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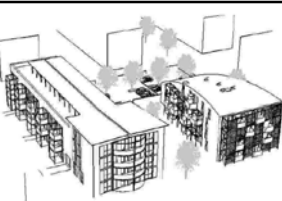


CEPHEUS-Projectinformation No. 38

Hannover (D) 32 Reihenhäuser



Kassel (D) 40 Wohnungen



Göteborg (S) 20 Reihenhäuser



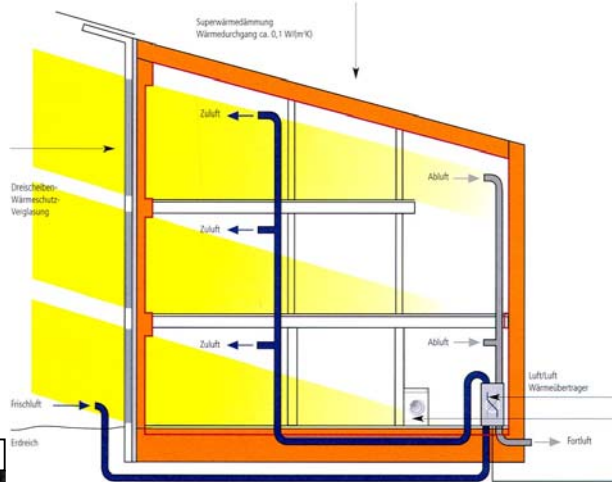
Nebikon(CH) 17 Reihenhäuser



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 Publical Report
July 2001

Dornbirn (A) 1 freistehendes Haus



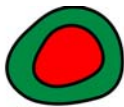
Kuchl (A) 25 Wohnungen



Egg (A) 4 Wohnungen



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



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Dr. Wolfgang Feist*



CEPHEUS-Projectinformation No. 38

Final Publical Report July 2001

Authors:

Dr. Wolfgang Feist (PHI)
Dipl.-Ing. Søren Peper (PHI)
Dipl.-Ing. Manfred Görg (enercity /
Stadtwerke Hannover AG)

Agent:

PASSIVHAUS INSTITUT
Rheinstr. 44-46
D-64283 Darmstadt
E-Mail: passivhaus@t-online.de
www.passiv.de

Hanover 2001

**This report is part of the European
research project CEPHEUS - Cost
Efficient Passive Houses as European
Standards supported by the EU.**

**Delivery by enercity /
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www.enercity.de/unternehmen/passivhaeuser

or

Mr. Matthias von Oesen
Glockseestraße 33
30169 Hannover
Germany
Fax: +49 (0)5 11 43 09 41 33 20
E-Mail: matthias.vonoesen@enercity.de

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**

1st Contractor

2nd Contractor *

<i>Name of company:</i>	Stadtwerke Hannover AG	Passivhausinstitut (PHI)
<i>Contact Person:</i>	Mr. Manfred Görg	Dr. Wolfgang Feist
<i>Address:</i>	Ihmeplatz 2 D-30449 Hannover Germany	Rheinstr. 44/46 D-64283 Darmstadt Germany

<i>Telephone No.:</i>	(+49) (511) (430-2784)	(+49) (6151) (82699-0)
	(country) (area) (number)	(country) (area) (number)

<i>Telefax No.:</i>	(+49) (511) (430-1846)	(+49) (6151) (82699-11)
	(country) (area) (number)	(country) (area) (number)

Report prepared by: <i>Name of company:</i>	Passivhausinstitut + Stadtwerke Hannover AG
<i>Contact Person:</i>	Dr. Wolfgang Feist + Mr. Manfred Görg
<i>Address:</i>	
<i>Telephone No.:</i>	please see above

Contract signed: 27.03.1998

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

3rd Contractor

Name of company: Rasch & Partner
Bauen & Wohnen GmbH
Contact Person: Mr. Folkmar Rasch
Address: Steubenplatz 12
D-64293 Darmstadt
Germany

4th Contractor

EFEM arkitektkontor
Mr. Hans Eek
Brogatan 2
S-41301 Göteborg
Sweden

Telephone No.: (+49) (6151) (8251-0) (+46) (31) (626-950)
(country) (area) (number) (country) (area) (number)

Telefax No.: (+49) (6151) (8251-99) (+46) (31) (626-885)
(country) (area) (number) (country) (area) (number)

5th Contractor

Name of company: Energieinstitut Voralberg
Contact Person: Mr. Helmut Krapmeier
Address: Stadtstr. 33
A-6850 DORNBIRN
Austria

6th Contractor

COOP de Construction
Mr. Thierry Wagner
9, Boulevard de la Tour d' Auvergne
F-35043 Rennes cedex
France

Telephone No.: (+43) (5572) (31202-61) (+33) (12) (99 35 01 35)
(country) (area) (number) (country) (area) (number)

Telefax No.: (+43) (5572) (31202-4) (+33) (121) (99 35 13 00)
(country) (area) (number) (country) (area) (number)

7th Contractor

Name of company: RENGGLI AG
Contact Person: Mr. Max Renggli
Address: Gleng
6247 Schötz/LU
Switzerland

Telephone No.: (+41) (62) (74822-22)
(country) (area) (number)

Telefax No.: (+41) (62) (74822-23)
(country) (area) (number)

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.

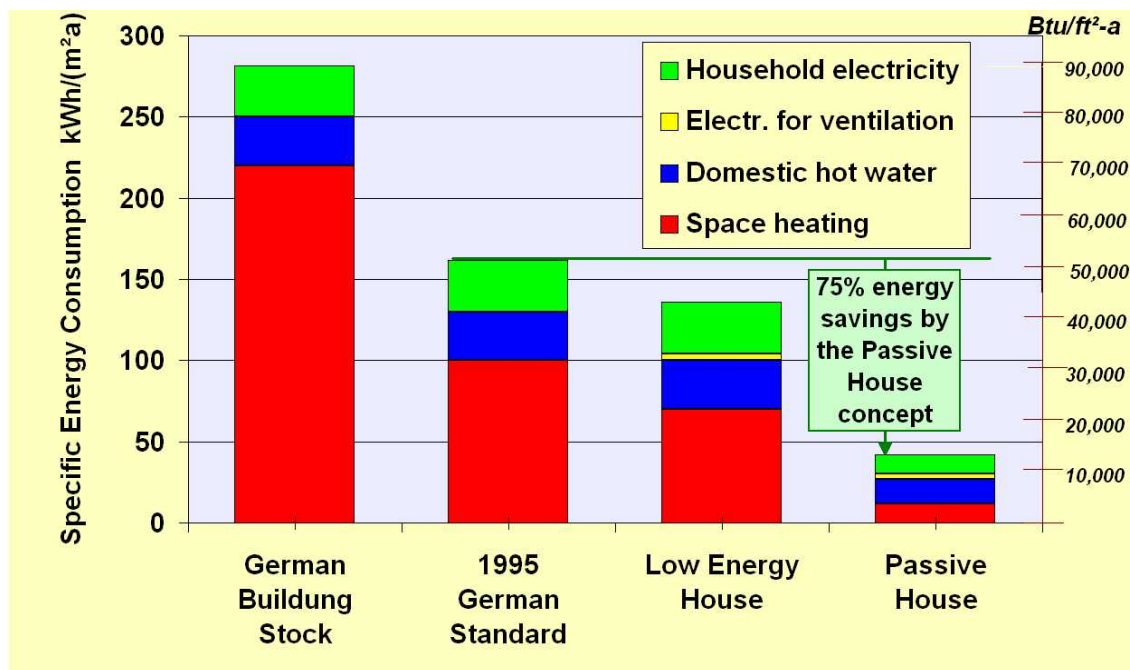


Figure 1: Comparison of specific energy consumption levels of dwellings

"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/(m²a). 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/(m²a). 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 Lùx (end-of-terrace), Jangster de Lùx (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/(m ² a)]	Q _H (measured *) [kWh/(m ² a)]
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/(m²a) target see Section 2.4.1

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

Cepheus-project		Building type			Construction			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. Supervindows	9. Active solar energy utilisation (x=thermal, PV)	10. Innovative packaged building services	11. Efficient 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, Gothenburg		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	Switzerland, 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

2.4 Quality assurance and evaluation concept

For CEPHEUS, a comprehensive concept for quality assurance and evaluation was planned and implemented. Its elements were:

1. Planning with the Passive House Planning Package (PHPP)

This makes it possible to plan Passive Houses without needing complex simulation techniques. The PHPP comprises sheets of a spreadsheet programme, with which the annual balances (according to EN 832) can be drawn up and building elements and components sized [PHPP 1999]. The PHPP was used to calculate all projects.

2. **Simulations**
Further issues relating to thermal comfort and the effects of different heat distribution systems were addressed using a dynamic simulation programme for the projects in Hannover and Dietzenbach [Feist 1997] [Feist 1993].
3. **Site and manufacturer advice**
Advice sessions at the building sites and with the manufacturers were used to tackle and solve numerous problems such as thermal bridging, condensation water problems and suchlike.
4. **Airtightness testing**
For all buildings, airtightness tests were carried out with a 'blower door' under 50 Pascal positive and negative pressure differences. The n50-value thus determined provides an indicator of airtightness quality.
5. **Thermography**
At some projects, additional thermographic quality testing was carried out.
6. **Initial adjustment of the ventilation systems**
Initial adjustment of the ventilation systems after the first trial run is essential to attaining the desired efficiency.
7. **Measurements conducted to evaluate operation**
A basic measurement programme was agreed for all houses. This concentrates on the measurement parameters requisite to assess the principal goals of the project (space heat requirement, final and primary energy consumption, occupant comfort). In some projects, further measurements were carried out (e.g. solar installation yield, electricity consumption of ventilation systems). In Kassel/D, Nebikon/CH, Rennes/F and the Austrian projects, with funding from national programmes, further parameters were recorded in selected dwelling units or projects (e.g. indoor air moisture and CO₂ content, hot water circulation losses, air velocities and temperature distributions in the ventilation systems, temperatures in the loam wall, etc.).
8. **User information**
At practically all sites, extensive instructions have been provided to users. For the Hannover sub-project, a 'user manual' was developed (Peper 2000a). In Rennes, such a manual will be distributed to the occupants in September.
9. **Social science evaluation**
In Hannover and Kassel (financed with national funding, not within CEPHEUS), social science evaluations have been or are being conducted, notably focussing on the satisfaction of users [Danner 2001] [Hübner 200].

3 Construction, installation and commissioning

(Is not contained in PFR)

4 Operation and results

4.1 Operating history

(Is not contained in PFR)

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 4 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 4: 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. In two of the projects (07-Dornbirn-Knie and 08-Salzburg-Gnigl) the values measured are still good, around 1 h^{-1} , but a better result would be possible by means of carrying out improvement work. In each of the cases where airtightness was far removed from the CEPHEUS target, this was due to systematic errors in airtightness design. CEPHEUS has thus proven 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, as long as rigorous planning of airtightness details (e.g. based upon [Peper 1999a]) has been undertaken.

4.2.2 Energy performance indexes

To gain measured data that is as robust as possible, an extension of the measurement period by a further year would have been expedient. 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. Moreover, a number of

buildings were not yet occupied when the measurements commenced. However, the European Commission did not approve an extension. In most cases the measured data thus had to be extrapolated to a complete year.

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. A precise definition of TFA calculation is given in [Schnieders 2001].

4.2.2.1 Energy balances of the projects

The Passive House concept pursues a loss minimization approach: As the energy balances of the CEPHEUS projects show, 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 example of 02-Kassel proves that a well-functioning Passive House can be realized even without rigorous solar architecture.

4.2.2.2 Energy consumption for space heating

4.2.2.2.1 Measured space heating consumption

Measured 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, in contrast to other components, is the decisive factor for energy consumption over the entire service life of the building.

Some projects achieve roughly the envisaged space heat consumption levels of ca. 15 kWh/(m²a), while others are significantly above this. A comparison of the projects is carried out below, based on computed adjustment of measured values for measurement periods and indoor temperatures.

Differences in space heat consumption levels within the sub-projects are larger than those among sub-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. Pfluger [2001a] analyses this in detail for the 02-Kassel multifamily building.

4.2.2.2.2 Normalized annual consumption levels

It is not purposeful to compare directly the unadjusted measurement results with previously calculated values: In addition to the influence of indoor temperatures, 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 1 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, and with the space heat requirement values calculated in advance (using the PHPP Passive House Planning

Package).

Compared to conventional new build, the CEPHEUS buildings saved 84% space heat over the area-weighted mean. In all houses that were already occupied before measurements began, savings figure more than 80%.

It is further striking that in most cases the measured values are slightly higher than the calculated values. This can be due in the first heating season to, for instance, the drying out of construction material moisture, habituation of users, and the initial fine-tuning of building services systems. For space heat, in particular, it can therefore be expected that performance will be significantly better in the following heating seasons than the data documented here.

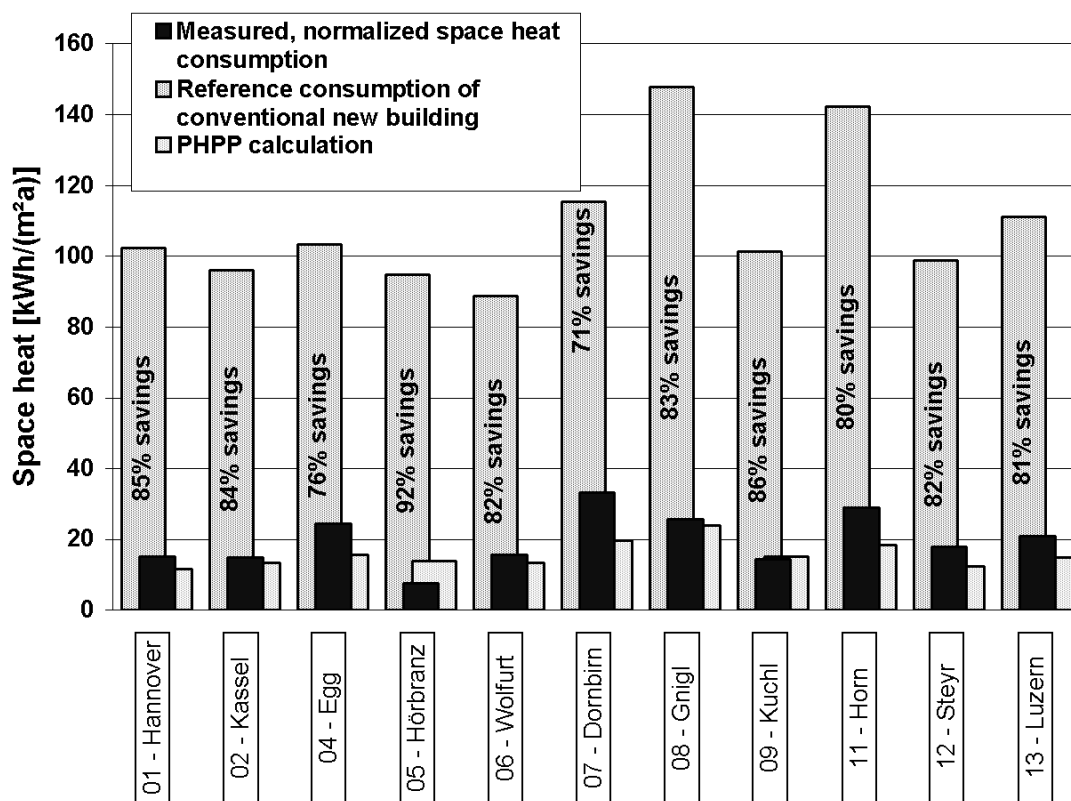


Figure 3: Space heat consumption levels determined by measurements, extrapolated for a whole year and normalized to 20°C indoor temperature ('normalized space heat consumption') compared to the consumption of conventional new buildings and to the values calculated in advance using the PHPP Passive House Planning Package

4.2.2.3 Energy consumption for domestic hot water

As in space heat consumption, the distribution of consumption levels among projects exhibits considerable variance. On average, the (conservatively extrapolated) consumption levels correspond roughly to the typical consumption of dwelling units with comparable occupancy ratios; in the 09-Horn and 11-Horn projects they are even significantly higher. To save primary energy, washing machines with domestic hot water connections were provided for in a number of projects.

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 (cf. also Section 2.3.12).

The 01-Hannover, 02-Kassel and 06-Wolfurt projects exhibit major savings compared to the typical consumption levels of dwellings with the same occupancy ratios. 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. 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.

4.2.2.5 Final and primary energy consumption

This section is concerned with the non-renewable proportions of final and primary energy consumption. The consumption figures stated include the entire electricity consumption for household uses, fans and building services, and electricity for joint uses across several dwelling units. 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. Schnieders [2001] provides details on the determination of consumption levels.

Proceeding from the findings of GEMIS 4.0 [GEMIS], representative primary energy factors were determined and applied uniformly to all projects. 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:

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

Figure 4 provides an overview of the useful, final and primary energy consumption levels of the projects (sites). The figure illustrates 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%. In projects whose values are significantly above the average, the causes were identified within the context of the quality assurance work (cf. also [Schnieders 2001] and the individual sub-project reports).

Low final energy consumption levels were achieved above all where heat pump systems were used for heating. Because of the low consumption levels achieved in the Passive House, the heat distribution losses gain relative importance in the breakdown of final

energy consumption. For primary energy usage, which is the decisive environmental aspect, household electricity consumption has particular importance. The influence of this is particularly marked in projects with high occupancy ratios. Heat production from wood pellets has a particularly positive impact upon primary energy consumption.

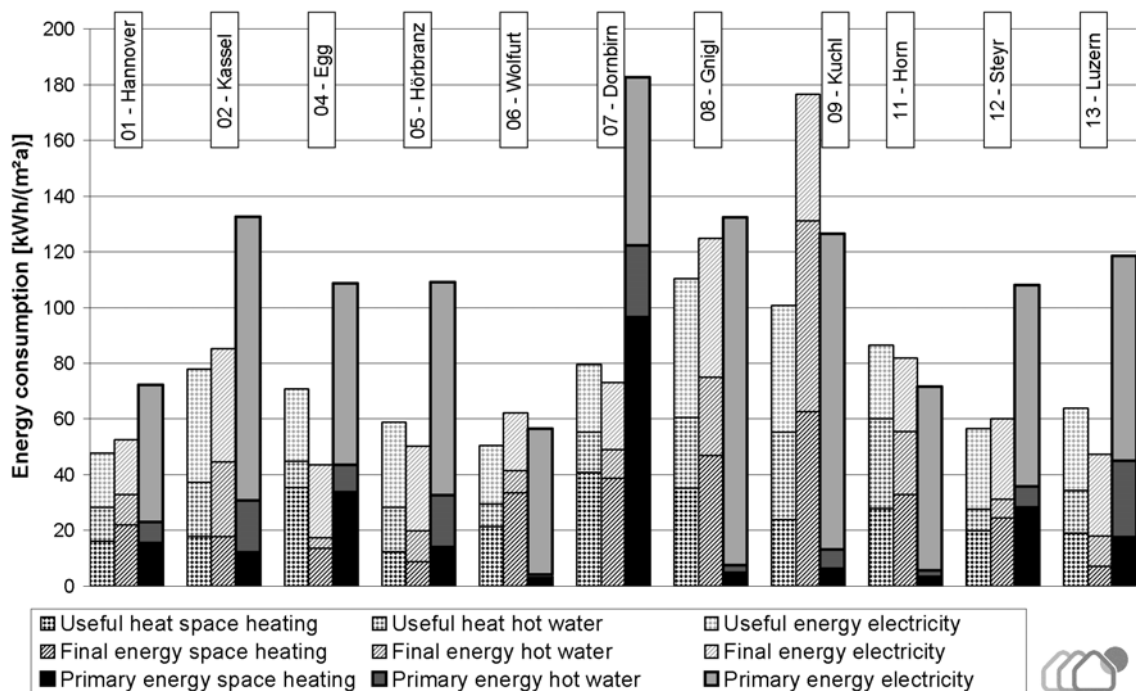


Figure 4: Comparison of useful, final and primary energy consumption for space heat, domestic hot water and all electricity applications in the houses. For each project, the cumulative bar at the left represents useful energy consumption, that in the middle final energy and that on the right primary energy consumption.

4.2.2.6 Heat loads

The downward leap in costs when the Passive House standard is reached occurs because the separate heat distribution system can be dispensed with: The max. ca. 10 W/m² heat load conveyable by means of the supply air which is required in any case suffices to keep the house warm.

The measurement results show that in general the maximum daily mean heat loads that were to be expected upon the basis of prior planning were indeed complied with. In many projects, a substantial proportion of the heat losses can be covered by solar gains.

4.2.3 Achievement of a zero CO₂ 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 CO₂ 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.

4.2.4 Maintenance of conditions of user comfort

4.2.4.1 Indoor temperatures in winter

The measurements show that in all CEPHEUS sub-projects the mean indoor temperature over all occupied zones and the whole measurement period was above 20°C from November to February. Occupants typically set temperatures between 21 and 22°C; the range of the occupied houses is, however, from 17 to 25°C. 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, it is evidently also desired.

Even in the houses with pure supplementary heating of supply air, 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.

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.

Mean indoor temperatures in these projects from May to August were 21.9°C and 23.6°C, respectively. Hourly means of 27°C are only exceeded in exceptional cases in some of the houses. 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 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 supply air blown into the room from a vent close to the ceiling in the internal wall. The measurements of air velocities and temperature stratification yielded exceedingly good results.

The results of the measurements were 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. A subsequent parameter study showed that, under Central European climatic conditions, a high level of indoor comfort can be ensured with supply air heating. For this, good window quality is critical.

4.2.4.4 Subjective assessment of comfort by occupants

The occupant survey conducted in Hannover has shown a very high level of satisfaction with the indoor climate, both in winter and summer. The indoor air quality and the ventilation system are also rated very positively. User satisfaction rose in the second heating season still further compared to the first heating season, e.g. concerning the ventilation system from 54% to 96%.

4.2.5 User acceptance

The high level of user acceptance is reflected in the surveys carried out in Hannover in the high level of fulfilment of expectations among occupants, and in Kassel in the distinct willingness of tenants to recommend Passive Houses to others. At both locations it has been found that the experience made in the first heating season has further enhanced the positive assessment among users.

4.3 Success of the project

The “**Cost Efficient Passive Houses as EUropean Standards**” 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.

4.4 Operating costs

A distinction is made between (poss.) additional operating costs for the passive house-specific components (e.g. ventilator, filter) and the energy costs for the provision of heat (heating and hot water).

The evaluation of 12 projects shows – a conservative estimate – on average only very low additional operating costs of 37 euro cents/(m²a) or 36 euros/per/residential unit. This is among others thanks to the new generation of ventilation systems suitable for passive houses with high power efficiency. Due to reduced costs compared with the reference case (lower demand rate for district heating, no costs for chimney sweeps) there are even savings in certain cases.

The high savings with thermal heat consumption of the passive houses are noticed with the variable energy costs for heating supply (without taking into account service and supply costs). These costs are reduced on average by 74% from DM 616/per/residential unit to 162 euros.

The total operating costs are reduced as an average of the 12 projects which can be evaluated so far by 68%.

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

Compared to an otherwise identical building that merely complies with the minimum local statutory requirements, the higher insulation, window and ventilation system standards of a Passive House lead to extra initial investment costs, but on the other hand also to investment cost savings, e.g. in the heating system or, in the case of 08-Gnigl/A, in noise insulation.

The data evaluated for 12 projects indicated extra investment costs ranging between 0 Euro/m² in 08-Gnigl/A and 337 Euro/m² (17%) in 07-Dornbirn – for the latter, it needs to be noted that this project also has very high specific overall building costs at 1,939 DM/m² (the average is 1,143 Euro/m²). On average over 12 projects, the specific extra investment cost is 91 DM/m² or 8% of total building cost.

Taking the operating cost savings into consideration (4.4), this results in a static payback period averaging 21 years. However, in this type of analysis the future energy price development introduces a relatively high degree of uncertainty.

A better measure for economic appraisal is provided by determining the costs of the energy conserved. For this, the extra investment for the efficiency technology and the solar thermal installations is levelized across 25 years of service life at 4% real interest; to this is added the additional operating costs of the Passive House components. By dividing the annual costs thus determined by the annual fuel savings, we receive a sum per kilowatt-hour saved. This ratio is well suited for comparisons with the present or potential future costs of energy supply.

The cost of the kWh heat saved in Passive Houses determined in this way averages across the 12 projects 6.2 EuroCent/kWh. This compares with present reference costs of final energy averaging 5.1 EuroCent/kWh. Compared to the cost price of solar thermal heat, which is currently 10 to 15 EuroCent/kWh, this is a very favourable value – and all the more so with regard to potential energy price increases across the long service life of buildings.

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

4.7 Environmental impacts

Implications for the environment

The reduction of the energy consumption for room heat is a significant contribution for achieving the targets in protecting the climate. This accounts for around 75% of the whole end energy consumption of private households and of approx. 40% of end energy consumption of all sectors in Central Europe. With the passive house concept it has been possible already to reduce the primary energy consumption for room heat compared with new buildings in accordance with standards laid down by law by more than 80% and the total primary energy consumption for heating, hot water and household electricity by 57% in the first heating period of the evaluated projects.

Figure 5: Comparison of the measured consumption values of all CEPHEUS projects (average areal weight) with the corresponding reference consumption.

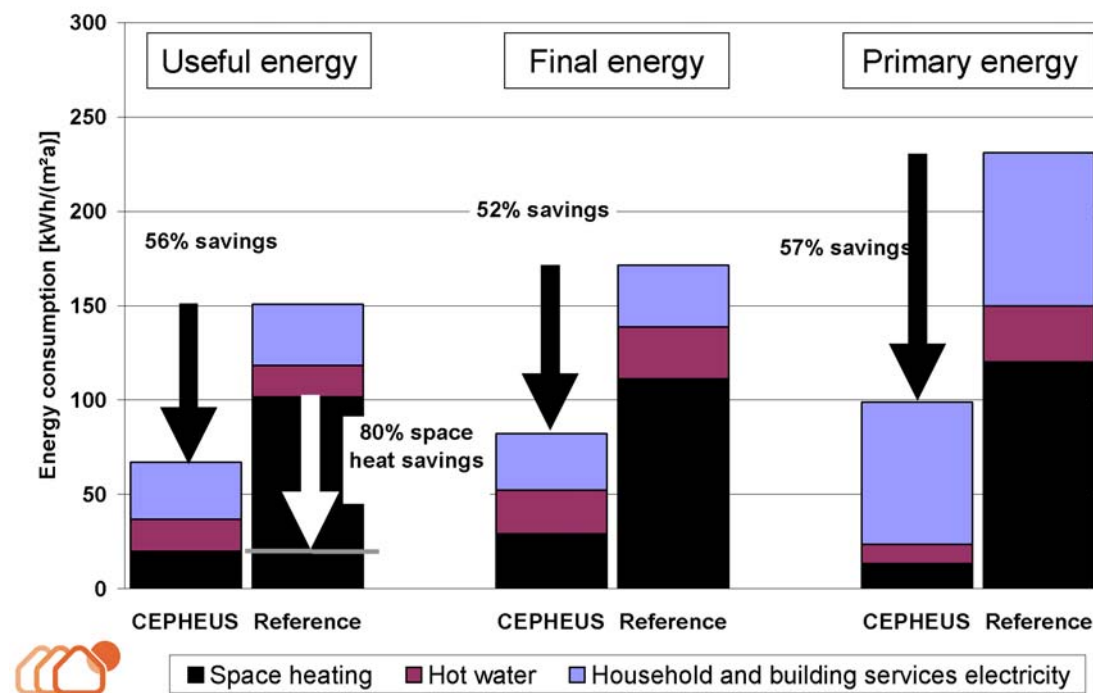


Figure 5: Comparison of the measured consumption levels of all CEPHEUS projects (floor-area-weighted mean) with the corresponding reference consumption levels

As demonstrated based on the example project 01-Hanover/D (see 4.2.3), the passive house concept offers in addition to this an excellent basis for climate-neutral living solutions, which take everything into account, at a low additional cost.

The concept also improves the interior air quality and sound insulation. All of these positive implications for the environment are associated with increased living comfort and less risk of structural damages.

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 $U_w \leq 0.8 \text{ W}/(\text{m}^2\text{K})$, 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

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9 Appendices

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