Energieinstitut Vorarlberg

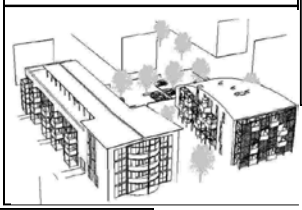
enercity positive energie
Die Marke der Stadtwerke Hannover

Passiv Haus Institut
Dr. Wolfgang Feist

CEPHEUS-Projectinformation No. 36

Hannover (D) 32 Reihenhäuser

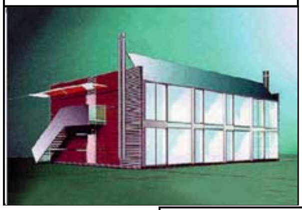
Kassel (D) 40 Wohnungen



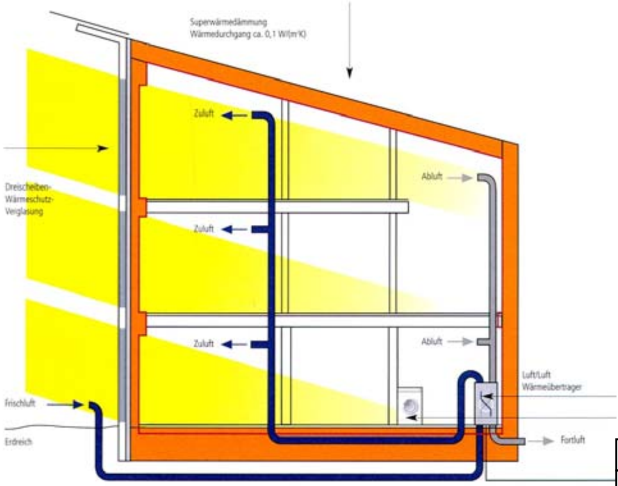
Göteborg (S) 20 Reihenhäuser

Nebikon(CH) 17 Reihenhäuser

Salzburg (A) 6 Wohnungen



CEPHEUS
cost efficient passive houses as european standards



Rennes(F) 40 Wohnungen

Steyr (A) 3 Reihenhäuser

Hörbranz (A) 3 Reihenhäuser

Horn (A) 1 freistehendes Haus

Wohlfurt (A) 10 Wohnungen

Hallein (A) 31 Wohnungen

Final Technical Report

July 2001

Dornbirn (A) 1 freistehendes Haus

Kuchl (A) 25 Wohnungen

Egg (A) 4 Wohnungen

Project supported by the Thermie-Program of EU (BU/0127/97)

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Die Marke der Stadtwerke Hannover

Passiv Haus Institut Dr. Wolfgang Feist

CEPHEUS-Projectinformation No. 36

Final Technical Report
July 2001

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Summary

Passive Houses are buildings in which the space heat requirement is reduced by means of passive measures to the point at which there is no longer any need for a conventional heating system; the air supply system essentially suffices to distribute the remaining heat requirement. The space heat requirement of the houses as built averages about 15 kWh/(m²a). This is less than one fifth of the energy requirement mandated by the building regulations currently in force in the participating countries.
CEPHEUS has tested and proven the viability of the Passive House concept at the European level. In Germany, Sweden, Austria, Switzerland and France, a total of 221 housing units in 14 building projects have been built to Passive House standards and are now occupied. Measurement campaigns have commenced in all building projects; this final report presents measured consumption data for the first heating season for 11 of the 14 projects. Despite all impediments attaching to such first-year measurements, the scientific evaluation already permits the conclusion that CEPHEUS was a complete success in terms of the:

- functional viability of the Passive House concept at all sites,
- actual achievement of the space heat savings target, with savings of more than 80 % already in the first year,
- practical implementability of Passive Houses in a broad variety of building styles and constructions,
- project-level economics, and
- satisfaction of building occupants.

The Passive House technology has triggered a fresh burst of innovation in the construction industry: Today (2001), the market already offers more than 20 Passive-House-compliant window products (with U_w-values below 0.8 W/(m²K)), 10 Passive-House-compliant heat recovery units (with effectiveness ratios above 80 %) and 5 packaged heat pump units. When the CEPHEUS project was originally proposed to the European Union’s Thermie Programme, units of such quality, with efficiencies higher than present standard products by a factor of 2 and more, were only available as individual hand-crafted items. In this field, Europe has now taken a clear leadership role. This is not only a success for environmental protection and resource conservation, but also an opportunity for innovation in the building industry. CEPHEUS has made publicly accessible all experience gained and the key planning tools for the Passive House concept. Today, every architect in Europe can access this information and implement Passive Houses.

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1 Project details

Final Technical Report

Project Reference Number: **BU/127/DE/SE/AT**

Title of Project: **CEPHEUS – Cost Efficient Passive Houses as EUropean Standards**

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Period covered by Final Report: from 01/98 to 03/01

Date of report: 30.07.2001 (* for further contractors, please see next sheet)

Project Reference Number: BU/127/DE/SE/AT

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2 Aim and general description

2.1 Aim of the project

2.1.1 Why build Passive Houses?

The Passive House standard offers a cost-efficient way of minimizing the energy demand of new buildings in accordance with the global principle of sustainability, while at the same time improving the comfort experienced by building occupants. It thus creates the basis on which it is possible to meet the remaining energy demand of new buildings completely from renewable sources – while keeping within the bounds set by the limited availability of renewables and the affordability of extra costs.

What makes the approach so cost-efficient is that, following the principle of simplicity, it relies on optimizing those components of a building which are necessary in any case: The building envelope, the windows and the automatic ventilation system expedient anyway for hygienic reasons. Improving the efficiency of these components to the point at which a separate heat distribution system can be dispensed with yields savings which contribute to financing the extra costs of improvement.

Both the computations carried out with theoretical models and the practical experience gathered with numerous projects show that, under Central European and comparable climatic conditions, such a strategy that builds primarily upon minimizing heat losses is fundamentally more efficient than strategies relying *primarily* upon passive or active solar energy use.

2.1.2 Definition of the Passive House standard

The term "Passive House" refers to a construction standard. The standard can be met using a variety of technologies, designs and materials. It is a refinement of the low-energy house (LEH) standard.

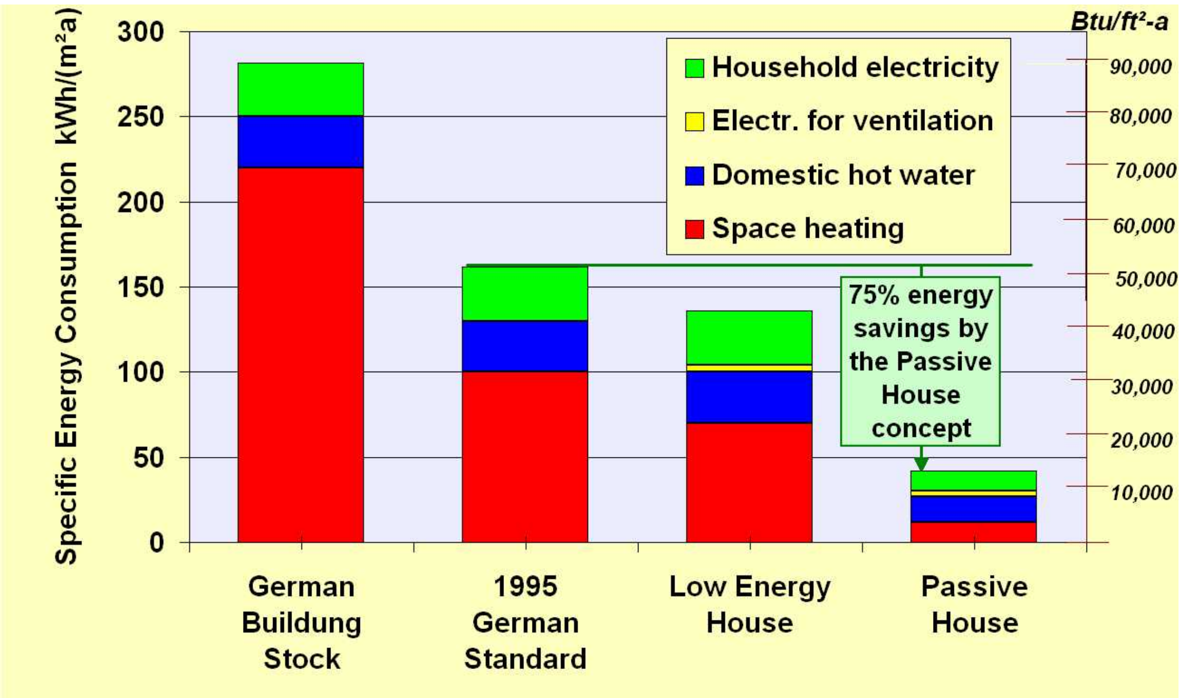


Figure 1: Comparison of specific energy consumption levels of dwellings

"Passive Houses" are buildings which assure a comfortable indoor climate in summer and in winter without needing a conventional heat distribution system. To permit this, it is essential that, under climatic conditions prevailing in Central Europe, the building's annual space heating requirement does not exceed 15 kWh/(m^2a). This small space heat requirement can be met by heating the supply air in the ventilation system – a system which is necessary in any case. Passive Houses need about **80% less space heat** than new buildings designed to the standards of the 1995 German Thermal Insulation Ordinance (Wärmeschutzverordnung).

The standard has been named "Passive House" because the 'passive' use of free heat gains – delivered externally by solar irradiation through the windows and provided internally by the heat emissions of appliances and occupants – essentially suffices to keep the building at comfortable indoor temperatures throughout the heating period.

It is a part of the Passive House philosophy that efficient technologies are also used to minimize the other sources of energy consumption in the building, notably electricity for household appliances. The target of the CEPHEUS project is to keep the **total primary energy requirement** for space heating, domestic hot water and household appliances below 120 kWh/(m^2a). This is **lower by a factor of 2 to 4** than the specific consumption levels of new buildings designed to the standards presently applicable across Europe.

2.1.3 The strategic goals of the CEPHEUS project

The construction and scientific evaluation of the operation of 221 housing units built to Passive House standards in five European countries had, in accordance with the project proposal, the following goals:

- To demonstrate technical feasibility (in terms of achieving the targeted energy performance indexes) at low extra cost (target: compensation of extra investment cost by cost savings in operation) for an array of different buildings, constructions and designs implemented by architects and developers in a variety of European countries;
- To study investor-purchaser acceptance and user behaviour under real-world conditions for a representative range of implemented cases;
- To test the implementability of the Passive House quality standard in several European countries with regard to cost-efficient planning and construction;
- To provide opportunities for both the lay and expert public to experience the Passive House standard hands-on at several sites in Europe;
- To give development impulses for the further design of energy- and cost-efficient buildings and for the further development and accelerated market introduction of individual, innovative technologies compliant with Passive House standards;
- To create the preconditions for broad market introduction of cost-efficient Passive Houses;
- To illustrate, for the concrete example of the Hannover-Kronsberg sub-project, the potential of the Passive House standard to provide a basis on which it is possible to meet the energy requirements of new housing in a manner that is both cost-efficient and, in sum over the whole year, produces zero greenhouse gas emissions (climate neutrality criterion);
- To present this sustainable – fully primary-energy- and climate-neutral – approach to the energy supply of new housing developments at the EXPO 2000 World Exposition in Hannover, in conjunction with all CEPHEUS sub-projects. (The Hannover-Kronsberg sub-project is a registered 'Decentralized EXPO 2000 Project'.)

2.2 Description of the sites

Figure 2: CEPHEUS sites

Project title	Address	Region	Long.	Lat.	Metres above m.s.l.	Project buildings and neighbouring structures
CEPHEUS 01 Germany, Hannover	D-30539 Hannover	Lower Saxony	E 9°44'	N 52°22'	90	4 house types: Jangster, Jangster de Lüx (end-of-terrace), Jangster de Lüx (mid-terrace), "123"
CEPHEUS 02 Germany, Kassel	D-34131 Kassel	Hesse	E 9°27'	N 51°18'	237	2 buildings on former military barracks site; surroundings: apartment buildings
CEPHEUS 03 Sweden, Gothenburg	S-42742 Göteborg	Bildal	E 12°0’	N 57°42’	5	4 terraces with 4 and 6 units per terrace
CEPHEUS 04 Austria, Egg	A-6863 Egg	Vorarlberg	E 9°54’	N 47°26’	545	Multifamily building in low-density neighbourhood
CEPHEUS 05 Austria, Hörbranz	A-6912 Hörbranz	Vorarlberg	E 9°45’	N 47°33’	426	Terrace in low-density neighbourhood
CEPHEUS 06 Austria, Wolfurt	A-6922 Wolfurt	Vorarlberg	E 9°45’	N 47°28’	420	2 identical (multifamily) buildings
CEPHEUS 07 Austria, Dornbirn	A-6850 Dornbirn	Vorarlberg	E 9°45’	N 47°25’	440	Single-family building in low-density neighbourhood
CEPHEUS 08 Austria, Gnigl	A-5020 Gnigl	Salzburg	E 13°5’	N 47°49’	450	Compact multifamily building Horizon shadowed by mountains
CEPHEUS 09 Austria, Kuchl	A-5431 Kuchl	Salzburg	E 13°9’	N 47°38’	469	2 L-shaped multifamily buildings
CEPHEUS 10 Austria, Hallein	A-5400 Hallein	Salzburg	E 13°6’	N 47°41’	445	4 buildings with 3 and 4 storeys, positioned around a courtyard
CEPHEUS 11 Austria, Horn	A-3580 Horn	Lower Austria	E 15°40’	N 48°40’	309	Single-family house in low-density neighbourhood
CEPHEUS 12 Austria, Steyr	A-4407 Steyr	Upper Austria	E 14°25’	N 48°5’	300	Terraced houses with shade-free south facade
CEPHEUS 13 Switzerland, Nebikon	CH-6244 Nebikon	Lucerne	E 7°59’	N 47°11’	492	Terraces, staggered
CEPHEUS 14 France, Rennes	F-3500 Rennes	Brittany	W 1°43’	N 48°4’	37	Multifamily building in urban setting

Table 1: Site data of the CEPHEUS sub-projects

2.3 Description of the installations

2.3.1 Basic elements of the Passive House approach

What makes a building a Passive House? The various components of the Passive House approach described in detail in Section 2.3 can be subsumed under the following basic elements:

1. Superinsulation
Passive Houses have an exceptionally good thermal envelope, preventing thermal bridging and air leakage. To be able to dispense with radiators while maintaining high levels of occupant comfort, it is essential to observe certain minimum requirements upon insulation quality.

2. Combining efficient heat recovery with supplementary supply air heating
Passive houses have a continuous supply of fresh air, optimized to ensure occupant comfort. The flow is regulated to deliver precisely the quantity required for excellent indoor air quality. A high-performance heat exchanger is used to transfer the heat contained in the extracted indoor air to the incoming fresh air. The two air flows are not mixed. The supply air can receive supplementary heating when required. Additional fresh air preheating in a subsoil heat exchanger is possible, which further reduces the need for supplementary air heating.

3. Passive solar gain
South-facing Passive Houses are also solar houses. Efficiency potentials having been exploited, the passive gain of incoming solar energy through glazing dimensioned to provide sufficient daylight covers about one third of the minimized heat demand of the house. To achieve this, the – in most cases newly developed – windows have triple low-emissivity glazing and superinsulated frames. These let in more solar heat than they lose. The benefit is enhanced if the main glazing areas are oriented to the south and are not shadowed.

4. Electric efficiency means efficient appliances
Through fitting the Passive Houses with efficient household appliances, hot water connections for washing machines and dishwashers, airing cabinets and compact fluorescent lamps, electricity consumption is also reduced greatly compared to the average housing stock, without any loss of comfort or convenience. All building services are designed to operate with maximum efficiency. The ventilation system, for instance, is driven by highly efficient DC (direct current) motors. High-efficiency appliances are often no more expensive than average ones, or pay themselves back through electricity savings.

5. Meeting the remaining energy demand with renewables
Cost-optimized solar thermal systems can meet about 40–60% of the entire low-temperature heat demand of a Passive House. The low remaining energy demand of a Passive House moreover makes something possible which would otherwise be unaffordable, and for which available supply would not suffice: Over the annual balance, the remaining energy consumption (for space heating, domestic hot water and household electricity) is offset completely by renewable sources, making the Passive House fully primary-energy- and climate-neutral. The Passive House approach thus permits climate-neutral new housing construction, at prices within the normal market range.

The first three basic elements are crucial to the Passive House concept. To fully minimize environmental impacts, however, the other two are necessary (electric efficiency) or expedient (meeting remaining energy demand with renewables) supplements.

2.3.2 Overview of sub-projects and innovative components

Sub-project	Building type	Construction	Dwelling units (DU)	Treated Floor Area	Living floor space	Q_H (computed) [kWh/(m²a)]	Q_H (measured *) [kWh/(m²a)]
CEPHEUS 01 Germany, Hannover	Terraced house	Mixed construction; Load-bearing structure made of prefabricated concrete elements; Exterior walls and roofs as prefabricated lightweight timber elements	32	3576	3805	11.8	15.3
CEPHEUS 02 Germany, Kassel	Apartment building	Solid construction (sand-lime blocks with external thermal insulation compound system)	40	3055	3164	13.4	15.1
CEPHEUS 03 Sweden, Gothenburg	Terraced house	Timber	20	2635	ca. 2704	12.4	n.d.
CEPHEUS 04 Austria, Egg	Multifamily building	Solid construction (brickwork with external thermal insulation compound system)	4	310	321	15.7	24.5
CEPHEUS 05 Austria, Hörbranz	Terraced house	Solid construction (brickwork with external thermal insulation compound system)	3	381	370	13.8	7.5
CEPHEUS 06 Austria, Wolfurt	Multifamily building	Mixed construction: Steel skeleton with reinforced concrete ceilings and stiffening concrete slabs; external walls made of prefabricated timber elements	10	1296	1200	13.5	15.7
CEPHEUS 07 Austria, Dornbirn	Single-family building	Mixed construction: Steel skeleton with reinforced concrete ceilings, prefabricated lightweight timber wall elements	1	125	133	19.7**)	33.2
CEPHEUS 08 Austria, Gnigl	Multifamily building	Reinforced concrete cellular framing, external walls as lightweight self-supporting construction	6	329	337	18.0**)	25.7
CEPHEUS 09 Austria, Kuchl	Multifamily building	Mixed construction: Reinforced concrete ceilings on steel columns, separately standing external walls in lightweight timber construction	25	1798	1400	15.1	14.3
CEPHEUS 10 Austria, Hallein	Apartment building	Mixed construction: Steel skeleton combined with timber framing	31	2318	2340	13.9	n.d.
CEPHEUS 11 Austria, Horn	Single-family building	Prefabricated house in mixed construction: Parts of external walls (E,W,N) in masonry, otherwise prefabricated timber elements	1	173	170	16.2	29.0
CEPHEUS 12 Austria, Steyr	Single-family building	Solid construction (sand-lime blocks with external thermal insulation compound system)	3	467	468	12.3	18.1
CEPHEUS 13 Switzerland, Nebikon	Terraced house	Timber	5	613	641	15.0	21.0
CEPHEUS 14 France, Rennes	Multifamily building	Load-bearing structure as reinforced concrete skeleton; southern external wall as straw-loam wall (ground floor to 3rd floor); otherwise external walls in timber construction	40	2601	ca. 2852	27.2**)	n.d.

* extrapolated and normalized from measurements in the first heating season, cf. Section 4.2.2.2.2 / n.d.: no measured data yet available over sufficiently long periods
**) on the transgressions of the 15 kWh/(m^{2}a) target see Section 2.4.1

Table 2: Overview of CEPHEUS sub-projects (building type, construction, units, areas, heat req.)

Cepheus-poject		Building type			Con-struc-tion			TFA	Breakdown of innovative technologies											
Sub-project No.	**CEPHEUS sub-project title**	Detached houses	Terraced houses	Multy-family houses	Solid + external insulation	Mixed construction	Lightweight construction	Treated floor area per DU (min-max) [m^2]	1. Superinsulation	2. Thermal bridge reduction	3. Airtightness	4. Subsoil air preheater	5. Hygienic ventilation	6. Heat recovery	7. Passive solar energy utilisation	8. Superwindows	9. Active solar energy utilisation (x=thermal; PV)	10. Innovative packaged building services	11. Efficien household appliances	12. Zero-energy-balance settlements
01	Germany, Hannover		32			x		75-120	x	x	x		x	x	x	x	x		x	x
02	Germany, Kassel			40	x			67-83	x	x	x		x	x	x	x	PV			
03	Sweden, Gothen-burg		20				x	138	x	x	x	x	x	x	x	x	x		x	
04	Austria, Egg			4	x			75-81	x	x	x	x	x	x	x	x	x		x	
05	Austria, Hörbranz		3		x			126-129	x	x	x	x	x	x	x	x	x	x	x	
06	Austria, Wolfurt			10		x		71-168	x	x	x	x	x	x	x	x	x		x	
07	Austria, Dornbirn	1				x		125	x	x	x	x	x	x	x	x	x	x	x	
08	Austria, Gnigl			6		x		48-68	x	x	x		x	x	x	x	x		x	
09	Austria, Kuchl			25		x		60-136	x	x	x		x	x	x	x	x PV		x	
10	Austria, Hallein			31		x		53-87	x	x	x		x	x	x	x	x		x	
11	Austria, Horn	1				x		173	x	x	x	x	x	x	x	x	x		x	
12	Austria, Steyr		3		x			154-158	x	x	x	x	x	x	x	x	x		x	
13	Switzer-land, Lucerne		5				x	123	x	x	x	x	x	x	x	x		x	x	
14	France, Rennes			40	x			46-118	x	(x)	x		x	x	x	(x)	x		x	

Table 3: Overview of the innovative components of the CEPHEUS sub-projects

2.3.3 Superinsulation of opaque building elements

2.3.3.1 Excellent thermal insulation as a basic precondition to the Passive House standard

The basic idea of the Passive House – to reduce heat losses to the point at which internal and solar gains render a separate heating system superfluous – requires as a first step an excellent thermal insulation of exterior building elements. While in a low-energy house ventilation heat losses predominate from a certain insulation standard onwards, this is not the case in the Passive House: The excellent airtightness and highly efficient heat recovery ensure that ventilation losses are very low; as a result, the greater part of the heat losses is again due to transmission through the building envelope.

Figure 3 shows the heat balance of a CEPHEUS end-of-terrace house across the heating season (computed). Insulation material thickness in the wall, roof and floor ranges between 30 and 42.5 cm, thermal bridges are prevented rigorously. Nonetheless, the heat losses through the opaque exterior elements account for 50 % of total heat losses. Keeping these losses as low as possible is therefore crucial to the functioning of Passive Houses.

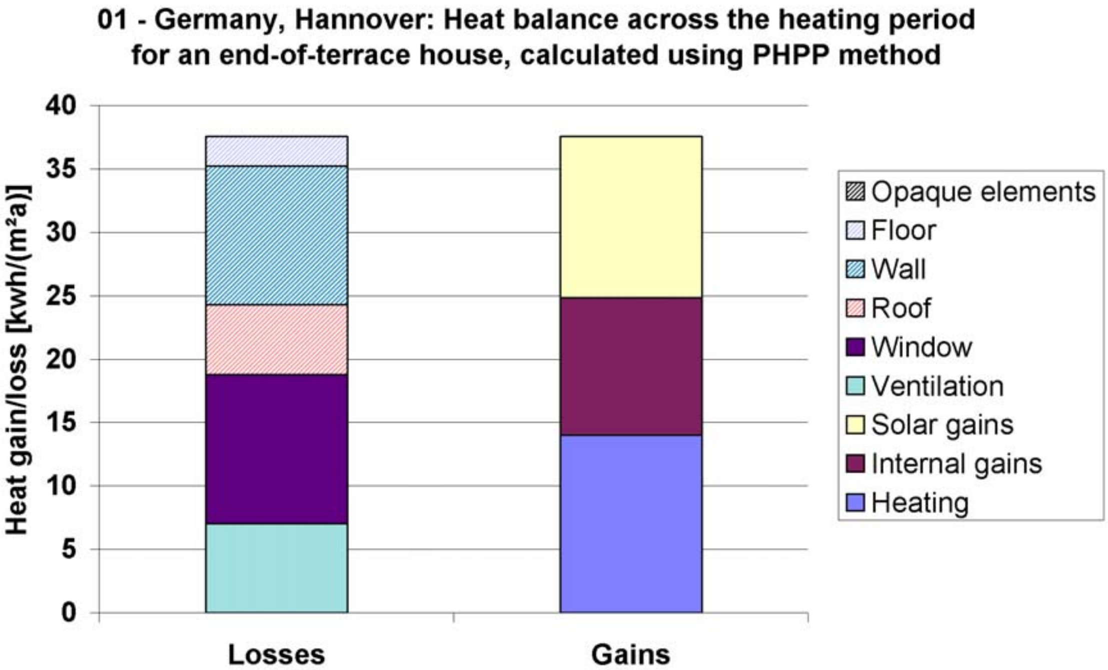


Figure 3: Heat gains and losses for an end-of-terrace house in the Passive House estate in Hannover-Kronsberg, Germany (per m^2 of living space)

In the CEPHEUS projects, the U-values of the exterior building elements generally range between 0.1 and 0.15 W/(m²K), cf. on this also Table 4. Greater insulation thicknesses are generally chosen for the roof, as this scarcely presents construction difficulties. In contrast, the floor slab or basement ceiling generally has smaller insulation thickness. This makes sense because the temperature difference to the subsoil or to the basement is only about half as large as that to the outdoor air.

The types of construction chosen are highly diverse: The CEPHEUS projects used in some cases reinforced-concrete flat roofs, in others classic rafter roofs or lightweight constructions with web beams. The exterior wall systems use sand-lime block or concrete walls with external thermal insulation compound systems (ETHICS), but also timber post-and-beam walls and prefabricated elements with box beams. In many cases the floor slab is made of reinforced concrete, whereby insulation can be placed both above or below the slab. Here, again, alternative lightweight timber constructions are possible.

Schnieders [2001] presents typical solutions for superinsulated exterior building elements in Passive Houses, of which some are briefly characterized in the following:

- Roof with web beams (11-Austria, Horn): The CEPHEUS project in Horn is a single-family house. The relatively unfavourable ratio between overall exterior surface area of the building envelope and the building's volume necessitated particularly good insulation of the envelope. For the roof, a structure with 406 mm TJI beams was chosen, insulated with cellulose. On the indoor side there is a building services space, on the outside there is conventional roof tiling. The U-value of this system is rated at approx. 0.09 W/(m²K).
- Reinforced-concrete gable wall element with external thermal insulation compound system (01-Germany, Hannover): The terraced houses in Hannover-Kronsberg are built using a mixed modular system: The gable walls, the partition walls between houses, the floor slab and the intermediate ceilings consist of prefabricated reinforced-concrete slabs and form the load-bearing structure, while the facades and the roof are lightweight elements with box beams. In the end-of-terrace houses, the windowless gable wall has a 40 cm polystyrene external thermal insulation compound system. The U-value of the finished wall figures 0.10 W/(m²K).
- Post-and-beam timber wall with PS insulation on both sides (03-Sweden, Gothenburg): The exterior wall of the terraced houses in Gothenburg has a load-bearing post-and-beam core (170 mm), with a 100 mm polystyrene insulation layer on both the interior and exterior sides of the timber studs. Taking the timber studs into consideration, the U-value of this construction is 0.09 W/(m²K). The walls were assembled on site on the finished floor slab and erected using a crane.
- 'Timber finish' on polystyrene insulation (04-Austria, Egg): For the multifamily building in Egg Wieshalde, a wall system was used that combines a solid brick wall with a wood facade. A 30 cm thick polystyrene insulation is glued onto the honeycomb brick wall, as in a conventional external thermal insulation compound system. The wood façade, with horizontal lathing and vertical boarding, was glued on without penetrating the insulation. Using the principle of glued-on lathing, every other kind of wall sheathing is also possible. The wall construction achieves a U-value of 0.12 W/(m²K). For this wall construction, registration of a utility model has been applied for at the Austrian Patent Office.
- Lightweight elements on steel skeleton (06-Austria, Wolfurt): Prefabricated timber elements with two types of construction were used for the exterior walls of the three-storey multifamily Passive Houses in Wolfurt. The load-bearing steel studs of the exterior walls are integrated into the interior side of these walls. Total insulation thickness ranges from 240 to 340 mm.
- In Rennes, the attempt was made to achieve the high insulation standard by using insulating materials that are available in the region and have low environmental impact in production and use. This was favoured by the slightly milder climatic conditions (on the not entirely adequate insulation quality for the Passive House standard see 2.4.1). The south façade of the building is a 52 cm thick loam wall (supplied to the site as blocks of 400 kg and 700 kg wieght), with a relatively high U-value of 0.77 W/(m²K). The other external walls are lightweight walls with timber boarding, hemp wool and natural gypsum panels (U=0.19 W/(m²K)). The paints used are also all naturally-based. This approach builds upon the "HQE – Haute Qualité Environnemental" (high environmental quality) standard that is currently much under debate in France, and was an important element in the marketing of the apartments.

2.3.3.2 Overview of the thermal insulation systems used in the CEPHEUS sub-projects

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Sub-project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Configuration exterior wall 1	Timber panel elements, MW	SL with PS-ETHICS	Timber studs with MW, int. & ext. PS	Honeycomb bricks with PS-ETHICS	Brick wall with cork ETHICS	Prefabricated lightweight elements	Timber panel elements	Web beams with MW insulation	Lightweight, MW, plaster coat	Timber studs with MW, PS-ETHICS	Lightweight concrete wall, sep. standing lightw. elements	SL with PS-ETHICS	Lightweight wall, MW	Lightweight wall with hemp insulation
U-value exterior wall 1	0.13	0.13	0.09	0.12	0.10	0.12	0.12	0.12	0.13	0.11	0.10	0.13	0.11	0.19
Configuration exterior wall 2	RC with PS-ETHICS	-	-	RC with PS-ETHICS	-	Copper-clad light-weight elements	Timber panel elements	-	Lightweight, MW, timber boarding	RC, inside PU, out-side PS-ETHICS	Web beams with cellulose insulation	-	-	Solid loam wall
U-value exterior wall 2	0.10	-	-	0.13	-	0.16	0.09	-	0.13	0.16	0.10	-	-	0.77
Configuration roof/ceiling 1	MW between web beams	RC ceiling, insulated on top	Masonite beam, MW	RC ceiling, PS on top	Mono-pitch roof, pre-fab. lightw. elements	RC flat roof with PS insulation	RC ceiling with MW insulation	Flat roof, RC with PS	Inclined roof, MW insulation	RC ceiling, PS laid on top	Inclined roof with web beams, cellulose	Rafters with insulation on top of rafters	Timber frame ceiling, MW	RC ceiling, insulated on top
U-value roof/ceiling 1	0.10	0.11	0.08	0.10	0.09	0.10	0.10	0.10	0.10	0.11	0.09	0.09	0.11	0.36
Configuration roof/ceiling 2	-	-	-	RC ceiling, PS on top	-	Terrace with VIPs	-	-	-	-	-	-	-	RC ceiling, insulated
U-value roof/ceiling 2	-	-	-	0.15	-	0.11	-	-	-	-	-	-	-	0.27
Configuration floor/basement ceiling	RC, PS on bottom side	RC, PS on top	RC, PS on bottom side	RC floor, PS above and below	RC ceiling, insulated on top	RC ceiling, MW on top	RC floor slab, PS on top	RC ceiling, PS on top, MW below	RC ceiling, PS on top	RC ceiling, PS on top	RC ceiling, web beams on top	RC ceiling, PS on top	Timber frame ceiling, MW	RC ceiling, insulated
U-value floor/basement ceiling	0.09	0.11	0.09	0.14	0.11	0.10	0.14	0.13	0.16	0.11	0.13	0.12	0.11	0.18

Table 4: Insulation of opaque exterior elements – Project overview.
SL: sand-lime wall, MW: mineral wool, PS: polystyrene, RC: reinforced concrete, ETHICS: external thermal insulation compound system. U-values in W/(m²K).

2.3.4 Reduced thermal bridging

2.3.4.1 Thermal bridging

Transmission heat losses account for by far the greater part of the heat losses of Passive Houses. These include the heat flows through the regular building elements. However, transmission heat losses also occur at corners, edges, junctions and penetrations. Areas where the regular construction of external building elements is disturbed represent thermal bridges.

Some thermal bridges can hardly be avoided. One example is the elevated heat loss along the external corner of a building. The heat loss caused by such, so-called 'geometrical' heat losses can be estimated very simply on the safe side by calculating heat losses on the basis of the external surface area of the building element in question. In this case the calculated heat loss of the regular building elements is higher than the exact multidimensional heat flow.

The situation is different in the case of, for instance, a projecting balcony slab: this has the effect of a cooling rib. The additional heat losses of such a 'structural' thermal bridge are substantial; calculation based on external dimensions underestimates them drastically.

The actual heat losses caused by thermal bridging can be computed using multidimensional heat flow programmes. However, such computation is time-consuming and expensive. Moreover, the planner of a Passive House is generally not served by knowing the heat losses of the building elements. The aim must rather be to find overall designs with minimized thermal bridge losses. This is where the 'thermal-bridge-free construction' approach comes into play.

2.3.4.2 Thermal-bridge-free construction

Fortunately it is not necessary to analyse all thermal bridges by means of multidimensional heat flow computation when planning a Passive House. It is namely possible to determine without computation whether a detail represents a severe thermal bridge, solely through painstaking geometrical analysis. The following four rules assist in reducing heat losses:

- Prevention rule: Where possible, do not interrupt the thermal envelope.
- Penetration rule: Where an interrupted insulating layer is unavoidable, thermal resistance in the insulation plane should be as high as possible; this indicates use of e.g. aerated concrete or, better still, timber instead of normal concrete or sand-lime bricks.
- Junction rule: At building element junctions, insulating layers should meet without any gaps. Insulating layers should join without interruption or misalignment.
- Geometry rule: Design edges to have as obtuse angles as possible.

If all details are implemented according to the above basic rules, then the remaining thermal bridge losses will generally be very small. The thermal envelope can then be termed 'thermal-bridge-free'. This is because the slightly elevated heat losses at some points will be compensated for by the reduction in heat flows attributable to geometrical thermal bridges. Within the context of CEPHEUS, a complete computation of all thermal bridges was carried out for a number of buildings. This illustrated the practical feasibility of thermal-bridge-free construction: The computation of transmission heat losses including all thermal bridges delivered a smaller result than the computation with external dimensions without consideration of thermal bridges.

If, for construction reasons, the rules cannot be complied with at some points, it suffices to only have the details in question computed. The CEPHEUS technical report on thermal bridging [Feist 1999a] provides a precise definition and reasoning of thermal-bridge-free construction; that report also further concretizes the basic rules. Examples and an overview of measures to reduce thermal bridging are contained in [Schnieders 2001].

The principle of thermal-bridge-free construction is an important outcome of the work within the CEPHEUS project. Some parts of the building community take the view that, from a certain level of performance upwards, improved thermal insulation of external building elements no longer makes any sense because from some point onwards the reduced heat losses of the regular elements are irrelevant compared to the heat losses of the thermal bridges. This view is definitely not correct: It is of course true that the relative share of thermal bridge losses rises in step with rising insulation standard of regular building elements if the same details are implemented as before. However, CEPHEUS has now shown that major efficiency improvements are possible in the implementation of building element junctions, too. A complex computation of all details is not always necessary. This simplifies the planning of Passive Houses considerably.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Windows installed within the insulation plane[1]	C	I	O	I	I	I	I	C	C	C	I	I	C	N
Insulation overlaps window frames [2]	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Insulation planes connect without interruption [2]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Junction of floor slab / basement ceiling with external wall [3]	Walls rest on individual concrete humps on the slab	Purenit levelling course at foot of wall	Insulation on bottom side of floor slab taken around the slab	Shallow foundation	Aerated cement block course at base of wall	BC insulation joins EW without interruption or misalignment, reinforced by cog structure	Lightweight wall elements, thermal-bridge-reduced	BC insulation connected to EW, loads borne by laminated timber	BC ins. joins EW without interruption or misalignment, reinf. concrete columns on foam glass strips	BC insulation above floor slab connects without interruption with lightweight EW	Ytong course for thermal separation	Foam glass strips for thermal separation	BC ins. conn. without interruption to EW, slightly elevated wood proportion	Underground car-park, reinforced concrete columns penetrate ceiling
Fixing of balconies	Separate in front of external wall, or none	Separate in front of external wall	Separate in front of external wall	no balcony	no balcony	no balcony	no balcony	Isokorb technique	Suspended from rafters and steel struts	Separate steel structure in front of external wall	Separate in front of external wall	no balcony	no balcony	Projecting reinforced concrete ceiling

Table 5: Project overview: Thermal-bridge-free construction.

1) C: centred, O: outer edge, I: inner edge of insulation plane, N: not in the insulation plane; 2) Y: yes, N: no; 3) BC: basement ceiling, EW: external wall

2.3.5 Airtightness

Growing importance attaches to the airtightness of building envelopes. Leaking envelopes lead to a great number of problems that particularly need to be prevented in Passive Houses:

- Condensation water damage: If an air flow occurs from the inside to the outside through a leakage in the envelope, there is a particularly high risk of condensation in the construction.
- Draughts: Where there is a flow from the outside to the inside, a cold air flow near the leakage is the result.
- Cold air lake: Cold air flowing into the building will form, in the lower storeys of the building in particular, a lake of cold air at the floor. This is felt by occupants to be particularly uncomfortable and is unacceptable in Passive Houses.
- Elevated energy consumption: Air that flows inward or outward through leakages does not pass through the heat exchanger.
- Ventilation through gaps and cracks provides no reliable contribution to indoor air quality, as it is subject to extremely large fluctuations.

As ventilation through gaps and cracks provides no benefit but can have substantial disadvantages, Passive Houses must have excellent airtightness. The principles for this were elaborated in a special CEPHEUS building physics guideline [Peper 1999a]:

- **The 'single envelope' principle**

To achieve good airtightness, it is above all essential to define a rigorous concept for an airtight envelope. This must be guided by the principle of a single airtight envelope that encloses the entire interior space.

- **Planar airtightness**

The following have been found to have sufficient planar airtightness: internal plastering (lime plaster, lime-cement plaster, gypsum plaster, also reinforced loam plaster); plywood board, hardboard, particle board and OSB; PE foils and other durably stabilized plastic foils; bituminous felt (reinforced) and tear-proof (reinforced) building paper.

- **Airtightness of building element junctions**

It is here that the focus of planning work must be placed. In [Peper 1999a] we have provided a systematic overview of the sealing concepts available for Passive Houses.

- **Airtightness of penetrations**

Prevention continues to be the best principle (exhaust fans below roofs; services in skirting); in many cases pre-sealing can be recommended (e.g. pre-plastering of building services walls). Penetrations of concrete slabs can be sealed well by means of swelling mortar or gypsum (applied in a sufficiently liquid state).

Table 6 shows the solutions for ***airtight building envelopes*** applied in the 14 CEPHEUS building projects. All types of construction are represented:

- *Solid masonry: 02-Kassel-Marbachshöhe, 04-Egg, 05-Hörbranz and 12-Horn*

In all of these projects, masonry with continuous internal plastering was used as the airtight plane. Plastering was applied continuously from the upper edge of the carcass floor to the bottom edge of the carcass ceiling. Junction airtightness is achieved here by ensuring that plaster connects tightly to the ceiling and floor ("Anputzen – apu"). The junctions to the roof construction were sealed in 02-Kassel through plastering to the concrete ceiling, in the other projects through plastering over ("Einputzen – einpu") foils. Generally lime-cement plaster was used; in 12-Horn however a loam plaster. Window junctions differ from project to project.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenbur	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland , Lucerne	France, Rennes
Planar airtightness of basic constructions														
Type of construction	mixed	solid	timber	solid	solid	mixed	mixed	mixed	mixed	mixed	mixed	solid	timber	mixed
Floor slab / basement ceiling	Con-crete	Con-crete	Con-crete	Con-crete	Con-crete	Con-crete	Con-crete	Con-crete	Con-crete	Foil	Con-crete	Con-crete	Foil	Con-crete
External wall 1	Foil G	Plaster	Foil I	Plaster	Plaster	Foil I	OSB	Foil	Foil	Foil G	Loam plaster	Plaster	Foil I	South: Plaster
External wall 2	Con-crete	-	-	-	-	Foil I	-	-	-	-	Foil G	-	-	North: Foil
Uppermost ceiling	-	Con-crete	-	Plaster	-	Conc. + DS	Con-crete	Con-crete	-	Con-crete	-	-	Foil G	Con-crete
Roof	Foil G	-	Foil G	OSB	Foil I	-	-	-	Foil	-	Foil I	*Alu. foil aPl ?*	-	-
Airtightness of junction details														
Ground floor floor slab / EW1	F-vkl	apu	Dprof	apu	apu	üF;k	Dprof	Mon	F-vkl	üF;k	apu	apu	üF;k	apu
Ground floor floor slab / EW2	-	-	-	-	-	üF;k	-	-	-	-	F-vkl	-	-	?
EW1 / EW2	-	-	-	-	-	üF;k	-	-	-	-	einpu	-	-	?
EW1 / window	F;Klb	Man	F-vkl	Fuab	Fuab	F-vkl	?	Kom	F-vkl	Fol-a	ÜpFl	Fuab	F-vkl	apu
EW2 / window	-	-	-	-	-	F-vkl	-	-	-	-	ÜpFl	-	-	?
EW1 / interior ceiling	FStr	apu	FStr	apu	apu	FStr	Dprof	Mon	F-du	F-du	apu	apu	F-du	apu
EW2 / interior ceiling	-	-	-	-	-	FStr	-	-	-		einpu	-	-	?
EW1 / uppermost ceiling (roof)	F;Klb	apu	üF;k	einpu	einpu	üF;k	Dprof	Mon	ÜF;k	F-vkl	einpu	?	üF;k	apu
EW2 / uppermost ceiling (roof)	-	-	-	-	-	üF;k	-	-	-		üF;k	-	-	?

EW = external wall

Table 6: Project overview: Solutions for airtightness of the building envelope

LEGEND for planar basic constructions:

Concrete	=	Concrete ceiling, airtight; Concr. + DS = concrete ceiling+vapour barrier foil on top
Foil	=	Polyethylene foil as airtight sealing; G=below gypsum panel; I= behind building services space
Plaster	=	Gypsum, lime or lime-cement plaster as internal plaster, applied continuously over whole surface
OSB	=	Oriented strand board
Alu.foil aPl	=	*Insulating panels, with interior aluminium lamination, glued with aluminium foil (note: not recommendable, and found to be insufficiently airtight in the project)*

LEGEND for airtightness of junction details:

apu	=	**a**nge**pu**tzt (plastering into corners)
einpu	=	Folie **ein**ge**pu**tzt (foil edge plastered over)
ÜpFl	=	überputztes Fliesklebeband (plastered-over adhesive fibre-mat strip)
Man	=	Dicht**man**schette, eingeputzt (plastered-over gasket)
Dprof	=	**D**icht**prof**il (sealing gasket)
F;Klb	=	**F**olie; mit **Kl**ebe**b**and angeklebt (foil; glued on with adhesive tape)
FStr	=	**F**olien-**Str**eifen, über die Verbindung gelegt, mit jeweiliger Dichtebene verklebt (foil strips laid over joint, glued to respective airtight plane)
üF;k	=	**ü**berlappende **F**olien; ver**k**lebt (overlapping foils; glued)
F-vkl	=	**F**olie-**verkl**emmt; Fol-a = Folie, Fuge mit Silikon abgespritzt (foil jammed; Fol-a = foil, joint injected with silicon)
F-du	=	**F**olie-**du**rchgehend (uninterrupted foil)
Mon	=	Folie - mit Montagewinkel am Beton befestigt (foil fixed to concrete by seat angle)
Kom	=	Kompriband (airtight elastic compression band)
Fuab	=	Fugenabspritzung mit Silikon oder Acryl - verfugt zum Fensterrahmen (joints injected with silicon or acryl)
?	=	*junction not planned in detail; problematic junction*

- *Lightweight timber: 03-Gothenburg and 13-Lucerne*

These two projects relied on foil systems; junction details use overlapping and glued foils. Projects involving lightweight constructions in the envelope also include 01-Hannover, 06-Wolfurt, 07-Dornbirn, 08-Gnigl, 09-Kuchl and 10-Hallein.

- The solutions with *mixed envelopes* are a special case. For instance, the 11-Horn single-family house was constructed with a lightweight wall to the south (foil solution) and solid walls to the east/west and north. Here junctions are sealed by applying interior plaster over the edges of the foils.

2.3.6 Passive-House-compliant windows

2.3.6.1 Basic requirements upon windows in Passive Houses

In a Passive House, windows need to even permit net solar gains, above and beyond their normal lighting function. The preconditions for this are: Low heat losses through the window, suitable glazing, and, if possible, southward orientation and low degree of shadowing. Because the Passive House no longer needs a separate heating system, a further requirement is that occupant comfort directly in front of the window must be ensured despite there being no radiator.

From the comfort requirement, the need for a window U-value of less than 0.8 W/(m²K) can be derived within Central European climate (cf. on this e.g. [Schnieders 1999a]). If a window is small, this value can also be exceeded slightly.

2.3.6.2 Passive-House-compliant glazing

The U-value of the glazing must also not exceed 0.8 W/(m²K). This value can only be achieved with triple low-emissivity (low-e) glazing (or by evacuated double glazing). The pane interspace in such glazing is filled with heavy noble gases in order to reduce convective heat transport. In order to also control the second important heat transport mechanism in the glazing, namely radiative heat transport, the surfaces facing towards the interspace are coated with an infrared-reflecting material. Such glazing achieves, depending upon the fill gas and the coating, U-values down to 0.6 W/(m²K) (including the additional coefficient for fill gas losses that occur during the glazing's service life).

Besides limiting transmission heat losses, the second function of the high-performance glazing is to permit passive solar gain. Consequently, the total solar energy transmittance (TSET, the g-value) needs to be maximized. Triple glazing with iron-free glass ('white glass') achieves a TSET of up to 60 %, which is hardly lower than that of conventional double glazing. However, for cost reasons, generally glazing with a TSET around 50% is used.

Schnieders [1999a] presents the energy balance of a south-facing window with triple glazing, on a monthly basis. This shows that even in the short heating season of the Passive House, from November to March, the energy balance is positive. In contrast, double low-e glazing has net losses in the core winter period.

It follows that the TSET of a Passive House glazing must reach a certain minimum value, as a function of the U-value. This requirement upon the glazing can be formulated as follows: $U < 1.6\ \mathrm{W/(m^2K)} \cdot g$. This ensures under a Central European climate that the energy balance of a south-facing window with this glazing is positive over the heating season of the Passive House – under the precondition that the window frame used is appropriate and shadowing is limited.

Passive-House-compliant glazing is now (2001) produced in series by various manufacturers. The Passive House Institute has certified the glazing of six manufacturers; further manufacturers supply high-quality triple low-emissivity glazing.

2.3.6.3 Glazing edge losses and their reduction

Low-e glazing has an edge seal that joins the individual panes and encloses the fill gas. The resultant thermal bridge at the edge gains importance with the high insulation standard of the Passive House envelope: An edge seal system using aluminium spacers can be responsible for 20–30 % of the heat losses of a Passive House window. In the Passive House, this thermal bridge is minimized by means of increasing the depth to which the glazing is inserted within the sash/frame, and by using stainless-steel or plastic spacers. [Schnieders 1999a] provides a detailed discussion of the heat losses of windows.

2.3.6.4 Passive House frames

A growing number of window frames of adequate quality for use in Passive Houses is available (cf. Figure 4).

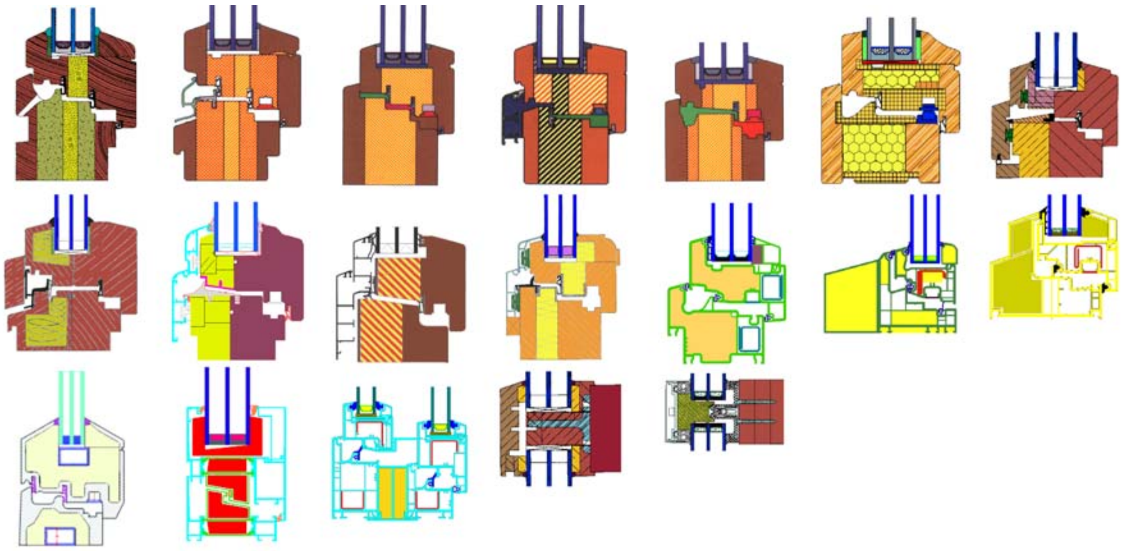


Figure 4: Overview of the window frames certified by the Passive House Institute as 'Passive-House-compliant components' (as per February 2001)

Window frames for Passive Houses need good thermal insulation; this can be achieved in various ways. Several manufacturers supply wooden frames with a core consisting of PU foam or Purenit (a recycled PU material, with relatively low thermal conductivity but nonetheless high load-bearing performance). Constructions consisting entirely of wood and wood-based materials are also available. Several manufacturers supply thermally-insulated plastic frames; these should permit a significant reduction in the price of this component in the future. All Passive-House-compliant window frames have an increased depth to which the glazing is inserted within the sash/frame, in order to reduce thermal bridging at the glazing edge.

2.3.6.5 Thermal-bridge-free installation

The excellent thermal qualities of the Passive House windows only bear fruit if the window is installed correctly. Particular problems arise in this connection in solid-construction buildings made of concrete or sand-lime bricks, because these materials have a particularly high thermal conductivity. If installation is poor, the U-value of the window can deteriorate by 0.5 W/(m²K). In contrast, if it is installed correctly then the thermal bridge loss coefficient of installation can even be 0.

Important aspects of correct window installation are the positioning within the insulation plane of the thermal envelope, and ensuring that insulation overlaps the window frame as far as possible. Jamb elements with high thermal conductivity, such as particle board, must be avoided as far as possible. However, individual point thermal bridges for window mounting are permissible. [Schnieders 1999a] sets out these rules and their background in more detail.

2.3.6.6 Overview of the windows used in the CEPHEUS sub-projects

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
U-value glazing[1]	0.8	0.6	0.7	0.7	0.6	0.7	0.7	0.6	0.7	0.7	0.8	0.6	0.6	1.3
g-value (TSET) glazing[2]	0.6	0.42	0.4	0.53	0.47	0.53	0.53	0.47	0.5	0.53	0.51	0.53	0.42	0.64
Type of frame	eurotec serie 0.5 Wood-aluminium	VEKA Artline Passivhaus PVC	SSC Snidex Wood	Sigg Standard wood frame	Fenster Bischof Wood	Sigg „Passivhaus“ Wood with Purenit	Fussenegger und Rümmele, Wood	Kogseder Wood-Aluminium with cork	Freisinger Drei3Holz Wood with insulation	eurotec eCO_2 PVC, PU-foamed inside	Improved wood permitting large insulation overlap	eurotec eCO_2 PVC, PU-foamed inside	Bachmann AG Wood-aluminium	Standard wood frame
U-value frame	0.57	0.80	n.d.	1.25	1.12	1.0	1.5	0.8	0.73	0.75	1.1	0.75	1.2	1.5
Edge seal (spacer)	Swisspacer	Stainless steel	Stainless steel	Thermix	Stainless steel	Thermix	Thermix	Thermix	Swisspacer	Thermix	Stainless steel	Thermix	Stainless steel	Aluminium
Orientation of main glazed areas	S	E/W	S	S	S	S/W/ N/E	S/E	SW	S/W/ N/E	S	S	SW	S	S

Table 7: Project overview: Windows.

1) Published (Bundesanzeiger) values or appropriately adjusted values, where the necessary information was available.
2) g-value (TSET) according to DIN 67507.

2.3.7 Air distribution system

To achieve the Passive House standard in Central Europe, a high-performance ventilation system with heat recovery is indispensable. These are systems with controlled air supply and extraction through a separate duct network distributing inflowing and outflowing air. In [Pfluger 1999], the planning guidelines are elaborated and experience in detailed planning and system operation discussed. Air distribution depends greatly upon the type of ventilation system and the geometry of the building. It became apparent in the CEPHEUS projects that individual systems continue to be realized most frequently today (see Table 8), preferentially for single-family and terraced units. In these systems, each dwelling unit is supplied separately through a heat exchanger.
The central ventilation unit (comprising heat exchanger, ventilators, filters, control system and possibly also sound absorbers) can be positioned both within and outside of the thermal envelope, but as close as possible to the entry point to the envelope. If a subsoil heat exchanger is used, it makes sense to position it in the basement or on the ground floor. If, in contrast, a frost protection heating register is used, then the central unit can also be placed in the attic or in a storage or building services room. For the supply air

duct network, sound absorbers are necessary both for the main duct and as telephonic sound absorbers in the individual ducts.

Individual systems can also be employed in multifamily and apartment buildings. However, the control of the exhaust air from the individual dwelling units can then be problematic. The contaminated exhaust air must be prevented from entering the air intake of the same or a neighbouring dwelling unit. In order to fully prevent all odour nuisance, the air can be exhausted through a common duct over the roof. A disadvantage of this option is the large number of necessary wall penetrations and the associated thermal bridges.

In centralized systems, several dwelling units are supplied with one heat exchanger. In the volume flow range above 1000 m³/h, high-quality counterflow heat exchangers from the air-conditioning sector are available in the most varied unit sizes. These can be positioned either in the basement or under the roof, or in a separate building services room.

Semi-centralized systems are those with a common heat exchanger but distributed ventilators [Otte 2000]. This variant of the centralized system utilizes the benefit of the lower cost associated with jointly used components such as heat exchanger, filters and possibly sound absorber, but implements flow control through the individual ventilators. Thus each dwelling unit can set the volume flow individually without having to accept a pressure loss caused by dampers. The supplementary heating of the supply air is then also in a distributed fashion through dwelling-specific heating registers; the setpoint indoor air temperature can thus be determined individually for each dwelling unit.

The outdoor air should enter the occupied zone as completely as possible and should convey contaminants as swiftly as possible to the extract air without impairing occupant comfort. This already summarizes the two most important principles of air distribution, namely that short-circuiting must be prevented and a directed flow through the building must be achieved from the supply air rooms (living rooms and bedrooms) towards the extract air rooms (functional rooms: bathrooms, WC etc.). The transfer zone is the zone in which there are neither supply air nor extract air vents. In these zones, transfer openings permit inflow from the fresh air rooms and outflow to the extract air rooms.

For the building services engineer, the most important design parameter is the air change rate, i.e. the ratio between the outdoor air volume supplied per hour and the room volume (unit: 1/h). However, if the outdoor air enters the extract air flow directly, i.e. if there is short-circuiting, then the purpose of the ventilation system is not fulfilled even if the air change rate is high. Consequently, not only the air change rate is important, but also the ventilation effectiveness (for a definition see [Pfluger 1999]). There are two options for preventing short-circuiting: If disk valves are used as supply air vents, then these must be positioned on the wall opposite the transfer opening. This provides good air flow through the room, but necessitates a relatively long supply air duct network. By means of wide-angle nozzles on the room ceiling, the supply air can also be conveyed into the room close to the transfer opening. The flow then initially remains under the ceiling and mixes almost completely with the air in the room. This makes it possible to use relatively short supply air duct networks, if the connection to the central ventilation unit is provided by means of rising ducts in the building core.

When positioning the supply and extract air vents care further needs to be taken that no draughts arise, i.e. that the permissible air speeds in the occupied zone are not exceeded. However, human 'draught sensitivity' depends not only upon air speed, but also upon air temperature. This aspect is relatively unproblematic for Passive House ventilation systems, because the supply air is already preheated before it enters the

room. Even if no supplementary supply air heating is provided for, the temperature after the heat exchanger is above 16.5°C.
An important criterion of occupant comfort for the ventilation system is noise protection. This is influenced not only by the central unit, but also considerably by the air distribution system. The most important elements in this connection are the duct network and the sound absorbers integrated within it, and the shapes and positions of the supply and extract air vents. To prevent structure-borne noise, the supply air duct network can be connected to the central unit with, for instance, canvas connecting pieces. The principle of structure-borne noise decoupling must of course also be applied with distributed systems that have individual ventilators in the dwelling units. Here, as implemented in e.g. project 02, rubber sleeves can be used to connect the ventilators.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Building type 1)	T	A	T	A	T	A	S	A	A	A	S	T	T	A
Positioning of heat exchanger 2)	R	4xR, 1xB, D	D	2xR 2xB	D	S	D	D	D	D	B	B	B	R
Heat recovery centralize, semi-centralize or distributed 3)	d	s	d	d	d	d	d	d	d	d	c	d	d	c
Subsoil heat exchanger used	no	no	no	yes	yes	yes	yes	no	no	no	yes	yes	yes	no
Supple-mentary supply air heating used 4)	yes	yes	yes	no	yes	yes	yes	yes (partly)	yes (partly)	no	yes	yes	yes	yes
Type of supply air valves 5)	W	W	W, U	I	W	W	I	W	W	U	W	D, W	W	D
Duct type 6)	Fo	Fo	Fo	Fo	Fo	Fo	Fo	Fo	Fo	p F	Fo	Fo	Fo	Fo

Table 8: Project overview of air distribution systems.
1) S: single-family house; T: terraced house; A: apartment building; 2) R: roof, B: basement, S: services room, D: dwelling; 3) d: distributed, c: centralized, s: semi-centralized; 4) (part): partial heating through supply air; 5) W: large distance nozzles, D: disk valves, I: induced swirl nozzles, U: upwelling slits in floor; 6) Fo: folded spiral-seam, p: plastic, F: flat duct

2.3.8 Subsoil heat exchanger for air preheating

Subsoil heat exchangers are a good way to keep the heat exchanger of the ventilation system frost-free. If laid at sufficient depth (approx. 1.5 m) a separate frost protection heating register or other defrosting devices can be dispensed with completely. Moreover, larger subsoil heat exchangers can contribute to supplementary preheating of the fresh air. Particularly where heat exchangers are less efficient, this improves the effectiveness ratio of the overall system. However, subsoil heat exchangers can only be cost-effective if the costs of excavation and laying are kept low. Laying within the excavated space needs no further excavation work and can thus be carried out very economically. However, higher efficiency can be achieved if the ducts are laid under the floor slab of the building. Further indications concerning configuration, design and sizing are set out in [Pfluger 1999].

Where packaged Passive House building services units comprising heat pumps are used, the use of a subsoil heat exchanger is in most cases requisite for winter-time operation. Consequently, there is a relatively large number of systems using subsoil heat exchangers within the CEPHEUS project.

Theoretically, subsoil heat exchangers could also be used for summer-time cooling of the fresh air. However, the pipe registers are generally sized for winter-time operation (fresh air preheating); consequently the summer-time cooling capacity is limited to less than one kilowatt (single-family house with ca. 120 m³/h). This can only provide a slight reduction in indoor air temperature; sufficient shading and night-time airing are much more efficient. In office buildings, in contrast, the subsoil heat exchanger can be so large that a significant contribution is provided to preventing summer-time overheating. Here, however, it needs to be noted that in summer-time operation in particular there will be condensation in the subsoil heat exchanger. No hygienic problems have yet been reported for this type of operation, but no complete scientific clarification of its impacts upon microbiological growth processes has yet been carried out. Regardless of the type of operation, the pipe registers must always be laid with an adequate slope in order to be able to discharge the condensate through a siphon to the sewerage.

No.	04	05	05	06	07	11	12	13
Project	Austria, Egg	Austria, Hörbranz House I	Austria, Hörbranz Houses II+III	Austria, Wolfurt (Block A+B)	Austria, Dornbirn	Austria, Horn	Austria, Steyr	Switzerland, Lucerne
Positioning of subsoil heat exchanger, distance to outer edge of the building 1)	e	e, 1 m	e, 1 m	e, 1 m	e, 1 m	f	p	e
Type of air flow 2)	T			T		T		parallel
Pipe material	PET pipe 160 mm	PE	PE	PE	PE	PE	HDPE	PE welded
Laying depth [m]	1.2-2	1.5	1.5	1.5	1.5	1.5	1.7-2.5	1.5 –1.7
Number and length of pipes [m]	4x40	1x28	1x45	4x35	1x25	ca. 2x 25	ca. 25	1x30
Diameter of pipes	DN 160	DN 200	DN 250	DN 250	DN 200	DN 160	DN 200	DN 200
Minimum outlet temperature (projected)		5 °C	5 °C	4 °C	5 °C	3 °C		
Minimum outlet temperature (measured)	4.1 °C		I: 5.6 °C II: 6.0 °C	A: 3.2 °C B: 4.1 °C				+ 2 °C
Heat exchanger effectiveness ratio (measured)	20 %		I: 32 % II: 33 %	A: 18 % B: 23 %				17 %
Operating season 3)	S/W	S/W	S/W	S/W	S/W	S/W	W	S/W
Filter 4)	b	b (F6)	b (F6)	b (F6)	b (F6)	b	b	b

Table 9: Project overview of the subsoil heat exchangers used.

1) b: below floor slab, e: in excavation, f: in front of building, p: partly in front of, partly below floor slab 2) T: Tichelmann, M: meander, S: special design 3) S: summer, W: winter, S/W: summer and winter 4) b: before exchanger, a: after exchanger

2.3.9 High-efficiency ventilation heat recovery

To bring the space heat requirement down below 15 kWh/(m²a), structural measures alone do not suffice in Central Europe. If simple air extraction systems or window ventilation are used, the index can scarcely be brought below 30 kWh/(m²a). Nor can the target generally be achieved with mediocre heat recovery systems (e.g. crossflow heat exchangers with effectiveness ratios of ca. 50 %).

It is only by means of high-efficiency Passive House heat recovery systems that the target can be achieved with an acceptable structural effort given the current state of the art. Effectiveness ratios of at least 75% are required; as field measurements conducted within CEPHEUS have shown, these ratios can indeed be achieved and even exceeded by means of counterflow heat exchangers.

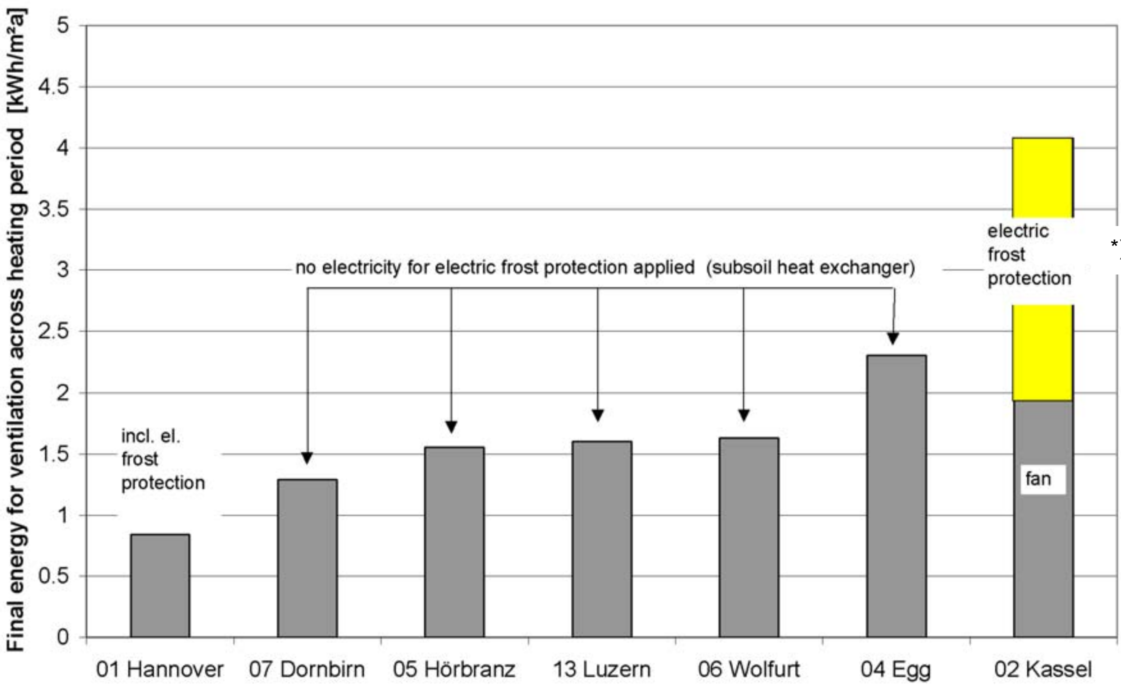
However, high overall efficiency is only achieved if the reduction of ventilation heat losses is not at the price of high electric power input. Electricity-saving fans and low pressure losses in the system are the preconditions to this. Under these preconditions, efficient systems achieve annual performance factors of 10 to 15 (ratio between heat saved and electricity consumed).

Into the 1980s, crossflow heat exchangers made of sheet metal were the main type used. This construction principle is relatively simple in manufacture, but has severe disadvantages in terms of heat transfer. For one thing, the heat recovery ratio is limited to 55%; for another, the longitudinal heat transmission in the metal plates further reduces the heat recovery ratio.

Today, high-efficiency heat recovery systems almost exclusively use counterflow heat exchangers made of plastic. The plastic fins are usually profiled, and can thus form quadrangular or triangular channels, thereby increasing the heat transfer surface. With such heat exchangers, effectiveness ratios above 75% can be achieved in present systems in practice. The Passive House concept has been an important pacemaker for this development.

In addition to improved heat exchangers, the introduction of electronically commutated motors (ECM) as fan drives and of improved wheel geometries have contributed substantially to improving efficiency. Wattage has been reduced considerably compared to conventional asynchronous motors. These motors were used for the first time for the ventilation of the dwellings built within the context of the 'Darmstadt Kranichstein Passive House' research project ([Feist 1992], [Feist 1994a]). The comparison of an asynchronous motor with electronic controller and an electronically commutated motor yields astonishing results. Even a high-quality asynchronous motor in the 30–100 W power input range can achieve at best an efficiency of 50%; if a controller or frequency converter is used, efficiency will drop to values below 5%. Depending upon the working point of the fan, the ECM motor almost always achieves 80%, but never drops below 60%. Not only the motor and the wheel determine the power absorbed by the fans, but above all pressure losses in the unit and external pressure losses in the duct network. It lies in the nature of the matter that the passage of air in the unit is associated with numerous changes of direction. In this regard, too, optimization towards minimized pressure losses has been possible in recent years by means of numeric flow simulation (CFD). External pressure losses can also be further reduced through meticulous planning of the duct system.

0.45 Wh per m³ air conveyed is the limit for ventilation systems compliant with Passive House standards. This is joined by the additional energy input for frost protection if no subsoil heat exchanger is used. The measured data of seven CEPHEUS projects in which the electricity consumption of the ventilation system was recorded separately show that consumption remained well below this limit (mean: 0.26 Wh per m³ air conveyed). Figure 5 illustrates the measured final energy consumption levels per m² floor space. In the CEPHEUS projects 04, 05, 06, 07 and 13 a subsoil heat exchanger provides frost protection; in the projects 01 and 02 this is provided by an electric preheating register. In project 02 (Kassel), the controller for this was set incorrectly, so that preheating already switched on at an outdoor temperature of ca. 5°C. This error will be corrected in the next heating season. It can therefore be expected that consumption for frost protection in this project will drop by some 1.5 kWh/(m²a). The mean value for the other projects is 1.54 kWh/(m²a).



*) incorrect setting of frost control system in the 1st heating season

Figure 5: Measured electricity consumption of ventilation systems

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Heat exchanger configuration 1)	d	c	d	d	d	d	d	d	d	d	c	d	d	c
Building type 2)	T	A	T	A	T	A	S	A	A	A	S	T	T	A
Manufacturer	Paul (D)	Lüfta (D)	Themovex (S)	AEREX without heat pump (A)	2xAEREX WP + 1x AEREX without heat pump	AEREX without heat pump (A)	AEREX WP (A)	Mag. Schöpf (A)	REWA (A)	Wernig (A)	REWA (A)	Westaflex (D)	AEREX WP (A)	Themovex (S)
Heat exchanger type 3)	channel	counter	counter	CC	CC	CC	CC	counter	counter	channel	counter	counter	CC	counter
Effectiveness ratio acc. to manufacturer or rating	99	85	90	79	79	79	79		80		80	89	79	82
Effectiveness ratio measured in the CEPHEUS project	78	83						79						
Exhaust air heat pump	no	no	no	no	yes	no	yes	no	no	no	no	no	yes	no
Control 4)	t,m	m	m	m	m	m	m	m	m	m	m	m	m	m

Table 10: Project overview of heat recovery systems.
1) d: distributed, c: centralized 2) S: single-family house, T: terraced house, A: apartment building 3) counter: counterflow, cross: crossflow, CC: cross-counterflow, channel: channel counterflow 4) m: manual, t: time-controlled

2.3.10 Active solar energy utilization

2.3.10.1 Contribution of active solar energy utilization

In Passive Houses, the active thermal utilization of solar energy is subject to exquisite boundary conditions. By far the greater part of annual heat demand (in some cases more than 70 %) is for domestic hot water (DHW) heating. As this demand arises largely evenly throughout the year, in contrast to space heating demand, the conditions for installations with a high solar fraction of overall heat supply are favourable. In agreement with figures reported in the literature, expedient solar fractions of DHW heating ranging from 55 % to 65 % result for Passive Houses, too [Rockendorf 1997b].

The thermal losses within the system are high (35 % to 40 % in single-family house installations, [Rockendorf 1997b]). This is regardless of the solar fraction. It is thus important to optimize piping lengths and storage sizes. System components should be positioned largely within the thermal envelope so that their losses contribute to meeting the space heat requirement during the heating period.

For single-family Passive House installations, the costs of solar heat are currently above the prices of conventional heat generation (e.g. by a gas burner). Multi-user installations with centralized buffer storage have a substantially lower heat price, comparable to that of conventional heat generation [Rockendorf 1997a].

2.3.10.2 Overview of solar installations in the CEPHEUS sub-projects

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Building type [1]	T	A	T	A	T	A	S	A	A	A	S	T	T	A
Solar thermal installation														
Manufacturer	Wagner Solartechnik	-	n.d.	Doma	Rosskopf	Doma	n.d.	Rosskopf	Doma	Sonnenkraft	Haglage (assembly kit)	Sonnenkraft	-	Clipsol
Type [2]	F	-	F	F	F	F	F	F	F	F	F	F	-	F
Configuration [3]	d	-	d	c	c	c	c	c	c	c	c	d	-	c
Collector area A_K [m²]	126	-	100	26	54	43	6	20	75	108	10	16.2	-	81
Collector slope	23.5°	-	27°	30°	90°	45°	45°	50°	25°	45°	18°	45°	-	55°
Orientation S (0°), W (90°)..	15°	-	340°. ...20°	38°	350°	0°	~ 0°	~ 20°	5°	45°	0°	0°	-	0°
Mounting [4]	r	-	r	r	f	s	r	s	r	s	r	r	-	s
Specific collector area (A_K/TFA)	3.5 %	-	3.6 %	8.4 %	14 %	3.3 %	4.8 %	6.1 %	4.2 %	5.2 %	5.8 %	3.5 %	-	3.1 %
Photovoltaic array	No	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No

Table 11: Project overview: Solar installations in CEPHEUS.
1) T: Terraced house, A: Apartment building, S: Single-family house, 2) F: Flat plate collector, 3) d: distributed, c: centralized, 4) r: roof-mounted, f: façade-integrated, s: separately field-mounted.

2.3.10.3 Solutions within CEPHEUS

The following section presents some of the solutions implemented within the CEPHEUS projects. In 05-Hörbranz, façade-integrated collectors were used. Here the collector and the external wall element are not thermally separated. The prefabricated wooden collector element is mounted on a wooden substructure. Oriented strand board (OSB) separates the absorber space from the cellulose insulation of the external wall construction. The simple construction needs no further vapour barrier towards the collector space. The glass cover is held on the sides by sections. The beneficial aspects of this design include the improved thermal insulation of the collector, the reduction of costs and the freedom from snow in winter. In addition to utilizing the excellent insulation of the external building element jointly, the integrated collector also reduces the transmission losses of the external element, because its temperature is elevated most of the time compared to the outdoor air.
The 90° slope reduces the annual yield of the solar installation compared to the optimum slope; on the other hand, the seasonal yield in winter is increased, and yield is more balanced over the year.

In 01-Hannover, a distributed solution provides a compact system. This reduces the piping lengths of the solar loop, the heat losses and the temperature decline to the hot water tap. The tap water storage is located within the thermal envelope in the roof storey of each terraced house. When supplementary heating is needed, use is made of a connection to the district heating network.

In some cases, centralized multi-user systems supply additional space heat. In 09-Kuchl (25 dwelling units), a 75 m² collector system and a wood pellet burner heat up a 3 m³ centralized buffer storage tank. Heat for space heating and for hot water heating are delivered in a dwelling-unit-specific manner. This combination of systems provides excellent primary energy performance indexes (in Kuchl the primary energy requirement for hot water and space heat figured some 11 kWh/m² from October 2000 to March 2001. The calculation is based upon a primary energy factor for wood pellets of 0.1).

2.3.11 Space heat distribution

2.3.11.1 A unique feature of the Passive House: How space heat is delivered is irrelevant

The core idea of the Passive House is to improve thermal insulation to the point at which the still necessary space heat requirement can be conveyed by the ventilation system. Heating loads in Passive Houses are limited to 10 W/m². At the same time, the thermal envelopes of Passive Houses are so well insulated that no disturbing radiative temperature asymmetries in the rooms can occur in connection with heat delivery. This means that the exact location of the heat source can be chosen freely; there is no longer any need for heated compensation surfaces. Similarly, the type of heat transfer, from purely convective through to radiative, can be chosen within a wide range.

A ‘classic’ radiator can continue to be useful in a Passive House, too. Thanks to the balanced radiative temperatures in the rooms, attention can concentrate on space-saving positioning and on optimizing the lengths of supply lines.

Building-element (floor or wall) heating with very low flow temperatures can also be used in Passive Houses. Where heat pumps are used, the low flow temperatures lead to high heat pump performance factors.

For Passive Houses, heat delivery via the air supply system is of particular interest. It follows from the requirements upon Passive Houses that a supply air distribution system is necessary in any case in order to bring fresh air into the occupied zones, which is needed for reasons of air quality. It is permissible to heat the supply air to ca. 50°C (higher temperatures could lead to dust carbonization in the supply air and possibly in the supply air ducts) by means of a heating register downstream from the heat recovery unit. The maximum heating capacity thus achieved covers the heating loads arising in Passive Houses comfortably. A part of the heat delivery already takes place through the supply air duct network; consequently, the supply air ducts must be positioned as completely as possible within the insulated and heated space. This heat delivery is even advantageous, as it reduces the supply air temperature at the supply air vent. In addition, this type of heat delivery can be put to use in order to transport heat into extract air rooms (e.g. bathrooms). Supply air heating can simplify heat delivery and distribution in Passive Houses significantly.

Space heat distribution is unproblematic as long as it proceeds within the thermal envelope. As heat distribution losses arise during the heating period, they benefit space heat almost completely. The same does not apply to hot water supply and circulation pipes, because these deliver heat throughout the year, not only in the heating season. Supply lines outside of the thermal envelope must be very well insulated. Any distribution losses that these cause gain importance greatly because of the low heat requirement of Passive Houses.

2.3.11.2 Overview of heat distribution systems in the CEPHEUS sub-projects

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Building type [1)]	T	A	T	A	T	A	S	A	A	A	S	T	T	A
Supplementary supply air heating	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Radiators [2)]	Bathroom	Bathroom	-	-	Bathroom, EH	Bathroom	Bathroom, EH	-	Several	Several	-	Bathroom, EH	-	-
Building element heating [3)]	-	-	-	F	-	-	-	W	-	-	W	-	-	-
Max. heating load [W/m^2] [4)]	7.1	7.5	5.3	10.6	11.0	10.9	14.9	11.8	9.4	9.0	12.3	8.2	10.0	15.3
Thermal zones	Bathroom, rest	Bathroom, rest	One	Several	Bathroom, rest	Bathroom, rest	Bathroom, rest	Several	Several	Several	Several	Bathroom, rest	One	One

Table 12: Project overview of heat distribution systems in CEPHEUS

1) T: Terraced house, A: Apartment building, S: Single-family house, 2) EH: electric heating, 3) F: floor, W: wall, 4) Calculated by PHPP method.

2.3.11.3 Solutions within CEPHEUS

This section presents some examples of the ways heat distribution was implemented in the sub-projects. In 01-Hannover, space heat is provided via the supply air. The supplementary air heating register is downstream from the heat recovery unit in the supply air system, and is positioned next to the hot water storage tank in the building services storey. Beyond an additional radiator in the bathroom, no further heat transfer systems are installed. This simplifies the heat supply lines and heat transfer to the indoor air greatly, making the associated systems very compact. During intensive two-week measurements (27.11.99 to 10.12.99) in one of the houses, only very small differences were found between the average air temperatures of different zones [Kaufmann 2001]. The deviations of the means are smaller than 0.3 K. In Hannover, the supply air heating is controlled by a central room thermostat. The small differences are indicative of balanced thermal comfort in the occupied rooms. Analysis of all houses during the heating season has shown that the supplementary air heating permits individual temperature selection, and that heating capacities were always sufficient. In the occupied houses, average indoor air temperatures across the whole heating season ranged from 19.4°C to 23.4°C.

The heat delivery of uninsulated supply air ducts can also be used to deliver additional heat to extract air zones. In the 02-Kassel and 13-Lucerne sub-projects, the uninsulated supply air ducts pass through the bathroom. In 13-Lucerne, this makes it possible to dispense with an additional heater in the bathroom. In 01-Hannover, in contrast, the ducts are insulated in order to counteract too early heat delivery through the longer duct system.

Building-element heaters are also used: floor heating in 04-Egg and wall heating in 08-Gnigl. The floor heating operates with a maximum flow temperature of about 35°C. The heating pipe network in the floor covers almost the whole occupied area. To deliver the normal heating loads required in Passive Houses (10 W/m^2), excess temperatures at the heating surfaces of about 1 K suffice [DIN 4725]; the flow temperature of 35°C is generous for a Passive House. A reduced heating surface ratio would be sufficient and would reduce costs. Floor heating generally counts among the more expensive solutions; however, in operation at low flow temperatures, it is a good supplement to heat production with heat pumps.

Insulation measures unfortunately often failed to consider the fittings; here a potential for further optimization remains.

In some cases redundant systems were used that transfer space heat to the rooms through supplementary supply air heating plus additional systems. These solutions meet their purpose, but increase the investment costs of the heating system. The next heating seasons will show whether this 'double' heating equipment is really necessary.

2.3.12 Heat supply for the CEPHEUS sub-projects

2.3.12.1 Options for meeting the low remaining heat requirement in Passive Houses

The supply of heat to Passive Houses differs from that of conventional residential buildings in decisive points: As set out above, the annual heat requirement is extremely low at 15 kWh/m². Due to the energy efficiency of the Passive House, the domestic hot water (DHW) requirement gains importance – indeed, it becomes the dominant heat requirement. Under these changed boundary conditions, small, simple supply systems become feasible, and the diversity of options grows. In view of the dominance of DHW over space heat supply, interest focuses primarily upon finding efficient and economical DHW supply systems; space heat supply is implemented in passing. Of course, all present supply variants in conventional houses are suitable for this, too.

In multifamily buildings, a distinction can be made between centralized and distributed heat supply systems. Centralized heat supply in multifamily buildings concentrates the low heat demand of the individual dwelling units. This makes it possible to use more complex and cost-intensive, conventional heating systems in multifamily Passive Houses.

Decentralized systems need only micro heat producers or are operated by district heat. Such systems can be positioned completely within the dwelling units. Supply lines are reduced, and heat losses largely benefit the dwelling unit during the heating season.

Supply with natural gas or district heat presupposes the corresponding infrastructure. Moreover, provision of a natural gas or district heat connection involves the levy of a basic charge which, given the small demand of Passive Houses, exceeds the energy costs of a house. Procuring district heat and establishing a heat transfer station only appears expedient for larger projects with more than 5 dwelling units.

Besides conventional supply variants, additional, new concepts suggest themselves for the Passive House. 'Packaged building services units' tailored specifically to Passive Houses are an innovation in building services engineering. Such packaged units comprise the entire ventilation technology, the DHW storage and the micro heat producer. In the interests of keeping total costs low, the investment costs of heat supply gain importance in the Passive House. Consequently, especially in single-family houses and with distributed heat supply, industrially premanufactured packaged units that already contain all building services system components are of particular interest.

2.3.12.2 Overview of heat supply systems in the CEPHEUS projects

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Building type [1]	T	A	T	A	T	A	S	A	A	A	S	T	T	A
Single-/multi-user system	S	M	S	M	S	M	S	M	M	M	S	S	S	M
Packaged unit	No	No	No	No	Yes/ No	No	Yes	No	No	No	No	No	Yes	No
Combination of DHW & SH [2]	No	No	No	Yes	No / Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Hot water [3]	S, DH	DH	S, e	S, B, e, SW	S, B, e/ S, B, G	S, B, W, e	S, B, AW, e	S, W	S, B, W	S, B, W	S, B, W	S, B, G	AW, e	S, B, DH
Space heat [3]	DH	DH	e	SW, S	AA/ G, S	W, S, B, e	AW	W, S	W, B, S	W, B, S	W, B, S	G	AW	DH
Main heat producer [3]	DH	DH	e, e	SW	AA,e/ G	W, e	AW, e	W	W	W	W	G	AW, e	DH
Manufacturer of heat producer	-	-	Themovex	Viesmann	Maico AEREX, Viesmann	Sommerauer & Lindner	Maico AEREX	KEB	Sommerauer & Lindner	Sommerauer & Lindner	Ökofen	Junckers	Maico AEREX	-
Heat capacity (DHW & SH) [W/m²] [2), 3)]	22.4	44.4	21.0	26.8	26.8 (AA)	20.8	27.3	106.7	27.8	34.5	57.9	32.1	27.7	15.4 (RW)

Table 13: Project overview of heat supply in CEPHEUS.

1) T: Terraced house, A: Apartment building, S: Single-family, 2) DHW & SH: Domestic hot water & space heat, 3) AA: Air/air heat pump (from the exhaust air), AW: Air(air/water) heat pump (from exhaust air, with service water heating), B: Buffer storage, DH: District heat, e: direct electrical, G: Gas-fired condensing boiler, S: Solar thermal installation, SW: Subsoil-water heat pump, W: Wood pellet heating.

2.3.12.3 Solutions within CEPHEUS

The heat supply systems of the projects range from conventional, centralized heating systems through to distributed, packaged units. In 05-Hörbranz, 07-Dornbirn and 13-Lucerne, packaged heat pump units are used. The exhaust air after the air/air heat exchanger provides the heat source for the compact, efficient heat pump. Through the combination with a subsoil fresh air heat exchanger, the exhaust air temperature remains between 6°C and 10°C even on cold days. In addition, the exhaust air contains the entire latent heat of the water vapour released in the house. For domestic hot water heating, a second condenser cycle passes through the water storage (only in Dornbirn and Lucerne). All building services systems, including the domestic hot water storage, are contained within two units, each having a base area of 0.6 m x 0.6 m. Preliminary evaluation of the measurement results in 07-Dornbirn shows in February and March 2001 performance factors of 3.2 for pure supplementary air heating operation.

Packaged heat pump units provide system simplification and space savings, as they dispense with the need for fuel storage and a chimney.

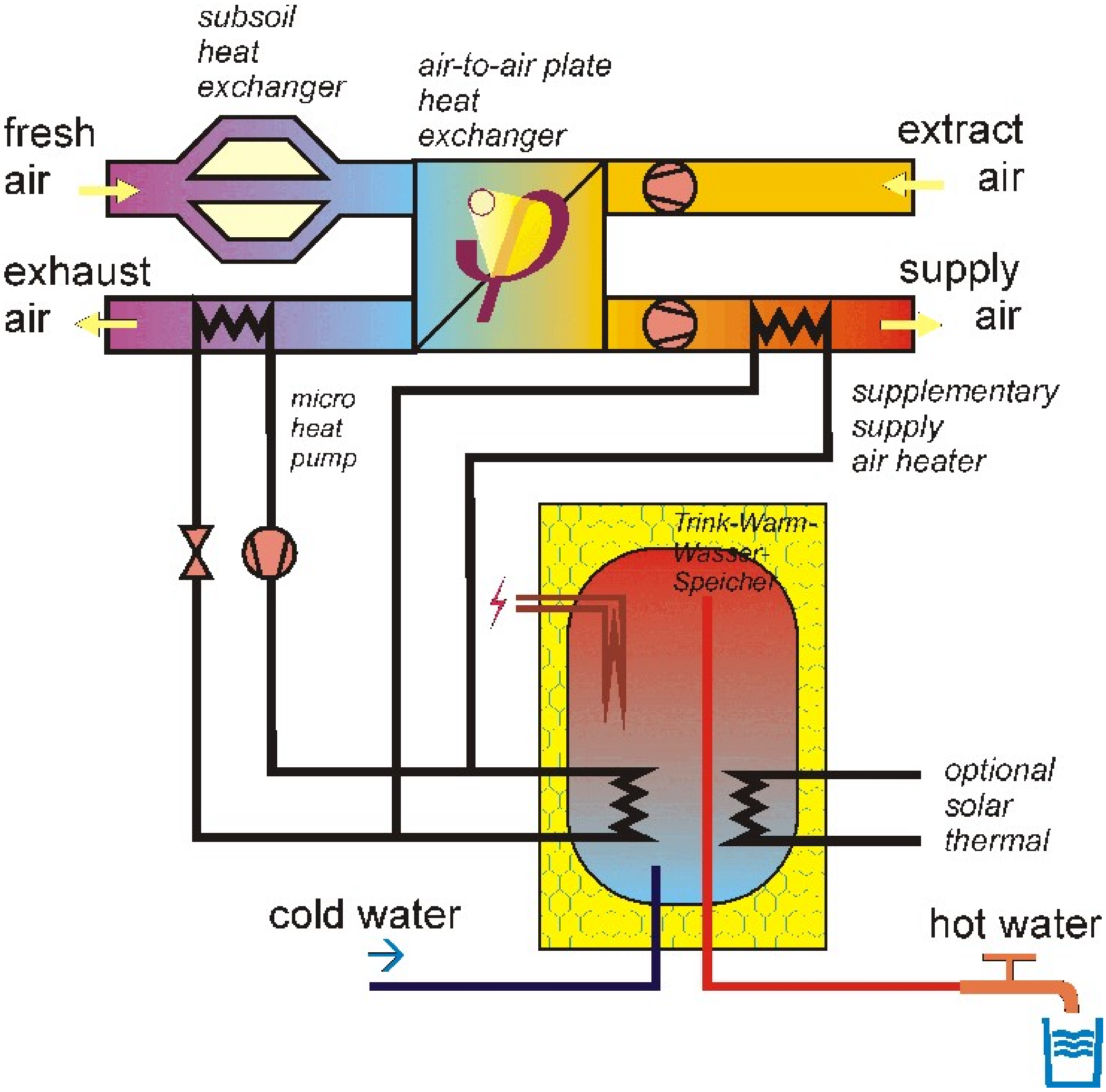


Figure 6: Schematic of the packaged heat pump unit.

In 04-Egg a subsoil heat pump ensures heat supply. Passive Houses provide excellent boundary conditions for this option. The low heat demand leads to a small load upon the subsoil register. These can accordingly be sized smaller; the piping system of ca. 1300 m length (corresponding to ca. 370 €/kW evaporator capacity) would have to be 3 to 4 times longer to supply a conventional heat requirement. As far as possible, the temperature of the subsoil loop is further raised by the solar thermal system. The performance ratio of 2.7 determined on the basis of data measured in the period from 1/2001 to 3/2001 is moderate, but exceeds the primary energy factor of 2.5.

01-Hannover, 02-Kassel and 14-Rennes are supplied with heat from a district heat network. In 01-Hannover, groups of 16 terraced houses share a heat transfer station. This is placed at the end of a row, from which it supplies two rows. While in the one row in which the transfer station is positioned the further heat distribution lines are within the thermal envelopes of the houses, the supply line to the second row is partly outside of the buildings. If the utilizable heat distribution losses are taken into consideration, i.e. the distribution losses during the heating season and within the thermal envelope, then in 01-Hannover in the measurement period from 10/1999 to 9/2000 the annual utilization ratio of heat transfer including all distribution losses figured 84%.

Five Austrian projects use wood pellet heating. In 08-Gnigl, a wood pellet boiler heats a buffer storage tank together with a solar thermal installation. The centralised heat supply of the multifamily building meets the demand for space heat and domestic hot water. Being a renewable resource, wood pellets are almost CO_2-neutral. The combination with a solar installation leads to excellent primary energy performance indexes of heat supply (cf. Section 2.3.10.3).

2.3.13 Equipment with lighting and major household appliances

In Passive Houses, the heat requirement for space heating is reduced massively; the requirement for domestic hot water is also reduced by efficient technologies. Under these circumstances, the household electricity requirement is the largest element of final energy demand for the dwelling; if it remains at the levels commonplace today, it is about twice as high as the energy demand for heating. Besides energy and CO_2 savings, in Passive Houses there is a further special reason to aim at high electric efficiency: Internal heat sources continue to generate heat in summer, too, when this is not needed or even disturbs. The task within CEPHEUS was therefore to trial tools by which it can be achieved that households are equipped with high-efficiency electric appliances.

To this end, the PHI produced two aids at the beginning of the project:

- An up-to-date list of particularly efficient household appliances was drawn up. Even within efficiency class A, only the best units of each type make it possible to meet the high requirements of the CEPHEUS target.
- The Passive House planning package (PHPP) includes a calculation component PHPP-EL (‘electric’) with which household electricity consumption can be appraised in advance if the efficiency of the units used is known. The use of this procedure was demonstrated by applying it to the CEPHEUS projects.

These publications were made available early on to all project partners.

2.3.13.1 Electric efficiency in the individual CEPHEUS projects

Different avenues were chosen depending upon country-specific features in the individual CEPHEUS projects.

- ***Provision of all households with a complete set of equipment with maximum efficiency (top-down ‘Equipment’)***

This was the approach chosen in those CEPHEUS countries in which initial equipment of dwellings with kitchens including electric appliances and with washing and drying equipment is normal practice: This concerns 03-Gothenburg (Sweden) and 13-Lucerne (Switzerland). In these cases, the developers of the Passive Houses drew up lists of units in the efficiency classes A and B, from which house buyers could choose the units purchased together with their dwellings.

- ***Qualified electricity efficiency advice and financial incentive (bottom-up ‘Incentive’)***

Where it continues to be up to occupants (owners or tenants) to purchase equipment, as is commonplace in Germany, Austria and France, the top-down approach is out of the question. In this case, the following tool was used by the developer Rasch & Partner for the Hannover-Kronsberg Passive House estate:

- A free *electricity efficiency advice session* was offered to each house buyer. This advice was provided by an employee of Rasch & Partner in Hannover.
- The advice session was carried out using the ‘Stromberatung’ (electricity advice) programme of Stadtwerke Hannover, which the Passive House Institute had

developed [INFO-4 1998]. This programme permits both initial appraisal of household electricity demand, and determination of the cost-effectiveness of the new purchase of more efficient units.

- If, using the 'electricity advice' programme, an annual household electricity consumption under normal use conditions with the equipment of a house of less than 18 kWh/(m²a) could be proven, house buyers had the incentive of the prospect of a rebate of DM 2000 on the buying price of their Passive House.

The last point, in particular, provided sufficient motivation for buyers both to make use of the advice offered and to actually invest in new equipment with higher efficiency.
18 advice sessions were carried out for house buyers in the Passive House estate. The anticipated electricity demand was determined assuming standard use conditions (such as a standard occupancy of 3.2 persons per household); a cost-effectiveness calculation was carried out for each new unit purchase. This led, assuming normal occupancy, to an average demand of 17.0 kWh/(m²a). After surveying the actual boundary conditions, notably household occupancy, the PHI carried out the calculation once again (ex posteriori). This resulted, for the 18 households advised, in a mean calculated value of 17.5 kWh/(m²a). Finally, actual measurements of household electricity consumption in the first year of occupation resulted for the 18 households under consideration in an average of 20.2 kWh/(m²a) (±1.3) [Peper 2001]. The measured savings for the households advised according to the bottom-up model thus figured 38% compared to the reference value of average German households (32.8 kWh/(m²a), cf. Figure 7).

As the consumption levels measured in the Hannover project show, the 'Advice plus Incentive' approach is highly successful. On the other hand, it is plain that the effort required for this model is relatively high.

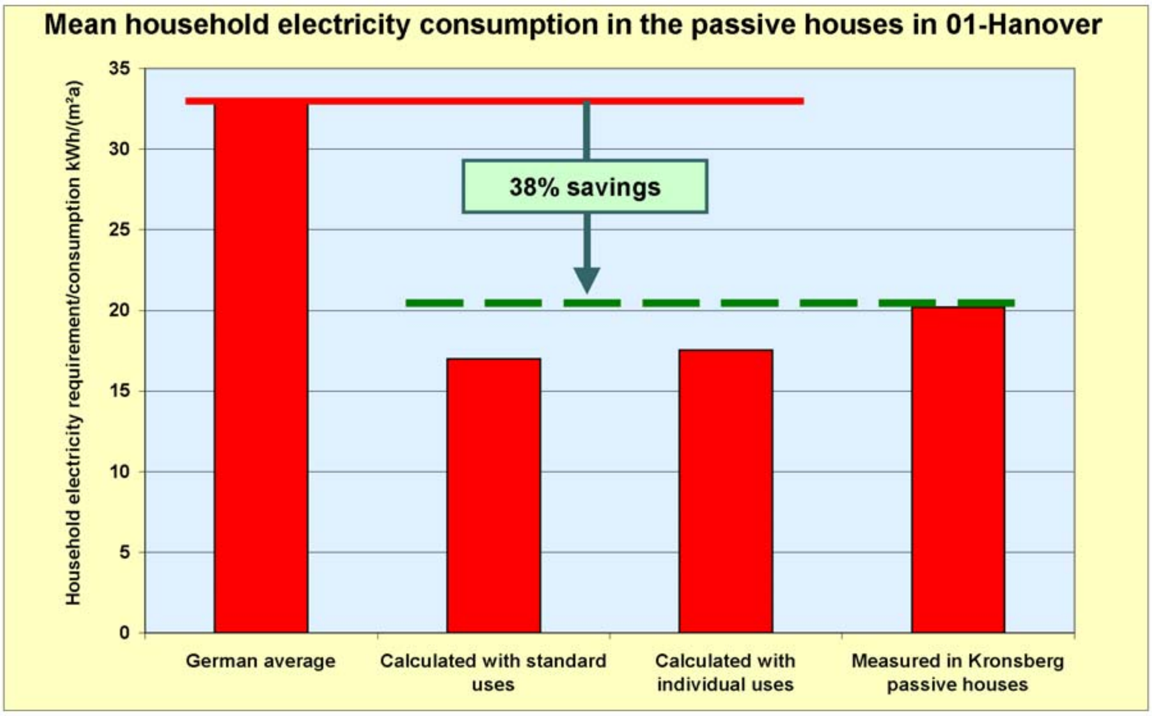


Figure 7: Electricity savings through efficient household appliances in 18 households advised in the Hannover-Kronsberg Passive House estate

The project in Rennes is a special case. Here the house buyers have formed a cooperative. At the regular meetings of the cooperative, the developer had to present the Passive House technology and the ecological building materials in great detail, and provided detailed instructions on their use. At one of these meetings, the Rennes energy agency provided detailed advice on electricity-saving lighting and household appliances, and the establishment of a purchasing cooperative for large household appliances was promoted. ADEME and EDF made grants available for the purchase of appliances in efficiency class A, amounting to Euro 152.45 (FRF 1000) for the purchase of 2 appliances and Euro 340.90 (FRF 2000) for the purchase of 3. Laundry driers were excluded from the grant scheme. In total, 16 out of 40 dwelling owners participated in the scheme.

- ***Electricity conservation advice without further incentive ('Advice')***

In several CEPHEUS projects it was neither possible to fit them completely with efficient new appliances, nor to offer financial incentives for purchasing new units. In these cases, advice was offered to the future occupants (buyers, tenants or co-owners). The success of this approach differed from project to project (cf. Table 14).

- ***Electricity conservation advice through written user information ('Info')***

Individual advice according to the model described above was not possible in all projects either. In some cases, households were provided with information on the efficiency of new electric household appliances by means of the user manual for the Passive House (02-Kassel).

- ***Equipment with specific electricity efficiency components ('Comp')***

A number of further innovative electricity efficiency approaches have been pursued in the CEPHEUS projects:

A study on efficient laundry drying [Ebel 1998] examined the opportunities to reduce the very high electricity consumption levels for laundry drying. A number of these options were tested experimentally in the CEPHEUS projects.

a) Drying in a laundry drying room outside of the thermal envelope

In terms of energy performance, this strategy is by far the most efficient: Basement or attic rooms can be used as drying room. In the CEPHEUS projects 06-Wolfurt, 09-Kuchl and 10-Hallein, joint drying rooms for households were established.

b) Drying in an airing cabinet upstream from the extract air vent of the ventilation system

The excellent results with a preliminary study led to the decision to fit all of the 32 terraced houses of the Hannover-Kronsberg Passive House estate with airing cabinets. The 'Nimo' type cabinets were purchased by the developer and converted according to proposals in [Feist 2000] for use in the Passive Houses.

c) Hot water connections for laundry washing machines and dishwashers

The connection of dishwashers and washing machines to the existing domestic hot water (DHW) system permits primary energy savings of 39% and, respectively, 37 % under the precondition that the hot water is heated using combined heat and power (CHP) or/and solar thermal systems or other renewable sources. This precondition is indeed given for most CEPHEUS projects, so that provision of hot water connections is one of the decisive construction measures facilitating improved household appliance efficiency. Table 14 shows in the 'Special components' line which CEPHEUS projects have domestic hot water connections.

d) Combined heat and cold in refrigeration equipment

The 10-Hallein sub-project implemented an innovative concept: In the basement, a room containing freezers for each of the 31 households was established; the compressors used for the freezers are all located in an adjoining room, whereby the condenser works on the cold water inflow of the hot water heating system. This provides on the one hand a low condensation temperature and thus high refrigerating performance factor of the compressors, and on the other hand means that the condensation energy is utilized throughout the year for hot water heating (therefore: combined heat and cold). Unfortunately, no measurement results were yet available for this interesting concept when the CEPHEUS project concluded.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Electric energy efficiency														
Objective	**to use efficient electric household appliances**													
Tools for implementing efficiency improve-ments	**Incentive + Comp**	**Info + Comp**	**Equipment**	**Advice, eff. appliances**	**Advice**	**Advice, contract**	**?**	**Info**	**Info**	**Info + Comp**	**Advice, contract**	**Advice**	**Equipment**	**Incentive**
Assessment of success	**excel-lent**	**medi-ocre**	**n.d.**	**medi-ocre**	**medi-ocre**	**good**	**n.d.**	**medi-ocre**	**medi-ocre**	**n.d.**	**satis-fac-tory**	**satis-fac-tory**	**good**	**n.d.**
Special components	Airing cabinet, DHW connections	DHW connections, compact fluorescent lamps in the stairwells				Partly gas cookers Drying room			Drying room	Ventilated drying room, centralized freezers with heat extraction	DHW connections for laundry washing machines and dishwashers	DHW connections for laundry washing machines and dishwashers	Equipment; one house also with compact fluorescent lamps	

Table 14: Overview of the electric efficiency measures implemented in CEPHEUS projects

LEGEND:

Incentive	=	Qualified advice for buyers combined with a financial incentive for purchasing new, efficient equipment.
Equipment	=	Initial equipment of the dwellings by the developer with particularly efficient appliances.
Advice	=	Electricity efficiency advice for buyers / tenants.
Info	=	Provision of information for buyers / tenants through the user manual for the Passive House.
Comp	=	Use of special components for efficient electricity use implemented by the developer in the Passive House; components are specified in the 'special components' line.
n.d.	=	Assessment not yet possible because no measured data yet available.

2.3.14 Zero CO_2 balance

On the basis of the greatly reduced energy requirement, achieved by means of 'passive' efficiency strategies, Passive Houses offer excellent opportunities to meet the remaining energy demand largely directly through renewable sources.

Due to the high share of domestic hot water heating in the total annual heat requirement (in some instances more than 70%) a normal, cost-optimized design of solar thermal installations provides, compared to conventional buildings, a high solar contribution to total heat requirement amounting to 40–60%. On the use of solar thermal installations in the CEPHEUS projects see Section 2.3.9.

For the same reason, Passive Houses offer similarly favourable preconditions to meet the entire heat requirement – preferably in combination with solar thermal use – through biomass use. Wood pellets suggest themselves particularly for this. In 5 Austrian

CEPHEUS projects, heat supply was provided in this combination of solar energy with wood pellets (see Section 2.3.11). These solutions are economically competitive with conventional supply by means of heating oil, natural gas or district heat.

On site at the Passive House itself, the use of photovoltaics (PV) suggests itself to meet the entire electricity requirement (over the annual balance) by renewables. To cover the average measured electricity consumption of the terraced houses in the CEPHEUS project of 2,400 kWh/a, this would require ca. 3 kW_p or 30 m² module surface area. There will generally be space for this in a southern-facing position on the roof or facade of a Passive House. The use of photovoltaics was realized in two CEPHEUS projects (02-Kassel and 09-Kuchl/A). However, PV facilities currently still incur relatively high investment costs (5–8 thousand Euro/kW_p), and thus would considerably increase the purchasing cost of a Passive House.

Substantially less cost is generated through the coverage of the overall electricity requirement (over the annual balance) by means of a share in a wind energy facility. This is the avenue pursued in the 01-Hannover project. A sum of DM 2,500 (= Euro 1,278) is integrated in the purchase price of the Passive Houses, providing for the purchase of a share of about 2 kW in a wind power facility planned nearby. This was to substitute over the annual balance not only the projected electricity consumption of the Passive Houses, but the total primary energy consumption for space heating, domestic hot water and household electricity – or the resultant CO_2 emissions (on the results achieved see Section 4.2.3).

The overarching goal of global climate protection, namely to substitute the remaining CO_2 emissions over the annual balance by means of renewable sources of energy, is thus achieved. Instead of energy-self-sufficient solutions that require high-input storage technologies, under the conditions of industrialized countries, where electricity distribution systems are ubiquitous, these systems can be utilized as, so to speak, 'virtual' storage.

Renewables themselves are not available in unlimited amounts either, and their use can also generate environmental impacts. For instance, for the entire new district of Kronsberg with 6,000 dwelling units when completed, the 4–5 large wind facilities required to substitute CO_2 emissions could be sited nearby on the Kronsberg hill. For the necessary three-fold number of wind turbines that would be needed if the district complied only to conventional consumption standards, it would be quite impossible to find enough sites for the turbines nearby.

Tapping all economically effective efficiency potentials is thus a decisive precondition to the broad-scale implementation of climate-neutral solutions. This is the only way to make it possible for renewables to make a substantial contribution to meeting energy requirements, such as is set out as a goal in the white paper on renewable energies of the European Commission. The Passive House concept offers an excellent basis on which to achieve this goal.

2.4 Quality assurance and evaluation concept

2.4.1 Planning using the Passive House Planning Package (PHPP)

The PHPP is a tool for specifying Passive Houses and their components. The PHPP comprises spreadsheet work sheets which can be used to compile annual balances and to size elements and components. The sheets are:

- Space Heat (annual heating balance according to EN 832)

- Thermal Bridges (inclusion of thermal bridging effects)
- Windows (window U-values according to EN 10077 and calculation of shadowing)
- Pressurization Testing (evaluation of building airtightness tests)
- Ventilation (specification of supply and extract air flows)
- Hot Water and Pipe Losses (specification of DHW supply)
- Heat Production
- Household Electricity (cf. also 2.3.12)
- Primary Energy Requirement.

The PHPP has now made it possible to carry out the planning of Passive Houses in many cases without complex, expensive simulation techniques that would not be readily accessible to all users. All CEPHEUS projects were planned and documented by the national project partners using the Passive House Planning Package made available by the PHI. The associated comprehensive documents are to be found in the individual documentations of the building projects. For each project, at least two different structural / engineering standards were calculated:

A) The structural / engineering reference standard
This reference standard is defined by the building standards and construction regulations applicable in the specific regions at the time when the building permit was granted. In calculating the reference standard, the architectural design and all other data were retained as far as possible. Only the following items were altered:

- Dwelling ventilation was assumed following normal regional requirements: i.e. for Germany / Austria / Switzerland no ventilation systems, and for France and Sweden simple air extraction systems without heat recovery.
- The windows were substituted by normal windows permissible under regional requirements: i.e. for Germany / Austria / Switzerland low-emissivity glazing in standard frames, for Sweden triple-glazing with one coating and standard frames.
- The insulation thicknesses of roofs, walls and floors were reduced such that they just comply with the respective standards and regulations.

The reference standards are thus dwellings of the same type of construction and geometry as would have been built typically in the partner countries in 1998–2000.

B) The actually realized construction standard (generally as Passive House)
We document here the *final planning status* of the individual projects. It emerged in the checking of calculations and in the later on-site building surveys that the final planning status does not always correspond exactly to the actual structural state of the building; in some cases, the PHI has drawn up additional data sets for the “present structural state following on-site building survey”. Figure 8 shows a comparison of the annual heating requirement according to PHPP for the 14 CEPHEUS projects, each calculated for the regional climate. The 15 kWh/(m²a) target is only exceeded significantly by 07-Dornbirn (a small single-family house at high elevation), 08-Gnigl (southern orientation of the large main glazed area was not possible under the site conditions) and 14-Rennes (here the national consultant had originally calculated a far lower value using simulation techniques).

For the building project in Rennes, the PHI undertook a new PHPP calculation, including a survey of quantities based on the building plans, because the initial calculation had used interior dimensions. In Rennes, there are major thermal bridging effects that have a considerable impact upon the energy performance index for the final planning status: Despite the very mild climate, a space heat requirement of more than 27 kWh/(m²a) is reached. This is due above all to the high heat losses despite the mild climate, notably caused by the poorly insulated southern wall and the thermal bridges that amount to 51 kWh/(m²a). The poor index arises even though a passive solar gain through radiation absorption was especially taken into consideration in the calculation. However, as a result of the poorer window quality in this project, the higher heat losses through the windows exceed the passive solar heat gains. Considering that the climate in Rennes is in fact very favourable for Passive Houses, it would suffice to improve the quality of window frames and glazing spacers to arrive at a better index.

The PHI has elaborated a variant for a building with the same geometry. See on this also the detailed presentation in [Schnieders 2001]. This variant showed that with the mild climate in Rennes, comparatively moderate measures would suffice to achieve the Passive House standard: Airtightness should reach an air leakage value below 0.55 h^{-1}, the loam wall in the southern facade would need to be insulated with about 120 mm insulation material (λ=0.035 W/(mK)), a thermally-broken spacer would need to be used in the glazing, window installation thermal bridges reduced and improved window frames with U_f = 1.1 W/(m²K) utilized. The double low-emissivity glazing is adequate here, but the protruding balconies would need to have a thermal break. By these measures, the heat losses could be reduced to 38 kWh/(m²a); passive solar gain could cover 39% of this, internal heat sources 23%. The Passive House limit of 15 kWh/(m²a) can thus be reached.

Due to the already advanced implementation stage of the project in Rennes, the PHI's proposals for improved thermal performance could no longer be taken into consideration. Despite the deficiencies set out above, the project in Rennes succeeds in reducing the annual space heat requirement compared to the reference standard by more than two thirds.

Figure 9 shows the heat requirement values for the Passive Houses as compared to the heat requirement of the reference cases. It is evident that in the final planning status all sites have a far lower heating requirement than would be required by the normal new-build standards at the sites. On average, the CEPHEUS measures reduce the annual heat requirement of the buildings by 83%.

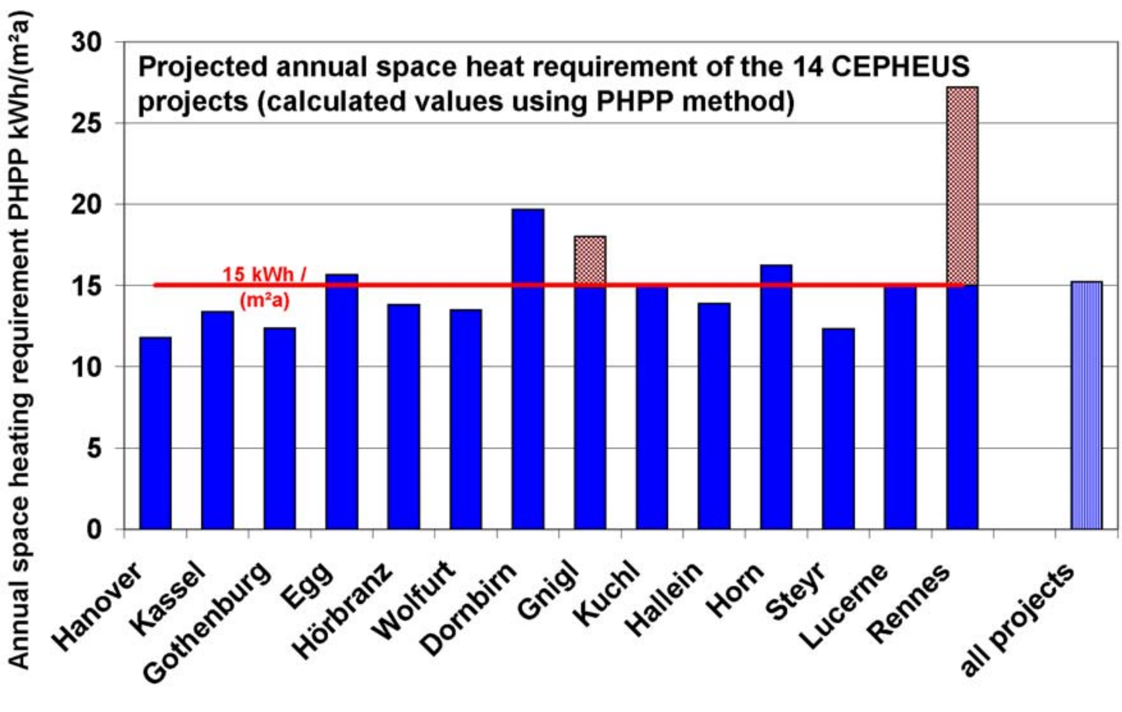


Figure 8: Annual heat requirement values calculated using PHPP for the 14 CEPHEUS building projects in the final planning status.

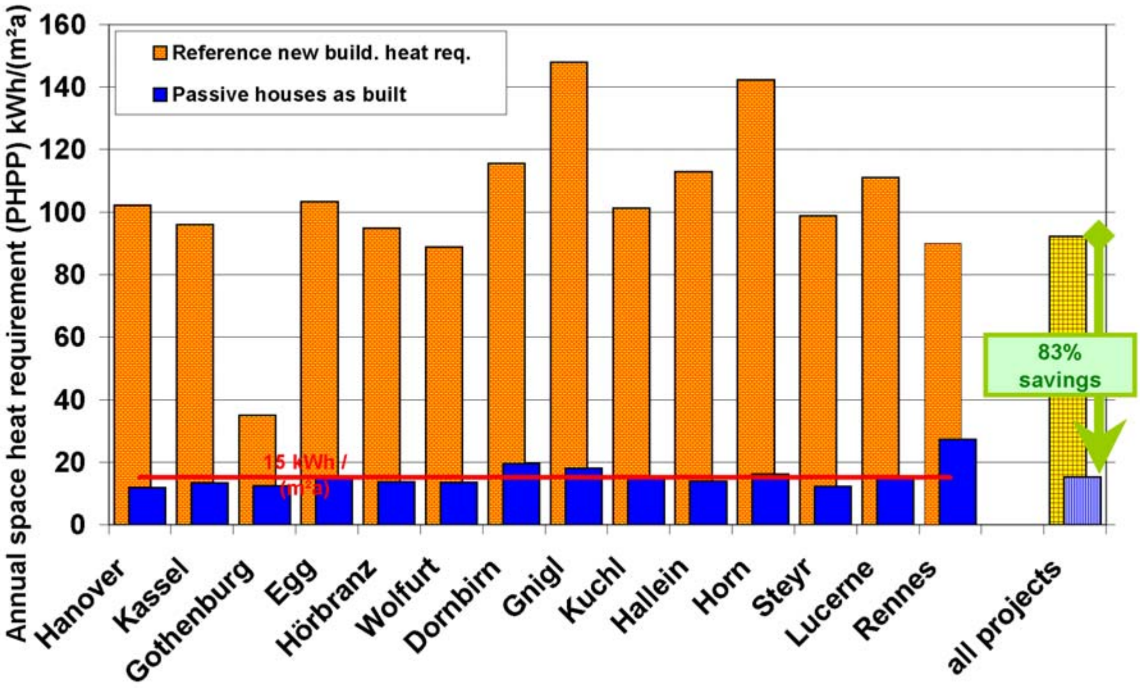


Figure 9: Calculated annual heat requirement of the reference buildings according to presently applicable construction law, compared to the planned Passive House standard.

Figure 10 illustrates for the example of the multifamily apartment Passive House in Kassel how such major improvements in energy efficiency were achieved: In the reference case, the heat losses due to transmission and ventilation add up to almost 120 kWh/(m²a). These losses are reduced in the energy balance by about 12 kWh/(m²a) solar heat gains and a further 11 kWh/(m²a) internal heat sources. Both contributions to the 'free heat' (incidental heat gains) are almost 100% utilizable; however, they only cover less than 20% of the heat loss, so that the heating system still needs to cover 80%, namely 96 kWh/(m²a). In the built Passive House, the balance is quite different: Owing to excellent insulation of opaque components and windows, and heat recovery, heat losses are cut by 73% compared to the reference case. The lower solar energy transmittance of the triple-glazing reduces the solar heat gains slightly; the internal heat sources, however, remain at the same level. Of the heat losses in the Passive House amounting to about 32 kWh/(m²a), the free heat contributions now cover 60 % – and this although the multifamily apartment building in Kassel is not rigorously designed as a solar building. At 13.4 kWh/(m²a), the remaining heat requirement is 86 % lower than that of the reference standard. The high energy conservation success of the Passive Houses can therefore also be explained in terms of the circumstance that due to low heat losses the relative importance of the free heat sources increases. The decisive aspect is that the resultant remaining heat requirement is so low that it can be supplied exclusively through conveyance in the ventilation supply air, which needs to be supplied anyhow. This condition is met in the 02-Kassel project.

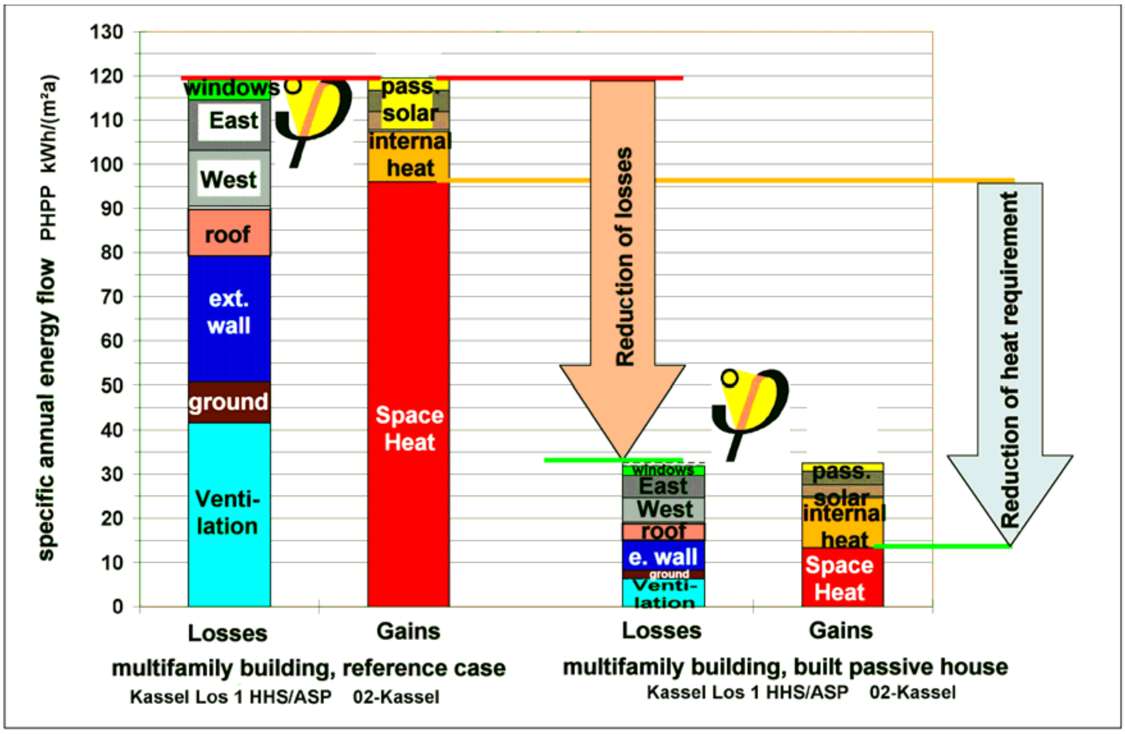


Figure 10: Heat balance calculated with PHPP for the example of the multifamily apartment Passive House in 02-Kassel-Marbachshöhe

2.4.2 Simulations

A realistic modelling of the thermal behaviour of buildings on time scales of less than one month is only possible by means of dynamic building simulation. This makes it possible to describe accurately the actual physical processes so that – as opposed to steady-state calculation techniques – it is also possible to make statements on, for example, the effects of different heat distribution systems or of night-time cooling in summer.

As a part of the CEPHEUS project, dynamic building simulations were carried out for the terraced houses in Hannover and for the pensioners' home in Dietzenbach (due to delays in construction work, the Dietzenbach project was subsequently no longer involved in CEPHEUS). The DYNBIL simulation programme used for this had already been validated in detail previously (cf. on this [Feist 1997] and [Feist 1993]).

The dynamic simulation of the Passive House terraces in Hannover-Kronsberg (see detailed report in [Schnieders 1998]) pursued two goals: First, the sensitivity of such buildings to modifications of a number of parameters and boundary conditions was to be analysed. Second, the question was to be clarified whether the houses can be kept evenly warm through only supplementary heating via the supply air and whether the cost reduction potential offered by the removal of the heating system can thus be realized.

In the basic variants, the simulation resulted in annual heat requirement values between 11.9 and 14.8 kWh/(m²a), whereby raising the indoor temperature by 1 K led to an approx. 20% higher heat requirement. Night setback provides no noteworthy savings. Thermal protection in summer proved an unproblematic issue; however, external shading would further improve the indoor climate in summer significantly. In all types analysed, the maximum required heat load remains reliably below 10 W/m². The southward orientation of the house rows is *not* decisive for the functioning of Passive Houses given the quality of the building envelope here; what is important is to substantially improve airtightness compared to conventional new build.

Heating the houses via the ventilation system is unproblematic. Even mean temperatures of 25°C can be achieved in this manner. Temperature differences between zones remain acceptably low; in the assumed worst-case scenario the difference between the warmest and coldest zone generally ranges between 1.5 and 3 K.

The simulation of the pensioners' home in Dietzenbach [Schnieders 1999] examined in more detail the transferability of the Passive House standard to apartment buildings. It further examined the suitability of the concept for the particular requirements in an old-age pensioners' home (high occupancy, high required indoor temperatures).

The feasibility of building old-age pensioners' homes to Passive House standards was proven: At an indoor temperature of 23°C a heat requirement of 24 kWh/(m²a) does albeit result, but at 20°C the heat requirement of the building is below 15 kWh/(m²a). Compared to the applicable standards of the German 1995 Thermal Insulation Ordinance (Wärmeschutzverordnung), the Passive House standard would save ca. 80 % heating energy. On the basis of the simulation findings, further improvement proposals were elaborated. However, given the design of the Dietzenbach project, heating to 23°C exclusively via the necessary supply air was not possible; this would require further improvements to the building envelope.

2.4.3 Site and manufacturer advice

The task of the Passive House Institute (PHI) was to tackle problems relating to construction engineering, building physics and building services in the planning and construction phases and to contribute to swiftly remedying these problems, thus permitting implementation of the building projects to the envisaged quality standard. Some of the issues that arose were:

- **Issue: Condensation in window frame; Projects: CEPHEUS-D**

The window frame envisaged for the CEPHEUS building projects, produced by the Pazen company, consists of a PU foam core clad on the indoor side with wood and on the outdoor side with an aluminium moulding. To analyse the condensation problem that arises, a newly developed methodology had to be applied to the frame until a condensation-water-free construction was found [Schnieders 1999a].

- **Issue: Thermal bridging due to window installation**

Window installation was optimized in cooperation with the Rasch & Partner building developer and the façade manufacturer. For this, a special box beam was developed that replaces the previously employed timber jamb. The window is installed in the wall by fixing it to this beam. Due to this installation, the heat losses of the windows are reduced by more than 10 %; this amounts to 8 kWh per square metre window area and year.

- **Issue: Thermal bridging of details in the CEPHEUS-D projects**

Thermal bridge computation and advice for the building developers of the German projects with regard to detailing: All junction details were analysed and optimized with regard to their heat losses, by means of detailed thermal bridge computations. For a large part of the Austrian projects and for the Swiss project, thermal bridge computations were carried out by the national project partners.

- **Issue: Is krypton fill gas replaceable by argon?**

During the planning phase, the price of the glazing fill gas krypton rose steeply within a short time. In cooperation with the manufacturers, the PHI succeeded in developing appropriate triple low-emissivity glazing for Passive Houses that makes do with the cheaper fill gas argon. This development prevented a cost increase in the construction of Passive Houses.

- **Issue: Airtight and thermal-bridge-free junction details**

In the German project, the Rasch & Partner developer and the contractor (Lehner company) were provided with advice on the prefabrication of façade elements with regard to airtightness, thermal insulation and the prevention of thermal bridging.

- **Issue: Passive-House-appropriate windows**

Due to the rising number of built Passive Houses, window manufacturers have a growing interest in the Passive House standard. Several window manufacturers were advised on the requirements upon Passive House windows and have started to develop corresponding components.

- **Issue: Heat losses of distribution lines**

The detailed heat balance for the planned German CEPHEUS projects revealed very high losses of the heat distribution lines. To remedy this, a proposal was elaborated that provides for permitting heat flow through the lines only intermittently during the summer.

- **Issue: Heat losses of hot water storage**

At on-site inspections it was found that the heat release of the hot water storage in the Hannover-Kronsberg project is very much higher than desired. An improved concept for future projects was developed in cooperation with the manufacturer Wagner & Co.

- **Issue: Air leakage of ventilation systems**

PHI staff also found that the ventilation systems in the built German project have avoidable leakages. Here, too, an improvement concept was developed and coordinated with the manufacturer (Paul company).

2.4.4 Pressurisation tests

Excellent airtightness of the building envelope is a crucial precondition to the viability of the Passive House standard. Testing the actually achieved airtightness of the CEPHEUS building projects was therefore one of the most important quality assurance measures.

Under the CEPHEUS contract, pressurisation tests were required in all sub-projects realized. The procedure for these tests is stipulated in EN 13829. For the test, a 'blower door' is installed in one of the window or door openings of the building to be analysed. After recording the boundary conditions, a number of measurement pairs (building pressure differences, air flow conveyed) are recorded under both positive and negative pressure differences. From the measured values, the building leakage curve is determined by means of linear regression on a logarithmic scale. In particular, this analysis leads to the so-called n_{50}-value as an index; this is the mean of the air leakage flow at 50 Pa positive and negative pressure in relation to the building air volume enclosed. The n_{50}-value is used as an index for the CEPHEUS projects.

The airtightness target of the CEPHEUS project was very ambitious: n_{50}-values were to be smaller or equal 0.6 h^{-1} in all projects. This value is lower by at least a factor of 2 than the existing or debated future requirements in the countries participating.
Airtightness tests were carried out in all CEPHEUS projects. In some projects, further studies were documented above and beyond the determination of the n_{50}-value and of leakage distribution:

In all houses in the Hannover-Kronsberg Passive House development, measurements were carried out with a counterpressure in the respective neighbouring houses that was equal to the measurement pressure, in order to eliminate the proportion of building leakage within the group of buildings. Subsequently, a meticulous error analysis was carried out that showed that the n_{50}-values in the measurements carried out have relative standard deviations of about $\pm 10\,\%$. This suffices for the accuracy required here.

In the apartment building project in Kassel, one multifamily building was subjected to a measurement programme. Here all units were measured once with individual unit measurements including all internal leakages within the building, and then a second time applying counterpressure in the stairwell and in all other units. Here, too, this procedure permitted determination of the internal proportion of building leakage.

Section 4.2.1 documents the results of the airtightness tests.

2.4.5 Thermographic imaging

Infrared (IR) thermography is a non-contact method of surface temperature measurement. It is applied frequently in building physics to monitor the thermal insulation of structures. The method allows rapid identification of critical points and thermal bridges, To interpret IR images correctly, it is essential to have detailed knowledge of the processes of radiation physics that are involved. The effects of the reflection of long-wave radiation from certain surfaces and different emissivities can easily lead to misinterpretation of IR images. The images documented within the context of the CEPHEUS quality assurance measures were created by experienced thermographers with scientific support and evaluation. The results provide a valuable data basis for the scientific evaluation of the CEPHEUS projects. In a number of cases they were also used to remedy critical points in built projects, such as leakages around windows or certain junction details. In some projects indoor thermography under subatmospheric pressure (blower door) was also used to locate air leakages. Ideally, such surveys are carried out in the early hours of the morning before sunrise, at outdoor temperatures that are as low as possible and under an overcast sky. This contributes to minimizing the influence of surface warming by absorbed solar irradiation and radiation emitted to the sky. Low outdoor temperatures improve image contrast.

The results for the individual CEPHEUS sub-projects are contained in the respective project documentations.

2.4.6 Initial adjustment of the ventilation systems

It is only by means of initial adjustment of the system following the first trial operation that the desired efficiency is attained. It is therefore essential that this item of work is a part of the tender or of the engineering contract, as the time required is considerable, particularly for adjusting the air outlets and exhaust valves in the individual dwelling units [Otte 2000]. The air quantities of the air valves are set through difference pressure measurement.

In addition to setting the air volume flows of individual rooms, setting the balance of the overall system is crucial. Some CEPHEUS projects already use volume flow controlled fans. These are capable of determining the volume flow out of the present torque and speed, and maintaining the volume flow at a constant pre-set value. A manual setting of balance is not necessary in such systems; nonetheless, measurements should be carried out to check balance.

By means of baffle crosses installed in the incoming fresh and outgoing exhaust air duct (if the central unit is positioned within the thermal envelope) or in the supply and extract air duct (if the central unit is positioned outside of the thermal envelope) the volume flow balance can be checked by measurements and then set. If this setting is dispensed with and the imbalance reaches values above 10%, then the in- or exfiltration losses rise significantly. If there is permanent air surplus, then in extreme cases structural damage can arise e.g. due to condensation in the thermal insulation. Experience has shown that the baffle crosses should remain permanently in the ductwork in order that, after several years of operation or changes to the ductwork, the system can be checked for balance again.

2.4.7 Measurements conducted to evaluate operation

2.4.7.1 Generic measurements

The purpose of this measurement project was not to provide detailed analyses of individual technologies, nor to provide all explanations for unexpected or possibly unexplainable results. The aim was rather to determine whether, in broad-based practical application under the most varied but everyday boundary conditions, these technologies deliver a positive overall result. Measurements therefore focussed primarily on the following:

Total heat requirement for the building:	Target: <15 kWh/m^2 a
Total final energy requirement for the building:	Target: <42 kWh/m^2 a
Total primary energy requirement for the building:	Target: <120 kWh/m^2 a
given compliance with the comfort parameter for indoor temperature:	= 20°C
taking into consideration the local climate in the measurement period:	Heating degree days

To determine these parameters, as a standard the following energy flows or temperatures were measured:

Energy flows across the building boundaries:	Electricity, wood pellets, gas, district heat, etc.
Climatic data:	Horizontal solar irradiation, outdoor temperature
Comfort parameter:	Indoor temperature
Heat requirement met by:	Water-to-air supplementary heating register or air-to-air heat pump in supply air flow, radiators, heating in walls or floors

The measured values were stored at least hourly by an automatic recording system. For the individual measured parameters, the following minimum standards apply to the whole measurement chain:

Parameter	Resolution	Accuracy
Electricity measurement:	min. 100 Imp/kWh	± 3%
Heat quantities:	min. 1 Imp/kWh	± 8%
Gas quantity:	min. 10 Imp./m³	± 5%
Temperatures:	min. 0.1°C	± 0.5°C
Solar irradiation:	min. 10W/m²	± 8%

In order to receive comparable figures, the various energy indexes were placed in relation to a reference area, the treated floor area (TFA). The method for calculation of TFA corresponds to that in the 2nd German calculation ordinance for calculating floor areas. The following adjustments were agreed upon in order to permit use of the method within the European context (for details see the annex):
A thermal envelope was defined, and only those rooms within this thermal envelope were considered in the TFA calculation. Ancillary rooms such as building services rooms, etc. within the envelope were only included with 50% of their floor area in the TFA calculation. The areas of rooms were calculated from the wall distances according to the carcass plans, i.e. the thicknesses of any interior plastering were included in the calculation of floor area. Areas with a room height of less than 1 m were not included. Areas with a room height between 1 m and 2 m were included in the TFA calculation with 50% of their area.

2.4.7.2 Further measurements

In all countries, the following further parameters were recorded in addition to those described above in a number of selected projects or dwelling units:

Water consumption	Hot water consumption (partly in kWh and/or litres) Cold water consumption (in litres)
Energy quantity	Solar yield (in kWh)
Electricity consumption	Overall ventilation system

2.4.7.3 Supplementary measurements in national programmes

Based upon expanded national measurement programmes made possible by national funding, in some countries the following additional parameters were recorded in selected projects or dwelling units. The precise listing of measured parameters and their assignment to projects is to be found in the detailed measurement project descriptions.

Austria:

Electricity consumption	Household electricity, air-to-air heat pump, subsoil heat pump, auxiliary energy for heating system, electric heating register for space heating and hot domestic water
Parameter of comfort	Indoor air humidity in all dwelling units
Thermal energy	Hot water circulation losses
Ventilation system	Air velocity in central supply air channel; development of air temperatures in the ventilation system: outdoor temperature, subsoil heat exchanger inlet, subsoil heat exchanger outlet, supply air after heat recovery, supply air after supplementary heating register, indoor air, extract air after heat recovery, exhaust air

Germany:

Climate	Wind speed, wind direction, air humidity, global and diffuse solar irradiation
Air moisture	Outdoor air, supply air after ventilation system, indoor air, extract air, exhaust air
Ventilation system	Air volume flow in supply and extract air Development of air temperatures in the ventilation system: outdoor temperature, supply air before ventilation unit, supply air after ventilation unit, supply air after supplementary heating register, indoor air, exhaust air
Temperatures	Hot water, cold water
Thermal energy	Hot water circulation losses

Switzerland:

Electricity consumption	Household electricity in heated/unheated zones; air-to-air heat pump in heating operation or hot water operation; electric heating register for hot water
Parameter of comfort	CO_2 levels
Temperatures	Indoor temperatures, supply air temperatures
Air moisture	Outdoor air, outdoor air after subsoil heat exchanger, indoor air, extract air, exhaust
Ventilation system	Set level of fan volume flow, air change rate by means of tracer gas measurement Development of air temperatures in the ventilation system: outdoor temperature, subsoil heat exchanger outlet, supply air after ventilation unit, indoor air, extract air before ventilation unit, exhaust air after ventilation unit, exhaust air at building outlet

2.4.8 User information

At numerous sites, extensive instructions have been provided to users concerning the special aspects that need to be considered when using the Passive House specific components. A further focus of advice efforts has been placed on electricity-saving behaviour, and, in detail, the purchase of energy-saving household appliances (see on this also 2.3.13.1).
For the Hannover sub-project, the PHI has developed a 'user manual' on behalf of Stadtwerke Hannover AG [Peper 2000a]. At several information events, held e.g. in Hannover, the questions of users concerning the Passive House approach and the associated user behaviour were answered.

In Hannover, a user information system was installed in 16 of 32 households. This visualizes the energy and water consumption level of the individual household, and places it in relation to that of all households. This gives users the opportunity to compare their own consumption levels with those of the other residents, in order to then possibly adjust or rate their own behaviour.

2.4.9 Social science evaluation

In Hannover and Kassel, social science evaluations have been or are being conducted. The purpose of these is to survey the acceptance of residents.

In Hannover, questionnaire surveys of residents in 2000 and 2001 assembled extensive data on the most varied issues for the entire Kronsberg district. These surveys were commissioned by the Kronsberg Environmental Liaison Agency (Kronsberg Umwelt Kommunikation Agentur, KUKA). In total, more than 2500 questionnaires were distributed, of which 900 were returned in a form suitable for evaluation. The KUKA surveys are also the first module of a broader social science evaluation, commissioned by Stadtwerke Hannover AG within the context of CEPHEUS for the Hannover-Kronsberg sub-project [Danner 2001]. The main goal of the comparative evaluation is to identify common features or differences among specific types of housing forms. The second module involved 1.5-hour personal interviews with all Passive House households in November 2000. Attention focused here particularly upon the assessments of occupants regarding various parameters of occupant comfort, housing quality and user behaviour. The third module was implemented in March 2001 in parallel with the survey of all Kronsberg residents, in the form of a follow-up written questionnaire survey. This survey queried the experience and user behaviour of occupants.

In Kassel, a social science evaluation is also taking place with the support of the German Federal Environmental Foundation (DBU) [Hübner 2001]. This is not within the context of CEPHEUS.

3 Construction, installation and commissioning

3.1 Suppliers of equipment and services

See on this the detailed listing in 9.2.

3.2 Project management

For overall coordination of the project and regular exchange among the CEPHEUS partners, a steering group was set up. This met semi-annually for one- to two-day working meetings, held alternately at the various partners. The steering group comprised:

- the overall CEPHEUS coordinator (Manfred Görg, Stadtwerke Hannover AG)
- the coordinator of overall scientific support (Dr. Wolfgang Feist, Passivhaus Institut, Darmstadt); responsible at the same time for the scientific support of the 02-Kassel project and, on behalf of Stadtwerke Hannover AG, for the 01-Hannover project
- at least one representative each of the CEPHEUS partners.
- Where required, representatives of the institutions commissioned to carry out project measurements were also invited to the meetings.

At the two meetings in Austria, the planners and developers of the Austrian sub-projects were also invited upon occasion, and subsequent working meetings were carried out with Energieinstitut Vorarlberg (EIV). One of the meetings in Austria and the meeting in Rennes / France were used to present the overall concept and the specific sub-projects to a wider expert audience.

The meetings of the steering group served

- to disseminate fundamental knowledge by the PHI,
- to consult on methods and parameters, e.g. regarding the measurement programme and the determination of surface / floor areas, and
- to engage in exchange on the progress of the sub-projects and the experience made.

Originally, an international panel had been planned, bringing together all architects, planners and scientific advisors involved in the sub-projects. In this panel, it had been envisaged to disseminate by the PHI and discuss intensively with the participants at a series of one-day working meetings the key issues of the innovative Passive House approach, such as thermal-bridge-free design, airtightness concepts, ventilation concepts etc. However, due to reductions required by the Commission, this panel unfortunately could not be realized. Instead, the PHI was only able to make written information available. In retrospect, this panel would have been highly useful in view of the quality requirements still unaccustomed to many architects and planners. At some sites, it would most probably have prevented a number of problems that arose in implementing the Passive House concept (see also Sections 3.3 and 2.4.3).

Within the context of centralized scientific project support by the PHI, limited project funds similarly meant that only one on-site meeting for project acceptance was possible for each international project. It would have been expedient to have held at least one further meeting for each building project at an earlier point in time (see also Section 3.3).

The 9 Austrian CEPHEUS projects received further support from Energieinstitut Vorarlberg (EIV). For this, special summer seminars were offered that disseminated the information elaborated by the PHI and provided support in concept development. The thermal bridge computations, n_{50} measurements and thermographic imaging were organized by the EIV.

3.3 Problems, solutions, successes

With a target of less than 15 kWh/(m²a), the Passive House standard pursues a very ambitious goal for energy efficiency in new housing construction. To attain this goal, particular efforts were necessary in planning, component selection and in quality assurance during construction work. Some of the components used have only been available at all for a few years, and know-how on their application could not be presupposed at the time of the CEPHEUS project – neither among planners nor among the craftsmen involved in the building work. For this reason, we had proposed for the original project submitted to the EU to establish an *international panel* of all building projects involved in CEPHEUS. The plan was to carry out one-day working meetings on the issues of thermal insulation, thermal-bridge-free construction, airtightness concepts, Passive House windows, ventilation systems and ways to provide the remaining heat requirement. In the course of the reduction of costs for the CEPHEUS project, this panel was cancelled. The Passive House Institute then sought to promote know-how transfer through other channels, by compiling written information on the above issues as early on in the project as possible and making it available to participants. Thus the CEPHEUS 'Project Briefings' (Nos. 1 to 10) were made available to all participants in the individual projects. In most cases this documentation was also used in planning; however, in some projects and on some components a more intensive study of the innovative details would have been desirable. In retrospect, it must be said that the proposed panel, bringing together planners and the main trades and professions involved in the work, would have greatly optimized the development of the project.

For central project support, only one working day was available for each international construction project. This was used for the *scientific-engineering project acceptance*. This acceptance has proven essential, in order to check and record project details at the right point in time (completion of the buildings). However, it would have been useful to have set an additional *earlier meeting date* by the central project management for each construction project. At this meeting, the *planning principles*, the approaches taken to meet the criteria, planning assistance on airtightness, thermal bridge reduction, window quality and ventilation systems and the quality assurance concept should have been discussed. Generally no funding was available for such meetings; nonetheless, the scientific support institute did organize such early meetings at the Kassel, Hannover, Hörbranz, Wolfurt and Lucerne projects in combination with other occasions (e.g. meetings of the steering group). This greatly promoted project progress and quality.

All projects were planned and calculated in advance using the Passive House Planning Package (PHPP; cf. 2.4.1). Here, again, an introductory course on this highly useful tool for project planners and timely checking of calculations would have been purposeful. In the meantime, the Passive House Institute offers certification of quality-tested Passive Houses on the basis of a PHPP calculation; for the projects in Hannover, Kassel and Lucerne such certification was carried out, with positive results in each case. For the other projects, the PHPP spreadsheets were only available at a relatively late point in time. For some projects, the PHI carried out the calculations again itself upon a documented data basis. Here it was found that the strict standards of the Passive House certificate would not be met by all projects. In particular, in some instances the principles of thermal-bridge-free construction have not been observed, and in some cases no optimized airtightness concepts have been elaborated. Nonetheless, the results are exceedingly favourable compared to conventional new build. If more funds had been budgeted for central scientific project support, the excellent results in the lead projects in Hannover, Kassel, Hörbranz, Wolfurt and Lucerne would have been transferable to the other building projects.

Concerning dwelling ventilation, it emerged that the conventional specification approaches used by most planners tend to result in excessive air volumes. The planning tools provided by the Passive House Institute (PHPP and the “PH-Luft” programme) provide more realistic values. In all projects thus specified, air quality proved to be excellent.

Building project: CEPHEUS-01 Hannover-Kronsberg

In Hannover-Kronsberg the intensive support of the project made it possible to identify and eliminate a number of critical points in the building services systems. Thus improvement work to the thermal insulation of the building services storeys of the houses was carried out successfully, going beyond the normal standard. This led to appreciable temperature reductions in these rooms. After about 1.5 years of operation, the balance settings of the ventilation systems in the houses were improved substantially by readjusting the systems.

The contacts to the occupants, in particular through several information events on the results of the consumption data analyses and the publication of a project-specific ‘user manual’, had a very positive effect upon the understanding of occupants for their own Passive Houses. This helped to remove misunderstandings and avoid unintentional user errors.

The data measured in the second complete heating season of the project (1.10.2000 to 30.4.2001) have underscored, with their lower heating consumption levels, the well-known necessity not to use the first year alone as measurement period.

Building project: CEPHEUS-02 Kassel-Marbachshöhe

The developer convened a planning team comprising owner representatives, architects, technical engineers and external consultants. In the construction phase, this team was extended to a ‘construction team’ by including the trades and professions involved in the building work. Within the context of the supporting CEPHEUS quality assurance, before each crucial construction phase consultations were held with the directly concerned trades and site supervision. Through this approach, it was possible to ensure correct implementation of the most important Passive House-specific detail solutions.

Some problems of the installation phase only became apparent in the operation phase. Evaluation of the data measured within the context of the CEPHEUS project revealed that a false setting of the controls for the frost protection heating register had led to unnecessarily high electricity consumption. A false mounting of the condensate siphon led to moisture damage in one central ventilation unit.

Inadequate airtightness of the duct penetrations in the ground floor was only remedied after completion of building work, with considerable extra effort. However, through these measures, a very good n_{50}-value of 0.35 h^{-1} was finally achieved.

The implementation of a number of low-thermal-bridge details, such as the levelling course at the foot of external walls made of recycled PU material or the GFK tie bar caused extra effort. Here permits had to be applied for from case to case.

Building project: CEPHEUS-13 Lucerne-Wegere (CH)

In this project – an exceedingly lightweight construction with a very high degree of prefabrication – engineering specialists were already consulted in the design phase. This proved a worthwhile investment, for it led to concentration and simplification of the access spaces for building services (ventilation, sanitary, electric). This concentration reduced costs and heat losses and improved the concepts. Often participants said “That doesn’t matter” or “Now I’ve been planning for x years and this has never played any role”. The installation personnel also needed to be convinced to give due attention to the details. A pipe that penetrates the airtight layer has to be sealed! “Why? For what? doesn’t matter”. In general it can be stated that the Passive House places higher requirements upon the whole planning and building team (Prof. W. Betschart, lecturer for heating and energy systems at the Lucerne college of technology and architecture (Hochschule Technik+Architektur Lucerne)).

3.4 Modifications (compared to the project proposal)

The *goals* of the CEPHEUS project, as set out in Section 2, have undergone no modifications whatsoever compared to the project proposal. Concerning the *innovative technologies* employed in the building projects, there were marginal modifications, but these are irrelevant in terms of the project goals.

Major modifications did however occur with regard to the *locations* and the volume of various sub-projects:

- Due to delays in marketing, that were attributable to reasons independent of the envisaged Passive House standard, a 2nd construction phase in Hannover with 12 terraced houses had to be taken out of CEPHEUS. So, too, did a second Swedish project in Malmö with 20 terraced houses (largely identical in construction to those in Gothenburg) and the pensioners home project in Dietzenbach/D with 18 dwelling units. In place of the Dietzenbach project, an equivalent multifamily building project in Kassel with 40 units was included in CEPHEUS, in consultation with the European Commission.
- For various reasons (delays in approval of the CEPHEUS project, withdrawal of building partners, problems in building plot purchase etc.) all Austrian projects had to be replaced (see overview). The built sub-projects are fully equivalent to the replaced ones in terms of diversity of building types and constructions, and the innovative technologies employed.

Projects according to contract (27.3.1998)					Projects built				
	Location	Dwelling units	House type	Con-struction		Location	Dwelling units	House type	Con-struction
1	Klaus/Vorarlbg.	6	T	Lightw.	04	Egg/Vorarlbrg.	4	MF	Solid
2	Hard/ „	18	MF	Lightw.	05	Hörbranz/ „	3	T	Solid
3	Feldkirch/ „	7	T	Mixed	06	Wolfurt/ „	10	MF	Mixed
4	Lochau/ „	12	T	Mixed	07	Dornbirn 1/ „	1	S	Mixed
5	Schwarzach/ „	39	MF	Mixed	08	Gnigl/Salzburg	6	MF	Mixed
6	Lustenau/ „	26	MF	Mixed	09	Kuchl/Salzburg	25	MF	Mixed
					10	Hallein/Salzburg	31	MF	Mixed
					11	Horn/Lower A.	1	S	Mixed
					12	Steyr/Upper A.	3	T	Solid
	Total	108				Total	84		

Abbreviations: T – terraced; MF – multifamily building; S – detached single-family house

Table 15: Modifications to the Austrian sub-projects

- In Switzerland, the project partner Renggli initially realized, instead of the originally planned 10 dwelling units at 3 locations, only 5 terraced units in Wegere/Nebikon in the canton of Lucerne.

The modifications set out above had no substantial impact upon the attainment of project goals.

3.5 Time schedule

Compared to the time schedules of Annex I to the contract, there have been larger or smaller time shifts in almost all sub-projects. These delays are normal for building projects. An overview:

- The 01-Hannover/D project began as planned in 09/1998; first occupants were already able to move in by late 12/1998 – earlier than originally planned. The measurement campaign began in Oct. 1999 with robust data; it was possible to evaluate two full heating seasons.
- Due to replacement of the Dietzenbach project by the 02-Kassel/D project, a new construction schedule had to be set up. Despite this, it was possible to measure data over a full heating season for this project, too.
- In 03-Göteborg/S, due to reasons of planning law there was a major delay of 15 months (from 10/98 to 12/99) in the commencement of building work. Because the final completion and occupation by the buyers were also delayed into May 2001, it was not possible to carry out any measurements of the use phase within the context of CEPHEUS. However, it is envisaged following on from CEPHEUS to evaluate the use of the houses over a period of at least 2 years, with national funding.
- The replacement of the Austrian projects led to a completely new time schedule. Nonetheless, as envisaged for CEPHEUS, it was still possible to conduct measurements at the projects, in most cases over a full heating season and at least over half a heating season.
- Implementation of 13-Nebikon/CH was delayed by about a year. However, here, too, it was possible to evaluate the measured data gathered over a full heating season.
- The 14-Rennes/F project was only able to commence with more than half a year delay, in Oct. 1999, due to delays in marketing. The construction phase, already scheduled to run for a lengthy period, was then further extended to March 2001 due to extremely difficult weather conditions in autumn and winter 2000. As a result, it was no longer possible to conduct evaluations of measured data for this sub-project within the time schedule of CEPHEUS. Nonetheless, all requisite measurement equipment has been installed and a two-year measurement programme will start in October 2001.

3.6 Costs

Despite the modifications set out in Section 3.4, the overall cost framework of the CEPHEUS project was complied with. The modifications of the sub-projects led to some cost shifts within the cost items of the CEPHEUS partners and among them.

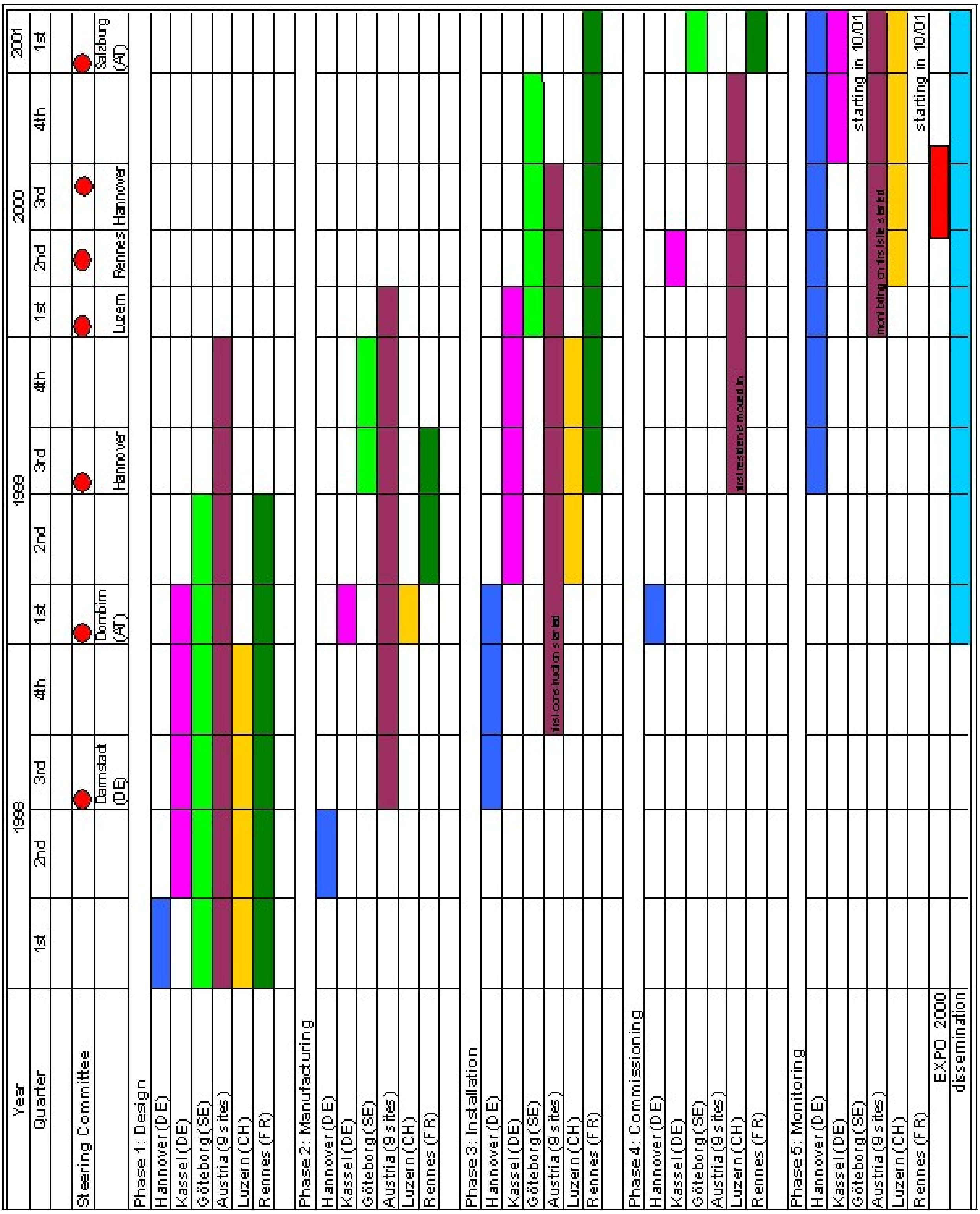


Figure 11: Time schedule

4 Operation and results

4.1 Operating history

In all CEPHEUS projects apart from 07-Dornbirn/A, project acceptance was carried out by the PHI. In all projects, it was obligatory to carry out blower-door tests to ascertain the airtightness of the buildings (see on this Sections 2.4.4 and 4.2.1). Where larger leakages were found, remedial work was subsequently carried out.

For all ventilation systems, the air volume flows were set for each individual room, and supply and exhaust air flows brought into balance (see Section 2.4.6). These initial settings are crucial to the proper operation of the supply and exhaust air systems.

In some projects, deficiencies had to be remedied in the first year of operation; this included control and measurement systems, and the thermal insulation of heating fittings and piping or hot water storage tanks.

It is generally known in the construction sector that energy consumption levels in the first heating season can be higher than those that develop later during continuous operation – this is due to structural drying, final building work that is still in progress, sub-optimal settings of the building services systems, and, finally, the habituation phase of occupants. This was also illustrated by the 01-Hannover project, where it was possible to carry out measurements over two heating seasons within the term of the CEPHEUS project [Peper 2001].

Users were generally instructed on the special features of a dwelling built to Passive House standards (ventilation recommendations, necessary filter changes and suchlike) when they moved in. For the 01-Hannover project, a detailed user manual was made available for this. Moreover, it has proven expedient to organize after a certain period of use an information event with the occupants, where both unresolved questions can be clarified and feedback can be provided on the energy performance indexes achieved.

The project in Rennes is a special case. Here the house buyers have formed a cooperative. At the regular meetings of the cooperative, the developer had to present the Passive House technology and the ecological building materials in great detail, and provided detailed instructions on their use.

In general, the ‘start-up’ of the Passive Houses did not develop very much differently than that of any other house.

4.2 Performance

4.2.1 Airtightness testing

In all CEPHEUS building projects, the remaining air leakage rates were measured by means of building airtightness tests in accordance with EN 13829. Table 16 shows an overview of the results.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project **n_{50}-value h^{-1}**	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes
Construction type	mixed	solid	timber	solid	solid	mixed	timber	timber	mixed	mixed	mixed	solid	timber	mixed
Mean n_{50} / h^{-1}	**0.30**	**0.35**	**0.31**	**0.51**	**0.47**	**0.33**	**1.1**	**0.97**	**2.23***	**0.58**	**0.61**	**1.6****	**0.57**	**11****

* In 09-Kuchl, a large internal leakage is probably the reason for the high n_{50}-value. Here it was not possible to conduct measurements under counterpressure.
** For these projects, only values from preliminary airtightness measurements were available at the time of analysis; due to major problems in the planning and implementation of the airtight envelope, these did not meet the CEPHEUS criteria. In the meantime, remedial work has been carried out for the projects concerned; however, new measurement results are not yet available.

Table 16: Measured volume-adjusted n_{50} building leakage indexes for the CEPHEUS projects as built

The results documented here show that the remaining air leakage rates ranged between 0.30 and 0.61 h^{-1} in 9 CEPHEUS projects. They are thus lower, by a factor of 40% and more, than the strictest national requirements currently applicable in Europe. The CEPHEUS target ($n_{50} \leq 0.6\ h^{-1}$) was achieved in 8 of the 14 individual projects (and in 11-Horn almost, at 0.61). In two of the other projects (07-Dornbirn-Knie and 08-Salzburg-Gnigl) the values measured are still good, around 1 h^{-1}; here a better result would be possible by means of carrying out remedial work on the junctions where air infiltration was identified (Dornbirn-Knie: window bars of the fixed glazing). In each of the cases where airtightness was further removed from the CEPHEUS target, this was due to systematic errors in airtightness design. In Rennes, for example, a systematic airtight plane within the lightweight external walls to the north of the building had initially been dispensed with (the manufacturer of the natural fibre insulation material had stated the view that an airtight layer would not be necessary for such a construction); this led to initially disastrously poor pressurization test results ($n_{50} \approx 11\ h^{-1}$). Airtight foils were then retrofitted, but it was no longer possible to implement systematically airtight junctions at their edges.

The airtightness measurements in the 32 terraced units in Hannover-Kronsberg were carried out with and without counterpressure in the neighbouring units. Only the results after deduction of internal leakage are relevant for the energy loss. These range between 0.17 and 0.4 h^{-1} ($\pm$10%), with a mean of 0.29 h^{-1}. An error analysis shows that the method of measuring under both positive and negative pressure differences can be carried out very accurately: The main sources of error lie in the previous preparation of the building and in the influence of wind-related pressure fluctuations [Feist/Peper 2001].

The measurements in the apartment building in Kassel were also carried out with and without counterpressure. Here the results in 23 units examined without retrofit measures ranged between 0.14 h^{-1} and 0.86 h^{-1}. Leakages found in four units were remedied. Even without the improvements thus yielded, the mean of this building (lot 1) figured 0.35 h^{-1}.

The principles set out in [Peper 1999a] and the specific solutions building upon these have proven themselves in the projects where they were applied rigorously. It is also interesting to note that wherever no rigorous airtightness design was presented, the results were far poorer. CEPHEUS has thus proven in practice that

- the high levels of airtightness requisite for the Passive House standard can be achieved in practice in all construction types in a reproducible manner,
- the recommendations made in [Peper 1999a] provide an excellent basis for airtightness, and
- rigorous planning of airtightness details is the key to success.

In most cases, the reliable airtightness solutions implemented in CEPHEUS are still relatively complex. However, in the follow-up, the learning processes in the projects have already led to simpler solutions becoming available in practice.

4.2.2 Energy performance indexes

Experience in previous building projects teaches that energy performance indexes, particularly those for space heat, are poorer in the first heating season than in the following ones. Consequently, the original CEPHEUS proposal provided for a measurement phase for all houses extending over two years; this, however, was not approved by the European Commission. As a result of delays in building work, as are commonplace in building projects and were scheduled for in the original CEPHEUS schedule, measurements in many CEPHEUS projects only cover a part of the first heating season. In most cases, the measurement results available for these projects were extrapolated to a complete year. For space heating, in particular, substantially better results can be expected for the following heating seasons than those documented here. The projects 03-Gothenburg and 14-Rennes were not yet occupied during the measurement phase, and the 10-Hallein project WAS only occupied partly from January onwards. Consequently, measurement results are not available for a sufficiently long period.

In order to render the energy indexes of the projects comparable, a uniform procedure for calculating treated floor area (TFA) was defined. The TFA essentially comprises the sum of the floor areas of all residential rooms within the thermal envelope; it includes half of the floor areas of ancillary rooms within the thermal envelope. The TFA is about half the size of the ‘gross floor area’ (in Germany: Bruttogeschoßfläche) that is frequently used as a reference. As a result, energy indexes are about twice as high as if they were based on the ‘gross floor area’. A precise definition of TFA calculation is given in [Schnieders 2001]. That publication also presents and discusses the measurement results in more detail than is possible here.

4.2.2.1 Energy balances of the projects

Figure 12 shows the heat balances of four different types of CEPHEUS project. The figure illustrates the loss minimization approach pursued in the Passive House: Heat losses are reduced to such a degree that about one third of them can be covered by solar gains, and a further third by internal heat sources. The heating system only has to cover the remaining third.

The contribution of solar gains to covering losses varies among building types. For instance, the multifamily building 02-Kassel is oriented east-west because of stipulations in the local development plan; the south-facing glazing areas are correspondingly small. As the windows facing east and west do not yield any net gains, they were sized according to day lighting requirements. The example of Kassel proves that even without rigorous solar architecture a well-functioning Passive House can indeed be realized.

In contrast, major solar gains are available in the 11-Horn single-family house. Due to the more unfavourable ratio between overall external surface area and volume, losses per square metre floor space are much larger here than in Kassel. However, as windows are oriented mainly to the south, in Horn considerable net solar gains can be achieved.

On the loss side, all projects have common features. Thanks to the high-efficiency ventilation heat recovery and the excellent airtightness of the building envelope, ventilation heat losses no longer play any great role. By far the greater part of the heat loss is attributable to transmission. Of these transmission losses, losses through the windows account for about half, the rest being lost through the large areas of the external walls, the base and the roof. On the whole, larger glazed areas lead to larger heat losses; however, with favourable orientation and shadowing these can be covered again by the solar gains.

The energy balances illustrate that minimized losses are the precondition to relevant solar gains. Heat losses through windows can only be overcompensated to a slight degree by solar gains. A noteworthy solar contribution to cover the other transmission and ventilation losses is therefore only possible if these losses are already low.

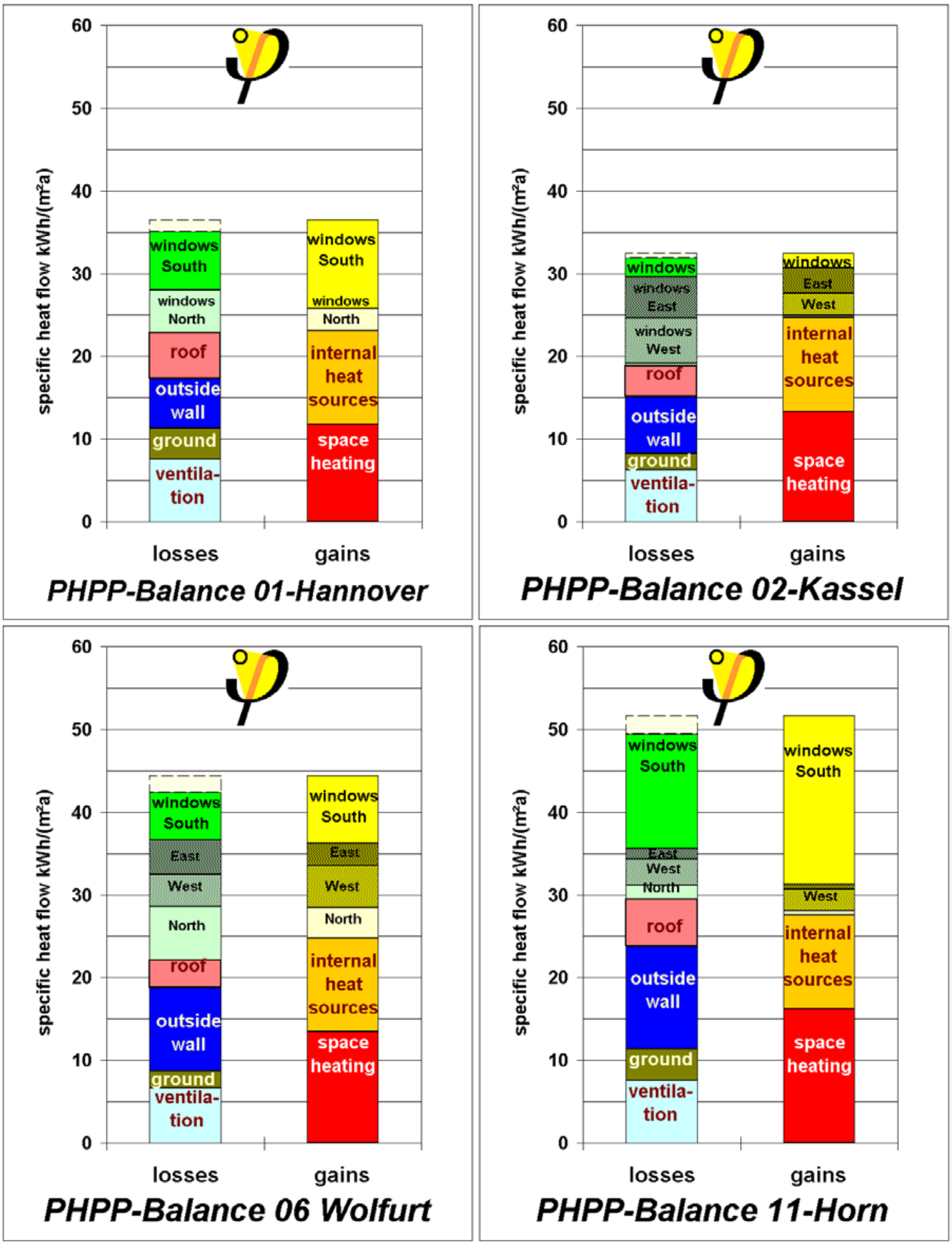


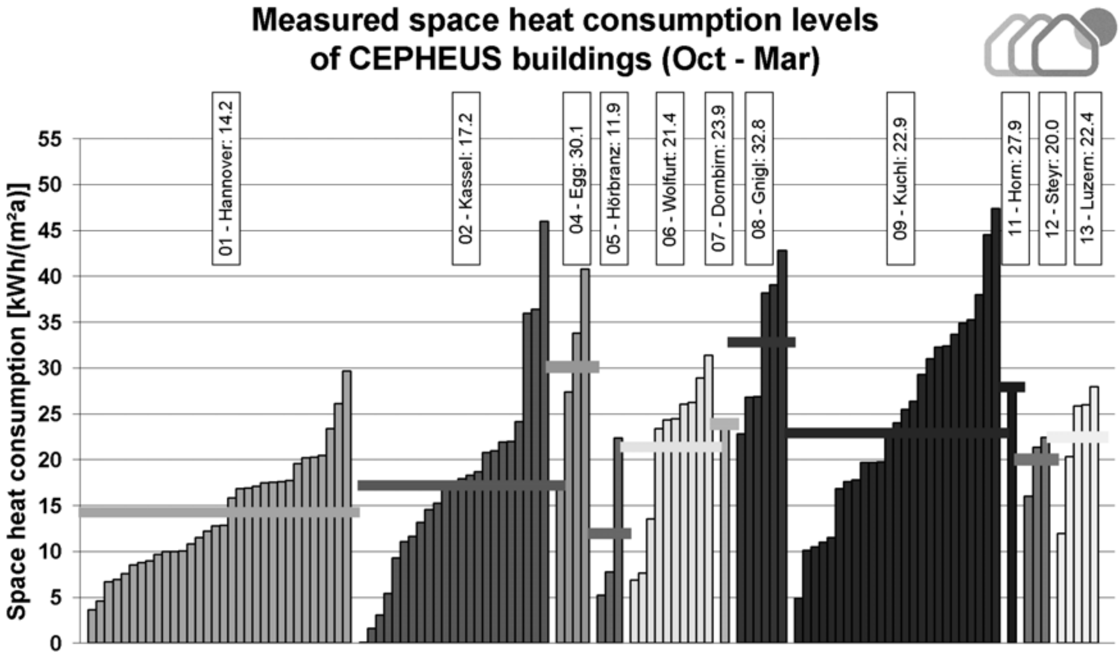
Figure 12: Energy balances of selected CEPHEUS projects

4.2.2.2 Energy consumption for space heating

4.2.2.2.1 Measured space heating consumption

Space heating consumption is the most important criterion for assessing the CEPHEUS Passive Houses, and depends primarily upon the thermal quality of the building envelope, which is the decisive factor for energy consumption over the entire service life of the building (50-100 years). In contrast, building services components and household appliances are generally replaced after about 20 years; their impact upon the total energy balance across the whole service life of the building is therefore smaller.

Figure 13 shows the measured space heat consumption levels for the CEPHEUS projects. The graph shows the space heat consumption per square metre (TFA) for each dwelling unit from October to March, insofar as data were available for this period. Some projects were only occupied for the first time during the period under examination here, so that the data contain consumption levels from heating-up phases and building operations; in some cases, data outages occurred at the beginning of the measurement period. As a consequence, the data for the 04-Egg, 05-Hörbranz and 07-Dornbirn projects refer to the period from 1 November and, respectively, 1 December onwards. Within each project, consumption levels are sorted by size. For each project, a horizontal bar indicates the TFA-weighted mean.



Fehler! Unbekanntes Schalterargument.

Figure 13: Measured space heat consumption of buildings in the winter measurement period.

The figure shows major differences in space heat consumption levels, both among the projects and among individual dwelling units within projects. Some projects achieve roughly the envisaged space heat consumption levels of ca. 15 kWh/(m²a), while others are significantly above this. However, the data refer to different periods and are therefore not directly comparable. A comparison of the projects is carried out below, based on computed adjustment of measured values for measurement periods and indoor temperatures.

The differences within individual projects are even larger than those between the projects. Such degrees of variance in space heat consumption are also known from measurements in the building stock. In addition to differences in the constructions of dwelling units, they are due above all to different indoor temperatures, the impact of which is particularly strong in multifamily apartment buildings (02-Kassel, 09-Kuchl and 06-Wolfurt).

Pfluger [2001a] analyses in detail the consumption variance among dwelling units for the 02-Kassel multifamily building. It emerges from this that a simple correlation analysis between the measured indoor temperatures and the individual consumption levels does not suffice to explain the fluctuations in consumption. If, however, we use a steady-state multizone model to compute the individual heat requirement values of the dwelling units on the basis of measured temperatures, then we arrive at a correlation coefficient of 0.65. Consumption differences can be explained by the different external heat losses (12%) and above all by the transversal heat flows between the units (33%). However, this explanation only succeeds if the physical conditions are modelled adequately in the multizone model.

4.2.2.2.2 Normalized annual consumption levels

It is known from simulation computations and from measurements that indoor temperatures have a great influence on space heat consumption in Passive Houses. It is therefore not purposeful to compare directly the measurement results shown in Figure 13 with previously calculated values, particularly as measurement data extending over a whole year are not available for all projects. In order to be able to make comparisons nonetheless, the measured values were extrapolated to a full year using the monthly procedure pursuant to EN 832, and normalized to an indoor temperature of 20°C. In the present instance, this type of extrapolation can be considered conservative (for a reasoning of this cf. [Schnieders 2001]).

Figure 14 compares the normalized space heat consumption levels to reference consumption levels of conventional new buildings that have the same geometry and are built in accordance with locally applicable construction law (cf. Section 2.4.1), and with the space heat requirement values calculated in advance (using the PHPP Passive House Planning Package).

Compared to the reference consumption of conventional new buildings, analysis of the normalized space heat consumption shows that the buildings saved 84% space heat over the area-weighted mean. Savings were lowest in those projects that were only occupied during or shortly before the measurement period and were not yet fully completed. In all houses that were already occupied for a longer period, savings figure more than 80%.

It is further striking that in most cases the measured values are slightly higher than the calculated values. To a certain degree this was also to be expected: Almost all measured values come from the first year of use. In some instances, the buildings were occupied in winter; heating up the cooled-down building components once can consume up to ca. 3 kWh/m² alone. The drying out of construction material moisture also takes place in the first winter and can elevate space heat consumption by 3 to 8 kWh/(m²a) (cf. on this [Pfluger 2001]). It takes some time for occupants to accustom themselves to the behaviour of the building service systems and the building itself, so that in the initial use phase additional consumption can occur that will not arise later. In principle it can be expected that the projects will consume less space heat in the following years.

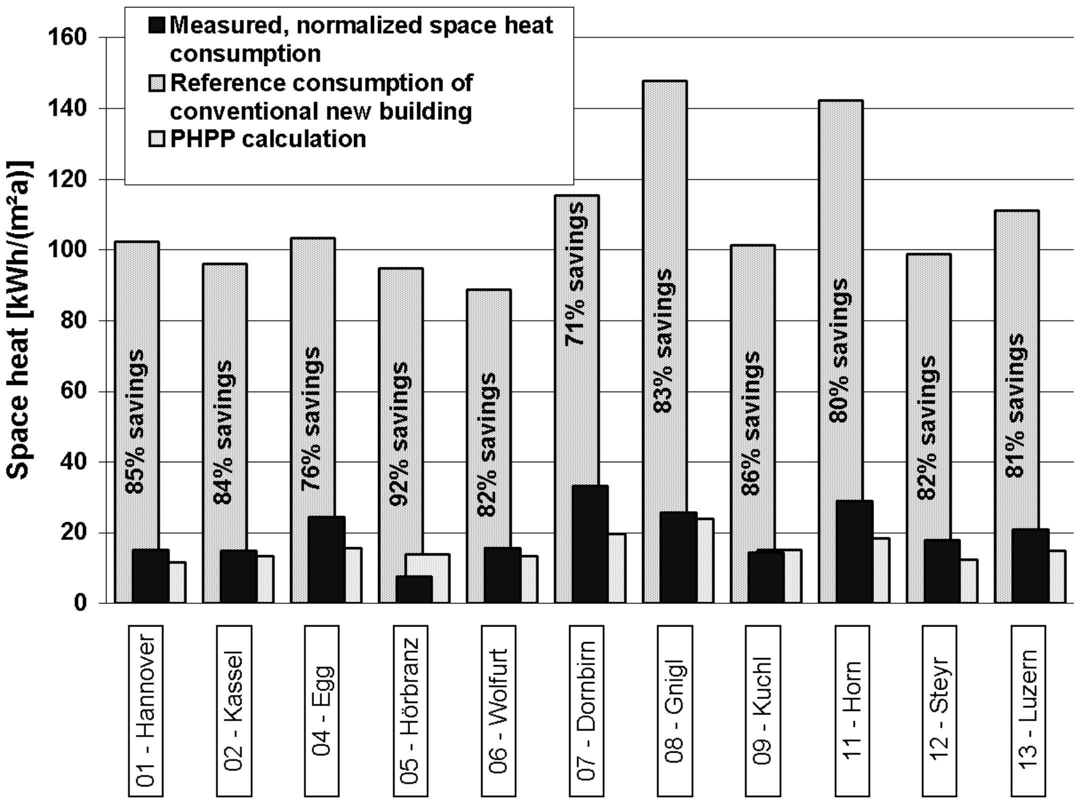


Figure 14: Space heat consumption levels determined by measurements, extrapolated for a whole year and normalized to 20°C indoor temperature ('normalized space heat consumption') compared to the consumption of conventional new buildings and to the values calculated in advance using the PHPP Passive House Planning Package

4.2.2.3 Energy consumption for domestic hot water

Figure 15 shows the measured useful heat consumption levels for domestic hot water heating. For most projects, only winter consumption levels were available; these were extrapolated to the whole year, neglecting the circumstance that hot water consumption will be slightly lower in summer.

As in space heat consumption, the distribution of consumption levels among projects exhibits considerable variance. On average, the consumption levels correspond roughly to the reference values, i.e. the typical consumption (25 litres per person and day at 60°C) of dwelling units with comparable occupancy ratios; in the 09 - Kuchl and 11 - Horn projects they are even significantly higher.

Hot water consumption is also a characteristic of the comfort demands of occupants. The study shows that the demands of the occupants of the CEPHEUS projects do not deviate significantly from the general average.

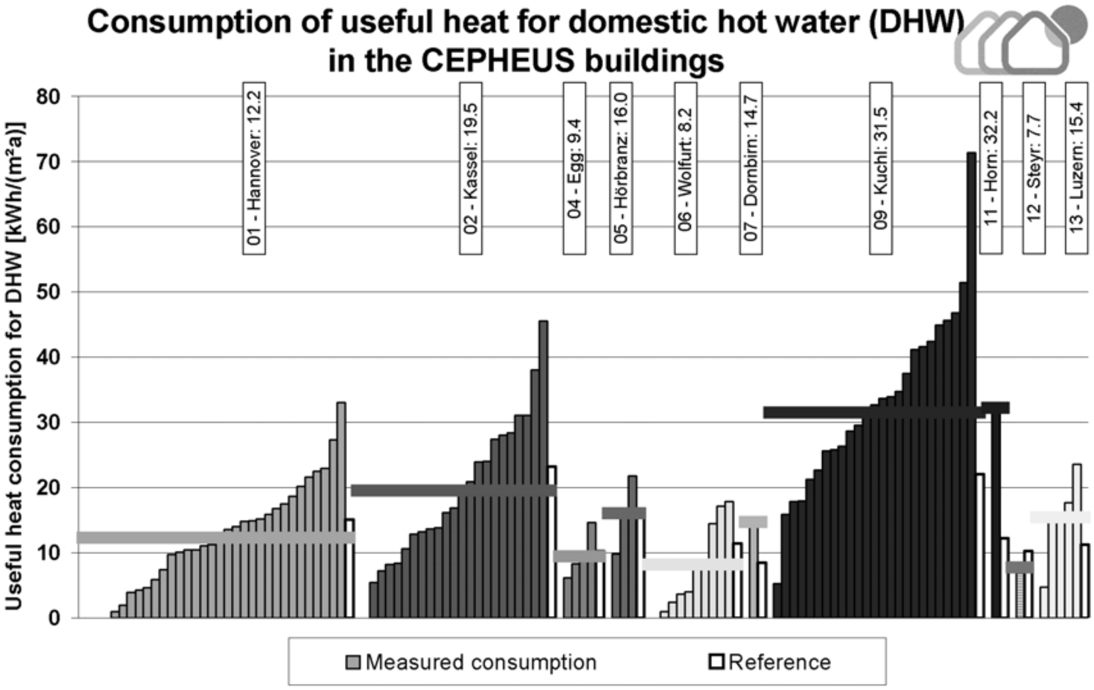


Figure 15: Measured useful heat consumption for domestic hot water, by dwelling units (data extrapolated, with the exception of 01-Hannover).

4.2.2.4 Household electricity consumption

Given the extremely reduced space heat consumption of Passive Houses, the share of electricity consumption in overall energy consumption is higher. This applies particularly in terms of primary energy (see on this also the analysis of the primary energy balance in Section 4.2.2.5). Consequently, the CEPHEUS projects also made efforts to reduce household electricity consumption. The electricity conservation approach is described in more detail in Section 2.3.12.

Figure 16 shows the measured household electricity consumption levels. Where no data were available for a complete year, the available measured data were extrapolated, assuming constant consumption levels throughout the year. As a basis for comparison, for each project the household electricity was determined that a typical house with the same occupancy ratio would consume at the same site. These reference values are based on statistical averages for household electricity without space heating and hot water heating. The different dwelling unit sizes were taken into consideration through a regression analysis (for details cf. [Schnieders 2001]).

The 01-Hannover, 02-Kassel and 06-Wolfurt projects exhibit major savings. In the other projects, consumption levels are only slightly below the reference values; in 07-Dornbirn, 08-Gnigl and 12-Steyr they are even higher.

In 01-Hannover only 24 of the 32 dwelling units were occupied permanently in the measurement period. If we consider only those permanently occupied houses in which personal electricity conservation advice was provided, we find savings of 38% compared to the reference value (cf. [Peper 2001]). It should be noted in this context that the measured value includes the electricity consumption of building services systems, including the ventilation system.

That household electricity savings are meagre in a number of projects compared to the space heat savings can be explained by the circumstance that in some projects the field of electricity was not given the same priority in implementation as the field of space heat. In the 01-Hannover and 06–Wolfurt projects, however, implementation of the electricity conservation approach was demonstrated convincingly.

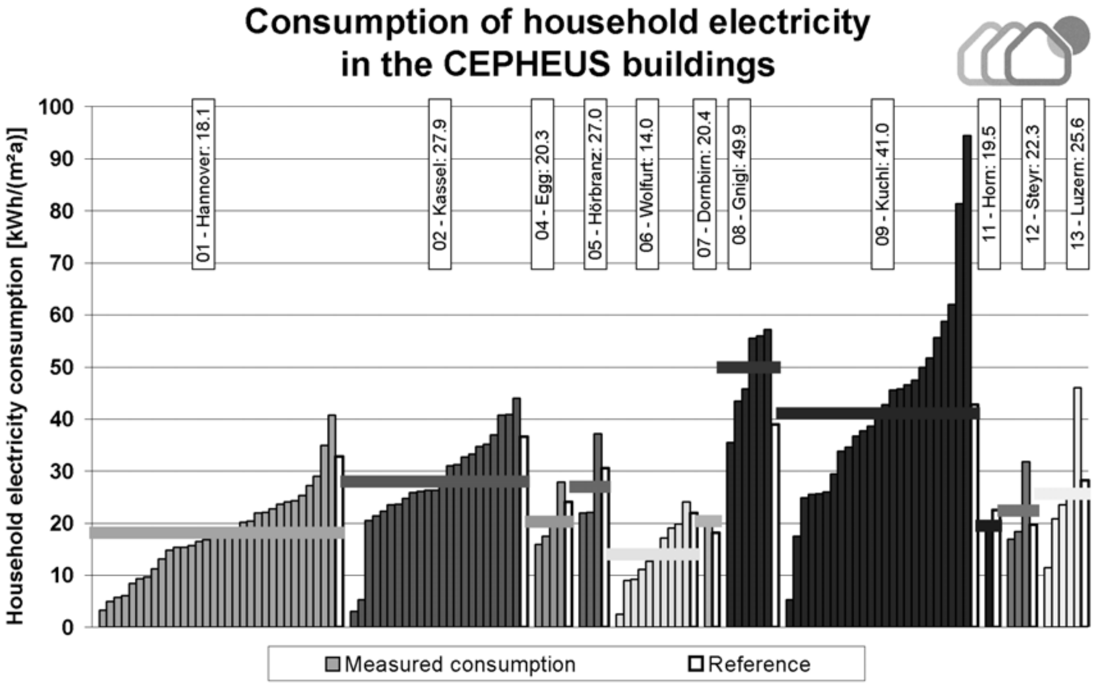


Figure 16: Measured household electricity consumption of the buildings.

4.2.2.5 Final and primary energy consumption

This section is concerned with the non-renewable proportions of final and primary energy consumption. Thus, for instance, energy consumption for hot water heating provided directly by a solar thermal installation are not included in the final energy consumption figures (when extrapolating the final energy consumption levels in winter for domestic hot water, an annual contribution of 40% was assumed uniformly for solar thermal installations). In contrast, consumption for household, fan and building services electricity and electricity for joint uses across several dwelling units are included in full in the consumption figures stated; where these arose, common electricity use was distributed evenly across the dwelling units concerned. The final energy consumption figures already contain any distribution losses and losses at heat producers.

As a rule, final energy consumption for space heat and hot water is higher than useful energy consumption. All systems with heat pumps are an exception, as these deliver more thermal energy than the electric energy they consume. For other electricity applications (household electricity, ventilation systems etc.) useful and final energy are identical.

The total annual final energy consumption of buildings could only be determined by means of extrapolation. Here space heat consumption was extrapolated in a manner similar to that described in Section 4.2.2.2, using the monthly procedure according to EN 832. However, normalization of indoor temperatures was dispensed with. Indoor temperatures during the unavailable months were assumed to be the mean of the measured indoor temperatures. Hot water and electricity consumption was extrapolated as set out in Sections 4.2.2.3 and 4.2.2.4.

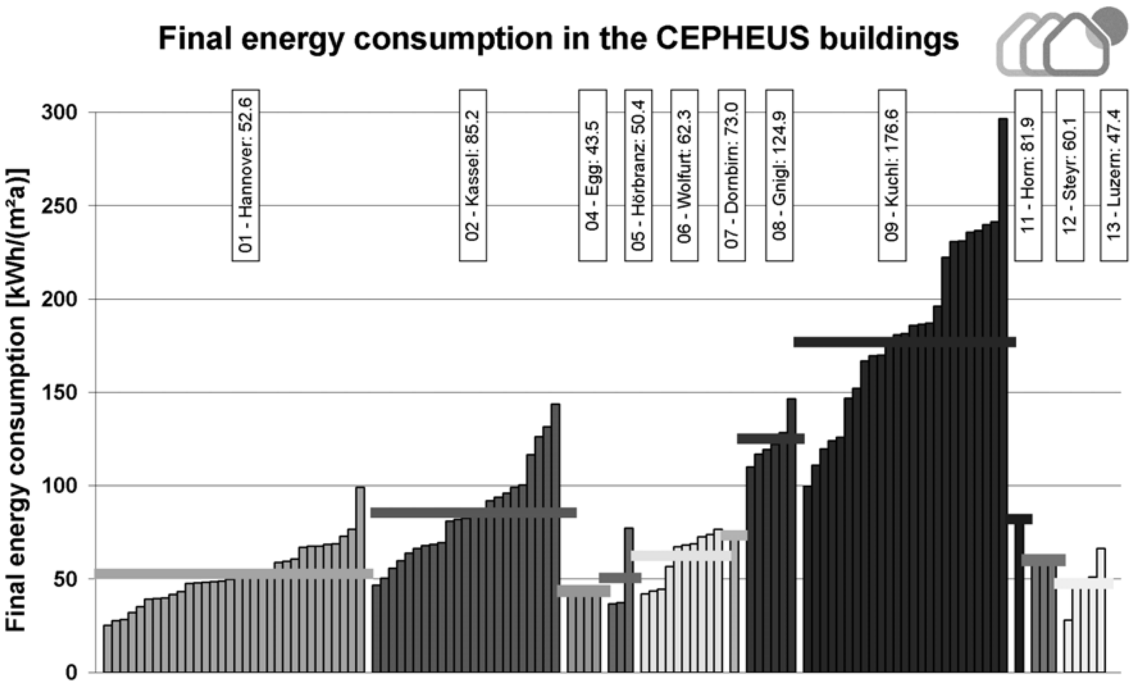


Figure 17: Measured final energy consumption of the buildings.
The values contain all non-renewable energy supplies to the buildings, incl. household electricity and all items of ancillary electricity consumption.

Proceeding from the findings of GEMIS 4.0 [GEMIS] the following primary energy factors were determined:

- Gas: 1.15
- Electricity: 2.5
- District heat: 0.7
- Wood pellets: 0.1

These are in each instance mean values of the non-renewable, cumulated energy requirement to supply the energy source in question to the building envelope. In individual cases, these values can deviate greatly from the actual conditions. Thus in the case of district heat, for instance, the type of heat production is decisive for the primary energy factor. In order to render comparable the building projects analysed here, primary energy factors representative for the European average were selected, rounded to the precision stated above and used uniformly for all projects.

Figure 17 and Figure 18 provide overviews of the measurements in all dwelling units. Where no data were available for a complete year, the available measured data were extrapolated. Figure 19 provides an overview of the mean useful, final and primary energy consumption levels of the projects (sites).

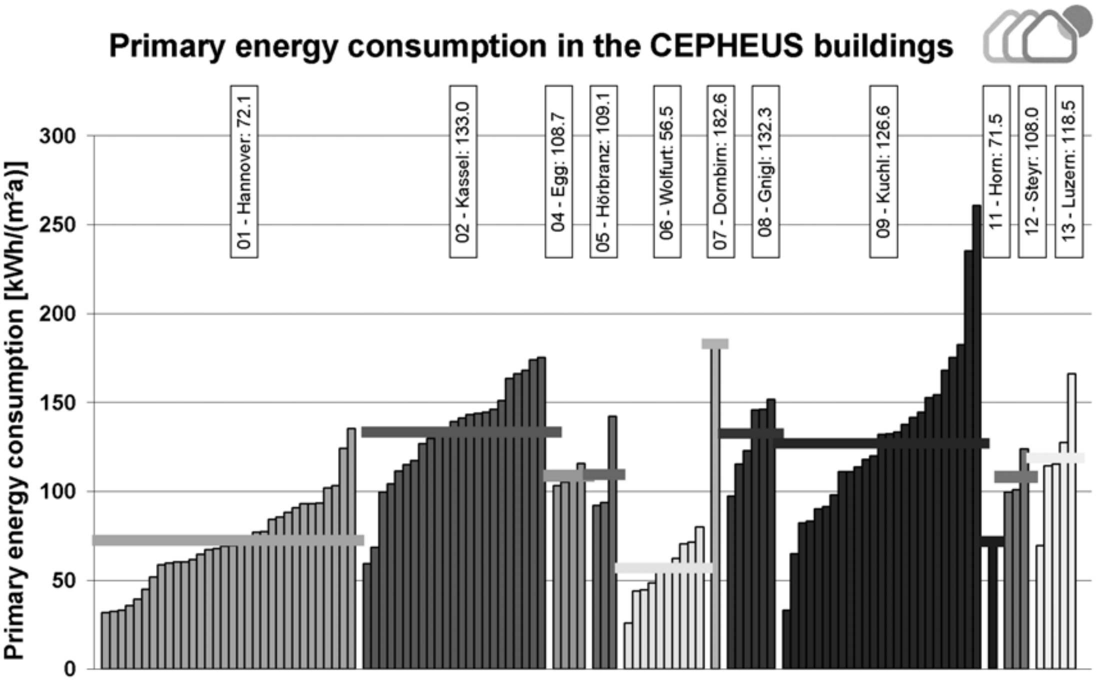


Figure 18: Measured primary energy consumption of the buildings, incl. all types of electricity consumption.
The data basis is the same as for the final energy consumption levels (Figure 17).

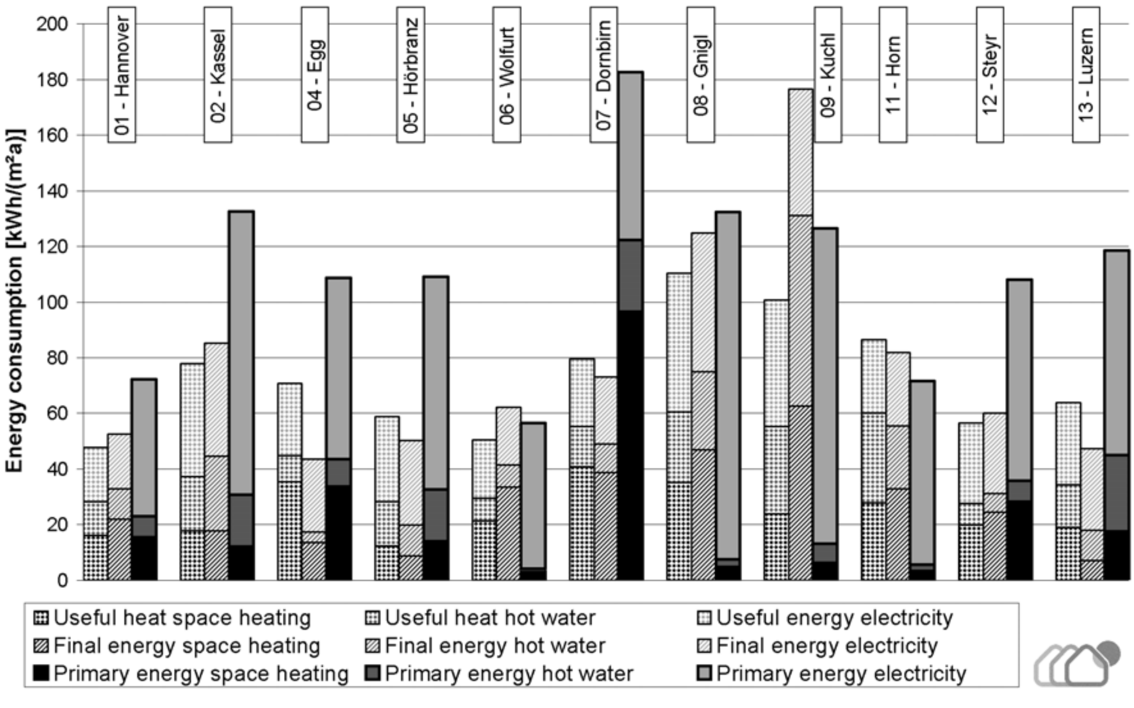


Figure 19: Comparison of useful, final and primary energy consumption for space heat, domestic hot water and all electricity applications in the houses.
For each project, the cumulative bar at the left represents useful energy consumption, that in the middle final energy and that on the right primary energy consumption.

The figures illustrate that the envisaged low space heating consumption levels were already almost achieved in the first measurement period in most projects. Moreover, in all projects exceedingly low primary energy consumption levels were achieved. Compared to conventional new buildings, useful, final and primary energy savings of more than 50% were achieved, space heat consumption was even reduced by 80% (see on this also Figure 32).

In the projects with district heat supply, the distribution losses were roughly balanced by the relatively favourable primary energy factor of the district heat. High electricity consumption levels and thus high primary energy values occur above all in projects with high occupancy ratios. The cause of the relatively high primary energy consumption of the 07-Dornbirn project is that a part of the measured values is still from the end of the construction phase. The heat recovery system was out of operation until mid-February; direct electric heating was used in this period. The results are therefore not representative for the consumption levels that can be expected in the future.

The comparatively high final energy consumption levels in 08-Gnigl and 09-Kuchl have various reasons: In Gnigl there is a relatively high space heat consumption level, resulting from an also relatively high calculated space heat requirement and high indoor temperatures. At the same time, the high occupancy ratio leads to high electricity and domestic hot water consumption per square metre floor area. The project in Kuchl also has a high occupancy ratio. In addition, extremely large distribution losses for space heating and hot water were measured here. The causes of this will be addressed before the 2nd year of operation.

Two factors emerged as being particularly important for the ratio between final and useful energy consumption:

- Very low final energy consumption levels can be achieved using heat pump systems such as packaged units or brine heat pumps. However, the coefficient of performance (COP) of the heat pumps corresponds roughly to the primary energy factor of the household electricity, so that the decision between heat pumps and conventional heat producers will be taken less from an energy perspective and more from the perspective of cost-effectiveness.
- Because of the low consumption levels achieved in the Passive House, the heat distribution losses gain importance particularly in cases where there is centralized heat production in larger buildings. Reduced distribution losses alone have the potential to yield further final energy savings of 20–30 %. The 01-Hannover project shows that with good system quality better results can be achieved.

For primary energy usage, which is the decisive environmental aspect, household electricity consumption has particular importance. Here major savings potentials are still untapped. Given replacement cycles of 7 to 10 years, the development, production and use of energy-efficient household appliances can have a far quicker impact in the existing building stock, too, than improvements to the buildings themselves. Improvements to the buildings concern primarily space heat consumption and their components have a service life of 40 to 100 years.

Heat production from wood pellets has a particularly positive impact upon primary energy consumption: In all projects using pellet boilers, the share of space heat and hot water in total primary energy consumption figured less than 15%. In these cases, household electricity consumption dominated the overall primary energy balance of the building.

4.2.2.6 Heat loads

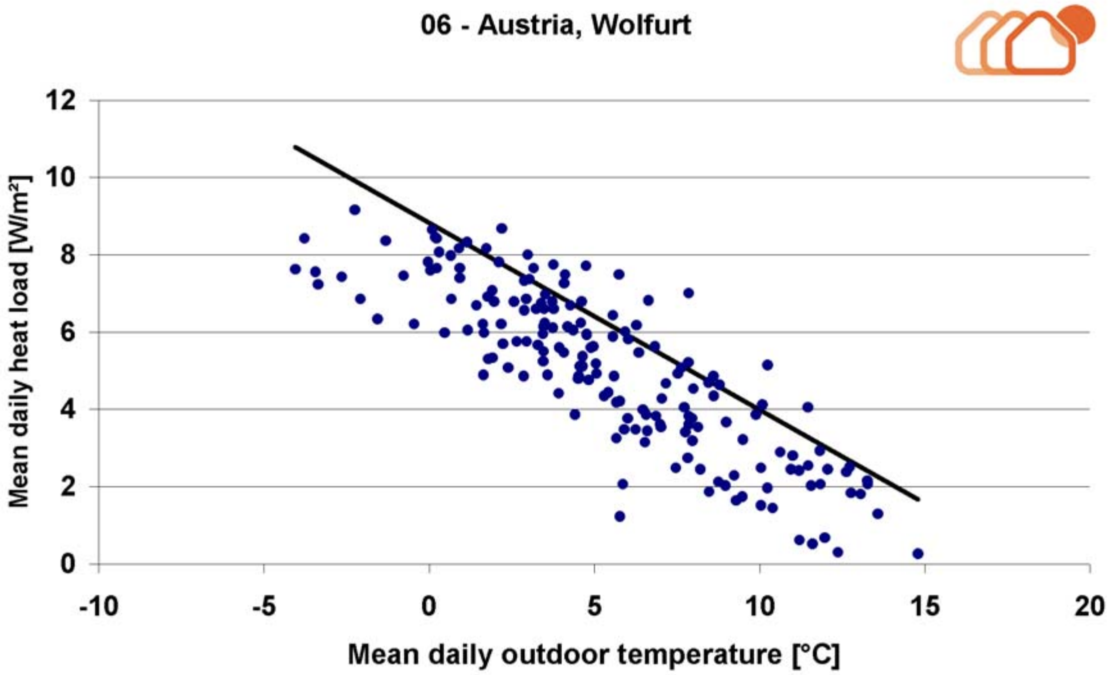
The downward leap in costs when the Passive House standard is reached occurs because the separate heating system can be dispensed with: The heat load conveyable by means of the supply air, which is required in any case, suffices to keep the house warm. The measured mean daily heat loads are therefore of particular interest. If we enter these in a graph over outdoor temperature, we can compare them with the theoretical heat loads computed from the specific heat losses and internal gains of the building for each day. This presentation provides information on the energy balance of the building and the quality of workmanship.

Figure 20 shows four such diagrams for selected projects. In 06-Wolfurt and 13-Lucerne the measured heat loads are on average slightly below the theoretical line. This is due to the solar gains, which can compensate for a part of the heat losses. Downward deviations from the theoretical heat load line occur particularly when outdoor temperatures are higher (in spring and autumn, with correspondingly longer periods of solar irradiation) and when outdoor temperatures are very low (which in Central Europe is always associated with a clear sky).

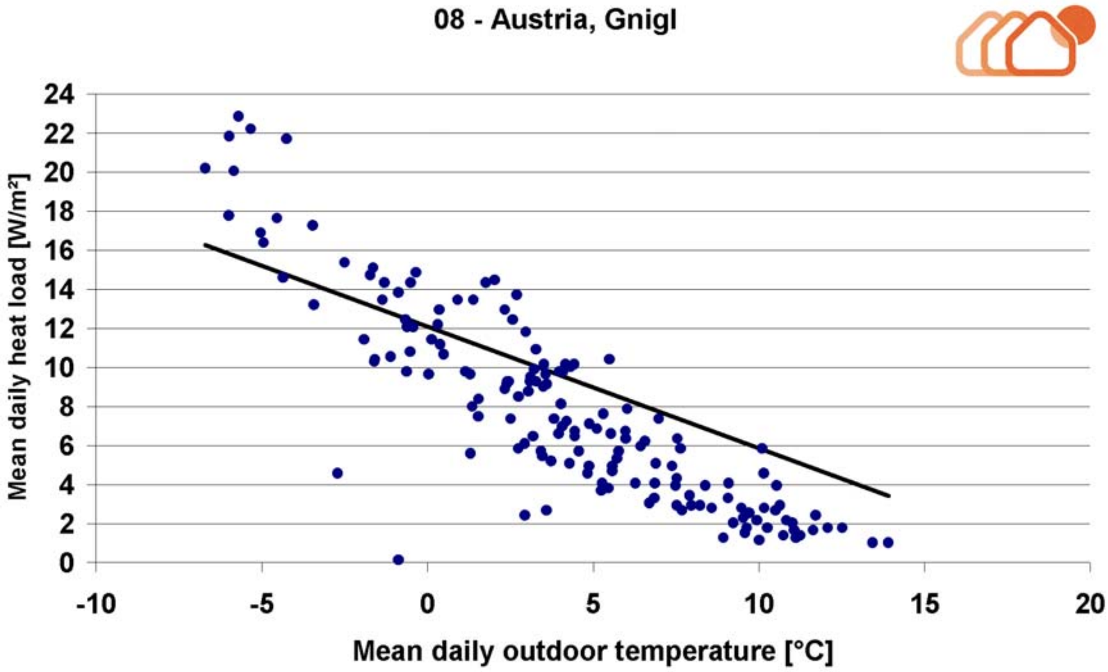
In 11–Horn, the measured heat loads fluctuate greatly around the theoretical heat load line. This is because this project is a single-family house. Due to the great thermal inertia of the Passive House, random fluctuations in heat loads can occur from one day to the next that only average out over a group of several dwelling units.

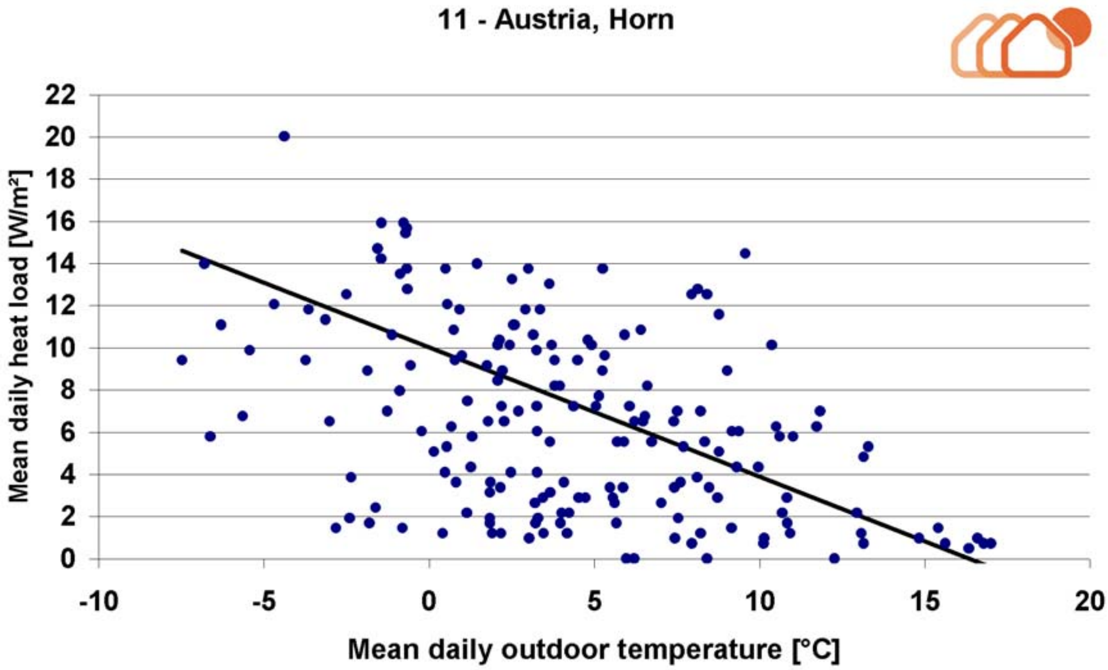
08-Gnigl is in a very shadowed site: In the core winter period no direct sunrays reach the house. In autumn and spring, in contrast, there are solar gains that correlate in the diagram with higher outdoor temperatures. This model explains why, compared to the theoretical values, the curve of measured heat loads over outdoor temperature is steeper.

06 - Austria, Wolfurt



08 - Austria, Gnigl





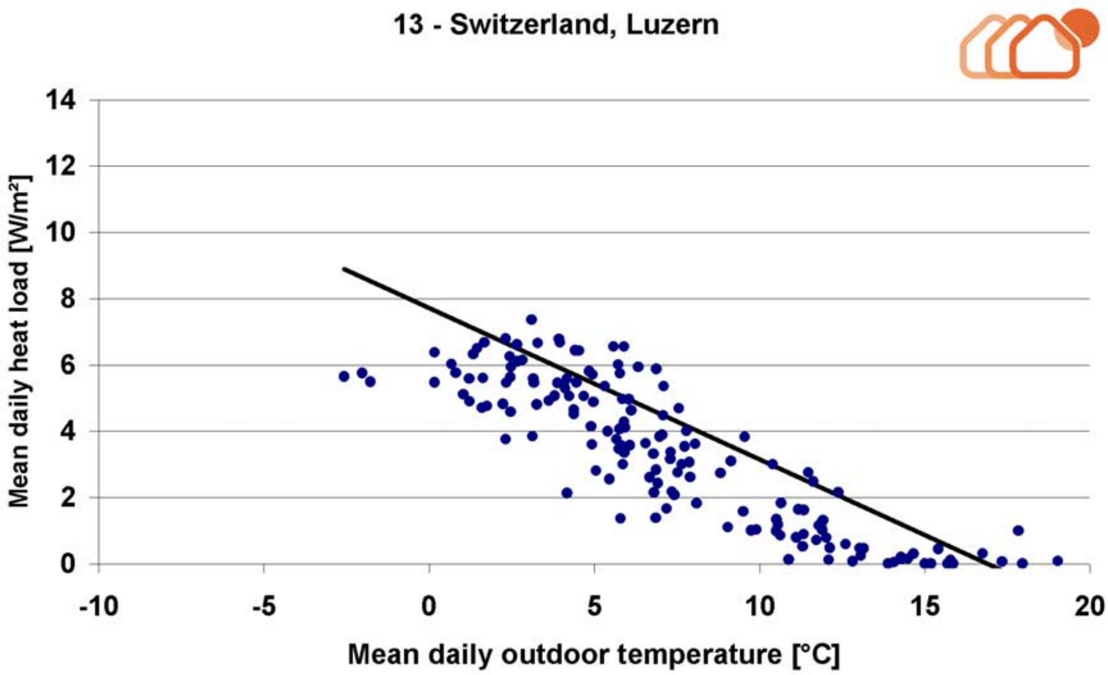


Figure 20: Correlation between mean daily heat load and outdoor temperature.
The straight line is the theoretical heat load on the basis of building-specific heat losses, internal gains and measured mean indoor temperatures (based on the final planning status).

4.2.3 Acheivement of a zero CO_2 balance

The realizability of this goal was to be demonstrated exemplarily only for the 01-Hannover project. The plan was to substitute over the annual balance the entire remaining primary energy requirement, or the associated CO_2 emissions, through a share in a wind power facility planned nearby. Subgoals were, first, to test the acceptance of a corresponding mark-up on the purchase price of a house, and, second, to identify the precise level of the necessary share.

The mark-up of DM 2,500 (= Euro 1,278) presented no marketing impediment at all. Only one purchaser refused to pay for this share, because of the (unfounded) worry of having to make further payments in the event of damage to the wind energy facility.

With the above-mentioned equity capital, due to the special ratio between equity and external capital of the wind park fund set up by the operator (Windwärts Kunst und Windenergie GmbH & Co. Betreiber KG), per terraced house 2.63 kW or 0.175% of the rated output of the total of 7 MW of the wind turbines erected was purchased. In the period from 1 July 2000 to 30 June 2001, the measured wind power production of these turbines figured 2,219,629 kWh/a (June figures extrapolated; [windwaerts]); the share of each Passive House in this figures 3,894 kWh/a or 35 kWh/(m²a). This corresponds to CO_2 savings of 26 kg/(m²a).

For the Hannover-Kronsberg district, the Stadtwerke Hannover utility determined the specific CO_2 emissions for space heating and domestic hot water on the basis of a natural gas fired small-scale CHP (combined heat and power) unit, arriving at a figure of 145.3 g/kWh$_{th}$. For the electricity substituted, a figure of 754 g/kWh$_{el}$ was assumed. Proceeding from the district heat consumption of about 35 kWh/(m²a) and the measured electricity consumption of the occupied houses of 23 kWh/(m²a), we arrive for the Passive House estate in Hannover-Kronsberg at total CO_2 emissions in the first year amounting to 23 kg CO_2/(m²a).

The share in the wind energy facility purchased by the buyers of the Passive Houses as a part of the house purchase price thus substituted the remaining CO_2 emissions by a factor of 116%. If the substituted heat production had been based on natural gas, the share in the wind facility that would have had to be purchased to meet the substitution target would have had to be slightly larger; if wood pellets were used as in some Austrian projects, it could have been smaller.

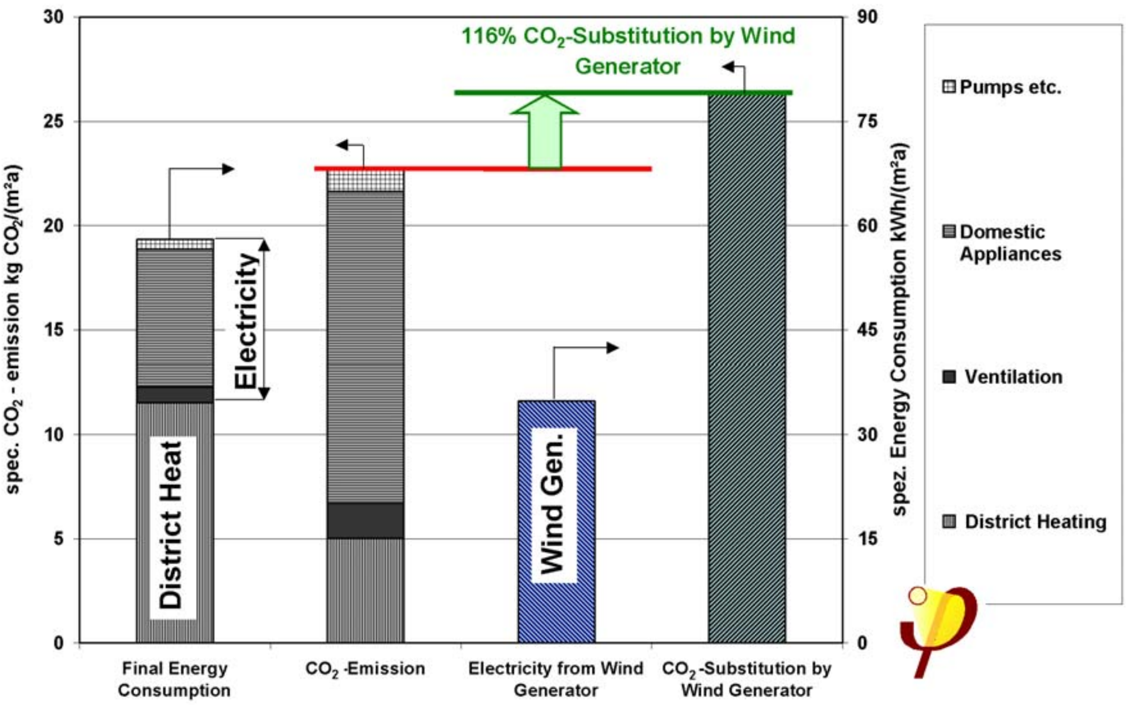


Figure 21: Substitution of the CO_2 emissions of the Passive House development in 01-Hannover by purchase of a share in the electricity production of a wind turbine.

4.2.4 Maintenance of conditions of user comfort

4.2.4.1 Indoor temperatures in winter

Figure 22 shows the mean values of the measured indoor temperatures in winter. The values generally refer to the months of November to February. 07-Dornbirn was only occupied in late December 2000; here the temperature data are for January and February.

The figure shows that in all CEPHEUS buildings the mean indoor temperature over all occupied zones and the whole measurement period was above 20°C. Occupants typically set temperatures between 21 and 22°C; the range of the occupied houses is, however, from 17 to 25°C (the mean temperatures below 17°C measured in 01-Hannover belong to unoccupied houses). When the insulation standard of a building is improved, a trend towards higher indoor temperatures can generally be observed: If the improved comfort is technically realizable at low cost, it is evidently also desired.

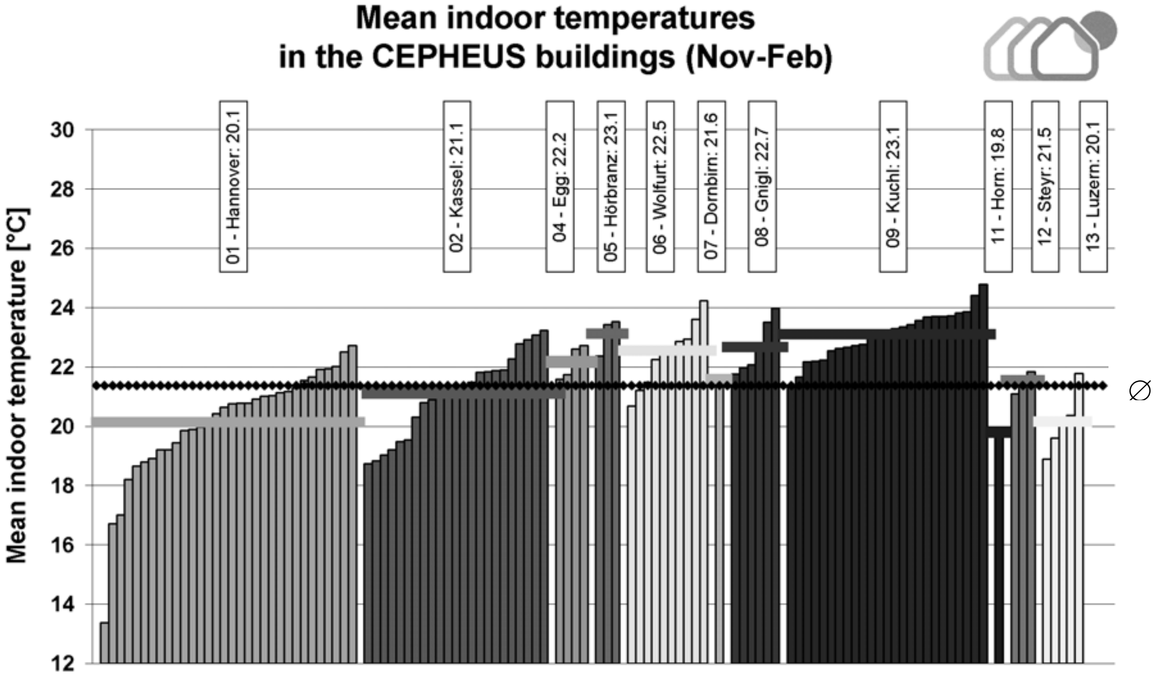
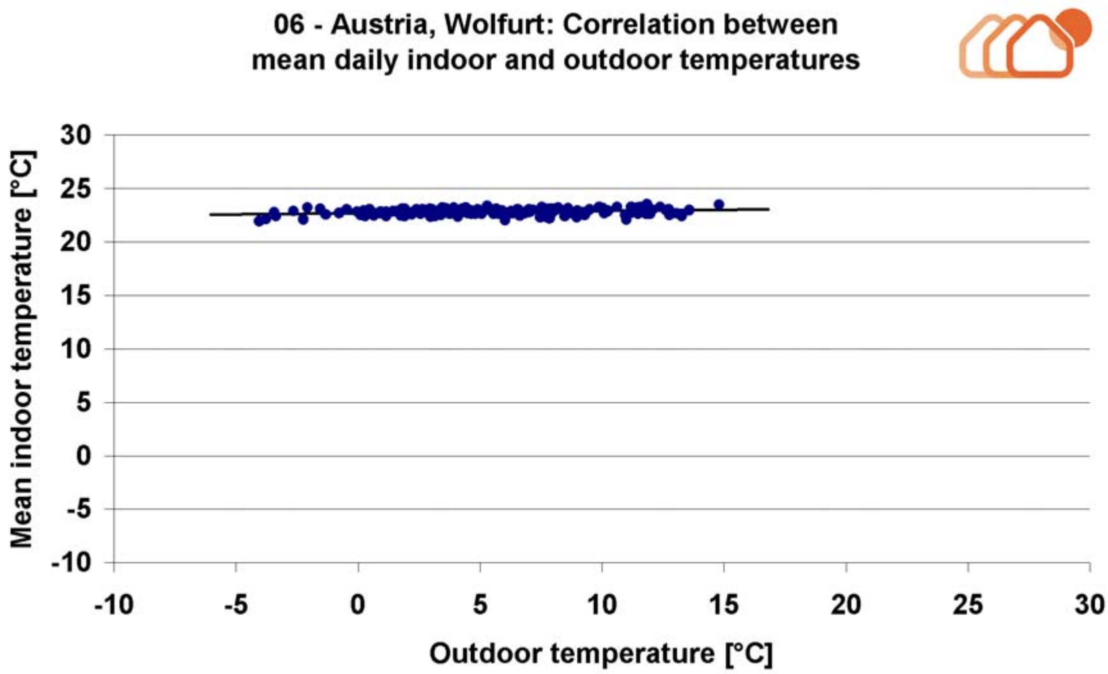


Figure 22: Mean indoor temperatures in winter (generally from 1 November to 28 February/lines show averages).

Figure 23 shows the indoor temperatures as a function of outdoor temperature for two representative buildings taken from Figure 20. The indoor temperature is almost independent of the outdoor temperature. The available heat load in the projects evidently suffices to guarantee the indoor temperatures desired by the users throughout the year.



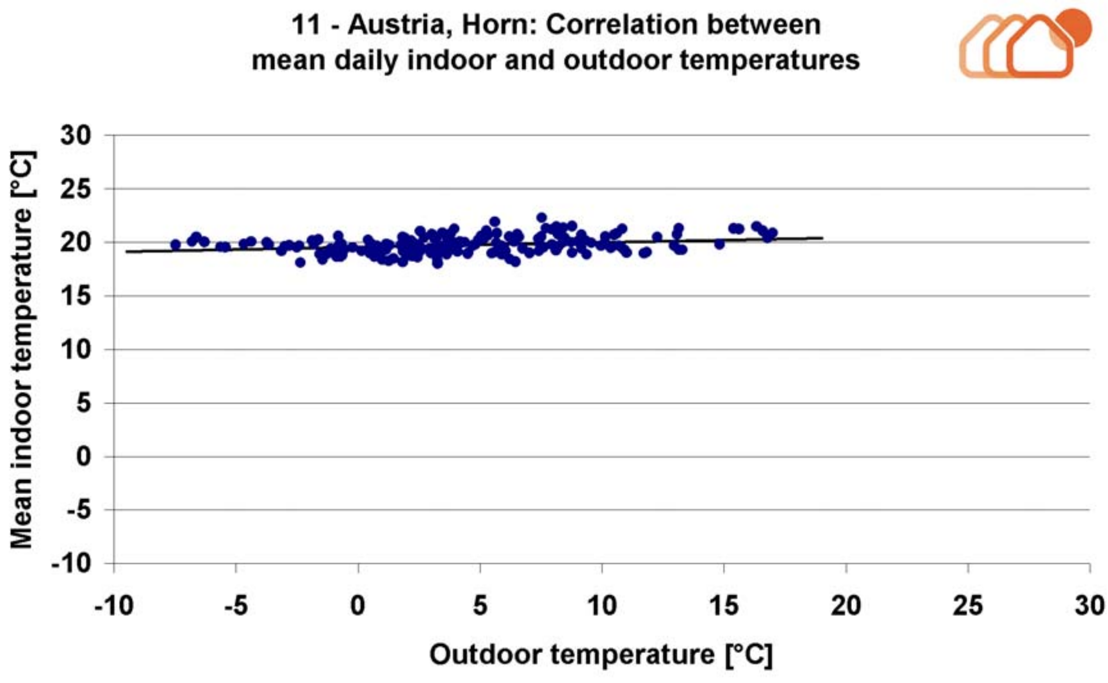


Figure 23: Correlation between indoor and outdoor temperatures for the 06-Wolfurt and 11–Horn projects, both from 1 October 2000 to 31 March 2001.

4.2.4.2 Indoor temperatures in summer

Due to the truncated measurement period, data for the summer were only available for two projects, namely for the terraced houses in Hannover-Kronsberg and in Lucerne. However, of the houses in Lucerne only one was occupied from April onwards; the other four were only occupied in August. In Hannover, 8 of the 32 houses were unoccupied during the measurement period or were not used for residential purposes.

In summer, the indoor temperatures are of particular interest: Should the excellent thermal insulation and optimized passive solar energy use perhaps lead in summer to overheating? Figure 24 presents the mean indoor temperatures between 1 May and 31 August. The figure further shows for each house the temperature that was not exceeded for 95% of the time in the stated months. This latter value is a better measure of summer-time comfort than the maximum temperature reached, as individual temperature peaks can occur in the absence of occupants or in exceptional situations and are thus not representative.

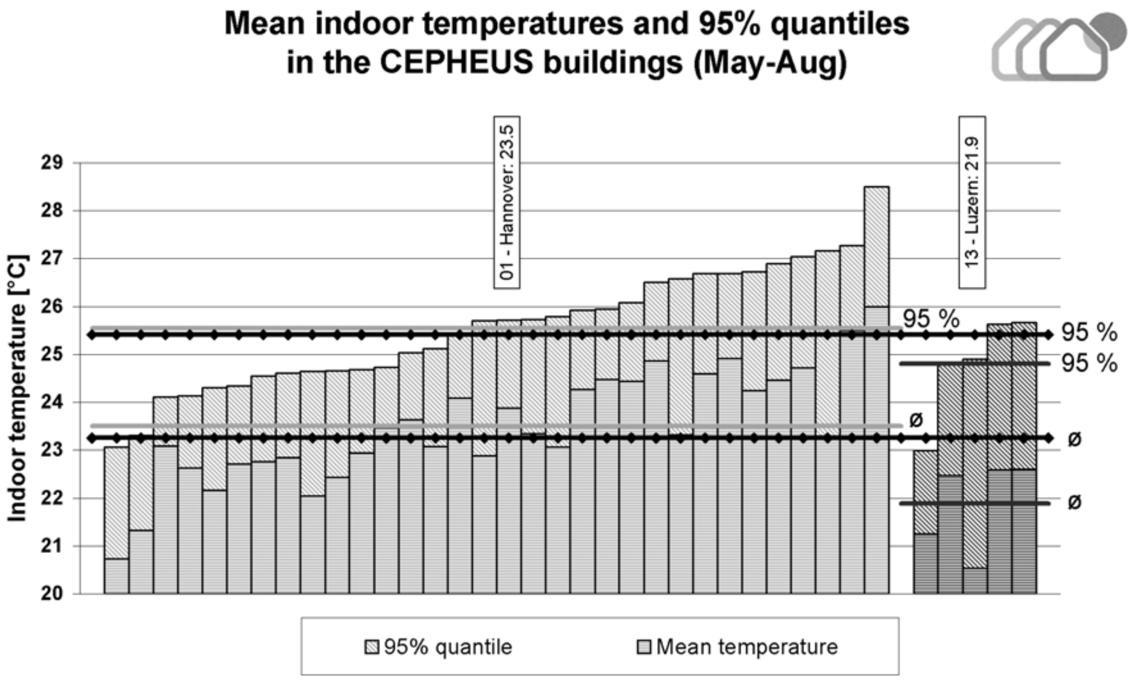


Figure 24: Mean indoor temperatures from May to August and 95% quantile of hourly mean values of average house-specific indoor temperatures for the 01-Hannover and 13-Lucerne projects.
The black lines cutting across Hannover and Lucerne represent the overall mean values of both sites.

These results show that the summer-time indoor climate is acceptable in all houses. Mean temperatures range between 21.9 and 23.6°C; a temperature of 27°C is only exceeded in exceptional cases in some of the houses. The peak values in Hannover were subject to conditions that explain the excessive temperatures: The house with the highest 95% quantile was heated during the studied summer period due to a control system malfunction; in the four months, 9.2 kWh/m² were consumed for space heating. The house with the next highest 95% quantile has the highest electricity consumption at the whole site, which leads to higher heat gains. 3rd place is taken by an unoccupied house in which consequently no windows were opened in order to release excess heat. Among the houses in Lucerne, the house occupied throughout the entire measurement period has the second highest temperature, very close to that of the (partly unoccupied) house with the highest temperature.

Closer examination of the temperature curves shows that the users can attain highly comfortable summer-time temperatures through appropriate ventilation behaviour. Occupancy ratios and shading elements are important, but are secondary to ventilation behaviour. These issues are discussed in greater detail in [Peper 2001].

4.2.4.3 Indoor air flows

To check indoor comfort levels, detailed field measurements were conducted in 13-Lucerne (Switzerland). The survey examined in particular the living room, which has glazing from floor to ceiling and is heated only through the supply air which is blown into the room from a vent in the internal wall close to the ceiling. The results of the measurements were evaluated by HTA Lucerne and the Passive House Institute and compared with computations made with the Fluent CFD programme.

Within the measurement accuracy, a good correlation was found between the simulation of indoor air flows and the measurements, both with regard to flow patterns and with regard to the temperature and velocity field. The ventilation effectiveness ratios were also simulated with sufficient accuracy.

By means of the CFD simulation, the course of the air flow in the room can be determined and visualized in more detail: As the measurements confirmed, the supply air rises from the vent to the ceiling where it initially remains. The current remains as desired initially under the ceiling and slowly broadens. The supply air reaches the vicinity of the window before the supply air current has dissolved. At the relatively cold window, the air cools down, falls downward and moves back into the room. Here the directed air flow dissolves due to the lack of driving forces, and the air moves largely at random through the room before leaving it through the extract vents.

Both the measurements and the CFD computations indicate that the air speed in the occupied zone is below 0.025 m/s and is thus, according to all available knowledge, outside of the range perceptible to human faculties. The occurrence of draughts can therefore be excluded in buildings constructed to the Passive House standard. At the design temperature, the temperature stratification in the occupied zone is at most 1.1 K/m; in this respect, too, an extraordinarily high level of comfort is achieved. If the Passive House standard is complied with, the radiative temperature asymmetries are so small that all conditions of currently applicable comfort standards are complied with. It can be stated in summary that the measurements of comfort-related aspects have delivered exceedingly good results by all criteria.

Finally, in a parameter study, the model parameters were varied towards more unfavourable values. Here it became apparent that the window U-value in particular has a decisive influence upon compliance with comfort criteria. With the Passive House standard at U_W = 0.85 W/(m²K) sufficient comfort can be achieved in the occupied zone under all boundary conditions normally encountered in dwellings. If 'normal' low energy house windows with U_W = 1.6 W/(m²K) are used, these conditions can no longer be complied with reliably – radiators then need to be positioned close to the window to balance the air flow.

The measurement surveys and numeric analyses documented here thus yield two conclusions:

- Under the conditions of the Passive House standard, and under Central European climatic conditions, a high level of indoor comfort can be ensured with supply air heating.
- If the construction quality, particularly of the windows, is poorer, larger temperature stratification effects and substantial radiative temperature asymmetries can arise.

4.2.4.4 Subjective assessment of comfort by occupants

The following discussion is based upon occupant surveys conducted in 2000 and 2001. The surveys covered, first, the whole Kronsberg district, and, second and third, personal interviews and written questionnaires with the Passive House occupants. This social science evaluation was carried out by the institute for environmental communication of

Lüneburg University, on behalf of Stadtwerke Hannover AG. The detailed results are reported in [Danner 2001] and [von Oesen 2001].
In the following, some of the main findings are expressed in percentages. By way of comparison, the corresponding percentages for all Kronsberg residents (Passive Houses, low-energy houses (LEH) and tenants) are stated as a second figure in brackets.

Satisfaction with the indoor climate in winter is stated by a substantial majority of occupants as good to very good. Not a single occupant gave a negative rating. Moreover, the higher surface temperatures and the even temperature distribution throughout the space (no temperature stratification) compared to 'normal' houses are experienced as highly pleasant. The statement made by an occupant during a press conference describes this phenomenon fittingly: "At last I don't have cold feet any more". After the habituation phase, satisfaction with the bedroom temperature during the heating season has also risen greatly. More than half of the occupants state that the temperature in the bedroom is just right.

For summer, too, the occupants confirm the measurement results – 88% of those surveyed state that they are satisfied or very satisfied with the indoor climate in summer. In particular, the cool air when windows are closed is given positive mention by many occupants. Most households apply night-time ventilation, as this has proven highly effective and, moreover, the way to carry it out is described in an easily understandable manner in the user manual.

Air quality is rated by 95% of occupants as good to very good. Not a single occupant gave a negative rating. This means that one of the main factors of residential quality is given a very good rating.

Ventilation habits during the heating season underscore the satisfaction of the Passive House occupants, as 82% (40%) of the Passive House occupants use the ventilation system exclusively to exchange the spent air. However, window ventilation is not dispensed with entirely. 7% (30%) open their windows for a few minutes, 4% (23%) for ca. 15 minutes and a further 7% (7%) even keep them tilted open for several hours. Evidently there is no definite need to use window ventilation in the Passive Houses; where window ventilation is made use of now and then, the system functions properly nonetheless.
When asked about their *satisfaction with their ventilation system*, **96% (55%) of the Passive House occupants state that they are very satisfied or satisfied**. Only 4% (28%) were only partly satisfied with the system. **Among the Passive House occupants, there was not a single negative assessment of the ventilation system with heat recovery – 0% (18%)**. In comparison to the other Kronsberg residents, it is apparent that the acceptance of the ventilation system is much higher among the Passive House occupants. The satisfaction of the Passive House occupants may be attributable to the circumstance that their ventilation system is different from that of other houses, which mostly use simple extract air systems. It was not possible to determine by the survey to what extent the assessment of ventilation systems depends upon specific types of systems.

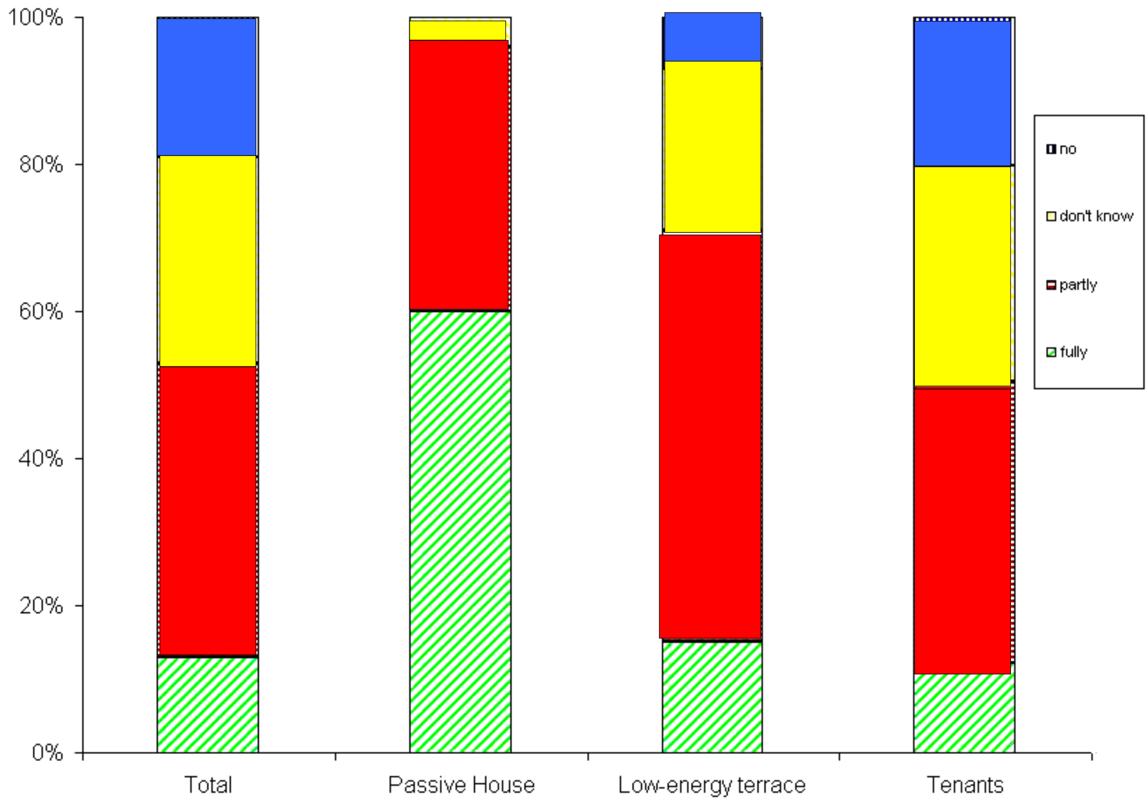


Figure 25: Acceptance of ventilation systems

Almost 90% of the Passive House occupants found it easy to get accustomed to the ventilation system; similarly, the handling of the system is stated to be uncomplicated. The overall measurement results are confirmed by the subjective perceptions of the occupants.

4.2.5 User acceptance

The high level of user acceptance among Passive House occupants is illustrated very clearly by the findings of the social science evaluations conducted in Hannover-01 and Kassel-02.

In Hannover-01 the following question was posed to the occupants: “Have your initial expectations been fulfilled until now?”

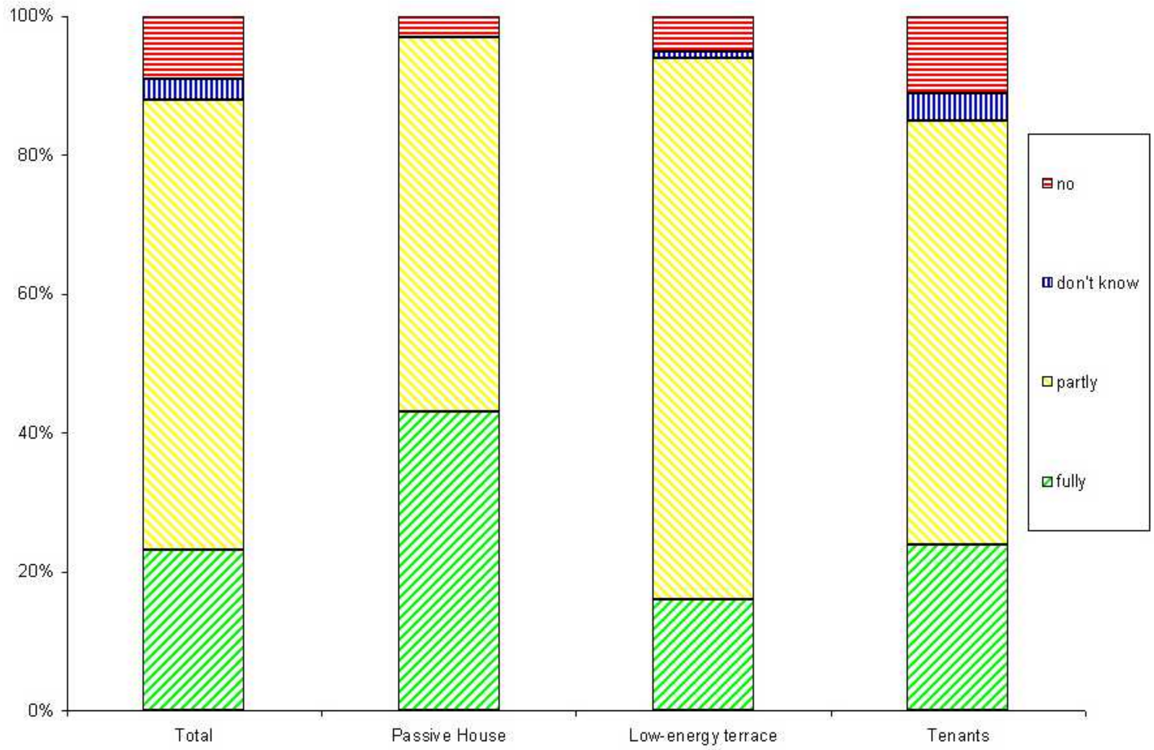


Figure 26: Fulfilment of the expectations of Kronsberg occupants

The figure illustrates very well the above-average satisfaction of Passive House occupants as compared to the occupants of low-energy houses or apartments. Only 3% (12%) are not satisfied or don’t know whether they are satisfied. For 43% (23%) expectations have been met fully. 54% (64%) find their expectations at least partly fulfilled.

In Kassel-02, the question was posed before and after the first heating season whether the users would recommend Passive Houses to others.

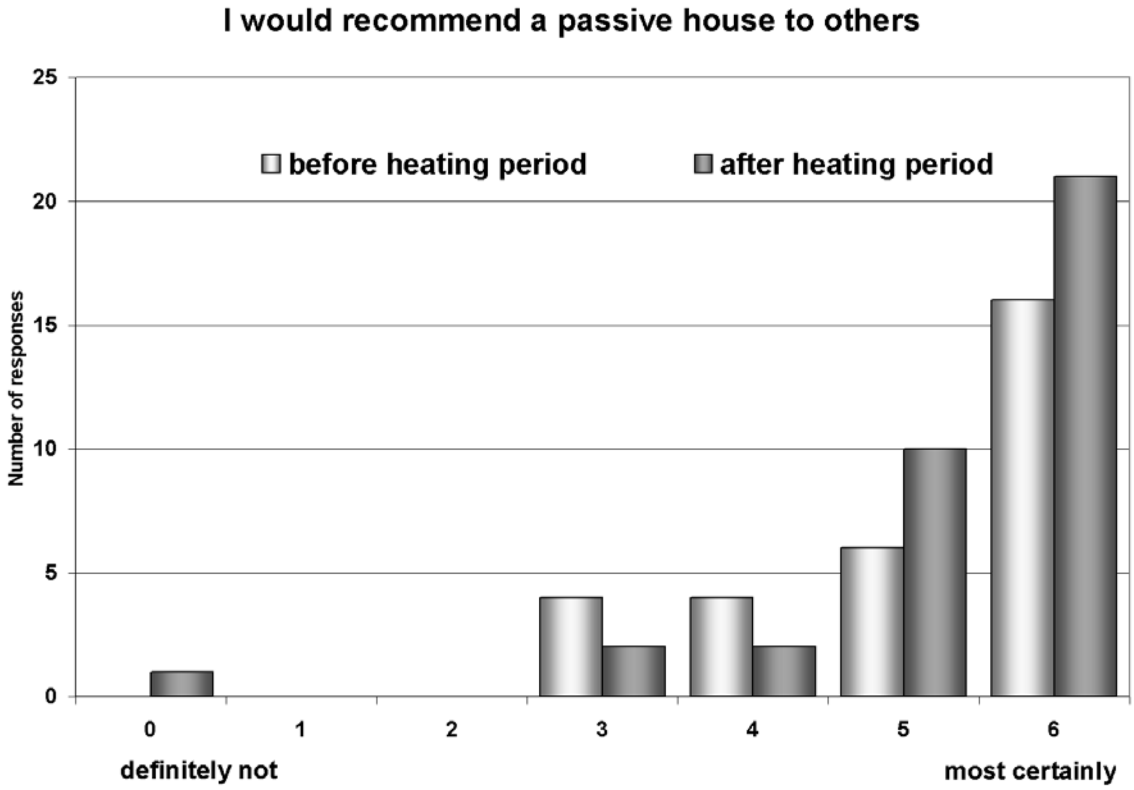


Figure 27: Results of a social science evaluation in the publicly-assisted rental housing construction sub-project in Kassel/Germany. Figure from [Hübner 2001]

This figure also illustrates very well the exceedingly high level of user acceptance in rental housing, too, as already set out in Section 4.2.4.4. Importantly, the substantially more positive assessment after the first heating season shows that initial scepticism has been dispelled by the experience made in the first winter with the pleasant and comfortable indoor climate.

4.3 Success of the project

The "**C**ost **E**fficient **P**assive **H**ouses as **EU**ropean **S**tandards" project has essentially achieved the strategic goals formulated in Section 2.1.4:

- At 14 locations in 5 European countries, a total of 221 dwelling units has been built to Passive House standards. A great variety of construction types and architectural designs has been realized. The building materials used are also highly diverse.
- For the great majority of the dwelling units, their function was evaluated at least during the first year of operation. The targeted space heat energy requirement of 15 kWh/(m²a) was already complied with during the first year of operation across the average of all buildings measured.
- Compared to other buildings erected by the developers according to the locally applicable building regulations, the extra costs of the building projects average less than 10%. Where the envisaged costs were overstepped, it is perceptible that they can be complied with.
- The extra construction costs that presently still remain can be further reduced in the near future, so that the Passive House standard will also become highly interesting from an economic perspective, too.

- In the built dwelling units, occupant comfort is excellent in both winter and summer; this is confirmed by the measurement results and by the subjective appraisals of users.
- It has been found that user acceptance of the Passive House standard is exceedingly high. This is a useful basis helping to remove reservations still encountered outside of the CEPHEUS project among building developers and housing associations (e.g. with regard to presumed complicatedness of the approach or, in Germany, with regard to ventilation systems).
- The quality standards for Passive Houses can be complied with as a matter of principle. This is confirmed both by experience made within CEPHEUS and by the wider development in the German-speaking countries.
- However, experience made particularly with the project in Rennes/F shows that among architects and planners the awareness of specific aspects (e.g. thermal bridges, airtightness) is still inadequate. It proved to be a handicap in the CEPHEUS project that almost all publications on the Passive House are as yet only available in German. It is therefore to be expected that introducing the Passive House standard will require intensified awareness-raising and training efforts in some European countries.
- The CEPHEUS project has generated important innovation impulses, particularly in Germany, Austria and Switzerland, for the (further) development of high-efficiency building components and technology components of Passive Houses (e.g. insulation systems, windows, ventilation systems, packaged heating units) and for broad market introduction of Passive Houses.
- The project in Rennes attracted great media attention in France. This attention focussed both on the high thermal insulation standard and on the ecological building materials used. The "HQE – Haute Qualité Environnemental" project approach, much debated in technical circles in France, will now be reviewed in its energy sub-aspect in order to integrate the findings derived from CEPHEUS. The national French energy agency ADEME will operate as lead agency in this process.
- In the shape of the planning tools for architects and building services engineers for the planning and construction of Passive Houses, developed and published within the context of CEPHEUS, pioneering technical fundamentals for disseminating the quality standard have been created. During the project term a major dissemination effect was already achieved through the regular contributions to the annual national and several regional Passive House conferences, and numerous publications in technical journals.
- At all 14 sites, there was an opportunity to inspect Passive Houses in use; in most cases this opportunity still exists. The resultant media reports have already served to make a wide audience acquainted with this new building standard.
- The excellent suitability of the Passive House standard as a basis for economically and ecologically viable, completely climate-neutral concepts for new settlement development has been demonstrated convincingly at the Hannover site.
- The project has delivered important experience and tools that can now be integrated in the directive of the European Parliament and Council on the energy profile of buildings, that is currently under debate.

4.3.1 Demonstration of the suitability of the Passive House approach as a European standard for particularly energy-efficient construction

Passive houses were erected at 14 sites in Europe in accordance with the objectives of the project. At all sites, the realization of the Passive House concept proved possible with present technologies: However, this requires use of particularly high-quality building elements and building services components, and particularly painstaking installation work.

The Passive House concept proved viable in all occupied dwellings: In 01-Hannover, 03-Gothenburg, 05-Hörbranz, 13-Lucerne (terraced houses), 02-Kassel and 06-Wolfurt (multifamily buildings) space heat supply to residential areas is solely by means of fresh air supply and is therefore limited to a heat load of ca. 10 W/m². In the winter of 2000/2001, this always provided sufficient heat supply in all dwelling units of these projects. In those projects in which retrofitting with conventional heating radiators had been prepared as back-up, this was not necessary in a single dwelling unit. It is thus clear through the accompanying measurements that the Passive House concept functions without fail. In 13-Lucerne, differentiated measurements were carried out of temperature layering and indoor air flows in a space heated exclusively through supply air heating ([Schnieders 2001a], see on this also Section 4.2.4.3). Here excellent comfort parameters were found in all occupied zones, both with regard to flow velocities of the air (≤ 0.025 m/s) and with regard to temperature layering (below 1.1 K/m) and radiative temperature asymmetry (maximum 3 K at 1 m above the floor and 35 cm in front of the window). This was confirmed by flow measurements in the 02-Kassel project [Pfluger 2001b].
Finally, the measurements of the annual space heating requirement in the built projects confirm both the overall functioning of the concept and the anticipated exceedingly high energy efficiency (cf.Figure 28).

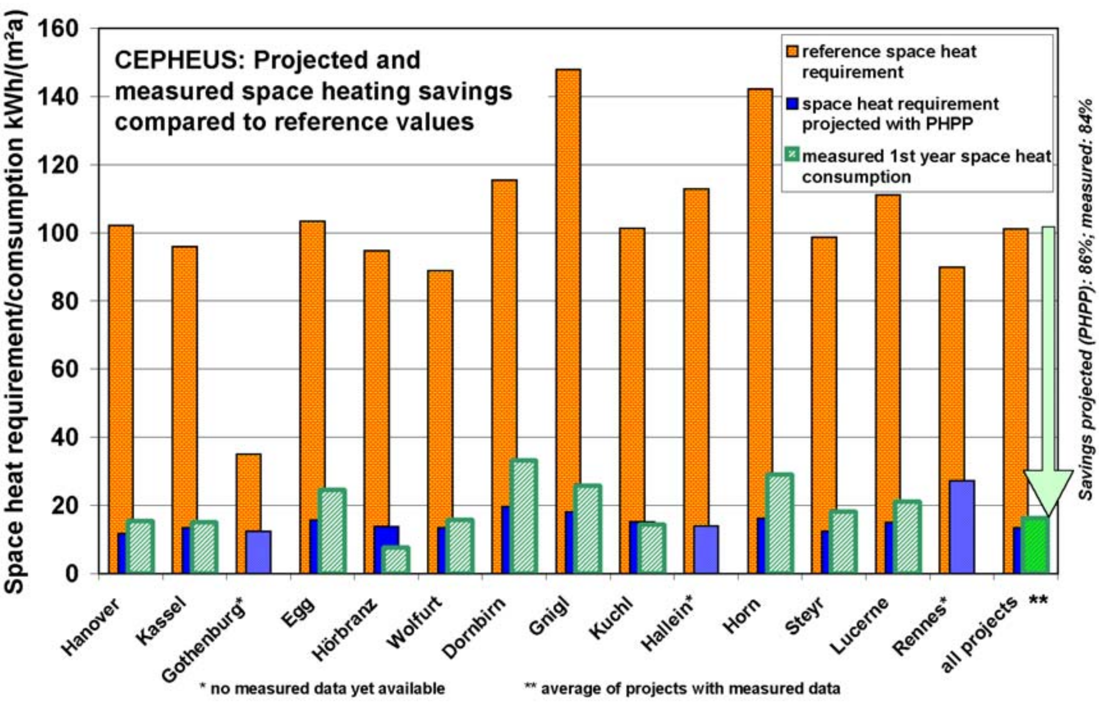


Figure 28: The functioning of the Passive House concept: Comparison of planned space heat requirement with the values measured in the first year of operation and the reference requirement of conventional new construction.

Although in 10 out of 11 projects with accompanying measurement programmes measurements are only available for the first winter – for which it is well known that additional consumption is to be expected because of construction material drying processes and other peculiarities of the first year – the normalized average space heat consumption of the 11 projects (totalling 130 dwelling units) figures around 16 kWh/(m²a) and is thus only slightly above the planned value for these projects. The space heating savings compared to conventional new construction (which has a space heat requirement around 101 kWh/(m²a)) figures 84%; 87% was planned, so that goal achievement in terms of space heating savings is already very high in the first year.

4.3.2 Proof of cost-effectiveness

The improved construction quality of the building envelope and the highly efficient ventilation systems in Passive Houses require extra investment. If the approach is pursued rigorously, this is counterbalanced by investment cost savings for the no longer necessary conventional heating system. However, it is presently (2001) not yet possible to reduce the overall costs of building services: With the exception of 03-Gothenburg and 08-Gnigl, the Passive House building services in the CEPHEUS buildings were ultimately slightly more expensive than conventional heating systems; this is joined by the extra investment for insulation and improved windows. In total, the extra construction and engineering system investment was found to be between 0 and 17% of the pure construction costs (cf. Table 19). These are already acceptable values today; the trend in extra investment continues to point downward. To the degree in which market demand grows for components such as Passive House windows and highly efficient ventilation systems, marginal unit cost will continue to decline. The Swedish project (03-Gothenburg) shows that the target of zero extra investment for the Passive House standard is indeed attainable.
If we apportion the extra investment to the years of service life of that investment and the extra operating costs to the saved heating energy, then we find for some of the CEPHEUS projects even today a ‘price per saved kilowatt-hour’ that is comparable to the purchase price of the energy sources used for heating (01-Hannover; 03-Gothenburg; 06-Wolfurt; 08-Gnigl; 10-Hallein). In the other projects, the ‘cost price’ of ‘energy savings’ is today still slightly higher than the energy price of the energy sources used. However, in all projects the costs are essentially lower than those of conventional solar hot water installations. The latter are widely viewed as acceptable investments in sustainable energy production; against this background, the efficiency measures of the Passive House concept must also be evaluated as already economically acceptable today.
The analysis of the development outlook of investment costs shows that within a few years project-level cost-effectiveness can be achieved even compared to present energy prices. This presupposes that the present growth in the number of projects implemented continues.

4.3.3 Impulses provided for the broader and accelerated introduction of the Passive House approach on the market

Largely due to the activities of the CEPHEUS partners – including activities beyond the context of the CEPHEUS project – the envisaged provision of impulses for a broader market introduction of the Passive House standard has already become very dynamic during the term of the project (more than 1,000 dwelling units built to Passive House standards in Germany alone (2001), speedily growing response to Passive House conferences and advanced training offers, growth in the number of suppliers of components complying to Passive House standards, follow-up projects of CEPHEUS partners, switch of KfW assistance criteria in Germany from low-energy to Passive House standard, establishment of an impulse and assistance programme for Passive Houses by the Stadtwerke Hannover AG utility within the context of the proKlima climate protection fund).

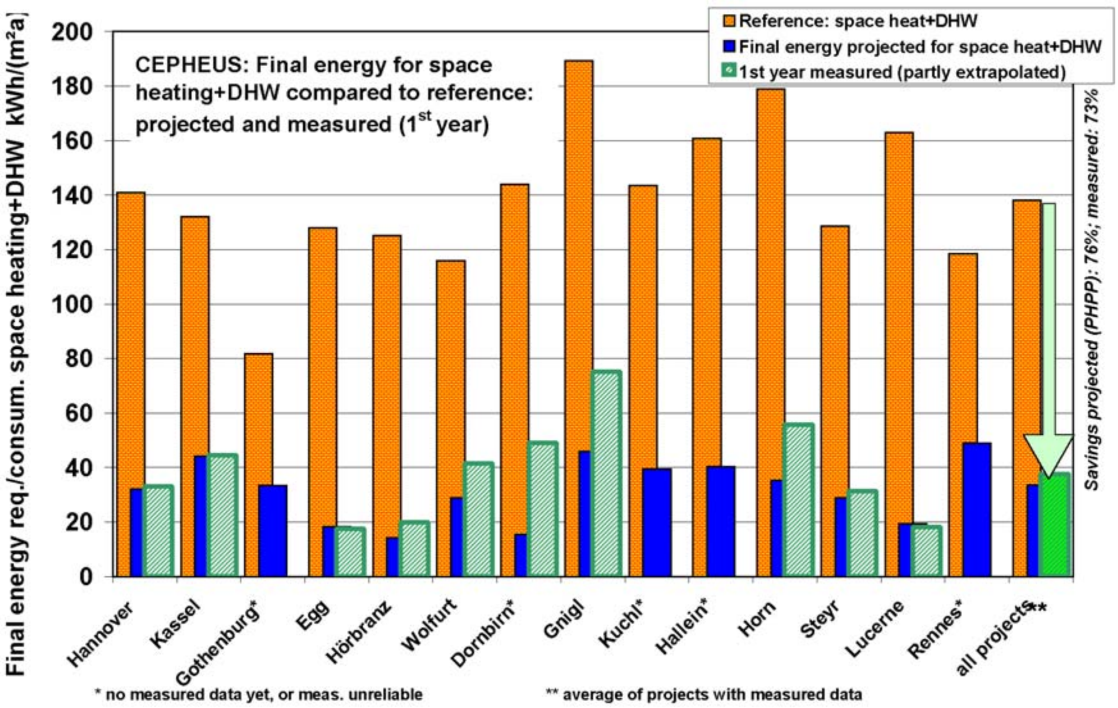


Figure 29: Growing numbers of passive houses in Germany

4.4 Operating costs

We distinguish here between the specific extra operating costs of the Passive House projects (e.g. filters for ventilation systems and electricity needed to operate the fans) and the annual final energy costs for providing space heat and domestic hot water ('heat+DHW').

a) Extra operating costs for Passive-House-specific technologies

The specific extra annual operating costs of the CEPHEUS projects include:

- Costs for replacing filters in the ventilation systems; although these costs can be allocated strictly speaking to indoor air quality and not to energy conservation, we include them in full in the economic balance because ventilation systems with heat recovery are not currently standard equipment in the countries involved.
- Annual operating costs for the electricity consumed by the ventilation equipment (fan electricity, controls, frost protection where needed). These costs are also included in full.
- Maintenance costs and any repair costs for the ventilation systems: These maintenance costs, however, need to be balanced against the corresponding maintenance costs of the conventional heating system that is either no longer necessary or smaller. Both costs can only be determined within broad margins of error. As a good approximation, we can assume that the costs are roughly equal; we have therefore assumed neither extra nor reduced costs for this.
- No special operating costs (maintenance, repairs etc.) were assumed for the passive components of the building envelope (insulation of walls and roof, windows). The products used here do not need more maintenance than the building elements in common use today; cost reductions that might be expected (owing to reduced risk of moisture damage to building structures) were not assumed in the calculation because no reliable data is yet available on this.

- Miscellaneous extra costs or cost reductions; these were quantified for 01-Hannover (reduced maximum demand charge for district heat supply) and for 13-Lucerne (no longer any need for chimney sweep).

Quantifies these costs items for 12 projects. The values for all projects result as weighted averages, with the dwelling units as the weighting factor. On average, the specific operating costs of the Passive House technology in the CEPHEUS projects figure 36 Euro/a/unit or 37 EuroCent/(m²a) (treated floor area, TFA). This shows that the operating costs, notably of the ventilation systems, are very low; this is thanks to the new generation of ventilation systems compliant with Passive House standards, that have high electric efficiency.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	
Operating costs	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes	**All projects**
3 Type of construction	mixed	solid	timber	solid	solid	mixed	timber	timber	mixed	mixed	mixed	solid	timber	mixed	
4 Number of dwelling units (DU)	32	40	20	4	3	10	1	6	25	31	1	3	5	40	**156**
5 Treated floor area (TFA) m²	3576	3055	2635	310	381	1296	125	328	1798	2318	173	467	613	2601	**15275**
6 Filter replacement Euro/DU/a	35	38	25	28	33	20	69	15		7	15	15	31		**27**
7 Auxiliary electricity consumption for ventilation Euro/DU/a	29	35	33	38	38	38	38	29		23	45	42	76		**33**
8 Misc. annual extra costs Euro/DU/a	-101	0	0	0	0	0	0	0		0	0	0	-68		**-23**
9 Type of misc. annual extra costs	Reduced max. demand charge district heat												No need for chimney sweep		
10 Total operating costs (without heat costs) Euro/DU	**-37**	**73**	**58**	**66**	**71**	**58**	**107**	**43**	**0*)**	**30**	**59**	**56**	**39**	**0**)**	**36**
11 Costs of final energy for heat+DHW Euro/DU/a	**217**	**162**	**286**	**165**	**208**	**111**	**224**	**74**	***)**	**77**	**163**	**228**	**401**		**162**
12 Costs of final energy for heat+DHW in the reference case Euro/DU/a	***953***	***485***	***506***	***410***	***789***	***622***	***744***	***429***		***498***	***1281***	***1017***	***1508***		***616***
13 **Operating cost reduction**	**81%**	**51%**	**32%**	**44%**	**65%**	**73%**	**56%**	**73%**	***)**	**78%**	**83%**	**72%**	**71%**		**68%**

*) No reliable figures can be stated at present.
**) No precise figures can be stated at present. They tend to be lower than in the reference case.

Table 17:Comparison of operating costs of the CEPHEUS projects to the reference cases

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	
Project **Energy prices**	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes	**All projects**
Final energy price: Reference EuroCent/ kWh	**6.1**	**4.8**	**4.7**	**4.1**	**5.0**	**4.1**	**4.1**	**4.1**	**4.1**	**4.1**	**4.1**	**5.1**	**7.6**	**3.4**	**5.1**
Final energy source	District heat	District heat	Heating oil	Heating oil	Natural gas	Heating oil	Heating oil	Heating oil	Heating oil	Heating oil	Heating oil	Natural gas	Heating oil	District heat	
Final energy price: Passive house EuroCent/ kWh	**6.1**	**4.8**	**6.5**	**11.7**	**11.7**	**3.0**	**11.7**	**3.0**	**2.8**	**2.6**	**2.7**	**5.1**	**16.9**	**3.4**	
Final energy source	District heat	District heat	Electricity	Electricity	Electricity	Wood pellets	Electricity	Wood pellets	Wood pellets	Wood pellets	Wood pellets	Natural gas	Electricity	District heat	
Electricity price EuroCent/ kWh	**11.5**	**11.2**	**6.5**	**11.7**	**11.7**	**11.7**	**11.7**	**8.8**	**8.8**	**8.8**	**13.7**	**12.9**	**16.9**	**10.2**	**9.9**

pure energy prices, without maximum demand charges, standby charges, or meter charges; value-added tax not included

Table 18: Final energy prices in 2000/2001 without value-added tax at the sites of the CEPHEUS projects

b) Annual energy costs of heat supply

In the reference buildings, the dominant operating costs are the energy costs for fuel (or district heat or electricity) to supply space heat and domestic hot water consumption (cf. line 12 in Table17). The Passive House technology cuts these energy costs very substantially. Because (with the exception of 01-Hannover) a full operating year had not yet been concluded in any project when the present final report was prepared, the final energy costs had to be determined based on the anticipated consumption levels of fuel, district heat or electricity for heating. Figure 30 illustrates the comparison between

- Final energy requirement for space heat ***and*** domestic hot water in the reference case (left column)
- Projected final energy requirement for space heat and domestic hot water of the Passive House buildings
- Extrapolated final energy consumption for space heat and domestic hot water of the CEPHEUS projects on the basis of available measurements.

On average, among the 10 projects included here the final energy savings for space heat and domestic hot water determined by the measurements amount to 73% compared to the reference case; in comparison to the computed 76%, this is already a very good result for the measurements in the first year of operation. On the basis of experience made in measurement campaigns elsewhere, we can assume that the projected savings will already be reached or exceeded in the second heating season. It is the consumption levels sustained in the future that are decisive for cost-effectiveness; these are represented better by the projection than by the extrapolations based on values measured in the first year – whereby deviations between the two are slight in any case.

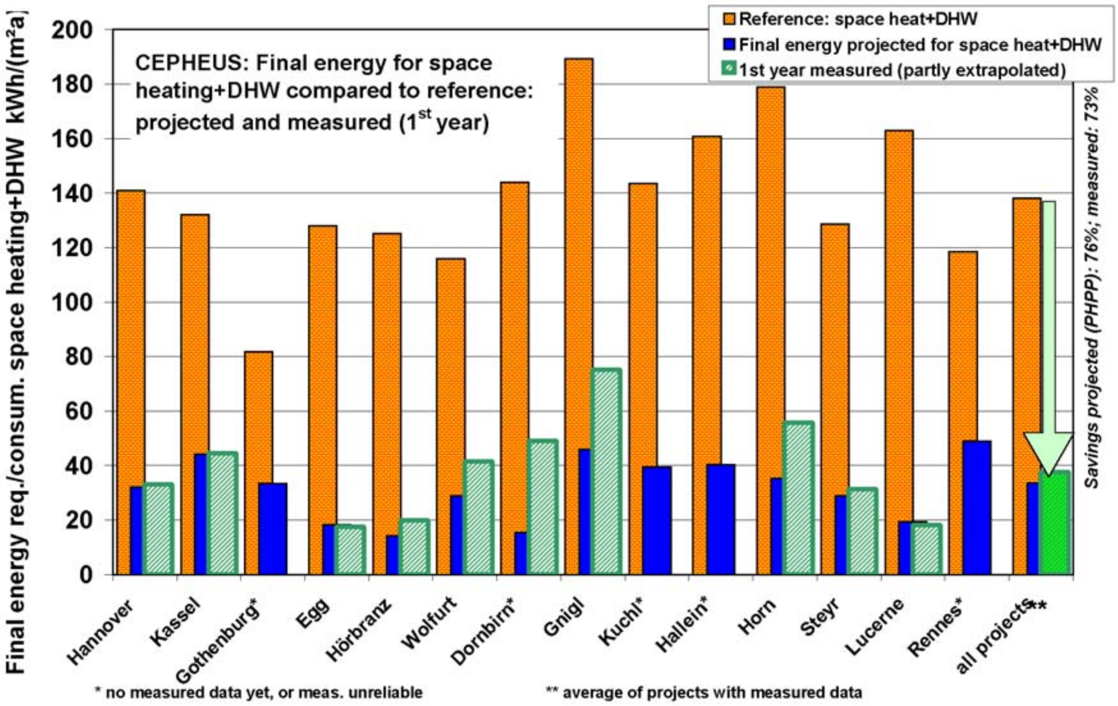


Figure 30: Comparison between the final energy consumption for space heat and domestic hot water in the reference case and the projected requirement and measured consumption (1st year) of the CEPHEUS projects

The final energy requirement values shown in Figure 30 result in the fuel (or district heat) costs of the reference buildings as listed in line 12 of Table17. These heating costs range between 3.8 (Sweden) and 12.3 (Switzerland) Euro/(m²a), averaging 6.3 Euro/(m²a). For the Passive Houses, the costs of final energy procurement are substantially lower: Line 11 documents the costs for the energy sources actually used in each specific project; these are district heat for 01 and 02, electricity for 03, 04, 05, 07 and 13, natural gas for 12 and wood pellets for the other projects. Table 18 lists the associated final energy prices: Fuel prices average around 5 EuroCent/kWh, electricity around 10 EuroCent/kWh. Line 13 of

Table 17 shows that the reduction in the cost of heat supply incl. DHW averages 68%. In the Passive Houses, the annual ancillary costs for space heat and hot water heating, incl. auxiliary electricity requirement, amount to an average of only 2.0 Euro/m².

4.5 Future of the projects

All Passive Houses within the CEPHEUS project were built for normal residential use. Only a few houses or units are being utilized for a limited duration for exhibitions and visits, and, in some cases, for trial occupancy.

As it is a fundamental element of the Passive House philosophy to optimize the energy efficiency of such components of a house which are necessary in any case, it can be expected that all engineering components of the houses will have the normal service life of such components. The construction standard will certainly be in compliance with any future statutory thermal insulation requirements. The built structure has a high capacity to sustain long-term value, and the danger of structural damage is reduced.

Measurement campaigns and social science evaluations will continue beyond the end of the CEPHEUS project at several sites. The demonstration effect of the occupied Passive Houses will also extend beyond the end of the project term.

4.6 Economic viability

Passive houses differ from conventional buildings in their considerably improved building envelope and highly efficient ventilation heat recovery. Both of these quality improvements require extra investment compared to the reference case of normal new buildings. This extra construction / engineering investment was supported as eligible costs within the Thermie project for the CEPHEUS building projects in 01-Hannover, 03-Gothenburg and 14-Rennes. In all other building projects, the construction / engineering investments were financed independently from the CEPHEUS programme: In particular, 02-Kassel and all Austrian projects received no support from CEPHEUS for extra construction costs. In these building projects, the CEPHEUS programme was limited to advice, scientific support, quality assurance (notably pressurization tests and thermography), measurement systems and scientific evaluation.
For the projects constructed with public-sector assistance ('social housing'), in particular, it was not simple to identify in a differentiated manner the specific extra costs for the Passive House standard: In publicly assisted housing construction there are cost ceilings that must be complied with; and were indeed complied with by the CEPHEUS projects. Conventional buildings generally incur the same costs; however, this does not mean that the improved quality of the Passive House standard was realized at 'zero cost' – costs were compensated for by negotiating special terms with the building contractors and by carrying out economy measures elsewhere. Here, even with great effort, it is impossible to allocate extra costs unequivocally to the Passive House standard. However, despite the circumstance that in some projects it is only possible to a limited extent to provide such an allocation, the fact that realization was possible without significantly transgressing conventional building costs shows that the extra investment remains within acceptable bounds. The present section only documents cost analyses for those projects for which the relevant data were provided by the project partners: These are 01-Hannover, 02-Kassel, 03-Gothenburg, 04-Egg, 05-Hörbranz, 06-Wolfurt, 07-Dornbirn, 08-Gnigl, 10-Hallein, 11-Horn, 12-Steyr and 13-Lucerne. 08-Gnigl is a special case: The developer and planner state that, given the extreme location of this residential building on a road with much traffic, the conventional expenditure for improved noise protection would have been higher than the cost of the Passive House standard. In the following analysis of cost-effectiveness, we take the extra cost of this project to be 0.

Reference buildings
The extra investment is determined as compared to a building of the same type and architecture, but without heat recovery, without Passive House window units and with reduced thermal insulation. The reference buildings are defined such that they comply with the respective national or regional requirements at the time when their permit was granted. The associated annual heat requirement values of the reference buildings are documented in Section 2.4.1.

Extra investments
The Passive House standard is developed from the reference buildings by introducing substantial quality improvements

- in thermal insulation (additive insulation thicknesses),
- in thermal bridge reduction,
- in attaining and checking airtightness (inter alia pressurization test),
- by installing triple low-emissivity glazing and Passive House window units, and
- installing high-efficiency heat recovery systems.

Each of these measures requires extra investment compared to the reference case. Table 19 lists the extra investments. The individual project documentations break down these figures in greater detail.
On the other hand, there are investment cost savings in some projects due to the simplification of the conventional heating system. In 03-Gothenburg, the savings in conventional building service systems already compensate for the extra investment in insulation, windows and ventilation. This is above all attributable to the circumstance that in Sweden a very good construction standard is already required by law and realized today: Ventilation systems (albeit without heat recovery) are the standard in Sweden, as is triple-glazing; insulation thicknesses do not have to be increased substantially for the Passive House. The anticipated trend is that the standard already achieved in Sweden will be introduced step by step in the rest of Europe, too (cf. the new Building Energy Conservation Ordinance (Energieeinsparverordnung) due to enter into force in Germany in 2002). The extra expenditure for the Passive House standard will then approach the present situation in Sweden in other countries too: With comparatively slight extra investment in components that are only marginally more expensive but have much higher quality, the step can be taken to the Passive House, i.e. to conceptually considerably simplified heating systems. In the Swedish project, the additional investment for the solar thermal collector installation remains an extra cost item.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	
Project **Invest-ment**	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes	**All projects**
Type of construction	mixed	solid	timber	solid	solid	mixed	timber	timber	mixed	mixed	mixed	solid	timber	mixed	
Number of dwelling units	32	40	20	4	3	10	1	6	25	31	1	3	5	40	**212**
Treated floor area (TFA) **m²**	3576	3055	2635	310	381	1296	125	328	1798	2318	173	467	613	2601	**19674**
Total building costs **TEur**	3333	3041	2400	376	527	1310	242	645	2600	3067	225	476	1277	2697	**22215**
Specific building costs **Euro/m²**	932	996	911	1215	1381	1011	1939	1965	1446	1323	1304	1019	2084	965	**1129**
Extra investment for energy efficiency and renewables TEur	397	255	40	40	66	102	42	(-20) Tak-en: 0	n.d.	229	28	72	122	265	**1659**
Extra invest-ment in %	**12%**	**8%**	**2%**	**11%**	**13%**	**8%**	**17%**	**0%**	**n.d.**	**7%**	**13%**	**15%**	**10%**	**10%**	**8%**
Specific extra investment Euro/m²	**111**	**84**	**15**	**130**	**174**	**79**	**337**	**0**	**n.d.**	**99**	**164**	**153**	**199**	**102**	**93**

Table 19: Extra investment for the Passive House standard in 13 CEPHEUS projects; incl. costs for solar installations
n.d.: no data can be stated

In the documented projects, the extra investment incurred by the Passive House standard and the solar installations averaged 91 Euro/m² Treated floor area, or 8% of building costs.

Operating costs
The operating costs for the Passive House installations are discussed in detail in Section 4.4: These comprise the heat costs, maintenance costs where such arise, electricity costs for the ventilation systems and the costs of filter replacement. The corresponding operating costs can also be determined for the reference cases.

Simple payback time
By dividing the extra investment in Table 19 by the operating cost savings in Table 17, we arrive at the (static) payback times. This figure is criticized because it fails to take into consideration interest and inflation; however, the European Commission demands statement of this figure in the final report.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	
Static payback times	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes	**All projects for which data is available**
Number of dwelling units	32	40	20	4	3	10	1	6		31	1	3	5		**156**
Treated floor area (TFA) m²	3576	3055	2635	310	381	1296	125	328		2318	173	467	613		**15275**
Static payback time a	**16**	**26**	**12**	**56**	**43**	**23**	**102**	**imme diate**		**19**	**27**	**33**	**23**		**21**

Table 20: Static payback times for the CEPHEUS projects (incl. solar installations)

Cost price of 'conservation energy'
We receive a better measure for economic assessment by determining the cost price of 'conservation energy'. This is defined as that cost of the final energy source used at which the measure carried out is still microeconomically profitable. If the actual energy price is higher than the cost price of conservation energy, then the measure under consideration yields a profit.

The cost price of conservation energy is determined as a real cost (i.e. inflation-adjusted at the present value of the year 2000) as follows:
- The additional investment is spread evenly across its service life to give equal annual capital costs (incl. interest and repayment of principal). A uniform real interest rate of 4%/a and service life of 25 a is assumed for building investments. This results in a capital recovery factor of 6.4%/a (in real terms).
- This is joined by the extra operating costs of the Passive House components (i.e. ventilator electricity and filter replacement) and any quantifiable additional operating cost savings (e.g. saved maximum demand charges for connection to mains-supplied energy services), but not the operating costs saved through the reduced fuel consumption.

The resultant total annual extra costs are divided by the fuel savings achieved compared to the reference case. This results in the cost prices of conservation energy (fuel) listed in Table 21 the table compares these results to the present final energy costs at the project sites.

The results show that cost prices around and below 6 EuroCent/kWh have already been reached in 01-Hannover, 03-Kassel, 03-Gothenburg, 06-Wolfurt, 08-Gnigl, 10-Hallein and 11-Horn; the average is 6.2 EuroCent/kWh and thus slightly above the average reference value of 5.1 EuroCent/kWh for externally purchased final energy. In these calculations the costs also contain the extra costs of the solar thermal installations whose specific cost prices are, at 10 to 15 EuroCent/kWh, significantly higher than present conventional fuel costs, as is well known.

01-Hannover
The costs shown in the figure also contain the cost price of the heat produced by the solar thermal installations. If we consider the energy efficiency measures of the Passive House standard by themselves, then the costs of the kWh saved figure 4.6 EuroCent/kWh here. The project documentation contains a detailed breakdown of the extra costs and of the associated additional utility [Feist 2001].

02-Kassel
Here relatively high costs were incurred through thermal bridge reduction and for post-and-beam constructions in the entry areas. Nonetheless, in this publicly assisted housing construction project the cost ceilings required by the German state of Hesse were complied with. For this project too, the project documentation [Pfluger 2001a] provides a detailed breakdown of the extra costs.

03-Gothenburg
Here the Passive House standard caused no extra investment, but the solar thermal installation did; this is joined by the operating costs of the ventilation system.

04-Egg
Here large window areas (also to the north) and comparatively complex building services systems led to higher investment costs. The outcome remains nonetheless within acceptable bounds.

05-Hörbranz
This building project consistently utilized sustainably produced insulating materials: Cork for the external walls, cellulose for the floor and roof. Each house has its own, large solar installation.

06-Wolfurt
The compact shape and functional design of this project make it an exemplar of cost-effective Passive Houses. The use of wood pellets as final energy source also serves to cut costs; the central positioning of the solar installation reduces the specific investment costs.

07-Dornbirn
This small single-family house is a prototype planned for future series production. According to the developer, substantial cost reductions are expected.

08-Gnigl
The planner and developer state that the Passive House standard even yielded cost savings; nonetheless, 0 extra/reduced costs were taken in the calculation. The cost price of conservation energy of 1.1 EuroCent/kWh results from the operating costs of the ventilation systems (electricity and filter replacement).

09-Kuchl
For this publicly assisted housing construction project, it was not possible to apportion costs satisfactorily to individual measures. Moreover, the measurement results in the first winter do not yet permit any reliable analysis and substantial deviations from the projections occurred. We have therefore postponed the cost-effectiveness analysis for this project.

10-Hallein
Here no measurement results are yet available; the calculation is therefore based on the projected values.

11-Horn
For a prototype single-family house, the extra costs have been limited well; follow-up projects by the same developer have even better economic results.

12-Steyr
The terraced houses realized in Steyr are overall relatively economical. As each of the three dwelling units has its own complete heating system with gas boiler and chimney, the cost savings potential of the Passive House concept has not been tapped fully here.

13-Lucerne
This is also a prototype of a newly developed building design with numerous innovative elements. The houses have basements under the whole floor area and have complex roof constructions. The developer (Renggli AG company) has simplified the design in the meantime and has already realized follow-up projects at lower extra costs.

No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	
Costs of kWh saved	Germany, Hannover	Germany, Kassel	Sweden, Gothenburg	Austria, Egg	Austria, Hörbranz	Austria, Wolfurt	Austria, Dornbirn	Austria, Gnigl	Austria, Kuchl	Austria, Hallein	Austria, Horn	Austria, Steyr	Switzerland, Lucerne	France, Rennes	**All projects**
Number of dwelling units	32	40	20	4	3	10	1	6		31	1	3	5		**156**
Treated floor area (TFA) **m²**	3576	3055	2635	310	381	1296	125	328		2318	173	467	613		**15275**
Costs of kWh saved EuroCent/kWh	**6.2**	**7.2**	**4.4**	**8.8**	**11**	**5.5**	**17**	**1.1**		**4.8**	**6.6**	**9.0**	**10**		**6.2**
Final energy reference costs 2001 EuroCent/kWh	**6.0**	**4.8**	**4.7**	**4.1**	**5.0**	**4.1**	**4.1**	**4.1**		**4.1**	**4.1**	**5.1**	**7.6**		**5.1**

Table 21: Cost prices of conservation energy (fuel) in CEPHEUS projects (incl. solar installations)

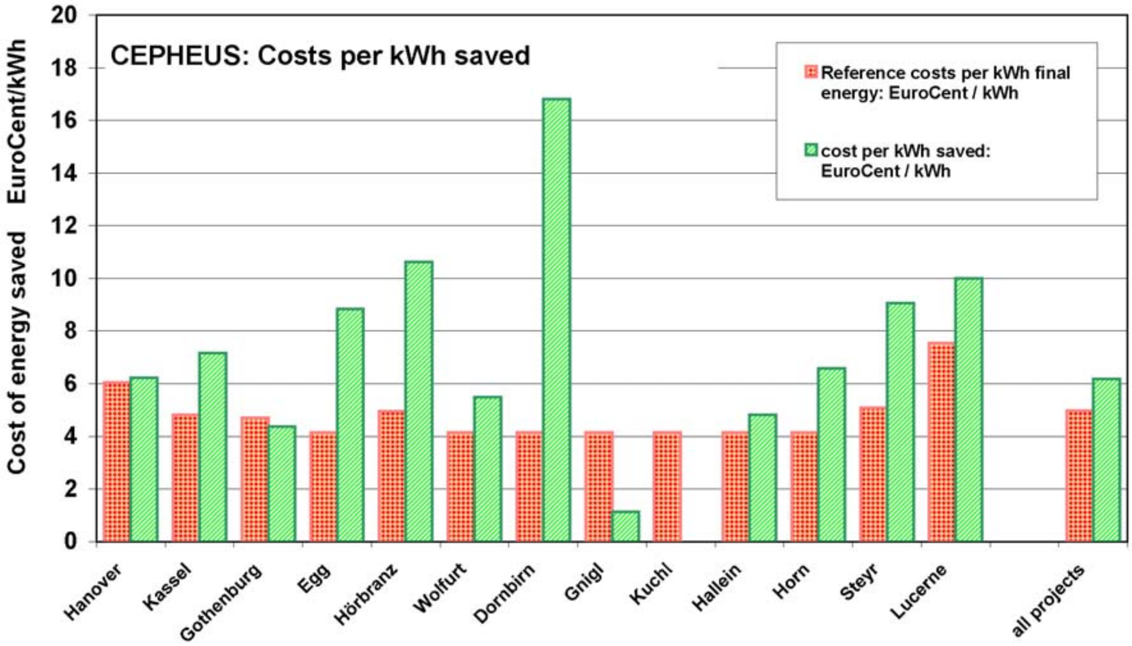


Figure 31: Cost price of conservation energy (incl. solar installations) compared to the present final energy prices (fuel or district heat) at the individual project sites.

4.7 Environmental impacts

To reduce the energy consumption of households, the initial aim must be to reduce energy consumption for space heating, for in central Europe this accounts for about 75% of the total final energy consumption of private households. Although the statutory thermal insulation requirements upon buildings have been tightened considerably in recent years in the countries participating in CEPHEUS, further heating energy savings of 80 to 90% are realizable.

CEPHEUS has shown that this potential can be implemented practically, namely

- in practice, in occupied houses with different user structures,
- at different Central European locations,
- by different planners and developers,
- in different building types: single-family houses, terraced houses and multifamily apartment buildings,
- at investment costs that are almost fully paid back by the saved heating costs.

The available measurement results illustrate clearly that in all projects the space heat consumption was indeed cut drastically compared to conventional new buildings (cf. also Figure 14). Per square metre floor area, the CEPHEUS buildings consume on average more than 80% less space heat than conventional new buildings constructed according to local building law. In the Passive Houses analysed, the three components of useful energy consumption – space heat, hot water and household electricity – now have roughly equal importance, while in conventional new construction space heat clearly dominates useful energy consumption. Considerable savings were realized not only in space heat consumption, but also in all other classes of useful, final and primary energy usage (Figure 32).

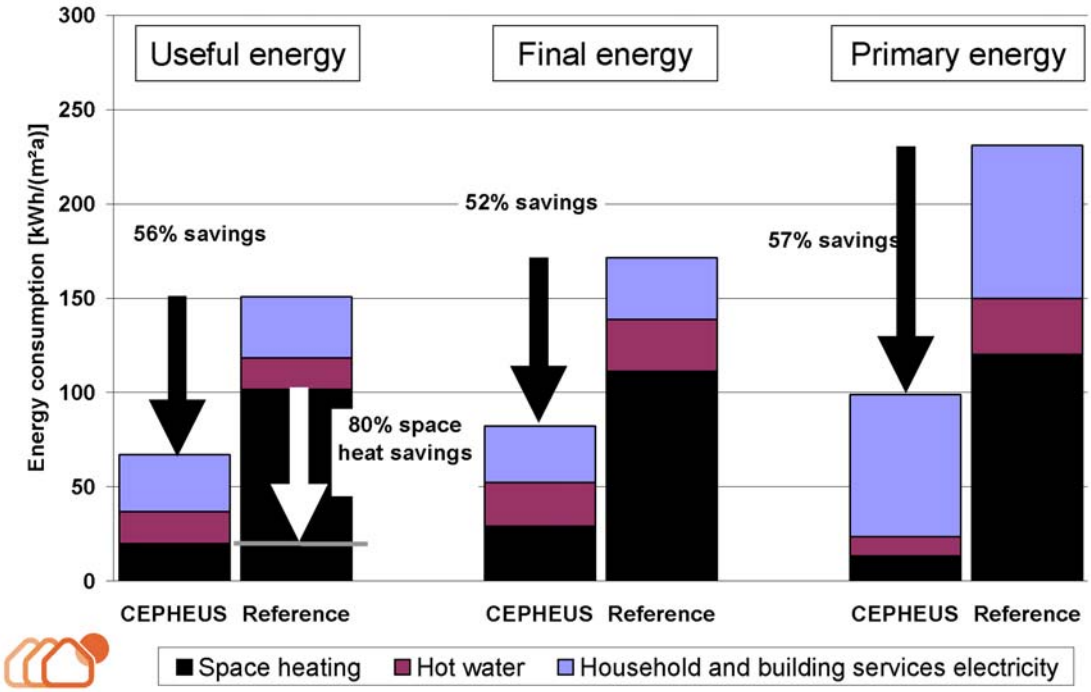


Figure 32: Comparison of the measured consumption levels of all CEPHEUS projects (floor-area-weighted mean) with the corresponding reference consumption levels

In the first heating season, the CEPHEUS projects have already saved more than 80% space heat; even more distinct savings can be expected for the coming years. Proceeding from the total primary energy savings already proven now, we arrive at annual savings of 13 MWh for a dwelling unit with 100 m² floor area. Applying the figures in [EU 1993] we arrive at the following annual savings of environmentally relevant pollutants:

	CO_2	SO_2	NO_x	Volatile Organic Compounds
Solid fuel	5200	23.4	2.6	21.71
Liquid fuel	3900	7.67	2.6	8.71
Gas	2860	0	2.6	0.52

Table 22: Pollutant reduction through the CEPHEUS projects per 100 m² floor area on the basis of the values measured in the first year

In addition to energy savings, the CEPHEUS buildings provide a number of further positive effects for the environment and the health of their occupants:

- In order to achieve the low heat loss, thermal bridges must largely be avoided and the building envelope must have excellent airtightness. Both aspects contribute to preventing the occurrence of condensation on the internal surfaces and inside the building elements. This reduces structural damage. The resultant longer service life of the building elements not only improves the cost-effectiveness of the building, but also reduces environmental impacts that would otherwise result from replacement and refurbishment.
- A further side effect of good airtightness is improved sound insulation, as no open joints can function any longer as sound bridges.
- Thanks to the air supply and extraction system with high-quality upstream filters, air quality in the buildings is excellent. Contaminants emanating from building materials and furnishings are removed continuously, while dust in the outdoor air is retained in the filter. Air change rates are set such that sufficient moisture is removed but the air does not become too dry.

Moreover, further positive environmental effects of the built CEPHEUS projects can be reported. A number of the projects have avoided CFCs on the building site, have utilized environmentally sound or low-contaminant materials and have separated wastes at the building site. The project-specific format sheets [EU 1993] report details.

The improved occupant comfort in the Passive Houses is also important. Social science studies prove a high satisfaction of users with the Passive House standard, among both owner-occupiers and tenants. Figure 27 shows an example: Occupants assess living in the Passive House very positively, and the satisfaction has risen further since the first heating season. Besides the low operating costs, the warm internal surfaces in particular and the ventilation systems are generally rated positively. User acceptance is key to the widespread implementation of the Passive House standard and thus also to the global effectiveness of its environmental protection aspects.

The cost efficiency of the CEPHEUS projects is key to implementation of the concept: Energy-saving construction will only then be able to contribute to climate protection and air pollution control if it is implemented broadly beyond demonstration projects. For this to happen, the energy-saving measures must at least be financeable. The economic viability of the measures is particularly advantageous as in this case also such decision-makers can be moved to implement the concept who appraise projects exclusively from an economic perspective.

5 Publicity, commercialization and other developments

5.1 Publicity and publications

- **Creating opportunities to get to know Passive Houses on site**

This was one of the strategic goals of CEPHEUS. The opportunity to inspect Passive Houses and to talk with occupants about their experiences and satisfaction is of crucial importance to provide a hands-on experience of the quality and comfort associated with this new standard and to remove any reservations, e.g. concerning ventilation systems. Consequently, as planned, opportunities were created in all national sub-projects to inspect the CEPHEUS building projects. At Hannover/D, Kassel/D, Wegere/CH, Rennes/F and Gothenburg/S at least one dwelling unit has been or is earmarked for one to two years for inspection purposes. For the Austrian sub-projects, agreements have been made with the purchasers/occupants that these must allow visits at least twice yearly over a period of 2 years after taking up occupancy. At all sites, there has been great interest in making use of these opportunities to visit the buildings.

- **Presentation of the CEPHEUS project at the EXPO 2000 World Exposition in Hannover**

The prime activity of the CEPHEUS project for disseminating the project approach and the results achieved to date was the presentation upon the occasion of EXPO 2000 in Hannover from 1 June to 31 October. Throughout this period, the CEPHEUS project was presented as a whole and with all of its sub-projects in an exhibition house in the Passive House estate in Kronsberg rented by Stadtwerke Hannover within the context of the CEPHEUS project, using posters and Powerpoint presentations. In addition, the exhibition house was fitted with technical exhibits by manufacturers. The presentation was supplemented by an exhibition titled "The Passive House hands on" Passivhaus zum Anfassen developed specially for this purpose by the PHI in cooperation with Stadtwerke Hannover. This included exhibits and posters presenting in a clear and tangible manner the basic elements of the Passive House approach (superinsulation, superglazing and high-efficiency heat recovery).

Throughout EXPO, the exhibition house was open every day for an average of 7 hours, and staffed with an expert advisor. In that period, some 1,650 visitors to the exhibition house were provided in-depth information on the approach and the project. The greater part (approx. 60%) of the visitors belonged to the 'expert interest' category. The individual persons and groups came from throughout Germany, and from Austria, Switzerland, Italy, Spain, Belgium, the Netherlands, Sweden, the Czech Republic, USA, Canada, Korea, China and Japan. Furthermore, the exhibition house was used by firms for working meetings and talks, and for seminars.

- **Lectures, publications and press conferences**

Reports were provided on the CEPHEUS project as a whole and on specific sub-projects at a broad range of expert conferences, press conferences and events in the participating countries.

Similarly, there were numerous publications in technical journals and conference proceedings. See on this the literature references in Section 7.

All the important details of the sub-projects, the surveys and analyses conducted and the results of the evaluations are documented in some 40 project reports. These can be requested from the project partners (www.cepheus.de; www.cepheus.at; www.passivehouse.com).

5.2 Patent activity

The CEPHEUS partners undertook no patent activity.

5.3 Outlook

CEPHEUS has succeeded in proving the viability of the Passive House concept for residential buildings in practice in central, northern and western Europe. Application of the concept is also of interest for other types of building uses; e.g. for office buildings, for which the viability of the approach has been demonstrated by the project built by Wagner & Co. in Cölbe near Marburg, Germany. Future studies should be carried out to examine both further types of building use and the adaptation of the concept to other climatic locations (southern and eastern Europe). Measurements conducted in the first heating seasons of the various building projects within CEPHEUS have already shown that the projected air supply quantities in the occupied zones, with air change rates of about $0.4h^{-1}$, suffice at all events, and in some cases even appear high (as indicated by dry indoor air in winter). The issue of optimizing ventilation with regard to projected volume flow, efficiency and user friendliness should be examined in more detail in the coming heating seasons.

The demonstration building projects with Passive Houses within CEPHEUS were, in total, ca. 8% more expensive in terms of initial investment cost than conventional new build; however, the building elements and components used are still small-scale series. In future, it will be possible to further reduce these extra initial investment costs. This has been demonstrated by follow-up projects by developers and architects who are already implementing the 3rd generation of Passive Houses. The number of built Passive Houses is presently growing by more than 100% annually. The replication potential is very high, because in principle every residential building can be built as a Passive House.

A first marketing study was prepared in 1999 by Büro für Solarmarketing (office for solar marketing). This forecast for the year 2005 a market share of the Passive House standard in new build ranging from 5 to 10% [Solar 1999] [Witt 1999].

During the period of the CEPHEUS project, the number of available Passive House components on the market has multiplied: While in 1998 there were only two manufacturers of Passive House windows with $U_w \leq 0.8$ W/(m²K), today (2001) there are more than 20. The situation is similar for external wall insulation systems, roof constructions and ventilation systems.

5.4 Commercialization

All CEPHEUS building projects have been marketed commercially with great success. By the end of the CEPHEUS project it had become apparent that the extra costs of the Passive Houses now being marketed are dropping. It can thus be expected that the Passive House standard will be highly promising in economic terms in the near future.

Rasch & Partner was one of the first firms to market Passive Houses commercially. Even before CEPHEUS, the first Passive Houses were implemented; these have been joined in the meantime by numerous others. Thanks to the high degree of prefabrication of the building elements, the houses can be offered at very competitive prices on the market. Their sales price differs only marginally from that of ‘normal-energy houses’.

The architects Hegger/Hegger/Schleif had also commercially marketed buildings similar to Passive Houses before CEPHEUS. The project in Kassel has now provided the breakthrough in publicly-assisted rental housing construction, too.

In Sweden, high energy standards have already been applied to construction for some time now. The step to the Passive House was thus not as large as in the other projects. The Passive House standard will establish itself there for economic reasons alone.

In Austria, a development similar to that in Germany is emerging. For numerous developers, the building of Passive Houses has in the meantime become routine.

In Switzerland, Renggli AG, a prefabricated house supplier, now offers Passive Houses in its catalogue. Other Swiss builders have also recognized the dynamics in this market segment and are now also offering different Passive House types.

For French circumstances, the project in Rennes is unusual: Marketing was initially sluggish, but after building work had commenced, COOP de Construction experienced the pleasant surprise that demand outstripped supply.

No other fact than that most of the developers participating in CEPHEUS are already implementing follow-up projects makes it clearer that there is a market Europe-wide for Passive Houses. Further impulses for marketing are coming from the positive findings of the (social) scientific studies. As already noted in Section 5.3, many manufacturers have now recognized the growth market in the Passive House sector and have developed corresponding products in order to market them in the coming years. This positive development indicates a market with considerable growth rates that also extends to the refurbishment of existing buildings.

6 Lessons learned and conclusions

The CEPHEUS project has met its goals (see 4.3). For a large number of dwelling units with very different building types and constructions in several European countries, the cost-effective implementability of the Passive House standard has been demonstrated. On average across all projects, the goals relating to heating energy and total primary energy savings were already attained in the first heating season. At the same time, important impulses were provided for further technology development and market development.

The range of measured (and desired) indoor temperatures and of specific heating energy consumption levels shows that the Passive House concept also functions when comfort demands are higher. Thanks to the very high thermal inertia of the Passive House, far smaller heating loads suffice than might be expected using conventional specification procedures. Even a total outage of heating supply over several days goes unnoticed.

The concept is efficient in itself and does not require a ‘standardized’ user behaving in an energy-aware manner at all times. Even if comfort demands are high, heat consumption only grows by small amounts. In almost all dwelling units, the measured consumption levels of Passive Houses have been below 40 kWh/(m²a), i.e. far below the average consumption levels of standard houses. An important outcome is that, across larger collectives of similar houses (Hannover) or units (Kassel, Kuchl), on average, space heat consumption normalized to 20°C already comes very close to the target of 15 kWh/(m²a) in the first heating season. Even demands for a substantially higher level of thermal comfort (= indoor temperatures), as measured in the rental buildings in Kassel and Kuchl, only leads to slightly higher consumption levels on average. The tendency that tenants in Passive Houses in particular 'allow themselves' higher indoor temperatures is not detrimental to the goals of resource conservation and climate protection. Indeed, in pursuit of the 'factor 4' concept, it is even highly positive if users of dwelling units built to Passive House standards can associate energy efficiency and climate protection with higher comfort and lower operating costs.

The findings of the social science evaluations show a very high degree of acceptance and satisfaction among users, and only slight habituation problems. Thus, from the user perspective, too, the concept has proven itself through the results of the CEPHEUS project as entirely viable in practice.

However, project experience has in some cases highlighted major deficits in knowledge among architects and consultants, and also among contractors, with respect to the quality requirements of energy-efficient construction. This concerns not only the very ambitious Passive House standard itself, but also the statutory requirements currently in place and the ongoing initiatives towards low-energy house standards. To improve the dissemination of building energy efficiency standards, it would be necessary to engage in more intensive education and further training of architects, consultants and craftsmen. Both within and beyond the context of CEPHEUS, the PHI, in particular, has developed a large amount of technical information in recent years in order to provide such information. However, most of this is only available in German; only parts are available in English too. To improve the dissemination of this material in the EU, it would be necessary to translate it into further languages. A book publication collating and updating the published knowledge would greatly assist the further dissemination of energy-efficient construction.

In the same vein, the experience gained in the project has shown that it is essential to the effective dissemination of knowledge that any further EU-wide building energy efficiency projects are supported by international panels of architects and consultants – these panels would facilitate an intensive transfer and exchange of experience.

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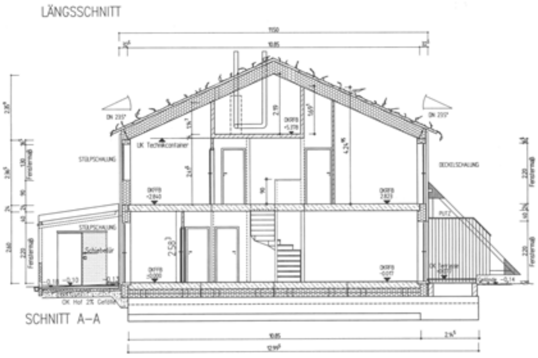
8 Photographs and brief documentation of building projects

CEPHEUS 01 Germany, Hannover-Kronsberg


Southeast elevation



Longitudinal section

Project brief	
Location	D-30539 Hannover (Lower Saxony, Germany)
Developer/client	Rasch & Partner GmbH, Dipl.-Ing. F. Rasch, Darmstadt
Architect	Dipl.-Ing. Arch. P. Grenz, Dipl.-Ing. F. Rasch
Engineers	Building services: inPlan GmbH, Dipl.-Ing. N. Stärz , Pfungstadt
Construction period	Commencement: 01.09.1998, completion: Dec. 1998
Building type	Terrace
Use	Owner-occupied
Number of dwelling units	32 (4 rows with 8 houses each)
Living floor space	3805 m²
Construction	
Type of construction	Load-bearing structure and gable walls: prefab. concrete elements; external walls and roofs: prefab. lightweight timber elements
Windows and glazing	Triple low-emissivity glazing, TSET: 60%, insulated wood-aluminium frames
U-values (W/(m²K))	Lightweight timber wall: 0.13; solid gable wall: 0.10; end-of-terrace basement ceiling: 0.10; mid-terrace basement ceiling: 0.13; roof: 0.10; glazing: 0.75; window frame: 0.57; whole window: 0.83
Building services	
Heating	Supplementary supply air heating and bathroom radiator, district heat supply
Ventilation	Distributed controlled ventilation with heat recovery from extract air
Hot water	Solar collector (4 m²) with 300 l storage; solar contribution ca. 50%
Electric appliances	Provision of advice on electric household appliances and grants for high-efficiency appliances; equipment of each dwelling unit with an energy-saving laundry drying cabinet integrated within the extract air flow
Energy parameters	
Total Floor Area (TFA)	Jangster de Lüx house type (mid- and end-terrace): 119.5 m², Jangster house type: 97 m², “123“house type: 75 m²
Annual space heat consumption (measured)	15.3* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	11.8 kWh/(m²a)

CEPHEUS 02 Germany, Kassel	

Lot 1: HHS/ASP project

Lot 2: Schneider project

Project brief	
Location	D-34131 Kassel (Hesse, Germany)
General contractor	HOCHTIEF AG, Fuldabrück
Client	Gemeinnützige Wohnungsbaugesellschaft der Stadt Kassel (GWG)
Architect	Lot 1: Hegger/Hegger/Schleif (HHS), Kassel and ASP Planungs- und Bauleitungs-GmbH, Kassel Lot 2: Prof. Dr. Schneider, Detmold
Engineers	Statics: Klute & Klute, Kassel Building services: InnovaTec Energiesysteme GmbH, Kassel
Construction period	Commencement: 28.4.99, occupied in May/June 2000
Building type	Apartment building
Use	Publicly-assisted housing
Number of dwelling units	40 (Lot 1: 23, Lot 2: 17)
Living floor space	3164 m²
Construction	
Type of construction	Solid (sand-lime with external thermal insulation compound system)
Windows and glazing	Triple low-emissivity glazing, TSET: 42%, window frame: PVC profile with additional internal and external insulating moulding
U-values (W/(m²K))	External wall: 0.13; ground/basement ceiling: 0.11; roof: 0.11; glazing: 0.6; window frame: 0.8; whole window: 0.82
Building services	
Heating	Distributed supplementary heating of supply air through heating registers; bathroom radiators, heat supply by district heat
Ventilation	Semi-centralized ventilation with heat recovery from extract air (centralized heat interchanger, distributed ventilators)
Hot water	Centralized hot water heating, 800 l hot service water storage in building services room, heat supply through district heat
Electric appliances	Energy conservation advice for occupants
Energy parameters	
Total Floor Area (TFA)	Lot 1: 1802 m² / Lot 2: 1253 m²
Annual space heat consumption (measured)	Lot 1: 15.1* kWh/(m²a), Lot 2: not within measurement programme *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	Lot 1: 13.4 kWh/(m²a) Lot 2: 15.0 kWh/(m²a)

CEPHEUS 03 Sweden, Gothenburg	

South elevation

Project brief	
Location	S-427 42 Bildal
Developer/client	Egnahemsbolaget, Gothenburg
Architect	EFEM arkitektkontor, Arch. Hans Eek, Gothenburg
Engineers	Building services: Bengt Dahlgren AB, Gothenburg
Construction period	Commencement: 31.12.1999, completion: 01.05.2001
Building type	Terrace
Use	Owner-occupied
Number of dwelling units	20 (two rows, one with 4 and one with 6 houses)
Living floor space	ca. 2704 m²
Construction	
Type of construction	Timber
Windows and glazing	Double low-emissivity glazing with coated glass, TSET: 40%, wooden window frames
U-values (W/(m²K))	External wall: 0.08; ground: 0.09; roof: 0.07; glazing:0.7; window frame: no information; whole window. 0.88
Building services	
Heating	Direct electric supplementary heating of supply air
Ventilation	Balanced supply and extract air flows with heat recovery from extract air
Hot water	Solar collectors (5 m²) and 500 l storage per dwelling unit
Electric appliances	Normal Swedish standard, but with energy-efficient household appliances
Energy parameters	
Total Floor Area (TFA)	2635 m²
Annual space heat consumption (measured)	No complete set of measured data is yet available for this project.
Space heat requirement (calculated by PHPP)	12.4 kWh/(m²a)

CEPHEUS 04 Austria, Egg	
 Southeast elevation	 North elevation
Project brief	
Location	A-6863 Egg (Vorarlberg, Austria)
Developer/client	Kohler Wohnbau GmbH, Andelsbuch
Architect	Fink & Thurnher, Bregenz
Engineers	Building services: Michael Gutbrunner, Dornbirn
Construction period	Commencement: Dec. 1999, completion: Sept. 2000
Building type	Multifamily building
Use	Owner-occupied
Number of dwelling units	4
Living floor space	400 m²
Construction	
Type of construction	Solid (brickwork with external thermal insulation compound system)
Windows and glazing	Triple low-emissivity glazing, TSET: 53%, standard wooden window frames
U-values (W/(m²K))	External wall: 0.12; ground: 0.14; uppermost ceiling: 0.10; glazing: 0.7; window frame: 1.25; whole window: 0.85
Building services	
Heating	Preheating of fresh air by subsoil heat exchanger, floor heating using heat pump (subsoil absorber)
Ventilation	Distributed controlled ventilation supply and extraction with heat recovery from extracted air
Hot water	Solar collector (35 m²), two 1000 l storage tanks
Electric appliances	Provision of advice for occupants, energy-efficient appliances only partly used
Energy parameters	
Total Floor Area (TFA)	310 m²
Annual space heat consumption (measured)	24.5* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	15.7 kWh/(m²a)

CEPHEUS 05 Austria, Hörbranz	

South elevation

East elevation

Project brief	
Location	A- 6912 Hörbranz (Vorarlberg, Austria)
Client group	Hofer/Österle/Amann
Architect	Ing. Richard Caldonazzi, Frastanz
Engineers	Building services: Ing. Christof Drexel, Bregenz
Construction period	Commencement: Oct. 1998, completion: June 1999
Building type	Terrace
Use	Owner-occupied
Number of dwelling units	3
Living floor space	394 m²
Construction	
Type of construction	Solid (brickwork with external thermal insulation compound system using cork)
Windows and glazing	Triple low-emissivity glazing, TSET: 47%, wooden window frames
U-values (W/(m²K))	External wall: 0.10; basement ceiling: 0.11; roof: 0.09; glazing: 0.6; window frame: 1.12; whole window: 0.83
Building services	
Heating	Preheating of fresh air by subsoil heat exchanger, supplementary heating of supply air by a water/air heat exchanger, heat pump or gas boiler as emergency heating
Ventilation	Controlled ventilation supply and extraction with heat recovery from extract air
Hot water	Façade-integrated solar collector (18 m² per house) with ca. 3000 l buffer storage
Electric appliances	High-efficiency appliances are used predominantly
Energy parameters	
Total Floor Area (TFA)	381 m²
Annual space heat consumption (measured)	7.5* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	13.8 kWh/(m²a)

CEPHEUS 06 Austria, Wolfurt	

South elevation East elevation

Project brief	
Location	A-6922 Wolfurt (Vorarlberg, Austria)
Developer/client	Errichtergemeinschaft Passivhaus Wolfurt-Oberfeld
Architect	Dipl.-Ing. Gerhard Zweier, Wolfurt
Engineers	Building services: GMI Gasser&Messner-Ingenieure, Dornbirn and Christof Drexel, Bregenz Building physics: Architecturbüro Dr. Lothar Künz, Hard
Construction period	Commencement: Feb. 1999, completion: Dec. 1999
Building type	Multifamily building (2 identical buildings)
Use	Owner-occupied: 8 dwelling units, one office, one atelier
Number of dwelling units	10
Living floor space	1300 m²
Construction	
Type of construction	Mixed construction: Steel skeleton with reinforced concrete ceilings and stiffening concrete slabs; external walls are prefabricated timber elements
Windows and glazing	Triple low-emissivity glazing, TSET: 53%, wooden window frames with core insulation made of recycled PU material
U-values (W/(m²K))	External wall 1: 0.12; external wall 2: 0.16; basement ceiling: 0.10; roof: 0.09; glazing: 0.70; window frame: 1.0; whole window: 0.82
Building services	
Heating	Supplementary heating through hot water register from the centralized buffer storage, the latter heated by a pellet boiler and a solar installation
Ventilation	Distributed controlled ventilation supply and extraction with subsoil heat exchanger and heat recovery from extract air
Hot water	Solar collector (total: 62 m²), 2500 l joint storage per building
Electric appliances	Provision is made for high-efficiency appliances
Energy parameters	
Total Floor Area (TFA)	1296 m²
Annual space heat consumption (measured)	15.7* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	13.5 kWh/(m²a)

CEPHEUS 07 Austria, Dornbirn	

West facade

South facade

Project brief	
Location	A-6850 Dornbirn (Vorarlberg, Austria)
Client	Fussenegger & Rümmele GmbH, Dornbirn
Architect	www.fuerrot.at, Götzis
Engineers	Building services: Drexel Solarlufttechnik und Ventilationsbau GmbH, Bregenz Building physics: Architecturbüro Dr. Lothar Künz, Hard
Construction period	Commencement: April 1999, completion: Oct. 1999
Building type	Single-family house
Use	Demonstration house
Number of dwelling units	1
Living floor space	124.6 m²
Construction	
Type of construction	Mixed construction: Steel skeleton with reinforced concrete ceilings, prefabricated lightweight timber wall elements
Windows and glazing	Triple low-emissivity glazing, TSET: 53%, wooden window frames
U-values (W/(m²K))	External wall 1: 0.12 external wall 2: 0.09; ground: 0.14; roof: 0.10; glazing: 0.70; window frame: 1.5; whole window: 0.89
Building services	
Heating	Preheating of fresh air by subsoil heat exchanger, supplementary heating of supply air by means of the air-air/water heat pump of the packaged ventilation unit
Ventilation	Controlled ventilation supply and extraction with heat recovery from extract air
Hot water	Solar collector (6 m²), 190 l service water storage (integrated in the packaged ventilation unit) fed by the air-air/water heat pump or (if necessary) directly electrically
Electric appliances	No information
Energy parameters	
Total Floor Area (TFA)	125 m²
Annual space heat consumption (measured)	33.2* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	19.7 kWh/(m²a)

CEPHEUS 08 Austria, Gnigl	

Northwest elevation

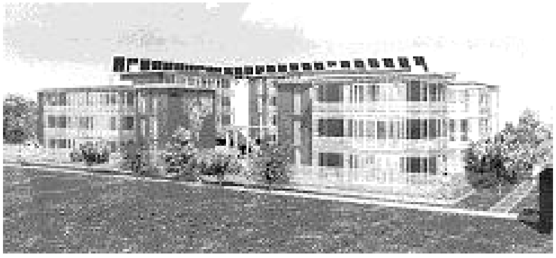
Southeast elevation

Project brief	
Location	A-5020 Salzburg-Gnigl (Salzburg, Austria)
Client	Heimat Österreich, Salzburg
Architect	Atelier 14, Mag. Erich Wagner, Mag. Walter Scheicher, Salzburg
Engineers	Building services: Eco Energie-Systeme, Dornbirn Building physics: Energie und Bau Institut, Dr. Georg Stahl, Salzburg
Construction period	Commencement: Nov. 99, completion: Sept. 2000
Building type	Multifamily building
Use	Publicly-assisted housing
Number of dwelling units	6
Living floor space	332 m²
Construction	
Type of construction	Reinforced concrete cellular framing, external walls as lightweight self-supporting construction
Windows and glazing	Special compound glass with krypton filling; glass façade is optimized both thermally and for noise insulation, TSET: 47%, cork-insulated wood-aluminium window frames
U-values (W/(m²K))	External wall: 0.11; basement ceiling: 0.13; roof: 0.10; glazing: 0.6; window frame: 0.8; whole window: 0.77
Building services	
Heating	Comined airborne and planar building-element heating system, centralized 3200 l buffer storage fed by pellet boiler and solar collector (20 m²)
Ventilation	Distributed controlled ventilation with heat recovery from extract air
Hot water	Solar collector and pellet boiler feed centralized buffer storage
Electric appliances	No information available
Energy parameters	
Total Floor Area (TFA)	328 m²
Annual space heat consumption (measured)	25.7* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	18.0 kWh/(m²a) (shadowing not considered) 24.0 kWh/(m²a) (real shadowing)

CEPHEUS 09 Austria, Kuchl	
 Courtyard aspect	 Block A elevation
Project brief	
Location	A-5431 Kuchl (Salzburg, Austria)
General contractor	Spiluttini Bau GmbH, Schwarzach
Developer/client	Bau Sparer Heim Siedlungsgemeinschaft, Salzburg
Architect	Own design by Bau Sparer Heim, Salzburg
Engineers	Building services: Team Pongau 3: Spiluttini-Kraner-Burgschwaiger Building physics: Dipl.-Ing. Erich Six, Salzburg
Construction period	Commencement: July 1999, completion: June 2000
Building type	Multifamily building
Use	Publicly-assisted housing
Number of dwelling units	25
Living floor space	1818 m²
Construction	
Type of construction	Mixed construction: Reinforced concrete ceilings on steel columns, separately standing external walls in lightweight timber construction, part of building has basement
Windows and glazing	Triple low-emissivity glazing, TSET: 50%, wooden window frames with wood-based insulation material
U-values (W/(m²K))	External wall: 0.13; ground: 0.15; roof: 0.10; glazing: 0.70; window frame: 0.73; whole window: 0.8
Building services	
Heating	Wood pellet heating and solar collector (75 m²) feed a centralized 3000 l buffer storage for space heat and hot water, with heat transfer to the dwellings via low-temperature radiators
Ventilation	Controlled ventilation supply and extraction with heat recovery from extract air
Hot water	150 l service water storage per dwelling unit, supplied by centralized buffer storage
Electric appliances	Energy-efficient household appliances, PV array (300 Wp) providing pump power for solar thermal installation
Energy parameters	
Total Floor Area (TFA)	1798 m²
Annual space heat consumption (measured)	14.3* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	15.1 kWh/(m²a)

CEPHEUS 10 Austria, Hallein	

Perspective



Project brief	
Location	A-5400 Hallein (Salzburg, Austria)
Developer/client	Experta Wohnbau-GmbH, Hallein
Architect	Otmar Essl, Hallein
Engineers	Building services: Erich Pusterhofer, Fürstenbrunn Building physics: Dipl.-Ing. Lukas & Dipl.-Ing. Fischer, Salzburg-Wals
Construction period	Commencement: Oct. 1999, completion: Dec. 2000
Building type	Multifamily building (4 buildings, arranged around an inner courtyard)
Use	Owner-occupied
Number of dwelling units	31
Living floor space	2335 m²
Construction	
Type of construction	Mixed construction: Steel skeleton combined with timber framing (3-shell wall construction), total insulation 38 cm (EPS and mineral wool)
Windows and glazing	Triple low-emissivity glazing, TSET: 53%, PVC window frames with PU foam interior
U-values (W/(m²K))	External wall 1: 0.11; external wall 2: 0.16; ground: 0.11; uppermost ceiling: 0.11; glazing: 0.70; window frame: 0.75; whole window: 0.79
Building services	
Heating	Remaining heat requirement met by wood pellet boiler and solar collector (120 m²), 5000 l buffer storage, distribution by central low-temperature system
Ventilation	Controlled ventilation supply and extraction with heat recovery from extract air
Hot water	Wood pellet boiler and solar collector feed centralized 5000 l buffer storage
Electric appliances	Use of high-efficiency appliances is envisaged
Energy parameters	
Total Floor Area (TFA)	2318 m²
Annual space heat consumption (measured)	No measured data are yet available for this project.
Space heat requirement (calculated by PHPP)	13.9 kWh/(m²a)

CEPHEUS 11 Austria, Horn	


South elevation


Northeast elevation

Project brief	
Location	A-3580 Horn (Lower Austria)
Client	Buhl Bauunternehmens GmbH
Architect	Dr. Dipl.-Ing. Martin Treberspurg, Vienna
Engineers	Building physics: Dipl.-Ing. Wilhelm Hofbauer, Vienna
Construction period	Commencement: April 1999, completion: spring 2000
Building type	Single-family house
Use	Owner-occupied
Number of dwelling units	1
Living floor space	179 m²
Construction	
Type of construction	Prefabricated house in mixed construction: Parts of external walls (E,W,N) in masonry, otherwise prefabricated timber elements with cellulose insulation
Windows and glazing	Triple low-emissivity glazing, TSET: 53%, wooden window frames (with greatly overlapping insulation)
U-values (W/(m²K))	External wall: 0.10; basement ceiling: 0.13; roof: 0.09; whole window: 0.80
Building services	
Heating	Preheating of fresh air by subsoil heat exchanger; wood pellet oven and solar collector (10 m^2) feed 800 l buffer storage (with internal 200 l service water storage), supplementary supply air heating and wall heaters (ground floor, first floor, bathroom) are supplied from buffer storage
Ventilation	Controlled ventilation supply and extraction with heat recovery from extract air
Hot water	200 l storage (integrated in buffer storage)
Electric appliances	Provision is made for high-efficiency appliances
Energy parameters	
Total Floor Area (TFA)	173 m²
Annual space heat consumption (measured)	29.0* kWh/(m²a), (first winter, before final completion) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	16.2 kWh/(m²a)

CEPHEUS 12 Austria, Steyr	

Southeast elevation North elevation

Project brief	
Location	A-4407 Steyr-Dietach (Upper Austria)
Developer/client	Procon Gesellschaft für Dorf- and Regionalentwicklung, Dietach
Architect	Procon, Ing. Ganglberger, Dietach
Engineers	Building services: Energie-Institut, G. Baumgartner, P. Hausdörfer, Linz
Construction period	Commencement: Sept. 1999, completion: Feb. 2000
Building type	Terrace
Use	Owner-occupied and rental
Number of dwelling units	3
Living floor space	512 m²
Construction	
Type of construction	Solid (sand-lime with external thermal insulation compound system)
Windows and glazing	Triple low-emissivity glazing, TSET: 53%, PVC window frames with PU foam core
U-values (W/(m²K))	External wall: 0.13; basement ceiling: 0.12; roof: 0.09; glazing: 0.70; window frame: 0.75; whole window: 0.77
Building services	
Heating	Preheating of fresh air by subsoil heat exchanger; gas boiler and solar collector (5.4 m²) feed 390 l buffer storage, which supplies the supplementary supply air heating
Ventilation	Controlled ventilation supply and extraction with heat recovery from extract air
Hot water	Supply from 390 l buffer storage
Electric appliances	Provision is made for high-efficiency appliances
Energy parameters	
Total Floor Area (TFA)	467 m²
Annual space heat consumption (measured)	18.1* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	12.3 kWh/(m²a)

CEPHEUS 13 Switzerland, Nebikon	

South elevation

Bird's eye perspective

Project brief	
Location	CH-6244 Nebikon (Lucerne, Switzerland)
Client	Renggli AG, Schötz
Architect	Susan Amrhein, Renggli AG, Schötz ASP Architectur und Bauleitungs GmbH, Kassel Lot 2: Prof. Dr. Schneider, Detmold
Engineers	Building services: bw Building services AG, Prof. W. Betschart, Hünenberg
Construction period	Commencement: May 1999; completion: Nov. 1999
Building type	Terrace
Use	Owner-occupied
Number of dwelling units	5
Living floor space	641 m²
Construction	
Type of construction	Timber
Windows and glazing	Triple low-emissivity glazing, TSET: 42%, wood-aluminium window frames
U-values (W/(m²K))	External wall: 0.11; ground: 0.11; roof: 0.11; glazing: 0.6; window frame: 1.2; whole window: 0.88
Building services	
Heating	Preheating of fresh air by subsoil heat exchanger, packaged ventilation unit with air-air/water heat pump for supplementary supply air heating and hot water heating
Ventilation	Controlled ventilation supply and extraction with heat recovery from extract air
Hot water	Service water storage is heated by the heat pump of the packaged ventilation unit or directly electrically
Electric appliances	Use of appliances with very low energy requirements
Energy parameters	
Total Floor Area (TFA)	613 m²
Annual space heat consumption (measured)	21.0* kWh/(m²a) *The measured values were normalized to 20°C indoor temperature and extrapolated across a full year.
Space heat requirement (calculated by PHPP)	15.0 kWh/(m²a)

CEPHEUS 14 France, Rennes

Southeast elevation

Project brief	
Location	F-35000 Rennes
Client	COOP de Construction, 35043 Rennes Cedex
Architect	Jean-Yves Barrier, F-37000 Tours
Engineers	Building services: O.A.S.I.I.S, F-13685 Aubagne Cedex
Construction period	Commencement: October 1999, completion: March 2001
Building type	Apartment building
Use	Owner-occupied apartments
Number of dwelling units	40
Construction	
Type of construction	Load-bearing structure reinforced concrete skeleton; southern external wall straw-loam (ground floor to 3rd floor); other external walls timber
Windows and glazing	Double low-emissivity glazing, TSET: 64%, standard wooden window frames
U-values (W/(m²K))	External loam wall: 0.77; external timber wall: 0.19; ground: 0.18; roof: 0.27; glazing: 1.3; window frame: 1.5; whole window: 1.9
Building services	
Heating	Supplementary supply air heating supplied by district heat, direct electric heating (radiative) in each room for room-by-room temperature control
Ventilation	Ventilation unit with centralized heat exchanger for heat recovery from extract air
Hot water	1500 l service water storage is heated by district heat and via 4000 l buffer storage fed by solar collector (81 m²).
Electric appliances	Advice, grants for max. 3 appliances, 3 compact fluorescent lamps free of charge
Energy parameters	
Total Floor Area (TFA)	2601 m²
Annual space heat consumption (measured)	No measured data are yet available for this project.
Space heat requirement (calculated by PHPP)	27.2 kWh/(m²a)

9 Appendices

9.1 Calculation of the reference area for energy measurements (Treated Floor Area, TFA in Section 2.4.7.1)

The reference area for the energy measurements, also called Treated Floor Area (TFA), is the most important number in the energy balance, because all gains and losses, including the final result, will refer to the TFA. Comparing heating energy consumptions and similar data between projects has no meaning if the TFA has not been calculated in the same manner. This is especially true for projects in different countries, as the calculation procedures for living area vary considerably from one country to the other.

The following calculation procedure is based on the Second German Calculation Ordinance (II. Berechnungsverordnung) for the calculation of the living area. It has been simpified in a few points and has been adapted to the requirements of the energy balance.

1. Before calculating the TFA, the thermal envelope[1] has to be defined. Only areas within the thermal envelope form part of the TFA.

2.1 The TFA of a dwelling unit or a house is the sum of the floor areas of the living rooms[2] of which it is composed.

2.2 For cellars, rooms for service appliances, etc. within the thermal envelope, but not being considered as living rooms, half of the area is taken into account.

3. Calculation of the floor area:

3.1 Generally, the floor area of a room is calculated from the inner dimensions of the finished building. For simplification, the dimensions of the building shell may be used; in this case, for walls with plaster 15 mm of plaster have to be taken into account.

3.2 The dimensions of the finished building are the clear dimensions between walls without taking into account wall coatings, base boards, scrub boards, ovens, radiators, etc.

4. Chimneys, pillars, columns, supports, etc. with less than 0.1 m² of floor area are not subtracted from the TFA.

5. Recesses of doors and windows are not taken into acocunt.

6. Inclinations:

6.1 Parts of rooms with a clear height of at least 2 meters are taken into account with their full area.

6.2 Parts of rooms with a clear height of at least 1 meter and less than 2 meters are taken into account with 50 % of their area.

6.3 Parts of rooms with a clear height of less than 1 meter are not taken into account.

[1] Thermal envelope: The outer surfaces of the insulated outer building components form the thermal envelope. The thermal envelope contains all heated rooms. For the energy balance, the energy flows across the thermal envelope are considered.

[2] Living rooms are all rooms within the *dwelling unit* that are either above ground level or whose window area is at least 10 % of the floor area. Corridors, storage rooms etc. within a dwelling unit are considered as living rooms, too. Stairs with more than 3 steps, landings and lifts are not part of the TFA.

9.2 Overview about the architects, planners and manufacturers

Projekt	Aufgabe	Name	Institutior	Staße	Ort	Land	Telefon	Fax	Email
1-Hannover	Gesamtkoordination	**Görg, Manfred**	Stadtwerke Hannover	Ihmeplatz 2	30449 Hannover	D	0049/511/430-2784	0049/511/430-1846	manfred.goerg@enercity.de
		von Oesen, Matthias	Stadtwerke Hannover			D	0049/511/430-2241	0049/511/430-2170	matthias.vonoesen@enercity.de
3-Göteborg	CEPHEUS-Partner	**Eek, Hans**	Göteborg Energi AB	Box 53	401 20 Göteborg	S	0046/31/626-950	0046/31/626-885	hans.eek@goteborgenergi.se
	CEPHEUS-Partner	Eek, Hans (privat)	Arkitekt Hans Eek	Finska gatan 25 D	441 56 Alingsås	S	0046/322/637766	0046/322/639077	helmrot.eek@telia.com
	Verantwortlich für Messungen	Ruud, Svein, Lundin, Leif	SP, Sveriges Provnings- och Forkningsinstitut	Box 857	501 15 Borås	S	0046/33/165-000	0046/33/131979	svein.ruud@sp.se leif.lundin@sp.se
	Simulationen, Berechnungen, Fe	Maria Wall Tekn Dr.	EBD, Energy and Building Design, LTH	Box 118	221 00 Lund	S	0046/46/2229662	0046/46/2224719	maria.wall@ebd.lth.se
	Berechnungen, Fundament, Kält	Carl Eric Hagentoft Prof.	Building Physics, Chalmers		412 96 Göteborg	S			
	Bauherr:	Bertil Rignäs	Egnahemsbolaget	Gamlestadsvägen 18 A	413 02 Göteborg	S	0046/31/7077000	0046/31/7077029	bertil.rignas@egnahemsbolaget.goteborg.se
		Mats Öjersjö	Egnahemsbolaget	Gamlestadsvägen 18 A	413 02 Göteborg	S	0046/31/7077000	0046/31/7077029	mats.ojersjo@egnahemsbolaget.goteborg.se
	Totalunternehmer:	Birger Lindgren	PEAB		401 80 Göteborg	S	0046/31/7008400	0046/31/7008420	birger.lindgren@peab.se
		Gunnar Tejlerdahl	PEAB		401 80 Göteborg	S	0046/31/7008400	0046/31/7008420	gunnar.tejlerdahl@peab.se
	Architekt, Projektierungsleiter:	EFEM arkitektkontor	EFEM, Architect	Heurlins Plats 1	413 01 Göteborg	S	0046/31/743 80 30	0046/31/743 80 39	efem@efem.nu
	Statik:	Henrik Karlsson	KM, Static consultant	Box 331	401 25 Göteborg	S	0046/31/7272677	0046/31/7272501	henrik.karlsson@km.se
	Fachplaner Haustechnik	Göran Andersson	Bengt Dahlgren AB, VVS-consultant	Regnbågsgatan 8B	417 55 Göteborg	S	0046/31/7202500	0046/31/7202501	goran.andersson@bengtdahlgren.se
	fachplaner Elektro	Stig Johansson	Probeko, Electric consultant	Box 6224	400 60 Göteborg	S	0046/31/84 47 20	0046/31/84 73 41	stig.johansson@probeko.se
	Landschaftsplanung	Bo Wiklund	Landskapsgruppen AB, Garden consultant	Vestagatan 2B	416 64 Göteborg	S	0046/31/61 73 52		
	Lüftungsanlage	Boerje Templer	Temovex	Kanonhatan 55	25467 Helsingborg	S			
4-Egg VA	Hauptansprechpartner (VK)	**Morscher**	Morscher Hausbau	Klaus 303a	6881 Mellau	A	0043/5518/26651	0043/5518/26654	morscher.hausbau@aon.at
	Bauträger/Bauherr	Morscher,Günther	Kohler Wohnbau GmbH	Hof 512	6866 Andelsbuch	A	0443/5512/2336-15	0443/5512/2336-71	
	Architekt	Fink, Josef	DI Jofef Fink & DI Markus Thunher	Bahnhofstr.7	6900 Bregenz	A	0043/5574/52250-0	0043/5574/52250-4	
	Fachplaner/Haustechnik	Gutbrunner, Michael	Technisches Büro Gutbrunner	Robert-Schumann-Str. 9b	6850 Dornbirn	A	0043/5572/35191-0	0043/5572/35191-6	tbgutbrunner@telemax.at
	Fachplaner/PHPP	Ritter, Gerhard	Technisches Büro Ritter	Bühel 440	6866 Andelsbuch	A	0043/5512/4884	0043/5512/4884	
	Fachplaner/Elektroplanung	Meusburger, Willi		Auf der Scheibe 552	6870 Bezau	A	0043/5514/3220	0043/5514/2480	
5-Hörbranz VA	Hauptansprechpartner	**Caldonazzi & Hopp(Mitarbeiter)**				A			
	Bauträger/Bauherr	Hofer/Österle/Amann	Bauherrengemeinschaft			A			
	Architekt	Caldonazzi, Richard	Caldo Bau GmbH	Alter Burgweg 446	6712 Thüringen	A	0043/5550/3600	DW -4	richard.caldonazzi@vol.at
	Fachplaner/Haustechnik	Drexel, Christof	Drexel Solarlufttechnik + Lüftungsbau GmbH	Kennelbacherstraße 36	6900 Bregenz	A	0043/5574/71856-8	0043/5574/71856-7	solarlufttechnik@drexel.vol.at
	Fachplaner/Elektroplanung	Caldonazzi, Richard		Alter Burgweg 446	6712 Thüringen	A	0043/5550/3600	DW -4	richard.caldonazzi@vol.at
	Fachplaner/Elektroinstallation	Rützler, Harald		St.-Ana-Str. 444	6712 Thüringen	A	0043/5550/3464		
6-Wolfurt VA	Hauptansprechpartner	**Drexel, Christof**				A			
	Bauträger/Bauherr	Drexel, Christof	Miterrichtergemeinschaft PH Wolfurt	Kennelbacherstraße 34	6900 Bregenz	A	0043/5574/71856-8	0043/5574/71856-7	solarlufttechnik@drexel.vol.at
	Architekt	Zweier, Gerhard		Im Dorf 8	6922 Wolfurt	A	0043/5574/704021	0043/5574/704024	gz@zweier.vol.at
	Fachplaner/Haustechnik	Gasser, Bernhard	GMI - Gasser & Messner Ingenieure	Schulgasse 22	6850 Dornbirn	A	0043/5572/33777	0043/5572/33777-7	
	Fachplaner/Bauphysik	Weithas, Bernhard	Architekturbüro Dr. Lothar Künz	Marktstraße 3	6971 Hard	A	0043/5574/77851	0043/5574/61689	
	Fachplaner/Elektroplanung	Meusburger, Willi		Auf der Scheibe 552	6870 Bezau	A	0043/5514/3220	0043/5514/2480	
	Fachplaner/Statik	Gehrer, Ingo		Eichenweg 11	6973 Höchst	A	0043/5578/72093-0	0043/5578/72093-0	
7-Dornbirn VA	Hauptansprechpartner	**Rümmele, Simon**				A			
	Bauträger/Bauherr	Rümmele, Simon	Fussenegger & Rümmele GmbH	Gütlestraße 5	6850 Dornbirn	A	0043/5572/24381	0043/5572/24381-20	
	Architekt	Rümmele, Simon	Fussenegger & Rümmele GmbH	Gütlestraße 5	6850 Dornbirn	A	0043/5572/24381	0043/5572/24381-20	
	Fachplaner,Haustechnik	Drexel, Christof	Drexel Solarlufttechnik + Lüftungsbau GmbH	Kennelbacherstraße 36	6900 Bregenz	A	0043/5574/71856-8	0043/5574/71856-7	solarlufttechnik@drexel.vol.at
	Fachplaner,Bauphysik	Weithas, Bernhard	Architekturbüro Dr. Lothar Künz	Marktstraße 3	6971 Hard	A	0043/5574/77851	0043/5574/61689	lothar.kuenz@vol.at
	Fachplaner,Elektroplanung	Hiebleler, Helmut		Hochstegstr. 10	6912 Hörbranz	A	0043/5573/82228-0	0043/5573/82228-10	
8-Gnigl SB	Hauptansprechpartner	Heftberger & **Scheicher**				A			
	Bauträger/Bauherr (VK)	Heftberger, Alfred	Heimat Österreich	L.V.Keutschach Str. 4	5020 Salzburg	A	0043/662/437521-0	0043/662/437521-39	
	Architekt	Scheicher, Walter	Atelier 14	Franz-Hattinger-Str. 14	5020 Salzburg	A	0043/662/640395-0	0043/662/643420	
	Fachplaner/Bauphysik	Stahl, Georg Dr.	Energie und Bau Institut	Bergstraße 22	5020 Salzburg	A	0043/662/875837	0043/662/875837	
	Fachplaner/TGA	Burggraf	Technisches Büro Burggraf	Macagnigasse 31/52	5020 Salzburg	A	0043/662/6208470		
	Fachplaner/Haustechnik	Schöpf, Walter	Eco Energie-Dienstleistung GmbH	Am Müllerbach 4a	6850 Dornbirn	A	0043/5572/21378	0043/5572/21378-4	contract.ecoenergie@vol.at
			ECO energie systeme gmbh & co	Hauptstr. 35	6974 Geissau	A	0043/5578/71367-0	0043/5578/71367-4	systeme.ecoenergie@vol.at
	Fachplaner/Elektroplanung	Morokutti, Bernhard	ETS Planungsbüro für Elektrotechnik	Lofererstr. 9	5760 Salfelden	A	0043/6582/73410	DW -14	
	Fachplaner/Elektroplanung	Salzmann, Klaus	ETS Planungsbüro für Elektrotechnik	Lofererstr. 9	5760 Salfelden	A	0043/6582/73410	DW -14	
9-Kuchl SB	Hauptansprechpartner	Haigermoser & **Kramer**				A			
	Bauträger/Bauherr	Haigermoser, Ernst	Bau Sparer Heim reg. Gen.m.b.H.	Bayerhamerstr. 57	5021 Salzburg	A	0043/662/876528-37	0043/662/876528-50	
	Architekt	Haigermoser, Ernst	Bau Sparer Heim reg. Gen.m.b.H.	Bayerhamerstr. 57	5021 Salzburg	A	0043/662/876528-37	0043/662/876528-50	
	Fachplaner/Bauphysik	Six, Erich	Energie-Optimierung	Josef Messner-Str. 32/13	5020 Salzburg	A	0043/662/642850	0043/662/642850-11	erich.six@netway.at
	Fachplaner/Haustechnik (VK)	Kramer, Franz		Am Hubdörfl 54	5602 Wagrain	A	0043/6413/8247 **5**413???	DW -76	
	Fachplaner/Elektroplanung	Steurer, Hans	TB Instaplan		5423 Faistenau 61/4	A	0043/6228/2728	0043/6228/27288	
	Fachplaner/Generalunternehmer	Hinterleitner, Georg	Spiluttini Bau GmbH	Dr. Franz Hainstr. 8	5620 Schwarzach	A	0043/6415/7795	DW -20	office@spilluttini.at
	Zimmereibetrieb (VK)	Burgschweiger, Rupert	Zimmerei Burgschwaiger Schwarzach	Salzburger Str. 48a	5620 Schwarzach	A	004,/6415/4226		
10-Hallein SB	Hauptansprechpartner	Essl, Otmar				A			
	Bauträger/Bauherr	**Essl, Otmar**	Experta Wohnbau Ges.m.b.H	Salzstadelstr. 2	5400 Hallein	A	0043/6245/88449	0043/6245/88449-15	essl@experta.at
	Architekt	Essl, Otmar		Salzstadelstr. 2	5400 Hallein	A	0043/6245/88449	0043/6245/88449-15	essl@experta.at
	Fachplaner/Haustechnik	Pusterhofer, Erich		Lärchenweg 22	5082 Fürstenbrunn	A	0043/6245/88449	0043/6245/88449-15	
	Fachplaner/Elektrotechnik	Taferner, Robert		Drosselstraße 13	5023 Salzburg	A	0043/6245/88449	0043/6245/88449-15	
	Fachplaner/Bauphysik	Lukas, Horst	Zivilingenieur-Arge	Bayernstr. 402	5071 Salzburg-Wals	A			
	Fachplaner/Bauphysik	Fischer, Ekkehard	Zivilingenieur-Arge	Bayernstr. 402	5071 Salzburg-Wals	A			
	Fachplaner/Statik	Dorrer, Fritz		Glockenstraße 19	5671 Bruck	A			
	Bauphysik (VK)	Zwittlinger, Rainer	Zivilingenieur-Arge	Bayernstr. 402	5071 Salzburg-Wals	A	0043/6662/584291-0	0043/6662/584291-4	zi-arge@eunet.at

Projekt	Aufgabe	Name	Institutior	Staße	Ort	Land	Telefon	Fax	Email
11-Horn NÖ	Hauptansprechpartner	**Seidl & Treberspurg**				A			
	Bauträger/Bauherr	Seidl, Josef	Buhl Bauunternehmens Ges.m.b.H.	Schillerstr. 163	3571 Gars/Kamp	A	0043/2985/2113-178	0043/2985/2113-295	josef.seidl@gmx.net
	Architekt	Treberspurg, Martin Dr.	Architekturbüro Treberspurg	Penzingerstr. 58	1140 Wien	A	0043/1/8943191	0043/1/8943191-15	treberspurg@netway.at
	Fachplaner/Bauphysik	Hofbauer, Wilhelm	Technisches Büro	Penzingerstr. 58	1140 Wien	A	0043/1/8943191-13	0043/1/8943191-15	technisches.buero.hofbauer@netway.at
	Fachplaner/Haustechnik	Schütz, Peter Dr.		Mauerbachstraße 42/12	1140 Wien	A	0043/1/979/5710	0043/1/9795716	
	Fachplaner/Simulation	Pokorny, Walter		Braungasse 12	1170 Wien	A	0043/1/4853962	0043/1/4811000	
	Fachplaner/Elektroinstallation	Herr Grob	Fa. Honeder Ges.m.b.H.	Apoigerstr. 87	3571 Gars	A	0043/2985/2300	Tel: 0043/664/4413826	
12-Steyr OÖ	Hauptansprechpartner	**Baumgartner, Günter**				A			
	Bauträger/Bauherr		Procon Gesellschaft für Dorf- und Regionalentwicklung	Zehetmerberg 20	4407 Dietach	A			
	Architekt	Ganglberger	Procon Gesellschaft für Dorf- und Regionalentwicklung	Zehetmerberg 20	4407 Dietach	A			
	Fachplaner/Haustechnik	Baumgartner, Günter	Energie-Institut	Schererstraße 18/3	4020 Linz	A	0043/732/381011	0043/732/381011-14	ei-baumg@energie-institut.co.at
	Fachplaner/Haustechnik	Hausdörfer, Peter	Energie-Institut	Schererstraße 18/3	4020 Linz	A	0043/732/381011	0043/732/381011-14	
A-allgemein	Hauptansprechhpartner Salzburg	Mair, Franz	Land Salzburg, Abteilung 15: Wirtschaft, Tourismus, Energie	Fanny-von-Lehnert-Straße 1 Postfach 527	5010 Salzburg	A	0043/662/8042-3788	0043/662/8042-763788	franz.mair@land-sbg.gv.at
	CEPHEUS-Projektleiter A	**Krapmeier, Helmut**	Energieinstitut Vorarlberg	Stadtstraße 33/CCD	6850 Dornbirn	A	0043/5572/31202-61	0043/5572/31202-4	Krapmeier.energieinstitut@ccd.vol.at
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