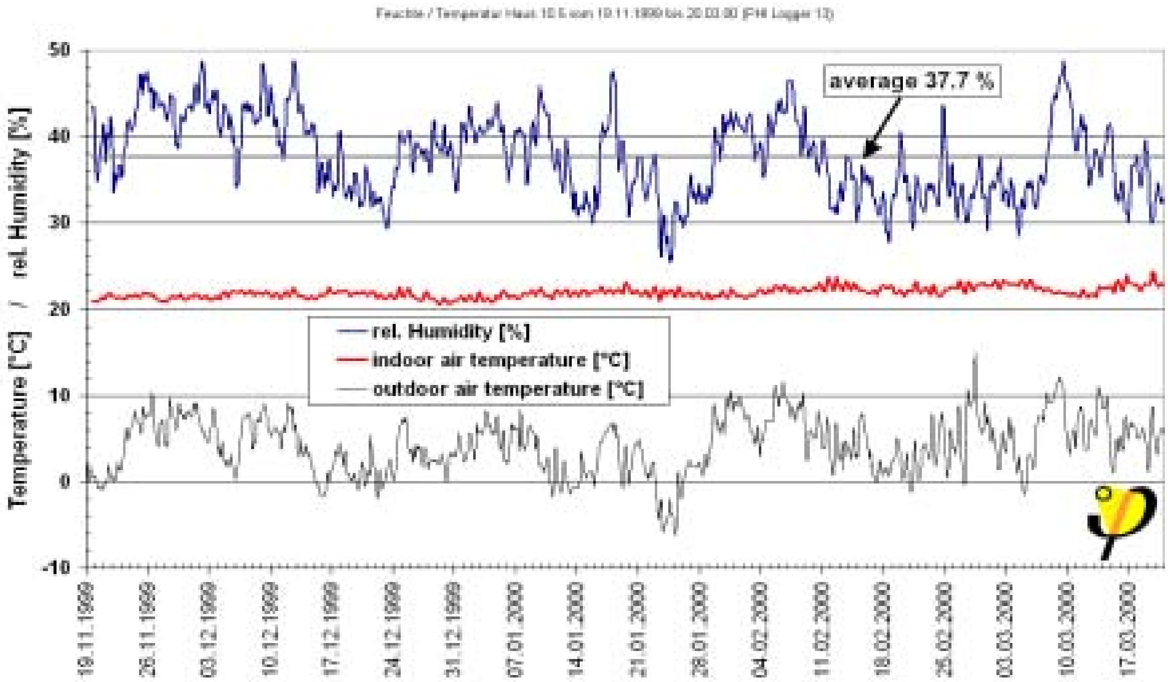


Abb. 78: Relative room air humidity and air temperature in the ground floor living room of a Passive House as well as the outdoor temperature evolution from 19.11.1999 to 20.03.2000. The stand alone data logger recorded the data from the building at 2-hour intervals. The floating averages of four data points are presented.

To explain the relative humidity variations, a section of time was chosen (10.12.1999 to 12.02.2000) and the relative humidity and outdoor temperature evolution in Abb. 78 then adjusted to each other. Figure 79 shows both evolutions. It is clear that they correlate well over large periods of time. It is therefore clear to recognise the main reason for the variations in indoor relative humidity.

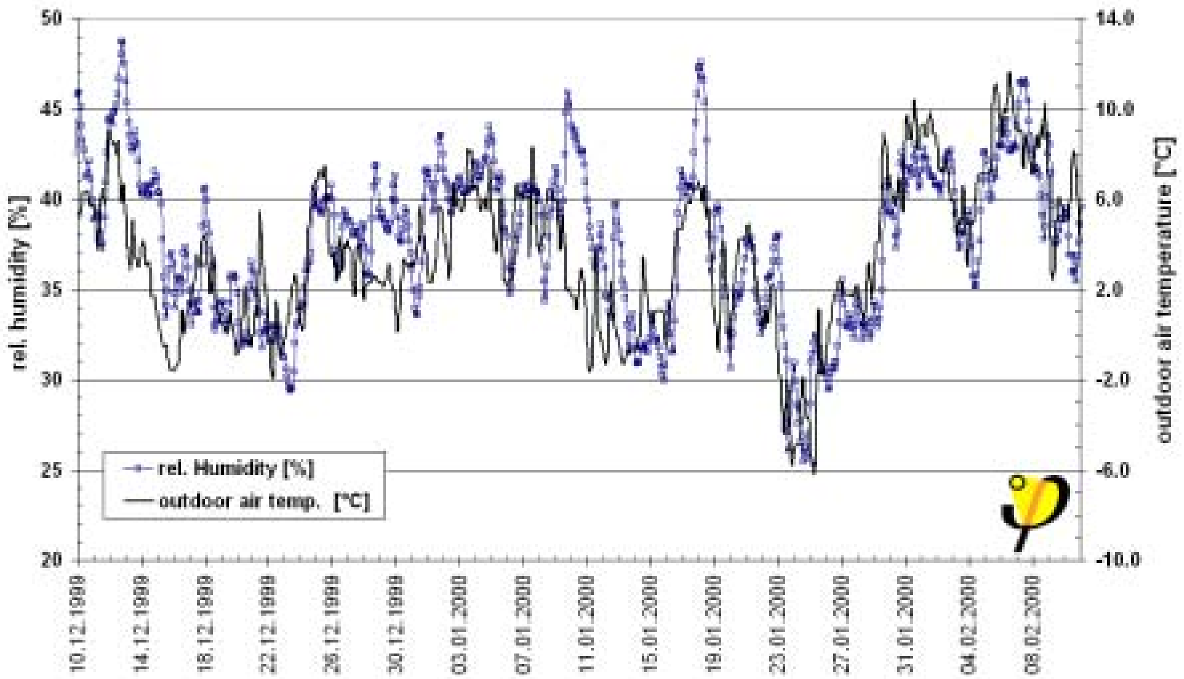


Figure 79: Correlation between the relative humidity and outdoor air temperature evolutions from 10.12.1999 to 12.02.2000 (derived from Abb. 78).

The relative humidity in the Passive Houses lies therefore in a range that is considered as being healthy. Even short-term values of less than 30 % relative humidity do not pose a problem. The deciding factor for relative humidity indoors is the outdoor temperature.

The air humidity indoors is raised by the existing humidity sources. The bigger the outdoor air volume added to the rooms, the more this humidity from the sources is diluted.

The following principles therefore result from this:

- If the indoor humidity is felt as being too high, the outdoor air change rate must be increased. This can be done in the Passive House by switching the ventilation system to a higher setting. However, according to the evaluated data, there is no reason for this to be done at any point in time.
- If the indoor humidity is felt to be too low, the outdoor air change rate must then be decreased. This can be done in the Passive House by switching the ventilation system to a lower (e.g. the basic) setting. Objectively, according to the measurement data, this is also not necessary; however, when individual occupants desire a subjectively higher relative humidity, this is easily achievable by switching the ventilation system to a lower setting. There are no reasons that speak against such a reduction, whether in terms of health or heating output available.

14.7 Passive House estate climate neutrality

The Hannover-Kronsberg Passive House estate demonstrates that the energy demand of a residential estate can be reduced so far through efficiency improvements that the remaining energy demand can be covered exclusively by sustainable energy sources. In fact, this is possible with technically feasible measures, reproducible in a Central European climate and with feasible costs. A wind power plant was built near to the estate on the Kronsberg in July 2000 to be used as renewable source of energy.

To test this aim of climate neutrality, one must analyse the measured primary energy consumption. The estate's total primary energy consumption during the first measurement year was about **83 kWh/(m²a)**. This value is a result of the primary energy values for the district heating supply of 35 kWh/(m²a) and the electricity supply of 23 kWh/(m²a) in the occupied houses. The following standard primary energy factors according to the CEPHEUS-guidelines were used for the preceding chains

- district heating from CHP plants: 0,7 $kWh_{Primary}/kWh_{Final}$
- average European electricity mix: 2,5 $kWh_{Primary}/kWh_{Final}$.

These extremely low primary energy consumption values can be compared to the share of electricity produced by the *windwaerts* Company's wind power plant. According to the operating company, the electrical production of the wind power plant from 01. July 2000 to 30. June 2001 was 2 262 102 kWh/a [windwaerts].

A 1.250,- Euro share of the wind power plant was included in the sales price of each Passive House. This financial share equals **2,6 kW** or 0,175 % of the rated output of the wind power plant. Based on the annual production of this power plant, one electricity production share equals **3969 kWh/a** or **35,5 kWh/(m²a).** This electricity production substitutes in a first approximation the electricity from the European power plant mix. Therefore the amount of primary energy produced by the wind power station is given by the avoided primary energy consumption of the power plants. This substitution can be calculated using the primary energy factor for the European electricity mix: 2,5 · 35,5 kWh/(m²a), this equals about **89 kWh/(m²a)** (see Figure 80).

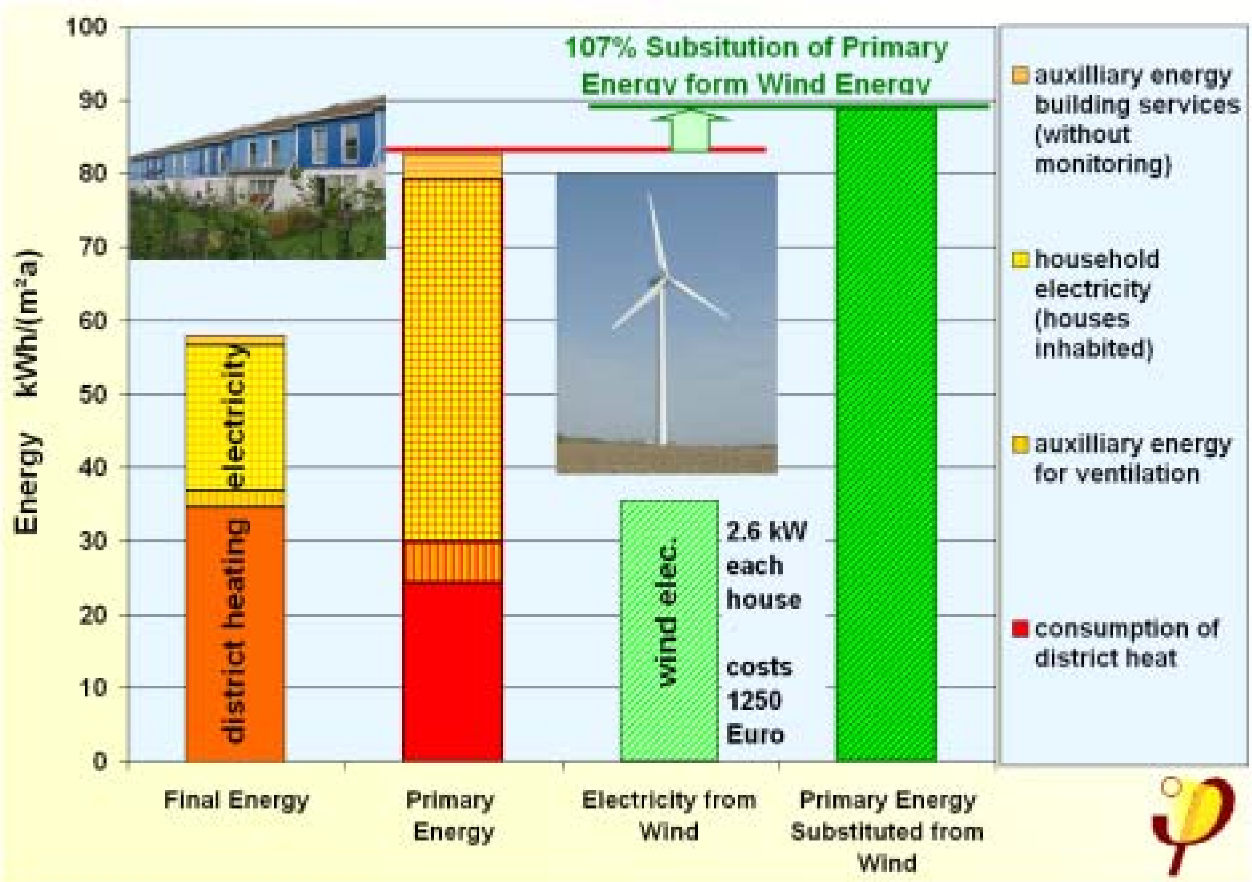


Figure 80: Primary energy consumption in the Hannover-Kronsberg Passive House estate in comparison with the substitution of conventional primary energy by wind energy shares to illustrate the climate neutrality.

An output share of 2,6 kW is very small in terms of energy economics. Appropriate locations for wind energy plants are actually available close to the consumer in many regions of Central Europe; where this is not the case, other renewable energy systems such as wood pellets and biogas can be used to produce the small amounts of energy required from sustainable agriculture and silviculture. The use of wood pellets has also been realised in other CEPHEUS projects.

A one-time participation of 1.250,- Euro is an economically justifiable charge: even without the revenues from the wind power plant, the annual capital costs would equal ca. 133 Euro/a, at 4% real interest rate and a 12 year useful lifetime. However, there are indeed revenues from the electricity production, and these are higher than the yearly operational costs; based on the currently agreed-upon compensation rates, it is likely that cost-effectiveness can be achieved. The additional capital investment in renewable energy production is therefore not an insurmountable barrier, since the required electricity production shares are so small.

The strain placed on nature and the costs increase if the primary energy demands of conventional houses have to be met, instead of those of a Passive House. A conventional house's factor 3 increase in demand can usually not be met by the space-requirements of renewable energy sources if they are to be located close to the consumer. In addition, the size of the financial share required is such that it would be a hefty surcharge on top of a house's purchase price. It is likely that such an increased share would also be cost effective under the current, mostly politically motivated, framework in Germany. However, this framework could be changed, meaning that the risk attached is much lower for the Passive House's required share.

With regards to the climate neutrality achieved here, it must be clearly noted that we are not dealing with a fully autarkic renewable energy supply system. The technical and financial effort required fort his would be much higher: the wind power plant's electricity supply is dependent on the weather and is not simultaneous to the electricity demand of such an estate. [Ewert 2000] demonstrated that with an output share as used here, it would be possible to cover individual requirements about 50% of the time. The remaining electricity is fed into the grid and used by other consumers – including those for whom a wind power plant located near to the consumer is not possible or not sensible. The aim of climate neutrality on paper is achieved as long as the majority of the electricity production share is supplied by the main grid from large thermal power plants, as is the case today.

An autarkic solution based on renewable energy sources would currently require considerable over dimensioning of the production systems, would be very expensive if wind energy were the only source and would require special investments into energy storage systems. This is even for Passive Houses economically difficult to realise; even in the future, however, the more sensible solution lies certainly with energy feed-in into the grid and the use of the grid as an energy storage system in itself.

With this in mind, the Kronsberg Passive House estate shows that it is already possible and economically feasible to compensate the additional primary energy consumption of a new estate through the simultaneous construction of renewable energy capacity. This is especially an important message because the argument is generally made that each new construction project leads only to additional consumption and additional strain. The example of the basically inconspicuous Kronsberg Passive House estate shows that an ecological and economic perspective exists, at least in terms of avoiding the additional strains due to the energy needs of new residential buildings. As the scale in front of the Stadtwerke Hannover's demonstration house illustrates (see Figure 81), a constructional and technically mature concept on the basis of Passive Houses is able to achieve this goal. As the results of this report show, this has not only been successful in terms of energy-use goals, but also in terms of very satisfied occupants and the respective advantages of thermal quality and air quality in the houses.

Figure 81: Information column (right) and scale (left, marked with the arrow) in front of the demonstration house of the Hannover-Kronsberg Passive House estate.

15 Literature

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16 Appendix: Format Sheets for Presentation of the Results of Building Projects

The „Format Sheets for Presentation of the Results of Buildings Projects 1-15“ [EU 1993], an evaluation of the Data according to EU rules, are included in the appendix as an addition to this report.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

1	ADMINISTRATIVE INFORMATION	REF.:	BU/00127/97/DE/SE/AT

COMMISSION OF THE EUROPEAN COMMUNITIES

THERMIE	JOINT RESEARCH CENTRE	GENERAL DIRECTORATE FOR ENERGY DG XVII

REPORTING FORMAT
ENERGY SAVING SYSTEMS FOR BUILDINGS

Project Reference Number: BU/00127/97/DE/SE/AT
Project Name : CEPHEUS
Cost Efficient Passive Houses as European Standards

LEAD CONTRACTOR		MONITORING CONTRACTOR	
Contact :	**M. Görg**	Contact :	**Dr. W. Feist**
Organisation :	**Stadtwerke Hannover**	Organisation :	**Passivhaus Institut**
Address :	**Ihmeplatz 2** **30 057 Hannover**	Address :	**Rheinstr. 44/46** **64 283 Darmstadt**
Telephone:	**0511/430-2784**	Telephone:	**06151/826990**
Telefax:	**0511/430-1846**	Telefax:	**06151/8269911**

PROJECT LOCATION

Street or location where the building(s) is (are) located: **Sticksfeld 30 - 124**

Town:	**Hannover**		Province/County :		**Niedersachsen**
Region :			Country :		**Germany**
Altitude:	**90** m.a.s.l.	Longitude	**9° 44'**	Latitude	**52° 22'**

Format Completed by:	**Oliver Kah**	(name)
		(signature)
	31. Mai 01	(date)

PROJECT EXECUTION

Starting Date of the project **01. Jan 98** Completion Date of the project **31. Mai 01**

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

2	LOCAL CLIMATE AND SITE INFORMATION	REF.: BU/00127/97/DE/SE/AT

Building location

Min. winter design temp.	-10	°C	Max summer design temp.	-	°C
Mean winter wind speed	4,5	m/s	Mean summer wind speed	2,1	m/s
Predominant wind direction in winter		northwest	in summer		northwest

METEODATA: Test Ref.Year - or over period from **Oct. 99** to **Sep. 00**

Data taken from **X** Direct meas. on site Meteo.station Long-term tables

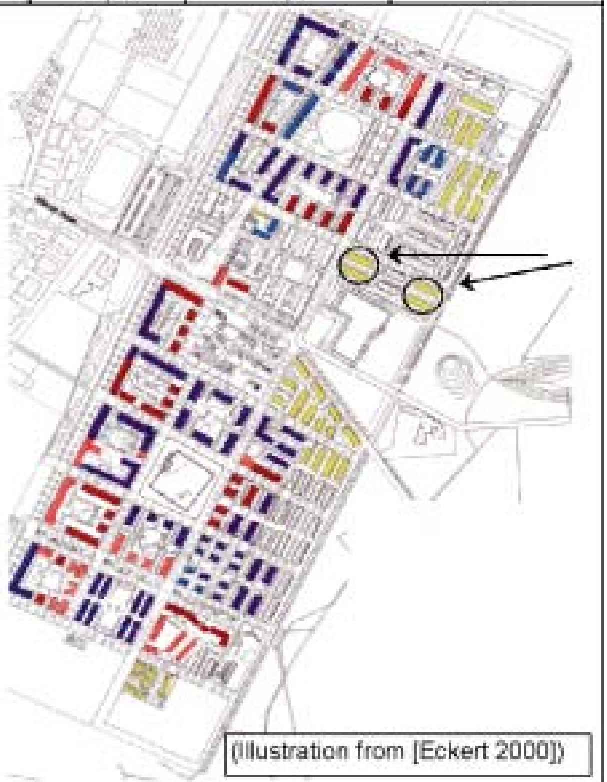
Location of nearest meteo. station **Hannover Langenhagen**

(Preferably, identify the nearest meteo station in the European Solar Radiation Atlas ISBN 3-88585-195-4)

Distance from project site to meteo.station: **17 km**

MONTH/YEAR		EXTERNAL TEMP Min/Mean/Max [°C]			HEATING DEGREE-DAYS (Base 18 °C)	COOLING DEGREE-DAYS (Base 24 °C)	MONTHLY MEAN SOLAR RADIATION [kWh/m² day]	MONTHLY MEAN REL. HUM [%]
JAN/	2000	-6,5	2,8	10,4	470,2	0,0	0,7	84
FEB/	2000	-1,1	5,1	15,3	360,4	0,0	1,3	79
MAR/	2000	-1,6	6,1	15,3	369,6	0,0	1,8	82
APR/	2000	-2,0	10,5	24,6	221,2	0,0	3,8	72
MAY/	2000	7,0	15,6	29,4	76,3	0,0	5,5	64
JUN/	2000	7,1	17,4	34,5	56,8	7,6	5,7	65
JUL/	2000	9,0	15,7	24,3	50,8	0,0	3,9	77
AUG/	2000	10,4	18,6	32,4	0,0	0,6	4,6	69
SEP/	2000	4,9	14,8	25,6	84,5	0,0	2,7	79
OCT/	1999	-1,5	10,0	19,5	244,5	0,0	1,8	81
NOV/	1999	-3,9	5,3	16,1	379,9	0,0	0,8	85
DEC/	1999	-2,1	3,5	9,2	448,3	0,0	0,4	81
TOTAL		-6,5	10,5	34,5	2762,4	8,3	2,8	77

LOCATION PLAN



(Illustration from [Eckert 2000])

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

3	**PROJECT DESCRIPTION & CLASSIFICATION**	REF.:	BU/00127/97/DE/SE/AT

PROJECT AIM AND BRIEF TECHNICAL DESCRIPTION

AIMS:

- Specific annual heat requirement of the passive houses: Less than 15 kWh/(m²a), so that a separate heating system is no longer necessary. Remaining heat requirement can be covered entirely through supplementary heating of the supply air that is required for acceptable indoor air quality.
- Total primary energy requirement of passive houses: Less than 120 kWh/(m²a) incl. household-electricity.
- Passive houses will be cost-efficient after market introduction, i.e. the additional investments in passive technologies are not higher than the expected capitalized energy cost savings over max. 13 years.
- At the Hannover site: Completely renewable coverage of total energy requirement (electricity) through integrated share in a wind turbine installation (cost-efficient, grid-bound neutral climate balance).
- Presentation of all projects at the EXPO 2000 World Fair in Hannover.

INNOVATIVE TECHNOLOGIES (ENERGY AND ENVIRONMENT) :

- Cost-efficient superinsulation technologies (reduced thermal bridges, airtightness).
- Further development of 3-pane low-emissivity glazing systems with U-value below 0.8 W/(m²K) with a high solar transmittance factor (60 %) for the passive use of solar energy.
- Windows with superframes (U-value of frame below 0.8 W/(m²K)).
- Heat recovery with high-efficiency counterflow air-to-air heat exchangers (efficiency greater than 75 %).
- Particularly efficient electric appliances, available on the market or modified; savings up to 75 %.
- Cost reductions through increased utilization of prefabricated elements.

BUILDING CATEGORY		ENERGY SAVING TECHNIQUES	
x	10 Residential	x	10 Building envelope improvement
	20 Commercial		20 Thermodynamic cycles for HVAC
	30 Industrial	x	30 Heat recovery systems
	40 Educational		40 Improved heat. & cool. plants & distrib. system
	50 Hospital		50 Thermal storage techniques
	60 Hotels & Restaurants	x	60 Passive heating and cooling techniques
	70 Public Administration		70 Advanced control and regulation
	80 Sports Facilities	x	80 Eff. lighting, daylight and electr. improvements
	90 Other		90 Other techniques

ENERGY SAVING AREA		fill Format Sheet No.:-
x	Integrated Design for Low Energy	7A
x	Building Envelope	6-A,B,C
x	Space Heating and Ventilation Systems	8A
	Thermal Energy Storage Systems	8-B,C
	Space Cooling and Refrigeration Systems	9
x	Passive Space Heating and/or Cooling	7-B,C,D,E,F,G
	Comb. Heat & Power + District Heat.& Cooling	10-A,B,C,D
x	Service Water Heating Systems	11-A,B
	Building Automation Systems	12-A,B
x	Lighting and Electrical Improvements	13-A,B
	Other	14

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

4	**PROJECT SUMMARY DATA**	REF.:	BU/00127/97/DE/SE/AT
N.B. (pr = predicted/design data = based on calculations ms = measured data = measured directly or in combination with calculations)			
No. of buildings in which demonstration occurs		**32**	
Building No.		**sum of all 32 buildings** (1)	
ENVELOPE			
2. Gross floor area (GFA)	[m²]	**4400**	
3. Treated floor area (TFA)(°)	[m²]	**3576**	
4. Tot. treated volume (TV)(°)	[m³]	**14745**	
5. Heat loss surface area (A)	[m²]	**7764**	
6. Tot. glazed area (A_{gl})	[m²]	**415,8**	
7. Shape factor (A/TV)	[m^{-1}]	**0,53**	
8.Ave.ceiling heigt (TV/TFA)	[m]	**3,15**	
9. Tot. heat loss coeff. (pr)	[W/m³°C]	**0,102**	
10.Tot. heat loss coeff (ms)	[W/m³°C]	**0,101**	
11. Bldg. thermal mass (Hi/Med/Low)		**HI**	
PLANT AND EQUIPMENT DATA			
1. Total number of heat generators		**district heating**	
2. Total installed capacity	[kW]	-	
3. Inst. capacity per building	[kW]	**1,2** (2)	
4. Type of generator(s)		**combined heating and power station - district heating**	
5. Energy source		**natural gas - combined heating and power station**	
6. Heating fluid (water or air)		**air**	
7. Temperature control type		**thermostatic PI for each dwelling**	
8. Ventilation type (nat or mech.)		**mech.**	
9. Estim.or meas. air change rate	[ach^{-1}]	**0,43**	
10. Mech. cooling capacity	[kW]	-	
11. SHW(**) production (combined y/n)		**n**	
12. SHW energy source		**gas - combined heating and power station / active solar**	
13. SHW total power rating	[kW]	**1** (2)	
14. SHW type (inst/storage/central)		**storage**	
15. Lighting installed Wattage	[W/m²GFA]	**not relevant**	
16. Lighting control type		**manual**	
17. Total rated elec. power	[kW]	**not relevant**	
OCCUPANCY and BUILDING UTILISATION			
1. Total permanent occupants		**80 (70**(3)**)**	
2. Number of visitors/day		**not known**	
3. Occupancy hours/working day		**15** (4)	
4. Occupancy hours/weekend day		**20** (4)	
5. Occupancy days/week		**7** (4)	

(*) Add further sheets if necessary (**) SHW = Service or Sanitary Hot Water

(°) Treated = comfort conditioned by heating or cooling systems

(1) The terraced house development includes 32 very similar houses, which are arranged in 4 rows. They are here considered as one building. The values represent the sum respectively the average of all houses.

(2) Per dwelling.

(3) Number of occupants referring to 22 permanently inhabited households.

(4) Investigation in one dwelling.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

5-A	ANNUAL ENERGY FLOWS AND DATA	REF.: BU/00127/97/DE/SE/AT

SUMMARY OF ENERGY PERFORMANCE DATA

Period FROM **Oct. 99** TO **Sep 00**

The energy data should refer to a 1 year period and should be normalised by the building Treated Floor Area TFA, (Sheet 4)

ENERGY End Uses	Quantities of Utilisation	Fuel Used	Convers. Factor (1)	Energy Supplied (kWh/m²TFA) Measured	Energy Supplied (kWh/m²TFA) Predicted
Space Heating	**3576** m² of Htd. Floor Area	**district heat.**	**0,7**	**20,8** (3) / **20,9** (4)	**17,3**
Space Cooling	- m² of Cond. Floor Area	-	-	**0**	**0**
Refriger-ation	- m³ of Ref.Vol. /ice	**incl. in "other"**	-	-	-
Service Hot Water	**942,2** m³ of SHW/a	**district heat.**	**0,7**	**13,7** (5),(4) / **8,8** (6)	**15,6** (5) / **12,0** (6)
Process Heat	- Prodn. Level(2)	**incl. in "other"**	-	-	-
Lighting	- m² of Lit Floor Area	**electricity**	**2,5**	-	**3,2**
Other El. Loads	**80** no. of Occupants	**electricity**	**2,5**	**23,3** (7), (4)	**15,5**

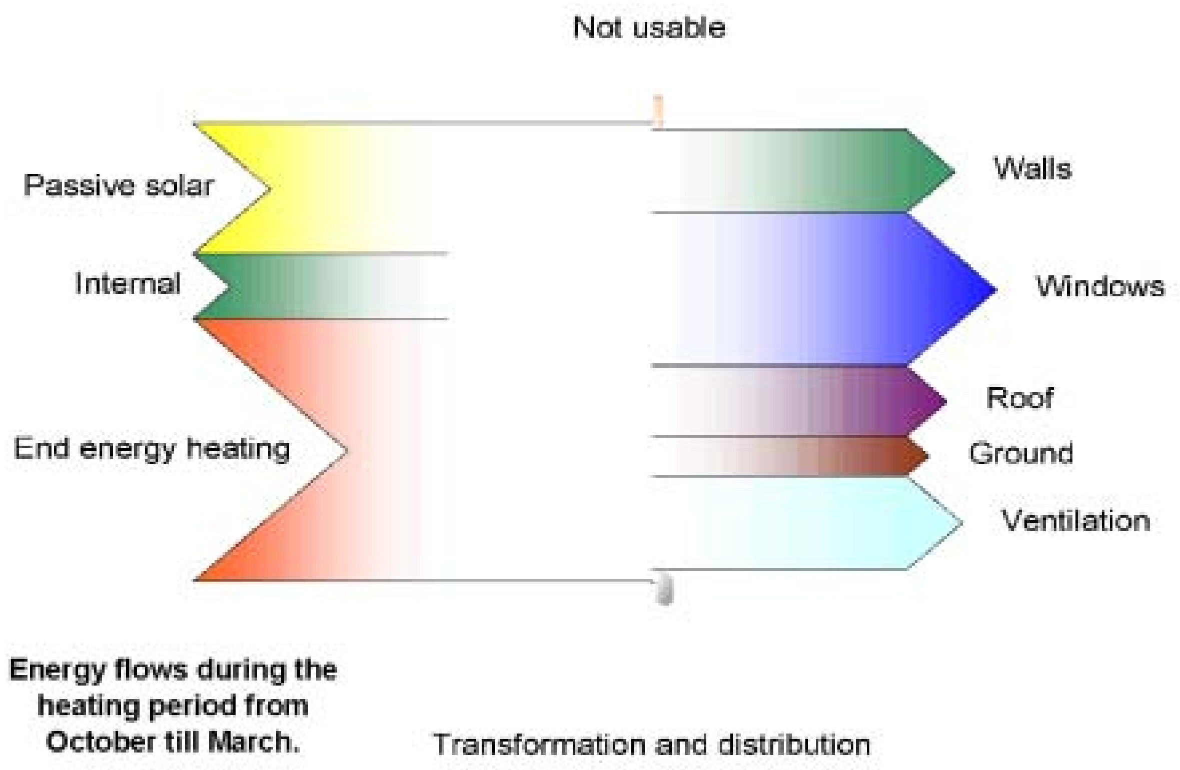
ENERGY TOTALS	EN. SUPPLY INDICATOR [kWh/m² TFA.yr.]	PRIMARY EN. INDICATOR [kWh/m² TFA.yr.]	PRIMARY EN. REQUIRED [GJ/yr.]
Thermal Energy	**34,6** (4)	**24,2**	**312**
Electrical Energy	**23,3** (4)	**58,4**	**751**
Total	**58,4** (4)	**82,6**	**1063**

(1) European conversion factor according to CEPHEUS from delivered to primary energy are used.
(2) Production level refers to building category, not to process heat = e.g. no. of beds for hospitals, no. of working places for offices, selling area for supermarkets, m² or m³ of pool for swimming pools, no. of students for school, etc.
(3) Value referring to all houses.
(4) Value referring to 22 permanently inhabited households.
(5) SHW provided by district heating
(6) SHW provided by active solar water heating system. Investigation in one dwelling.
(7) Total electrical energy consumption.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

5B-1	ENERGY FLOWS AND INDICATORS	REF.:	BU/00127/97/DE/SE/AT

SANKEY DIAGRAM OF ENERGY FLOWS DURING THE HEATING PERIOD FROM OCT. TILL MAR.



MONTHLY ENERGY DATA

MONTH	ENERGY LOADS [1] [kWh/month]		ENERGY REQUIRED [1] (Measured*) [kWh/month]		ENERGY SUPPLIED [1] (Measured) [kWh/month]	
	Thermal	Electrical	Thermal	Electrical	Thermal	Electrical
JAN	23053	6532	13329	6532	15855	6532
FEB	19187	6000	8580	6000	10862	6000
MAR	18363	5992	6971	5992	9497	5992
APR	14924	5600	2339	5600	4783	5600
MAY	8540	5725	1329	5725	1329	5725
JUN	5623	5301	711	5301	711	5301
JUL	4131	5398	924	5398	924	5398
AUG	3479	5673	277	5673	277	5673
SEP	5795	5793	610	5793	610	5793
OCT	12306	5688	1546	5688	4072	5688
NOV	16405	5909	7269	5909	9714	5909
DEC	20524	6578	13207	6578	15733	6578
TOTAL	152331	70188	57092	70188	74366	70188

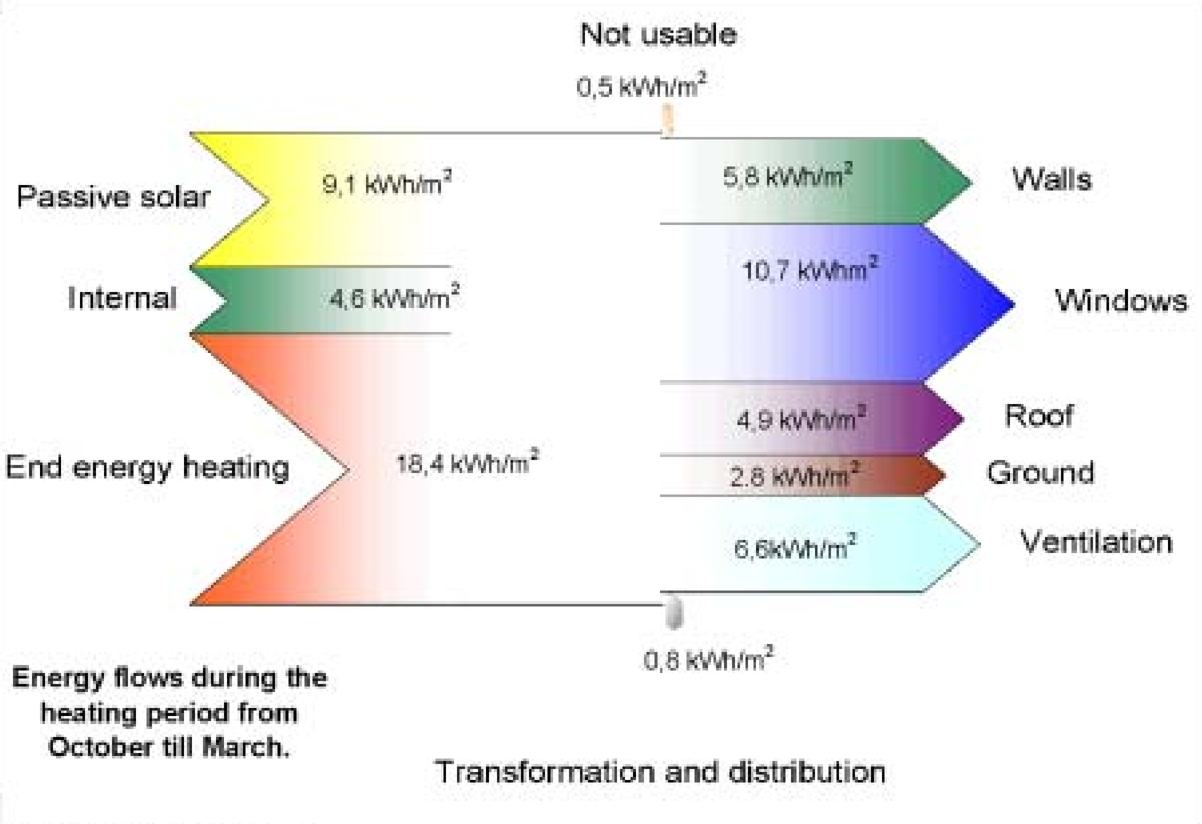
* The original notes on the completion of the format sheets and the original format sheets themselves are contradictory in this point. Here, measured data are used.

(1) The given data refer to all 32 houses.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

5B-2	**ENERGY FLOWS AND INDICATORS**	REF.:	BU/00127/97/DE/SE/AT

SANKEY DIAGRAM OF ENERGY FLOWS DURING THE HEATING PERIOD FROM OCT. TILL MAR.



MONTHLY ENERGY DATA

MONTH	ENERGY LOADS [kWh/(month m²)]		ENERGY REQUIRED (Measured*) [kWh/(month m²)]		ENERGY SUPPLIED (Measured) [kWh/(month m²)]	
	Thermal (1)	Electrical (2)	Thermal (1)	Electrical (2)	Thermal (1)	Electrical (2)
JAN	6,4	2,2	3,7	2,2	4,4	2,2
FEB	5,4	2,0	2,4	2,0	3,0	2,0
MAR	5,1	1,9	1,9	1,9	2,7	1,9
APR	4,2	1,8	0,7	1,8	1,3	1,8
MAY	2,4	1,9	0,4	1,9	0,4	1,9
JUN	1,6	1,8	0,2	1,8	0,2	1,8
JUL	1,2	1,8	0,3	1,8	0,3	1,8
AUG	1,0	1,8	0,1	1,8	0,1	1,8
SEP	1,6	1,9	0,2	1,9	0,2	1,9
OCT	3,4	2,0	0,4	2,0	1,1	2,0
NOV	4,6	2,0	2,0	2,0	2,7	2,0
DEC	5,7	2,3	3,7	2,3	4,4	2,3
TOTAL	42,6	23,3	16,0	23,3	20,8	23,3

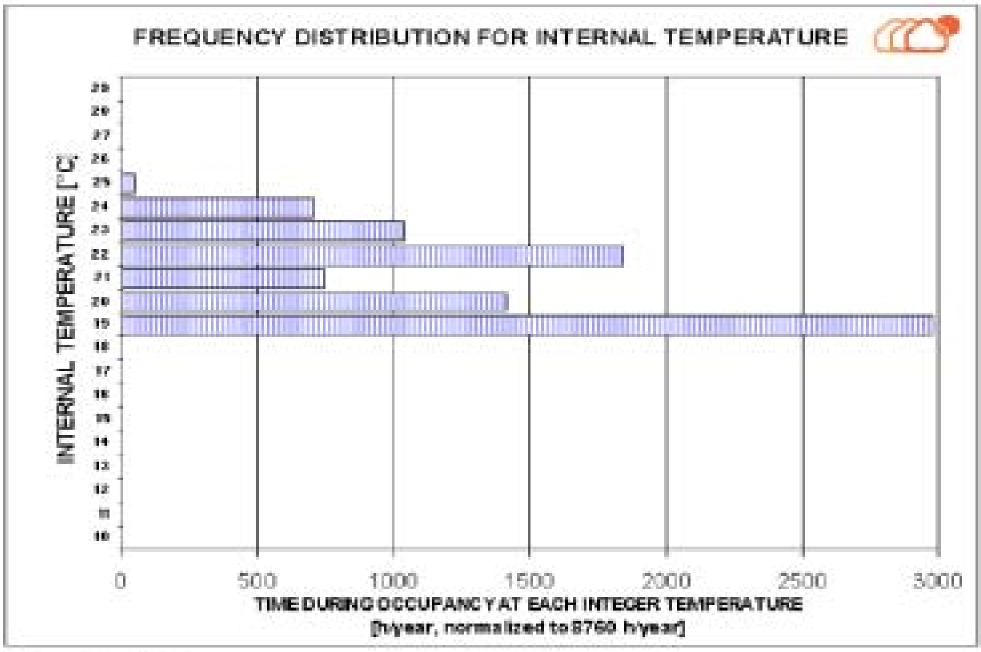
* The original notes on the completion of the format sheets and the original format sheets themselves are contradictory in this point. Here, measured data are used.
(1) The given data refer to all 32 houses.
(2) Electrical energy referring to 22 permanently inhabited households.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

5C-1	**DETAILED ENERGY PERFORMANCE** **(Predicted)**	REF.: BU/00127/97/DE/SE/AT

BUILDING / ZONE:(For large buildings complete one sheet for each area served by separate plant)

FREQUENCY DISTRIBUTION FOR INTERNAL TEMPERATURE (dry bulb °C)



PERFORMANCE DATA

	UNITS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
		CLIMATE & OCCUPANT EFFECTS												
External Heat Losses (fabric & fresh air)	kWh/m²	6,3	5,3	4,9	3,3	2,4	1,5	0,9	0,8	1,8	3,3	4,4	5,6	40,5
External Heat Gains (fabric & fresh air)	kWh/m²	1,4	1,5	2,2	3,7	3,6	4,0	4,3	3,4	3,0	2,2	1,4	0,8	27,1
Occupant Gains	kWh/m²	1,6	1,4	1,6	1,5	1,6	1,5	1,6	1,6	1,5	1,6	1,5	1,6	18,4
		EQUIPMENT EFFECTS												
Appliances Energy (1) (computers, catering, lifts, etc.)	kWh/m²	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,5
Lighting Energy	kWh/m²	0,3	0,2	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	3,2
		ENERGY CONSUMPTION												
Cooling Input Energy	kWh/m²	-	-	-	-	-	-	-	-	-	-	-	-	-
Heating Input Energy (including humidification)	kWh/m²	5,0	3,5	1,7	0,0	0,0	0,0	0,0	0,0	0,0	0,1	2,3	4,7	17,3
Pumb Absorbed Energy	kWh/m²	0,1	0,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	1,0
Fan Absorbed Energy	kWh/m²	0,3	0,3	0,3	0,3	0,1	0,0	0,0	0,0	0,0	0,3	0,3	0,3	2,2

TOTAL ANNUAL ELECTRICAL ENERGY CONSUMPTION 18,7 kWh/m²

TOTAL ANNUAL DISTRICT HEAT CONSUMPTION 33,1 (2) kWh/m²

TOTAL ANNUAL ENERGY COSUMPTION 51,8 kWh/m²

HEATING PLANT ANNUAL EFFICIENCY 95 % COOLING PLANT ANNUAL COP -

(Excluding distribution losses, pump and fan power)

(1) Total monthly electrical energy consumption without lighting energy.

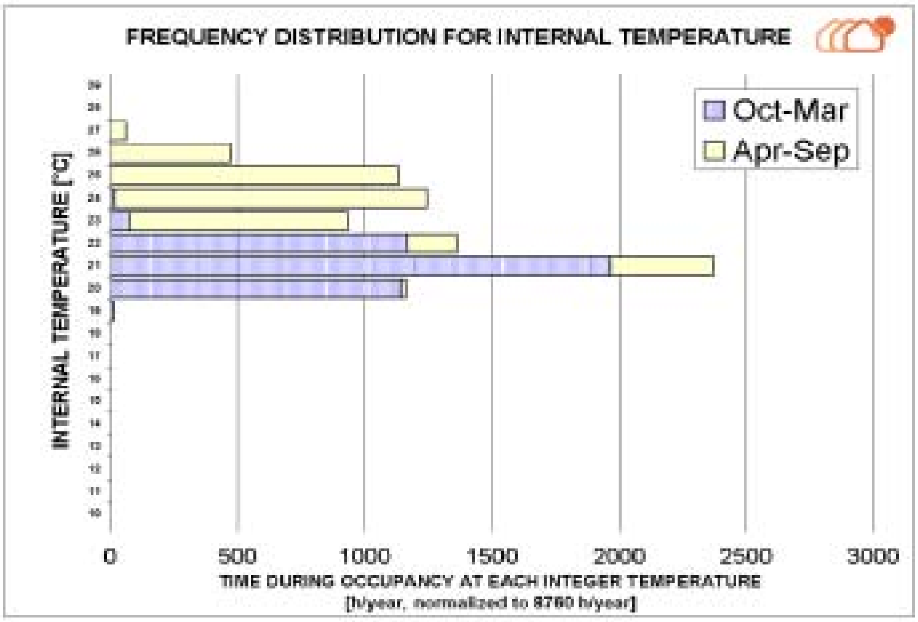
(2) District heat consumption for space heating and domestic hot water (including hot water supply for domestic appliances).

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

5C-2	**DETAILED ENERGY PERFORMANCE (Measured)**	REF.: BU/00127/97/DE/SE/AT

BUILDING / ZONE:(For large buildings complete one sheet for each area served by separate plant)

FREQUENCY DISTRIBUTION FOR INTERNAL TEMPERATURE (dry bulb °C) (1)



PERFORMANCE DATA

	UNITS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
		CLIMATE & OCCUPANT EFFECTS												
External Heat Losses (2) (fabric & fresh air)	kWh/m²	6,0	5,2	5,0	3,8	2,5	1,6	1,1	1,1	1,8	3,3	4,4	5,6	41,4
External Heat Gains (2) (fabric & fresh air)	kWh/m²	1,4	1,7	1,8	3,0	3,6	3,4	2,7	3,3	2,5	2,2	1,0	0,7	27,3
Occupant Gains (3)	kWh/m²	0,8	0,7	0,8	0,8	0,8	0,9	0,9	0,9	0,9	0,7	0,7	0,8	9,8
		EQUIPMENT EFFECTS												
Appliances Energy (4), (7) (computers, catering, lifts, etc.)	kWh/m²	2,2	2,0	1,9	1,8	1,9	1,8	1,8	1,8	1,9	2,0	2,0	2,3	23,3
Lighting Energy	kWh/m²	-	-	-	-	-	-	-	-	-	-	-	-	0
		ENERGY CONSUMPTION												
Cooling Input Energy	kWh/m²	-	-	-	-	-	-	-	-	-	-	-	-	0
Heating Input Energy (including humidification)	kWh/m²	4,4	3,0	2,7	1,3	0,4	0,2	0,3	0,1	0,2	1,1	2,7	4,4	20,8
Pumb Absorbed Energy	kWh/m²	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1,1
Fan Absorbed Energy (5)	kWh/m²	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	2,2

TOTAL ANNUAL ELECTRICAL ENERGY CONSUMPTION 23,3 (7) kWh/m²

TOTAL ANNUAL DISTRICT HEAT CONSUMPTION 34,6 (6), (7) kWh/m²

TOTAL ANNUAL ENERGY COSUMPTION 58,0 kWh/m²

HEATING PLANT ANNUAL EFFICIENCY 95 % COOLING PLANT ANNUAL COP -

(Excluding distribution losses, pump and fan power)

(1) Internal temperatures distribution of one typical dwelling.
(2) Values are determined by using measured climate data.
(3) According to known occupancy the occupant gains are calculated.
(4) Total monthly electrical energy consumption.
(5) Including electrical anti-freeze heating of the heat recovery unit.
(6) District heat consumption for space heating and domestic hot water.
(7) The given data refer to 22 permanently inhabited households.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

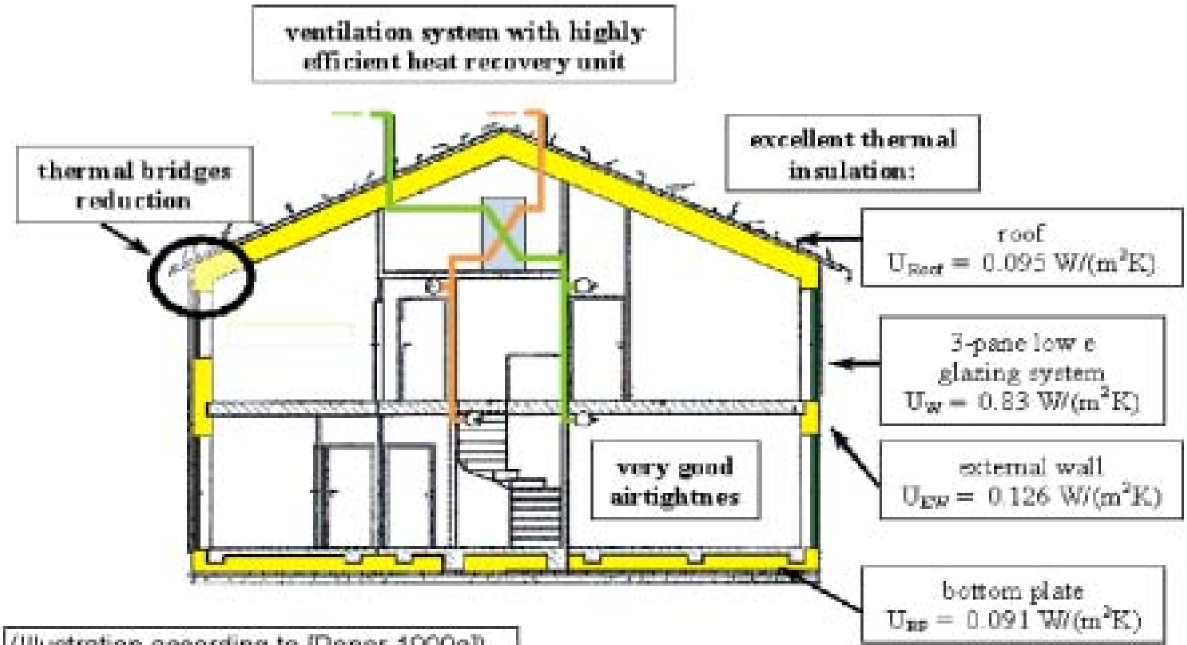
6-A1	BUILDING ENVELOPE SPECIFICATION	REF.: BU/00127/97/DE/SE/AT

APPLICATION DESCRIPTION AND DATA: Complete this sheet only if applicable

DESCRIPTION OF ENERGY SAVING FEATURES

- Superinsulation technologies: U-values of all opaque envelope elements below 0.15 W/(m²K).
- Reduced thermal bridges.
- Very good airtightness (PE-films in lightweight elements, airtight connections): n_{50} < 0,6 /h.
- Use of passive solar energy; large south oriented windows.
- 3-pane low-emissivity glazing systems with U-value below 0.8 W/(m²K) and a high solar transmittance factor (60 %).
- Windows with superframes (U-value of frame below 0.8 W/(m²K))
- Heat recovery with high-efficiency counterflow air-to-air heat exchangers (efficiency greater than 75 %).
- Solar collectors for production of domestic hot water.

SKETCH OF ENVELOPE, HIGHLIGHTING NOVEL ASPECTS



(Illustration according to [Peper 1999a])

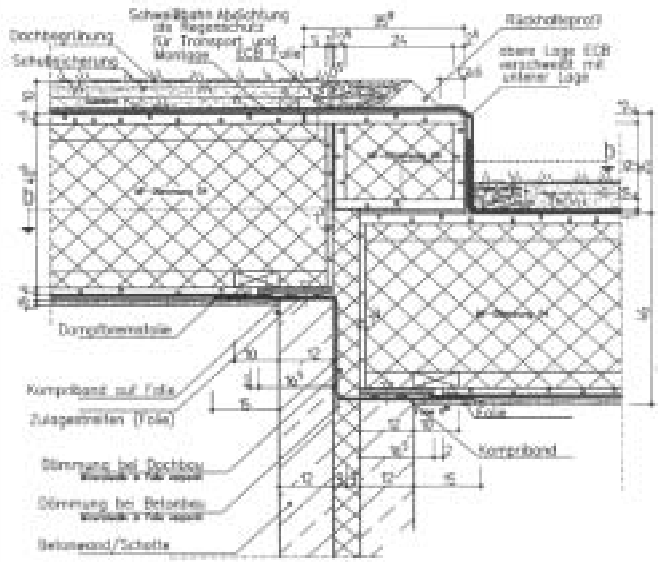
FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

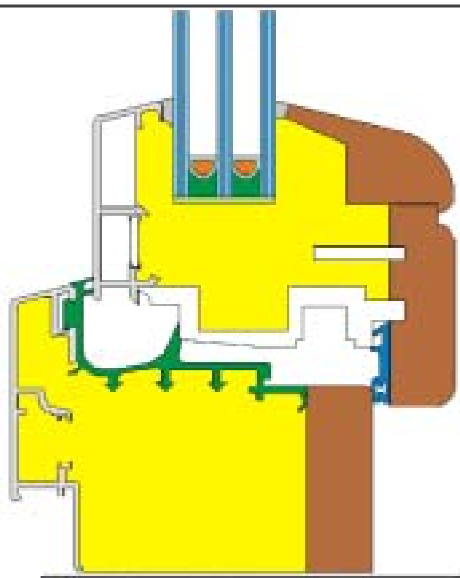
6-A2	BUILDING ENVELOPE SPECIFICATION	REF.: BU/00127/97/DE/SE/AT

APPLICATION DESCRIPTION AND DATA: Complete this sheet only if applicable

DESCRIPTION OF ENERGY SAVING FEATURES

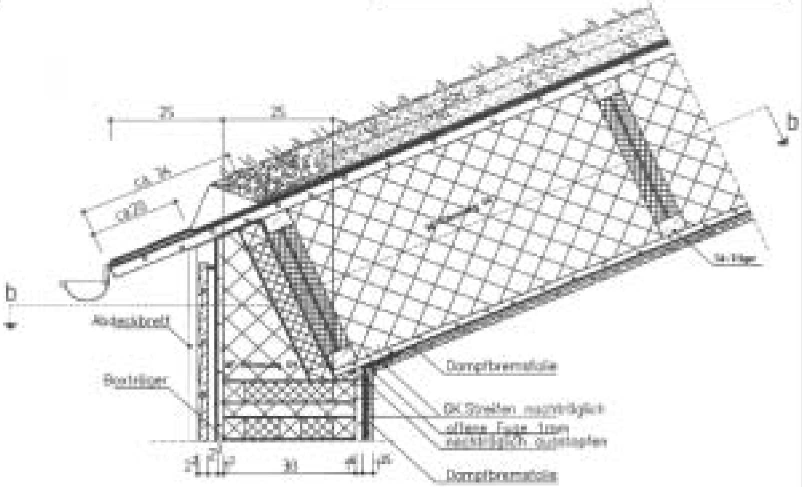
HIGHLIGHTING NOVEL ASPECTS



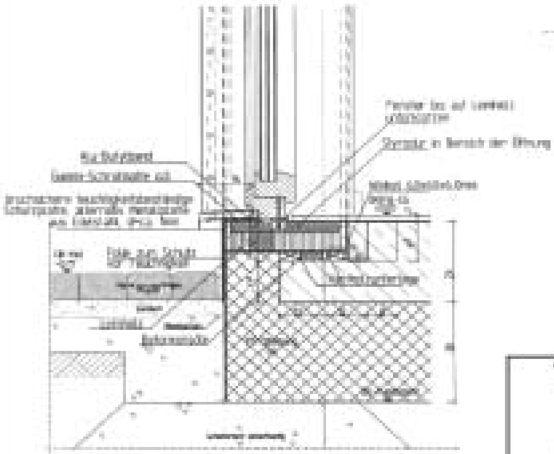


Thermal bridge reduction
superinsulated window frame
(illustration according
to copy of manufacture)

Thermal bridge reduction and airtightness
roof/verge
(Illustration from [Feist 2001])



Thermal bridge reduction and airtightness
eaves/roof
(Illustration from [Feist 2001])



Thermal bridge reduction and airtightness
external wall/base
(Illustration from [Feist 2001])

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

6B-all	BUILDING DRAWINGS	REF.:	BU/00127/97/DE/SE/AT

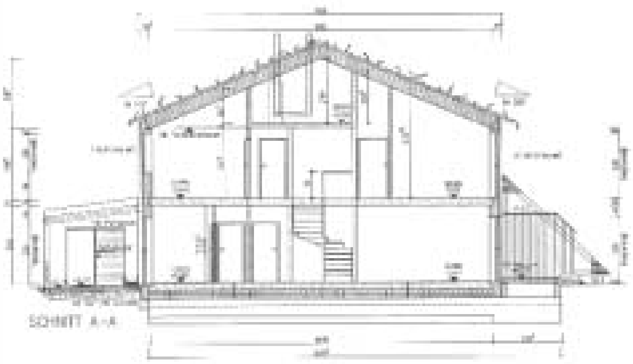
APPLICATION DESCRIPTION AND DATA: Complete this sheet only if applicable

Building type **10 Residential** TFA: 3576 (1) m²

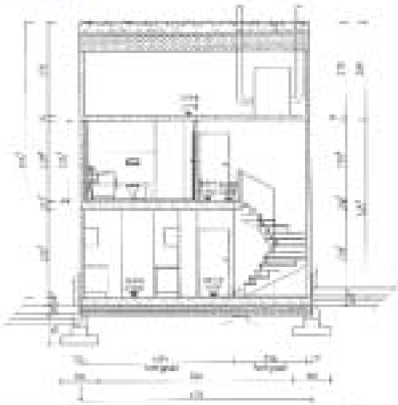
Complete seperate copies of sheets 6B and 6C for each different building type

Each copy should be identified by adding successive numbers in top lefthand corner:e.g. 6B-1, 6B-2 ,6C-1, 6C-2, etc

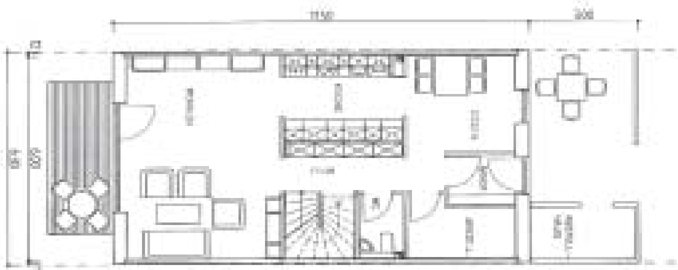
View from southeast



Sectional view from east
(Illustration from [Feist 2001])

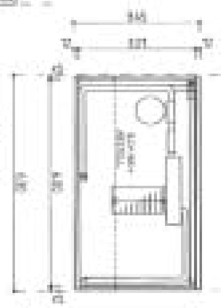


Sectional view from south
(Illustration from [Feist 2001])



Ground floor

Upper floor



Top floor

Plan views
(Illustrations from [Feist 2001])

(1) Sum of all 32 dwellings.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

6C	ENVELOPE INSULATION ANALYSIS			REF.:	BU/00127/97/DE/SE/AT
APPLICATION DESCRIPTION AND DATA: Complete this sheet only if applicable					
Building type	10 Residential			TFA: 3576 [(1)]	m²
Complete seperate copies of sheets 6B and 6C for each different building type					
Each copy should be identified by adding successive numbers in top lefthand corner:e.g. 6B-1, 6B-2 ,6C-1, 6C-2, etc					
Actual Building Heat Loss Coefficient	0,418	[W/m²k]	or	0,133	[W/m³k]
Heat Loss Coeff. according to Norms [(2)]	1,56	[W/m²k]	or	0,50	[W/m³k]
Actual Yearly Space Heating Consumption	57,5	[MJ/m²]	or	18,2	[MJ/m³]
Space Heating Cons. according to Norms [(2)]	385	[MJ/m²]	or	122	[MJ/m³]

OPAQUE BUILDING ENVELOPE PARTS OR COMPONENTS

Azim. /Tilt Angle	Envel. Part or Compnt.	Composition Materials (out to in)	Total Thckn. [cm]	Cont-iguity Fctr[1]	Insulation Type Position and Thickness [cm]		Overall U-value [W/m²K]	Surf. Area [m²]
e. or w./90°	façade lightweight construction	chipboard, mineral wool, chipboard, gypsum board	34,5	1	λ = 0,04 W/(mK), 30cm		0,13	1716,8 [(1)]
n. and s./90°	façade concrete construction	rendering, thermal insulation, concrete	42	1	λ = 0,04 W/(mK), 40 cm		0,09	665,7[(1)]
n. and s./23,5°	roof 1	chipboard, mineral wool, chipboard, gypsum board	45,7	1	λ = 0,04 W/(mK), 40 cm		0,095	2393,0[(1)]
-	ground 1	thermal insulation, concrete, impact sound insulation, wooden floor	59,5	0,4	λ = 0,04 W/(mK), 42 cm		0,091	2178,9[(1)]
n. and s./23,5°	roof 2	chipboard, mineral wool, chipboard, mineral wool	39	1	λ = 0,04 W/(mK), 12 cm + 22 cm		0,11	95,7[(1)]
-	ground 2	concrete, thermal insulation, concrete	42	0,4	λ = 0,04 W/(mK), 18 cm		0,209	88,0[(1)]
-	-	-	-	-	-	-	-	-

Data on doors should be reported in the upper or lower table, according to wether they are opaque or glazed.

WINDOWS AND OTHER GLAZED COMPONENTS

Azim. /Tilt Angle	Type of Glazing	Frame Material	Air Infiltration [m³/hm²]	Night shutter type	Average Shading Factor	Overall day U-value	Overall night U-value	Glazed Area [m²]
south/90°	low e, triple	metal, plastic, wood	-	-	0,89	0,83	0,83	361,7[(1)]
north/90°	low e, triple	metal, plastic, wood	-	-	0,91	0,83	0,83	264,2 [(1)]
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-

[1] 1.0 for outside / 0.85 for ventilated, non-heated spaces / 0.60 for non-vent., non-heated spaces / 0.40 toward ground

(1) The settlement consists of 4 passive house rows with 32 dwellings. The houses are very similar therefore the data are given in sum.

(2) Values according to the german norm: Verordung über einen energiesparenden Wärmeschutz bei Gebäuden (Wärmeschutzverordnung), Bonn 8/1994.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

7-A	**INTEGRATED DESIGN FOR LOW ENERGY**	REF.:	BU/00127/97/DE/SE/AT		
APPLICATION DESCRIPTION AND DATA: Complete this sheet only if applicable					
		Thermal	Electric	Total	Tot. primary
Reference(*) Ann. Consumption	[kWh/m².yr.]	**141** (1) (2)	**32,8** (3)	**173,8**	**244,2** (4)
Actual Annual Consumption	[kWh/m².yr.]	**34,6** (2), (5)	**23,3** (6), (5)	**58,0**(5)	**82,6**(5)
Ratio Actual to Ref. Consumption		**25%**	**71%**	**33%**	**34%**
Fraction of Load provided by Renewables		-	-	-	-
(*) Take as reference the values for the specific building(s) derived or imposed by national norms					

(1) Reference values according to the German norm: Verordnung über einen energiesparenden Wärmeschutz bei Gebäuden (Wärmeschutzverordnung), Bonn 8/1994.
(2) Annual consumption for space heating and domestic hot water.
(3) Without electric energy for mechanical ventilation
(4) Assumption: Reference heat generator is a low temperature boiler with a conversion factor of 1.15 for gas.
(5) The given data refer to 22 permanently inhabited households.
(6) With electric energy for mechanical ventilation

TECHNIQUES APPLIED IN THE PROJECT

ENERGY SAVING TECHNIQUES	RENEWABLE ENERGY TECHNIQUES	
(See Format Sheet no.3)	X	Solar Active
10 Building envelope improvement	X	Solar Passive
30 Heat recovery systems	-	Solar Photo-Voltaic
60 Passive heating and cooling techniques	X	Wind
80 Eff. lighting, daylight and electr. improvements	-	Small Scale Hydro
	-	Biomass
	-	Other

DESCRIPTION OF THE MOST IMPORTANT INTEGRATION ASPECTS

- The houses have mechanically balanced ventilation systems. The heat requirement of them is so low that the remaining heat is distributed by the supply air. No additional heat distribution is needed. No recirculated air is needed.
- Large south oriented windows for passive solar gains and reduced use of artificial lighting.
- Heat for space heating as well as hot water are provided by district heat. One transfer station supplies the heat for 16 dwellings.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

7-B	DIRECT PASSIVE SOLAR GAIN	REF.: BU/00127/97/DE/SE/AT

APPLICATION DESCRIPTION: Complete this sheet only if applicable, use a separate copy for each different building type

Building type: **10 Residential** TFA: 3576 m²

	Predicted #	Measured #	
1. HEATING SEASON USEFUL SOLAR HEAT GAIN (1)	7,7	7,9	kWh/m²TFA
2. HEATING SEASON WINDOW HEAT LOSS (1)	7	6,1	kWh/m²TFA
3. HEATING SEASON NET GAIN (2-1) (1)	0,7	1,8	kWh/m²TFA

GLAZING PARAMETERS (Refer to notes in Guidelines section 2.2.6A)										
1. Façade orientation	East	South East	195° (SE)	South West	West					
2. Tilt (deg. from horiz'l)	-	-	**90**	-	-					
3. Area m²	-	-	**11,5**	-	-					
4. Glazing layers (1,2,3)	-	-	**3**	-	-					
5. New technology *	-	-	**LE**	-	-					
6. % Frame	-	-	**31%**	-	-					
7. Frame type *	-	-	**M ,P+TB**	-	-					
8. % facing sunspace	-	-	-	-	-					
9. Total solar transmittance	-	-	**0,6**	-	-					
10. U-value (day) W/m²k	-	-	**0,83**	-	-					
11. U-value (night) W/m²k	-	-	**0,83**	-	-					
SHADING PARAMETERS										
A.Shade type *	-	-	**VE**	-	-					
B.Shade location *	-	-	**EXT**	-	-					
C.Shade material *	-	-	**textile**	-	-					
D.Shade colour *	-	-	**Medium**	-	-					
E.Projection (m) *	-	-	**0**	-	-					
F.Shade operation *	-	-	**MECH**	-	-					

*New technologies	LE: Low Emissivity coating(s)		AE: AErogel	TI: Transparent Insulation
	PG: Prismatic Glazing		VG: Vacuum Glazing	SC: Solar Control glazing
*Frame type	W:Wood	M: Metal	P: Plastic	(+)TB: (+)Thermal Break
*Shade type	ST: STructural, SS: Sliding/folding Shutter, RS: Roller Shutter, VE: VEnEtian, AW:AWning			
*Shade location	EXT: EXTernal	IGL: InteGraL	INT: INTernal	
*Shade material	W:Wood	M: Metal	P: Plastic	(+)INS: (+)INSulation
*Shade colour	Light, Medium, Dark			
*Projection	Maximum projection from face of glazing in horizontal plane in meters			
*Shade operation	MAN: MANual	MECH: MECHanically operated		AUTO: fully AUTOmatic

(# predicted = based on calculation or simulation / measured = measured directly or combination of measurement & calculation)

(1) The values refer to southerly facing windows (October till March).

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

8-A	SPACE HEATING & VENTILATION SYSTEMS	REF.:	BU/00127/97/DE/SE/AT

APPLICATION DESCRIPTION AND DATA: Complete this sheet only if applicable

Building Type:	house/residential		
Treated Floor Area (TFA) [m²]:	3.576	**No. of Floors:**	2
External design Temperature [°C]:	-10	**External Design Humidity:**	-

HEATING PLANT DESIGN DATA

Heating Source:	district heat / CHP		
Is Plant Integrated with a Combined Heat & Power System/District Heat:			Yes

Fuel Input:

Natural Gas	Biogas	Landfill Gas	Gas oil/Diesel	Other
X				

Manufacturer	Zeppelin (CHP), Viessmann (boiler plant)	Modell	Typ G35 16 B (CHP), Turbomat 6000 - RN (boiler plant)
Total efficiency	0,94	(CHP)	

HEAT DISTRIBUTION SYSTEM

		Heat Generator	Air Heater (supply air)
Distribution System	Ventilation System	**Supply Temp. [°C] (Nov. - Mar.)**	
Heat Distribution Fluid	air	Mean Supply Temp. [°C]	27,0
		Max. Daily Sup. Temp. [°C]	55,5
Installed Capacity [W/m²]	10	**Max. Daily Mean Heating Load [W/m²]**	9

VENTILATION SYSTEM DESIGN DATA

BUILDING ENVELOPE'S AIRTIGHTNESS

Pressurization Test	yes	**Mean Air Change** (pressure difference 50 Pa) n_{50} **[1/h]**	0.29 (1)

VENTILATION SYSTEM

Distribution System	central ventilation system per dwelling, short air ducts			
Pressure Loss of Ventilation System [Pa] (at air flow)		design values		
	60 (2) (60 m³/h)	105 (2) (120 m³/h)	175 (2) (150 m³/h)	
Fresh Air Ventilation				
	design value		measured value	
Electrical Efficiency [Wh/m³ air]	from 0.3 to 0.35		0,22 (2)	
Ventilation Control	manual			

EARTH-TO AIR HEAT EXCHANGER

Length of Ducts [m]	not used	**Diameter of Ducts [m]**	not used
Depth [m]	not used	**Number of Ducts**	not used

HEAT RECOVERY SYSTEM

Manufacturer	Paul Wärmerückgewinnung, Mülsen, Germany	
Type/Set-Up of Heat Exchanger	counterflow air-to-air	central per dwelling
	Design Value	**Measured Value**
Efficiency	87%	78%
Annual Energy Efficiency [-] (saved ventilation losses in relation to enery consumption of ventilation system)		10,8

DESIGN DATA FOR HEATED ZONE

Building Overall Heat Loss Coefficient	**Predicted**	**Measured**
UA/m² [W/(K m² TFA)]	0,424	0,418
UA/m³ [W/(K m³)]	0,102	0,101

ZONE DISCRIPTION

Floor Area TFA [m²]	3576	**Volume [m³]**	14745
Occupant Density [m²/person]	35,3 (3)	**Internal Gain [W/m²]**	2,1
Infiltration Rate [ac/h]	0,02	**Fresh Air Ventilation [l/(s person)]** (excluding Infiltration)	10,5 (3), (4)
Internal Air Temperature (dry bulb) [°C]	20		

(1) Mean values of 32 dwellings.
(2) Value refers to one dwelling of 120 m² TFA.
(3) Value refers to the 22 permanent inhabited dwellings.
(4) Standard ventilation.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

11-A	SERVICE WATER HEATING SYSTEM	REF.: BU/00127/97/DE/SE/AT

APPLICATION DESCRIPTION AND DATA: Complete this sheet only if applicable

Consumption Data

Typical number of building occupants during working days **70** (4) wkends **70** (4)
Typical daily HW cons. from whole system, working days [l/d] **2211** (4) wkends [l/d] **2211** (4)
Temperature of SHW at points of use: **47** [°C]
Total annual consumption of cold water: **1612654** (4) [l/yr.] hot water **809210** (4) [l/yr.]
How is consumption data derived,- calculated (persons x litres/pers/day), measured, estimated?
measured

Service Hot Water Production
X Central — Combined with central boiler — Separate production
X Independent boilers in each dwelling
Independent boilers at points of use
Other (Specify)

Fuel Used:	Winter	Summer
Principal Source	**active solar system**	**active solar system**
Backup Source	**district heat**	**district heat**

(if electricity, give % produced at off-peak rate, where applicable **-**)

Type of heater — Instantaneous — X With storage

If Storage: Auxiliary Heating Tank Storage Data

Storage type: Single Volume — Multi modules x (32 modules) (2)
Percent of max. rated daily consumption **300** %
Total storage volume: **32 x 300** (5) litres — Auxiliary heater thermostat setting **-** °C
Storage heat loss coeff[1] **2,9** (6) W/K — Ave. daily heat losses[1] **32 x 1,7**(5), (6) kWh/day

If any energy source is **solar** or **recovered heat**: Pre-heating Tank Data

Separate tank — Integral with auxiliary heating tank X
Pre-heating water storage volume **130** litres
Pre-heating tank storage heat loss coeff. **2,9** (6) W/K

Heat Exchanger:	None	External	Internal to preheat. tank X
if internal, location in tank:	top	bottom X	all around
type of heat exchange	with intermediate fluid X		direct contact

Heater
Manufacturer
Model [2] **district heat** — Type **-**
No. of units of the same model: — Ave. rated power of each generator kW
Total rated power **-** kW — Maximum supply capacity **-** litres/min
Generation efficiency [3] in Winter **-** — in Summer -
Low temperature heat source (for heat pumps only) **-**

Distribution system (if applicable) (7) — Gravity **-** — Pumped circulation **-**

Rated circulation pump power **-** kW — Piping total length - m
Pump circulator running time **-** hr/day — Piping heat loss - W/m
Ave. daily heat losses from distribution system **-** kWh/day

HW meters: none — 1 per building X — 1 per dwelling or zone

HW control: none — timer X — Build. En. Man. Sys.

[1] Provide both design and measured values
[2] If more than 1 model, use additional sheets
[3] COP for heat pump heaters

(4) The values relate to 70 persons of 22 permanently occupied houses.
(5) The project describes 32 terraced houses, 22 of them were permanently occupied during the measuring period.
(6) Design value.
(7) No circulation distribution system in the houses.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

11-B	ACTIVE SOLAR WATER HEATING SYSTEMS	REF.: BU/00127/97/DE/SE/AT

APPLICATION DESCRIPTION: Complete this sheet only if applicable: use a separate copy for each different water heater

COLLECTOR ARRAY

Gross Area: 4,3 [(1)] m² Aperture area: 3,95 [(1)] m² Absorber area: 3,8 [(1)] m²

Inclination to the horizontal: 23,5° deg

Orientation (S, SW, etc.): 195° (southeast)

COLLECTOR TYPE

Flat Plate X

Unglazed

Evacuated tube

Other:

MANUFACTURER

Wagner & CO

HEAT TRANSFER FLUID

WATER WATER + GLYCOL X AIR OTHER:

COLLECTOR GLAZING:

SINGLE GLASS: X OTHER:

GLASS SEALANT: -

ABSORBER COATING

BLACK PAINT: SELECTIVE chromium-nickel : (α = 95% ε = 12%)

COLLECTOR PERFORMANCE CHARACTERISTICS:

ETA ZERO = 76,4% LOSS COEFFICIENT = 3,1 W/m²K

Data based on: Absorber Area m² / Gross Area m² / Aperture Area 3,95 [(1)] m²

Data based on: Collector mean temperature X Collector inlet temperature

COLLECTOR FLUID CIRCULATION:

BY PUMP X (pump rating = 60 [(1)] W) RPM-regulated (30%-100%)

BY FAN (Air collectors) (fan rating = - W)

BY THERMOSIPHON

COLLECTOR CIRCUIT CONTROL:

DIFFERENTIAL TEMPERATURE CONTROLLER X

SOLAR SENSOR

OTHER: RPM-regulated X

(1) Data given per dwelling.

FORMAT SHEETS FOR **ENERGY SAVING IN BUILDINGS**

14	OTHER ENERGY SAVING TECHNIQUES	REF.: BU/00127/97/DE/SE/AT

APPLICATION DESCRIPTION AND DATA: This is a free format sheet to be used for projects which are not covered by other sheets.

PROJECT DESIGN CHARACTERISTICS AND PERFORMANCE DATA

The drying wardrobes use the exhaust air of the ventilation system. They are installed in all houses.

All dwellings have the possibility to connect the dish-washer and the washing machine with the domestic hot water (DHW) supply to avoid electrical heat production as much as possible.

All inhabitants were advised to equip their households with energy saving electric appliances e.g. light, cooling and freezing, dish-washer, and washing machine.
The use of energy efficient appliances was supported.

SIMPLIFIED SCHEMATIC VIEW OF TECHNIQUE

drying wardrobe