The Triple-E House — Energy Efficient, Economical, and Ecological

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This paper takes a comprehensive look at the parameters of environmentally concerned home building:

1. Energy calculations include space heating, domestic hot water and household electricity with *primary* energy use as the measure of energy efficiency.
2. Design, construction details, and supply systems are planned together.
3. Components are chosen in an *economical relation* according to the desired standard of living, resource-efficiency, durability and changeability.

In regard to these principles, a building system for economical *and* ecological low-energy (low-e) houses was developed. This TRIPLE-E-HOUSE requires only 40% of primary energy for a typical German low-e-house that only takes into account reductions in rates of space heating per m^2 floor area. Several prototypes have been built since 1988 to show that this goal can be reached by state-of-the-art components at a cost level that does not differ significantly from average new houses. The essential features are:

1. Very compact building shape.
2. High insulation standard, minimized thermal bridges, air-tightening (improved balloon frame system).
3. Large scale, double pane low-emissivity-glazing.
4. Exhaust air-system with low electrical consumption.
5. Quick-response heating system with condensing furnace.
6. Water saving faucets and showerheads. Solar collectors for domestic hot water.
7. Consideration of efficient electrical appliances in design process.

In addition to reach the ecological aims, the “TRIPLE-E-HOUSE” includes: water saving toilets and a rainwater cistern; choice of building materials according to environmental compatibility; consideration for future demolition: the recyclability, or better, the re-usability of materials.

Introduction

Low-e-houses have been tested in Europe since the late seventies especially in Scandinavian countries. In West-Germany first attempts in this direction started about the 2nd half of the eighties. In the last three years we met precarious discussions about new building regulations (WVO, Warmeschutzverordnung) with which low-e-houses should become the general standard for new buildings in Germany (BM BAU 1992, Ehm 1993). But the tug-of-war of different lobbies has now created a poor compromise: the requirements of the new standard that will come into force in 1995 are not stronger than those the Scandinavian countries already had 20 years ago (Adamson et al. 1986; IWU 1992). Probably for political image reasons the German government still tries to label this as low-e-standards. But in its final decision the “Bundesrat” (2nd legislative Chamber in Germany) cleared up that a further reduction of the space heating demand (about 30% compared to the new decree) will be necessary to reach the low-e goal. The “Bundesrat” suggested to begin this step in 1999 (Bundesrat 1993).

On the other hand several German states started promotion programs for low-e-houses in the last years. Their requirements are similar to those we know from e.g., the Nordic countries and lead to a heating energy demand per m^2 living area up to 0.02 kWh/K/d (Feist 1993). Taking into account the average German climate (3,500 Kelvin-degree-days) low-e houses in Germany should not need more than 70 kWh/m^2/yr for heating.

The Aims of the Triple-E-House

If we want to reach a comprehensive understanding of energy efficiency in housebuilding we have to remember that the main factor for CO_2-emissions is the annual *primary* energy consumption. Thus all data in Figure 1 are given in units of primary energy.

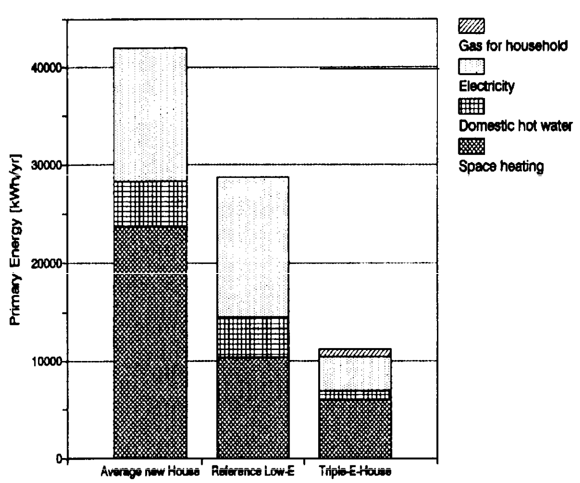

Figure 1. Annual Primary Energy Requirements for Different Types of German Houses

The concept of the TRIPLE-E-HOUSE considers space-heating as well as domestic hot water supply and electricity use. Taking electricity into account may lead to relevant changes of strategies for optimizing energy-efficiency *and* economy. Furthermore, available and reliable solar DHW-systems can significantly reduce the primary energy need.

Being aware of these criteria, the TRIPLE-E-HOUSE was developed to find a new approach to energy-efficient housing. Compared to a typical German low-e-house 19% of the primary energy requirements can be saved by a compact house design and the thermal improvements of a modern wood construction system. Water and electricity saving technologies and a solar collector for DHW lead to a further reduction of 43%. The total annual primary energy consumption of a four-person household in the TRIPLE-E-HOUSE is calculated to be about 19000 kWh lower than in the reference low-e-building.

Building Philosophy and Building costs

Building low-e houses in Germany is usually carried out in the following way: building as usual plus improvements with additional insulation and air-tightening, low-emissivity-glazing, mechanical ventilation and improved furnaces. This means extra costs from $10,000 to $20,000 for a single family house (about 5 to 10% of the total cost for a 140 m^2 house) (Eicke and Feist 1990; Lehringer 1992). Whether you think that this is very much, depends on your point of view. Compared to the expensive experiments with passive solar design in the eighties, the additional costs seem rather moderate. Looking at the tightly fitting building budget of most home owners and the high interest rates for every additional expense, the possibilities for extra investments could become very slim. Our conclusion, drawn from advising and planning talks, is simple: there is no use in trying to persuade people by calculating long term savings (on inevitably uncertain data) when they know for sure that every extra DM (or $) will cost 7-8% per year (and this for at least two decades in the future). On the other hand, most people have a rather long list of wishes (including many "ecological" topics) they want to fulfill when building their new home. The goal from the first moment of the planning process should be to design a house with as much ecological "extras" as possible, *without extra costs.* It is the real challenge for any concerned architect to help owners to find a cost-neutral way to an energy-efficient and environmental space for their joy of life. The TRIPLE-E-HOUSE concept was developed with this ambition and it has been built at costs which do not differ significantly from those of average new houses in Germany. What could be the way to make this possible?

When analyzing the present construction costs and future consumption prices, we have defined three different groups of investments which have to be looked at, while calculating housing concepts.

1. Special technologies, such as mechanical ventilation, solar power systems, condensing furnaces and rainwater cistern need rather high investments while their cost saving potential is relatively low.

2. At moderately higher costs we can get a much better thermal insulation and airtightness with substantial corresponding consumption savings.

3. Lower construction costs *and* lower consumption costs can be achieved by a compact building shape, smaller floor area and by replacing the basement by an extension at ground level.

Table 1. Comparison of House Data

	Unit	Reference Low-e-house	Triple-e-house
Floor area	[m^2]	140	115
Building volume (outside)	[m^3]	508	381
Surface envelope (outside)	[m^2]	403	309
Window/Floor-area	[—]	23%	33%
Storeys	[—]	1 1/2	1 1/2*
U-values**			
Wall	[W/m^2k]	0.34	0.21
Roof	[W/m^2k]	0.29	0.16
Ground	[W/m^2k]	0.50	0.34
Windows	[W/m^2k]	1.52	1.52
Heatlosses	[W/k]	215	149
—per m^2 floor area (-12°C)	[W/m^2]	46	39
Primary energy for spaceheating***	[kWh/yr]	10,370	6,070
Net-heating energy	[kWh/yr]	9,370	5,330
—per m^2 floor area	[$kWh/yr/m^2$]	67	46
Heating system	Condensing, gas-fired furnace		
Ventilation	Mechanical exhaust ventilation system		
Domestic hot water		Central supply by furnace and 100 l tank	Solar system 300 l tank backup furnace
Consumption (at 45°C)	[l/d]	200	140
End-energy for DHW	[kWh/yr]	3,960	920
Electricity for household appliances, pumps, and vents (end-energy)	[kWh/yr]	4,750	1,960

* Although the shape of the house looks like a 2-storey building the 2nd floor is not a "full storey" according to German building codes. Because the height above less than 2/3 of the 2nd floor area is higher than 2.30 m it is allowed to build it in areas where only houses with one full storey are permitted.

** U-values include thermal bridges

*** Calculated mean internal gains: 610 W (Ref.-low-e) and 400 W (Triple E)

From this economical point of view we recommend decisions like this: Use the large possible savings of group (3) to make at first (2) and then (1) affordable! The proposals of the TRIPLE-E-HOUSE design for this way of thinking and acting are as following:

The active heated core of the house has a very compact outline: nearly square shaped floorplan, 1 and 1/2 storeys with a high jamb wall (1.60 m) and a roof pitch angle of 22.50. So the 2nd floor can be used as a full storey up to the ridge. But the heat exchanging surface is more than 10% smaller than in a typical German dormer house with 450 slope. This reduces the heat losses and makes a difference in building costs of $12,000).[1]

A service extension as an outbuilding on the north side replaces an expensive basement and saves at least $12,000.[2] Friends of non-electric cooling and cellaring will find that a small natural cellar beneath the service extension is included in this calculation. Avoiding a basement also eliminates additional heat losses which are caused by the basement staircase.

The design of the basic version of the TRIPLE-E-HOUSE also dares to reduce dwelling area from average 140 to 115 m^2. An optimized floorplan reduces lost spaces (corridors, stairways etc.). Generously enlarged dimensions of windows and glazed areas (38 m^2 instead of typically 26 m^2 for a house of this size) create bright and

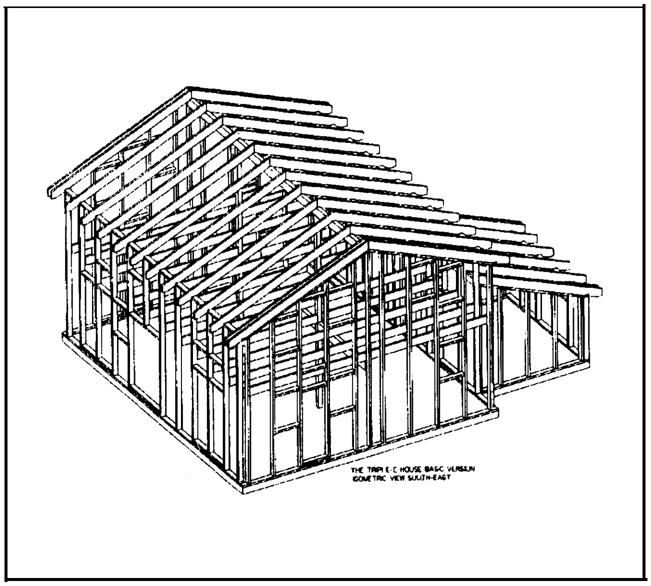

Figure 2. Loadbearing Timber Structure of the TRIPLE-E-HOUSE

wide looking rooms, avoid any feeling of narrowness, and enable to experience a "small-is-beautiful" life. If rational facts help to push forward such a decision: The net reduction of building costs of the smaller but brighter home can be assumed by $15,000.[1] The high standard of modern glazing ($U = 1.3\ W/m^2K$) allows to use windows as this kind of architectural tool without being anxious about too much negative effects on the energy balance although the typical mid-European climate does not offer much sunshine in the heating season of a low-e house.

In total these measures for a more compact building decrease the annual primary energy demand by 2,200 kWh (see Table 2, step 1 + 2). These savings do not need any venture investment. They decrease the ruining costs of the houseowners in two different ways—they cut the energy bill, and bring down the loans from the bank. Thus, these measures allow to spend the saved money for further improvements of the thermal performance of the building and the service systems which will be described in the following chapters.

A Modern Wood Frame Construction

Most houses in Germany are built from brickwork. But in the last two decades the use of wood construction has increased significantly. Beside the traditional post-and-beam structures, stud-wall framing with stiffening board planking is becoming the most important method on market. Initially-in the early eighties—the German Association of Carpenters adapted the North-American type of studwall framing to the German DIN-Standards. At the federal promotion program "Cost-efficient Building 1982-1987" some innovative architects showed that using this rather simple technology could lower the prices per m^2 of dwelling area up to 20%, compared to conventional masonry houses.

Related to the typical German wall (30 cm light weight bricks), a wooden stud-wall construction reaches 10-20% better U-values with only 12 cm insulated cavities. But for using this system in low-e constructions, some thermally relevant details have to be improved.

Reducing Thermal Bridges

It is a widely spread opinion that thermal bridges are a minor problem in wood constructions. Calculating the mean U-value of a typical German timber frame system (grid dimension: e = 62.5 cm, width of the studs: b = 6 cm) according to the standard (DIN 4108, wood partition = b/e) leads to a result which is only 16% worse than the U-value of the insulated space between the studs. But in practice this stud-wall construction has—compared to the b/e-calculation-a lot of additional studs, head and sole runners, trimmings and lintels. If we had tried to build the design of the TRIPLE-E-HOUSE this way, the partition of uninsulated wood in the external walls could have reached about 35% ! This would have meant a U_m-Value of only 0.47 [W/m^{2}K], nearly 60% higher than in the undisturbed area (see Figure 4). To achieve a U-Value of 0.25 [W/m^{2}K] (often recommended as upper level for low-e-buildings), an insulation and stud thickness of more than 25 cm would be necessary because of the thermal bridges.

The system we finally chose, is still made of solid wooden studs with 6 cm width and a stiffening board (plywood or OSB, 15,5 mm). But the part of solid wood per m^2 could be reduced to only 17% by the following measures:

1. The modular grid is 81.5 cm instead of 62.5 cm. The clear width of 75.5 cm allows to insert windows in pleasant proportions, without additional trimming and framing (EUZ 1992).

2. The modular unit of the construction is identical with the designing unit. This requires some more planning discipline from the architect but avoids a lot of extra studs .

3. The basic static system is similar to the American balloon framing. This saves up to 5 plates which normally would have been used in the junction of the partition ceiling (platform framing). Only one sole and one top plate are necessary (see Figure 2 and 5).

4. The additional studs (house corners, element joints, load transmission) have been reduced to minimum static necessity. In total the structural system is of

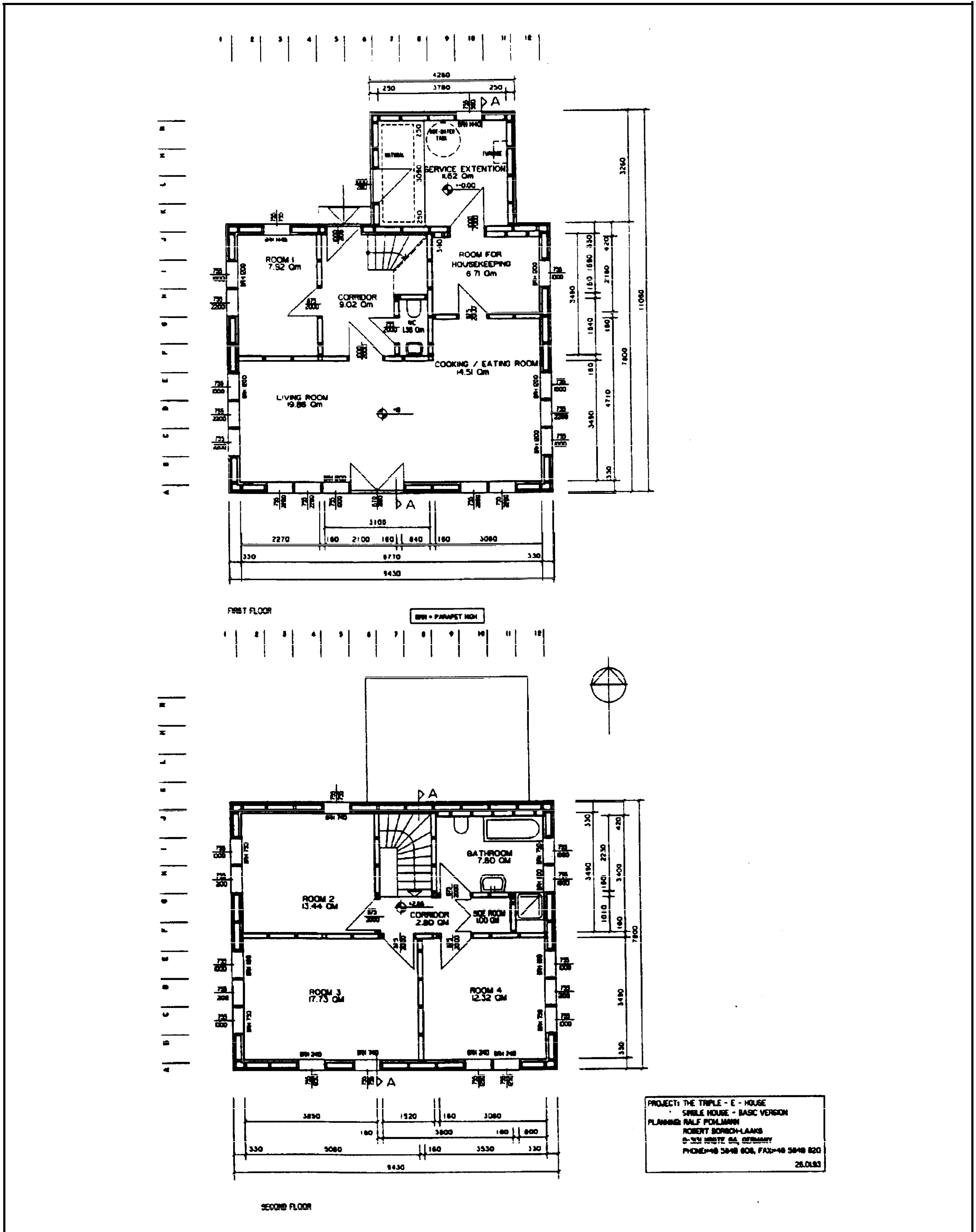

Figure 3. Groundplan for First and Second Floor

Table 2. Three Steps to Reduce Heating Energy Requirements*

	Primary energy consumption for heating per year	**Energy savings per year**
Reference low-e-house (low jamb wall, 45° roof slope, rectangular floorplan, floor area 140 m^2, window area 32 m^2)	10,366 kWh	—
1st step: Compact shape (Changes: high jamb wall, 22.5° roof slope, nearly square shape floorplan)	9,372 kWh	994 kWh
2nd step: Small and bright design (Shape like 1st step. Changes: reduced floor area, 115 m^2, but larger window area, 38 m^2)	8,016 kWh	1,356 kWh
3rd step: Thermal improvements (Shape like 2nd step. Changes: reduced thermal bridges, additional insulation, improved airtightness)	5,060 kWh	2,956 kWh

* All amounts are calculated with a mean internal gain load of 610 W, because of comparability to the reference low-e-house. This is—according to the usable part of the additional solar gains in step 2 and 3— a worse case study. The heating demand of the "real" TRIPLE-E-HOUSE is about 20% higher than "3rd step" in this table because of lower consumption of household electricity (see Table 1).

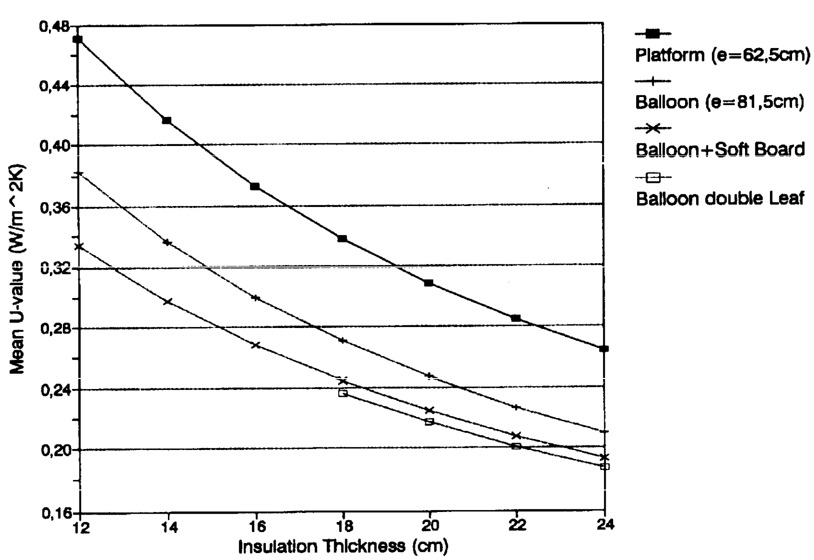

Figure 4. Mean U-Value and Insulation Thickness for Different German Timber Framing Systems

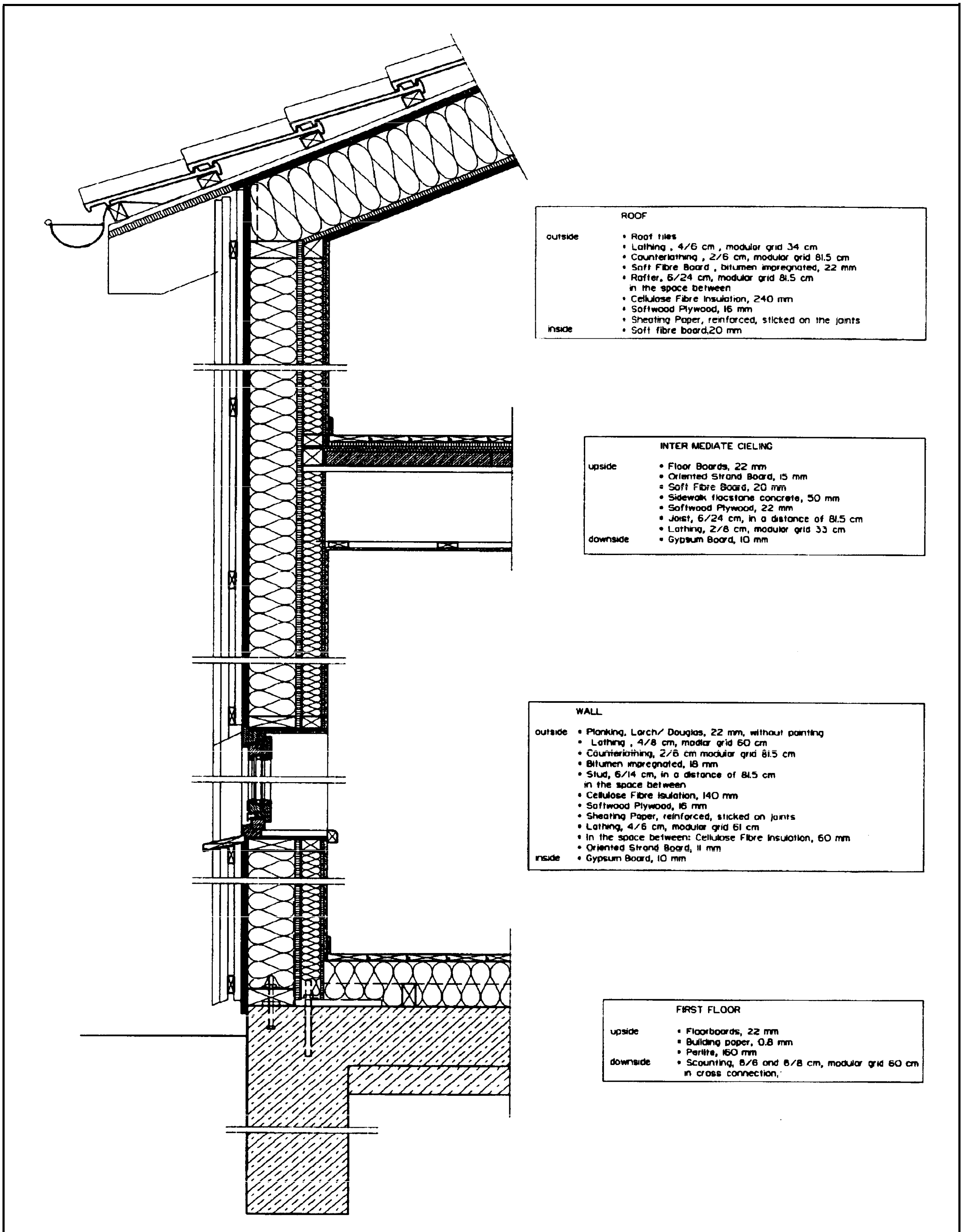

Figure 5. Vertical Section of the TRIPLE-E-HOUSE

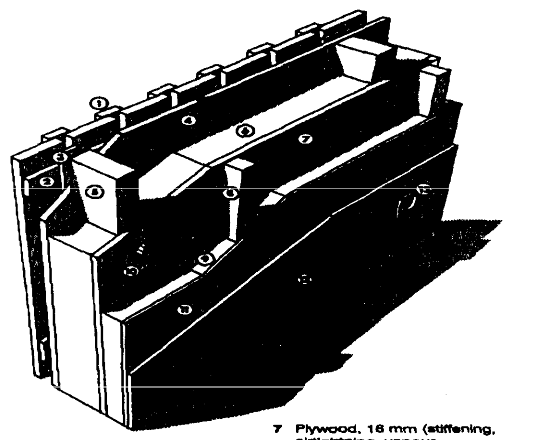

Figure 6. The Wall of the TRIPLE-E-HOUSE

course designed according to the high security level of the German stud-wall standard (DIN 1052).

It is evident that this construction method reduces costs in a double way: On the one hand: less use of timber saves money for material and labour. On the other hand, fewer thermal bridges allow to reach *the same U-value* with ca. 6 cm less insulation and wall thickness (see Figure 4).

Improved Air-Tightening Technique

There is a completely new idea in the wood construction system we used: The stiffening panel is fastened to the *inside* of the loadbearing structure. So all connections between roof, wall, and ceiling plates can be done in a simple way by circular beams on the inside (see Figure 5). This makes it possible to fix the suspension of the floor joists inside of the paneling without penetration points. The airtightness of the building envelope (a big problem in many of the German light built dwellings) can be made in a rather simple way. This does not only prevent unwelcome heat losses, but it is also a secure protection against moisture damage by vapor convection.[3] Hereby different measures are cooperating, securing against and completing each other:

1. Avoiding problematic points while planning the details (e.g., penetrations or changing of the position of the tightening layer between inside and outside of the structure). The windows get their basic sealing by an overlapping fold surrounding the frame.

2. Basic tightening by undestroyable board material at the most effective place (inside of the studs and rafters) with mechanically (screwed) and therefore durably fixed connections.

3. The remaining joints at the unit junctions and edges and between window frame and studs are taped with strips of reinforced building paper of high tensile strength, using a durable glue.

4. Blower door tests have shown that drafts at "forgotten" spots can also be eliminated by the relatively high airflow resistance of the applied cellulose fiber insulation. Its treatment ("in situ" insulation process, joint free blown into the ready cavity) protects against convective loops between warm and cold side of the structure.

In the daily building practice the advantage of these easy to handle air-tightening measures has been proved. Taping of the joints can be done by do-it-yourself work of the owners after a short instruction. Blower door testing is a self-evident part of supervision in this construction system. The test results have always been obviously lower than the requirements of the Swedish building code (in average about 50%) (Dorschky and Walther 1992).

More Improvements for a Long Durability

The advantages of the stud-wall system we used do not increase the building costs. So there is still money left for further improvements in the TRIPLE-E-HOUSE:

1. On the outside of studs and rafters, a soft fiber board (18-22 rein, bitumen impregnated) gives a further 10% reduction of the Urn-value (see Figure 4). It provides a reliable extra protection of wood and insulation against humidity, while shell work is still going on. It acts as exterior surface for the blown-in insulation and keeps draft away by a circular tongue and groove joint.

2. On the inner side of the plywood boards a thick lathing (with a 2nd layer of 6 cm insulation in between) carries the internal facing. These laths have a different modular grid, providing a slightly further reduction of thermal bridges. The much more important reason for this double leaf construction is to create a space for service installations (electrical wires, outlets, plumbing etc.) without any danger to hurt the airtightness level (plywood + taping). Unavoidable penetrations for the ventilation system, outside lights, supply lines to service extension, etc. can be effectively taped inside this extra space where they are concealed. Moreover static load-bearing

elements such as lintels, supports for ceiling joists and for the ridge purlin can be hidden in there.

The internal mounting on the roof slope is much easier designed because special measures for wiring are not required. Therefore, we use a 20 mm soft board as sheathing directly fixed on the (taped) plywood surface, It can be painted or covered with a wall paper. Because of its low heat conductivity, it has also some effect on reducing the thermal bridges of the rafters. By this, the TRIPLE-E-HOUSES' roof slope gets a total insulation thickness of 28 cm.

A conclusive view at the construction system shows that its low U-values (0.16 - 0.21 W/m^2K thermal bridges included!) are the most important factor for the very low heating energy demand of the TRIPLE-E-HOUSE (below 50 $kWh/m^2/yr$). These thermal improvements save another 3,000 kwh primary energy (see Table 2). The construction costs are only about $6,000 higher than those for the same stud-wall with only one layer of insulation between 14 cm studs and 16 cm rafters (see Reference building).

Service Systems: Mechanical and Ecological

There is no use to complain about a simple truth: efficient service systems save some amount of energy and water, but usually they do not save enough money to pay the interest rates for their installation costs (Borsch-Laaks et al. 1993/2). But, on the other hand, there are many reasons to install them. Some examples: A mechanical ventilation improves the indoor air quality and-if it is designed properly–convenience and thermal comfort. If you use a rainwater cistern for flushing your toilets rainy days won't drag you down as much as before. And what can be more exciting on a clear winterday than looking at the thermometer of your solar collector, reading 50°C— and then starting your dishwashing. So, do it, invest in an ecological future, not because of sophisticated calculations of pay-back-time, but because it makes at least as much fun as a brand new sportscar (and it is much less expensive).

But there is a restriction to be made. Spending money on ecological service mechanics should not lead to a lack of money for the basic things which decrease the heat losses. Technical equipment has much shorter lifecycles than, for instance, an outer wall. Improvements of the supply systems sometimes are easy to be installed later, when the next replacement is necessary. Thus, following the TRIPLE-E-HOUSE concept, we should do our energy conservation homework before we go to the hightech playground. But if we follow the suggestions we made above to reduce building costs by a compact design, then there is enough money left to install some energy and water efficient mechanical service systems.

Four State-of-the-Art Services

Our choice of components is rather conservative and limited to state-of-the-art appliances that have proved their reliability for at least 10 years and which are known by some of the local craftsmen:

1. Exhaust ventilation system for bath, water closet (WC) and kitchen with a central box fan and air inlets in living and sleeping rooms (optional with automatic humidity control). Estimated reduction of ventilation heat losses 3,300 kwh/yr (EUZ 1992). Extra cost: ca. $3,000-$4,000.3

2. Condensing gas furnace (optional with cushion storage) with microprocessor control. Improvement of the annual efficiency: 5-8%. Extra cost: ca. $1,650-$3,300.3

3. 5 m^2 solar collector with 3001 well insulated tank. 60% covering of the annual domestic hot water need. Primary energy savings: 3,100 kwh/yr. Additional costs: $7,300.[3]

4. 6 m^3 rainwater cistern with compressor pump. Saves about 38,000 l/yr for toilet flushing, (car) cleaning, and garden irrigation. Costs: $3,600.3

These four alternative service systems lead to extra costs from $15,500-$18,500. This is about the same amount that we have saved by designing a compact building shape.

Conservation First!

These investments into an environmental life style only make sense, when we look for the prior rule "conservation-first!", also in the field of service technologies. This means:

1. Pay attention for a good air-tightening and check it by blower door testing while installing a mechanical ventilation. Penetration of ducts and air inlets should be mounted tightly, otherwise you lose control of the airflow.

2. Think of distribution losses in the pipe grid also inside the heated area. Scandinavian research has shown that a high thermal output of uninsulated interior distribution lines impairs the ability of the system to react property to the actual changes of the heating load. This can lead to unacceptable high room temperatures and an increasing of the mean heating load up to

50%(!) (Egon Lange in Adamson et al. 1986). An accurate planning and calculating of the pipe system, the thermostatic valves and their pre-setting and a supervised adjusting of the whole system is urgently recommended. Low-e-houses react much stronger and quicker to changes of internal or passive solar loads. Only a very sensitive and quick responding heating system can use a maximum part of these free sources. Therefore, the choice of radiators is also a question of energy efficiency. The TRIPLE-E-HOUSE uses one layer plain radiators with low thermal mass as a satisfying compromise between quickness, cost and design.

3. Looking at the domestic hot and cold water supply, the environmental sources (solar and rain) will only get a chance to deliver a major part of the need when water saving measures have been done before. Low flow faucets and showerheads. toilets with 61 Der flush and stop-and-go function do their job with 30-50% less water use. Installing this equipment is much cheaper than to build larger solar and rain collectors. Thus conservation is the basis for getting the alternative sources down to a reasonable cost level.

There is another spot where cost and energy efficiency can meet. The high insulation standard of walls and windows make the uncomfortably cold air drop on freezing winterdays an experience of the past. From the thermal comfort view point it is now allowed to place radiators nearly everywhere in the rooms (see Erhom et al. 1986). In the TRIPLE-E-HOUSE the radiators are placed on internal walls. This helps to reduce installation costs (shorter lines), thermal losses and electric energy for the circulation.

It is even more important to think about transportation energy, when air has to be moved. It is urgently recommended to place all rooms that need mechanical services, in the same comer of the house and situate the service room next to it. Reduction of installation costs and energy consumption is the profit for this designing discipline. This concern applies to all lining, but especially to the ventilation. In the TRIPLE-E-HOUSE the ducts are as short as possible, and have low friction losses. By this, the smallest available fans are well suiting for a comfortable airflow.

Mostly Forgotten: Electrical Efficiency

Energy conservation in the field of electrical household appliances is usually not considered as a topic of building design. But a look at the energy use of a typical low-e-house (see Figures 1 and 7) evidently shows that electricity is the dominating factor of primary energy use. There are two reasons for that:

In Germany, most of the current is produced in condensation power plants with an overall efficiency of 33%. This means-turned into positive thinking-that every kWh that is saved by the user has a threefold effect on the other side. And this should be the scale for saving our limited resources and for being careful with our environment. But even if we only refer to end-use electrical energy, the standard amount of 4,000-5,000 kwh/yr (4 person household) is approximately as high as the total space heating energy demand for the TRIPLE-E-HOUSE.

In the services chapter we already insisted that some sophisticated planning can keep the additional power for fans and pumps on a low level. But this is only the tip of the iceberg. We think, in contrary to the customary opinion, that house design can provide many improvements of the efficiency of the household. Some examples from the TRIPLE-E-DESIGN:

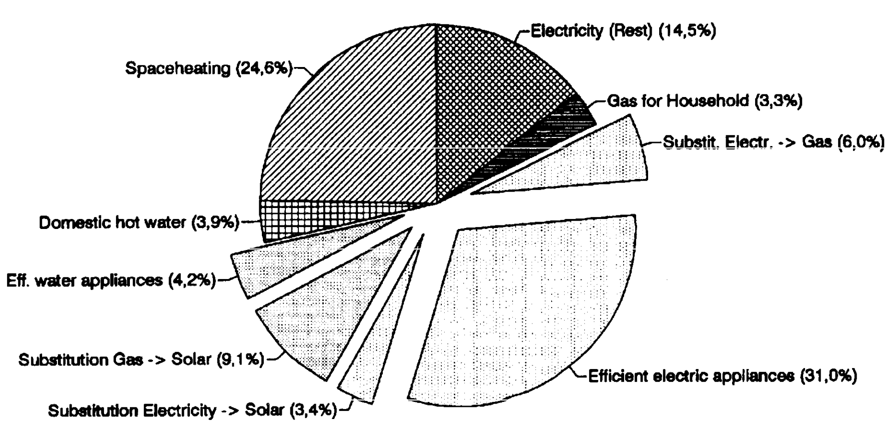

Figure 7. Primary Energy Savings by Efficient Service Systems and Remaining Demand (100% = 24.500 kWh/hr)

1. The generous dimensions of window areas (also for the rooms on the northern side of the house) replace artificial lighting with daylighting.

2. For washing machine and dishwasher a connection to the (mainly solar) hot water system is prepared.

3. A gas junction in the kitchen allows cooking and baking with direct use of primary energy.

4. A freezer, situated in the cool service extension nearby the kitchen needs 20-30% less than the same equipment in the heated area.

Moreover electricity saving depends on the availability of better household appliances. An actual inquiry of the market gives some surprising results (Michael 1993):

The best devices need 40-60% less electricity and water than the average ones for the same service. A comprehensive look at the economy of household appliances shows that the consumption costs are much more important than the differences in their purchase prices. Choosing energy and water efficient products can save several thousands(!) of $ in the devices' lifetime. Although they are usually more expensive furniture-built-in cooling devices are mostly much worse than stand-alone ones ("white products").

Getting the right information at the right time may help the owners to find a solution for their new kitchen that doubles the efficiency, but does not cost more than an all-built-in design with worse equipment. Figure 7 shows that decisions according to electrical appliances concern to more than 60% of the primary energy need of a low-e-house. Therefore, we offer advice to every owner who wants an energy concerned choice of equipment (and lighting too). Experience shows that it is really possible to get a 75% lower electricity consumption without being forced to renounce reasonable electrical devices.

Environmental Choice of Materials

The third "E" of the TRIPLE-E-HOUSE means "ecological" in a comprehensive sense: It means choice of building materials and the way of their treatment should be done according to environmental compatibility. These criteria forced us to think over aspects like:

1. Primary energy need for manufacturing of the materials.
2. Use of limited, non-renewable raw materials.
3 Waste disposal, recyclability, reusability.
4. Influences on in-door air quality and environment.

It is very difficult to get to conclusive decisions in this field. Energy balances can be calculated easily. But research on the *quantitative* ecological balances for building materials including all steps from beginning (hauling of the raw materials) till the end (waste disposal) is just even starting. Therefore only a few of the decisions we had to make could be assured with calculations based on scientific data (e. g., primary energy use for the construction). In all other cases, environmentally concerned, qualitative assumptions were the only things we could do. The following examples may show the direction of the way we try to go:

1. The primary energy use for the building materials in 1 m^2 outer wall of the TRIPLE-E-HOUSE is 50-70% lower than in masonry constructions with the same U-value (see Table 3).[5]

2, Most materials in shell work and finish work are made from grown-again raw materials (especially wood), from remainder of foresting and timber-cuffing (soft fiber boards, Oriented Strand Boards) or from recycling processes (cellulose fiber insulation, building papers, and gypsum boards).

3. The special kind of on all side planked but diffusion-open wood construction makes it possible to avoid preservatives for nearly all of the timber (Schulze 1992). The interior surfaces can be coated with solvent-free natural paints.

4. The use of plastic film as vapour barrier is unnecessary because of a condensation-free sequence of panels with graduated vapour transmissivity (EUZ 1992).

5. Instead of possibly harmful isocyanurate foam, impregnated polyurethane and buthyl-rubber tapes air-tightning is done with jute felts, reinforced building papers and solvent-free latex or acrylic glue.

6. In the service systems, environmental compatible, chloride-free polyethylene and polypropylene pipes are used (no PVC anywhere).

7. Nearly no composite, laminated or sandwich materials are used and most connections can easily be undone (screwing instead of nailing or shooting). This means, instead of a later conversion or demolition, these materials are reusable or, at least recyclable, because you can separate the different materials. By this we give future generations a chance of dismantling instead of destroying and help already to prevent the origin of future building waste.

Table 3. Primary Energy Use for Manufacturing the Building Materials for 1 m^2 Super Insulated Wall (u-value ca. 0,20 W/m^2K)

	Wall thickness [cm]	Primary energy [kWh/m^2]	Index [-]*
Masonry, double clay brick wall, 14 cm mineral fiber core insulation	51	320	170
Masonry, lime-sand brick, 18 cm PS-insulation, synthetic resin plaster	39	188	100
Prefabricated wall, 18 cm MF-insulation + 4 cm PSE, synthetic resin plaster	27	125	66
TRIPLE E HOUSE, 20 cm cellulose fiber insulation, larch boarding	33	96	51

* Index = 100 stands for the most common low-e wall system in Germany

Conclusions

The concept of the TRIPLE-E-HOUSE offers a new approach to energy and cost efficiency for single family houses. About 20% of the building costs (compared to an average German house) can be saved by means of architecture (compactness, optimized floor plan, replacement of the basement by an outbuilding on ground level). These savings are used to finance improvements according energy-efficiency, durability of an advanced wood frame construction, and an environmentally concerned choice of building materials, These suggestions aim at (in the final account) a cost-neutral way to build energy-efficient and ecological houses.

The calculation of the annual primary energy requirements for space-heating, domestic hot water and household appliances shows a reduction of 73%, compared to an average new house and 60% compared to a typical low-(heating) energy-house in Germany. The consumption costs based on today's purchase prices for energy and water can be reduced from $190/month in an average new home to $90/month in the TRIPLE-E-HOUSE (Borsch-Laaks and Pohlmann 1993).

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Endnotes

1. $1 = 1,65 DM. These costs were estimated from the result from invitations to tender in the state of Nordrhein-Westfalen in 1992 (see Borsch-Laaks et al. 1993). The prices, specified per unit (e.g., per m^2 wall), and therefore also the cost savings refer to the construction standard of the TRIPLE-E-HOUSE as it is presented in this paper.

2. This amount depends strongly upon the local situation in the subsoil and construction permission norms.

3. Basic information about the typical problems and possible solutions in the field of air-tightening in light-build constructions of Germany and Switzerland can be found in: Borsch-Laaks 1990; EUZ 1992; Eike 1990; and Zumoberhaus 1990.

4. Detailed calculations of building costs and consumption savings can be found in Borsch-Laaks and Pohlmann 1993 and Borsch-Laaks et al. 1993.

5. In mid- and north-European climate the thermal mass of the outer walls has only little influence on their annual energy balance (less than 3%) (Adamson and Feist 1988).

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