The Triple-E-House: Energy-efficient, economical, ecological

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1. SYNOPSIS

This paper takes a comprehensive look at the parameters for an environmentally concerned housebuilding practice. Several prototypes built since 1988 show that this goal can be reached by state-of-the-art components, and at a cost level which does not differ significantly from average new homes.

2. ABSTRACT

This paper takes a comprehensive look at the parameters for an environmentally concerned housebuilding practice: A) Energy calculations include spaceheating and domestic hot water as well as household electricity with primary energy use as the measure of energy efficency B) Design, construction details, and supply systems are planned together C) 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-e-houses was developed. The *primary* energy requirement of this TRIPLE-E-HOUSE amounts to only 40% of a typical German low-e-house which only takes into account reducing the rates of spaceheating 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, and at a cost level which does not differ significantly from average new homes. The essential features are:

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

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

3. INTRODUCTION

Low-energy-houses have been tested in Europe since the late seventies, especially in Scandinavian countries. In West-Germany first attempts in this direction started not before the 2nd half of the eighties. Nowadays, we meet precarious discussions about new building regulations with which low-e-houses should become the general standard for new buildings in Germany. The declared intention of the federal government to cut the CO_2-emissions led to a blue-print of an improved thermal insulation decree last year ("Wärmeschutzverordnung", WVO, BMBAU 1992, Ehm 1993).

In the meantime it seems that the discussion about the new German standard will lead to results, which may cause some confusion, especially on an international level. The tug-of-war of different lobbies is about to create a poor compromise: the limits of the "WVO" will (in practice) cause a specific space heating requirement of 100 $kWh/m^2/yr$ and more for single family-, semi-detached and row houses (IWU 1992). Probably, for political image reasons, the authorities still want to label these values as low-energy-standards. These values are about 30% lower than those of average new German houses in the last decade. But if we compare it to experiences, which have been made in other European countries, the new German code will be no reason to claim leadership in CO_2 - reduction. The Scandinavian countries for instance had already similar requirements, when they started their experiments with low-e-buildings about 15 years ago. [1] (Adamson et al.1986, Blomsterberg in EUZ 1992)

On the other hand several German states started promotion programs for low-e-houses in the last years. Their requirements are about the same we know from e.g. the Nordic countries and so the living-space-related heating energy need may reach results about 60 - 70 kWh/qm/yr (Feist 1992).

4. 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 comsumption. Thus all data in Figure 1 are given in units of primary energy.

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 as well as 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 nearly 20% of the total primary energy requirements can be saved by a compact house design and the thermal improvements of a modern wood construction Water and electricity saving technologies and a solar collector for DHW lead to a further

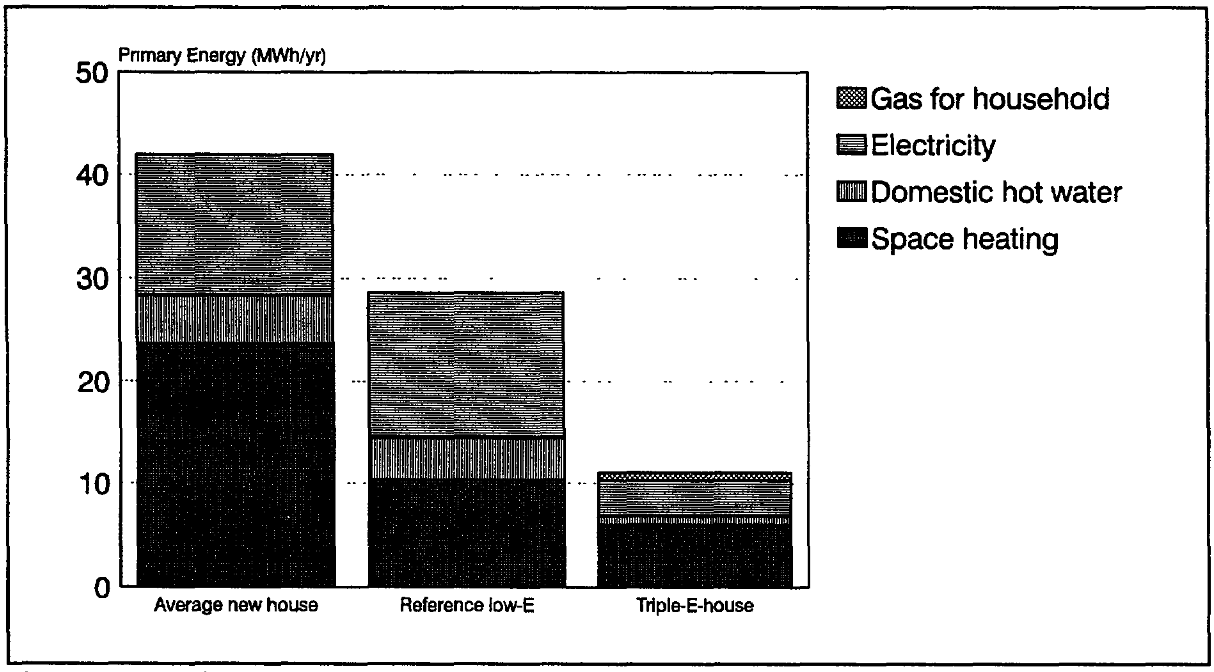

Figure 1. ***Annual primary energy requirements for different types of German houses***

Table 1. *Comparision of House Data*

	Unit	Reference low-e-house	Triple-e-house
Floor area	[m²]	140	115
Building volume (outside)	[m³]	508	381
Surface envelope (outside)	[m²]	403	309
Window/Floor-area	[--]	23%	33%
Storeys	[--]	1 1/2	1 1/2 (2)
U-values *)			
Wall	[W/m²K]	0,34	0,21
Roof	[W/m²K]	0,29	0,16
Ground	[W/m²K]	0,50	0,34
Windows	[W/m²K]	1,52	1,52
Heatlosses	[W/K]	215	149
do., p. m² floor area (-12°C)	[W/m²]	46	39
Primary energy for spaceheating **)	[kWh/yr]	10.370	6070
Net-heating energy **)	[kWh/yr]	9.370	5330
do., per m² floor area **)	[kWh/yr/m²]	67	46
Heating system	Condensing, gas-fired furnace		
Annual, total effiency (ηa)	[--]	95,1%	92,4%
Ventilation	Mecanical exhaust ventilation system		
Energy demand for Ventilation	[kWh/yr]	5110	3360
Airchange at Δp = 50 Pa	[ach/h]	3,4	1,5
Domestic hot water		Central supply by furnace and 1001 tank	Solar system 300 l tank backup furnace
Consumption (at 45°C)	[l/d]	200	140
End-energy for DHW	[kWh/yr]	3960	920
Household appliances, pumps, and vents (end-energy)	[kWh/yr]	4750	1960

reduction of about 40%. The total annual consumption of a four-person-household in the TRIPLE-E-HOUSE is calculated to be about 18.000 kWh lower than in the reference low-e-building.

5. BUILDING PHILOSOPHY AND BUILDING COSTS

Building low-e houses in Germany is usually carried out in the following way: Building as usual, plus improvements by additional insulation and airtightning, low-emissivity-glazing, mechanical ventilation, and improved furnaces. This means extra costs from 7.500 to 15.000 ECU for a single-family house --about 5 to 10% of the total cost for a 140 m² house--(Eicke and Feist1990, 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 bugdet of most home owners and the high interest rates for every additional spending, the possibilities for extra investments could become very slim. Our conclusions 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 ECU) will cost 8 - 9 % per year (and this for at least two decades in the future).

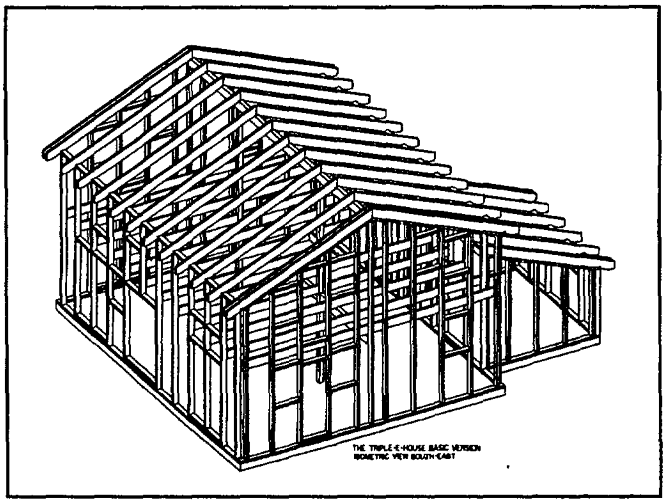

Figure 2. ***Loadbearing timber structure of the TRIPLE-E-HOUSE.***

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 "e-xtras" as possible, <u>without extra costs in the final account</u>. It is the real challenge for any concerned architect to help owners to find a cost-neutral way to an efficient and environmental room for their joy of life. The TRIPLE E HOUSE concept was developed with this ambition and 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 analysing the construction costs in the moment and consumption prices in the future, 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 <u>and</u> lower consumption costs can be achieved by a compact building shape, smaller floor area, and by replacing the basement by an extension at the ground level.

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 ground plan, 1 and 1/2

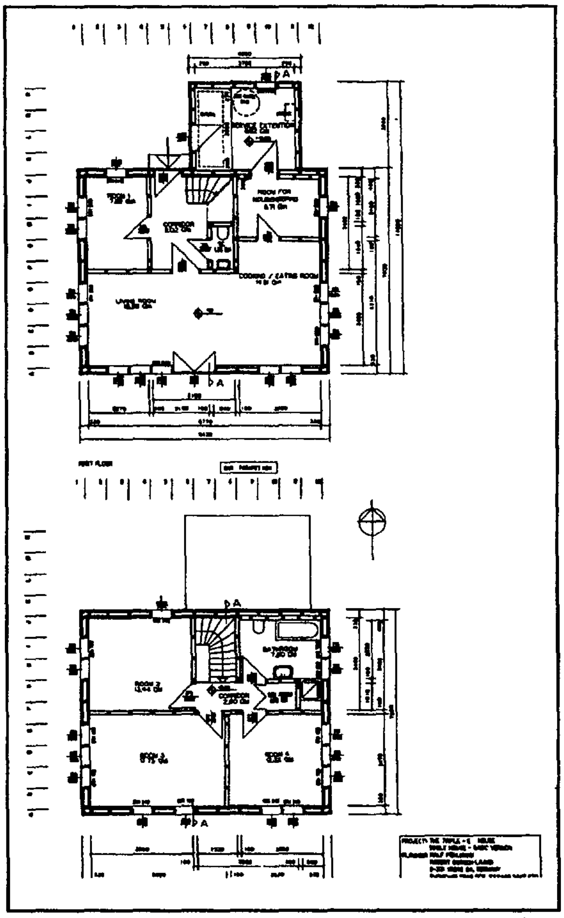

Figure 3. ***Ground plan for first and second floor***

Table 2. ***Three steps to reduce heating energy requirements***

	Primary energy consumption for heating per year	Energy savings per year
Reference low-e-house (see table 1)	10.366 kWh	---
1st step: Compact shape (high jamb wall, 22,5° roof slope, square shaped ground plan)	9.372 kWh	994 kWh
2nd step: Small and bright house design (floor area 115 m², window area 38 m²)	8.016 kWh	1.356 kWh
3rd step: Thermal improvements, additional insulation, improved air tightness	5.060 kWh	2.956 kWh

storeys with a high jamb wall (1,60 m), and a roof pitch angle of 22,5°. 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 45° slope. This reduces the heatlosses and makes a difference in building costs of 12.000 ECU.[2]

A service extension on the north side replaces an expensive basement and saves about 10.000 ECU.[3] Friends of nonelectric cooling and cellaring will find that a small natural cellar, beneath the service extension, is included in this calculation. Renouncing a basement also avoids additional heatlosses which are caused by the basement staircase.

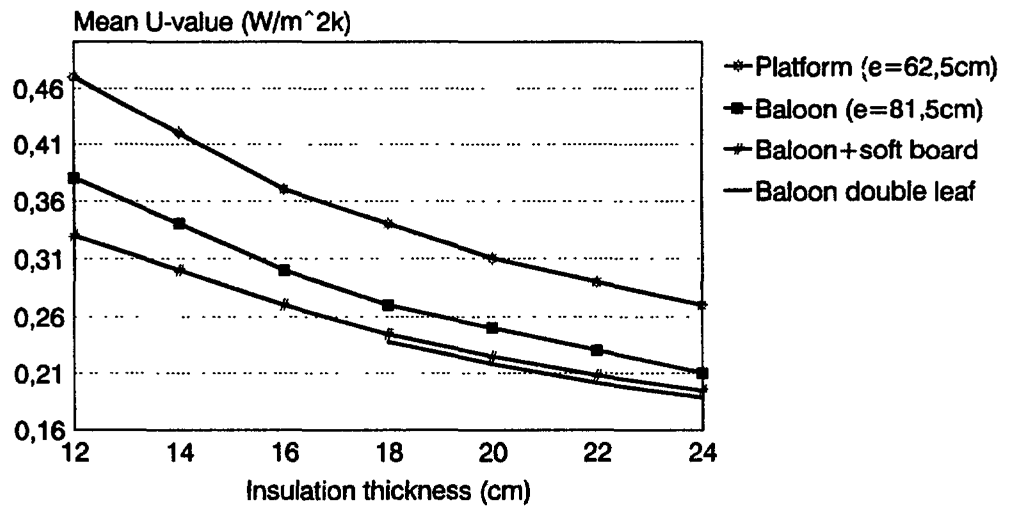

Figure 4. ***Mean U-value and insulation thickness for different German timber framing systems***

The design of the basic version of the TRIPLE E HOUSE also dares to reduce dwelling area from average 140 to 115 m^2. The generous dimensions of windows and glazed areas (38 m^2) create bright and wide looking rooms, and avoid any feeling of narrowness. An optimized ground plan enables 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 ECU.[2] The high standard of modern glazing (U = 1,3 W/m^2K) allows to use windows as a mean of architecture without being anxious about too negative effects on the energy balance.[4]

In total, these measures for a more compact building decrease the annual primary energy demand by 2.350 kWh (see Table 2). These savings do not need any venture investment. They decrease the running 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 discribed in the following chapters.

6. 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, timber 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 timber 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 timber frame construction reaches 10-25% 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.

6.1. 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: 62,5 cm, width of the studs: 6 cm) according to the standard (DIN 4108) leads to a result which is only 16% worse than the U-value of the insulated space between the studs. But in practice this system is usually built with 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 using this common German timber framing construction, it would have about 35% (!) uninsulated wood in the external walls (instead of only 9,6% assumed by the DIN-method). This would have meant an U_m-Value of only 0,471 [W/m^2K], nearly 60% higher than in the undisturbed area (see Figure 4). To achieve an U-Value of 0,25 [W/m^2K] (often recommended as upper level for low-e-buildings), an insulation and stud thickness of more than 25 cm would be necessary in this system.

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

- The modular grid is 81,5 cm instead of 62,5 cm. The clear width of 75,5 cm allows to insert windows in pleasent proportions, without additional trimming and framing (Pohlmann in EUZ 1992).

- 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.

- The basic static system is similar to the American balloon framing. This saves up to 5 rails, which normally would have been used in the junction of the partition ceiling when constructing with the typical platform framing. Only one sole and one top rail are necessary (see Figure 2+5).

- The additional studs (house corners, element joints, load transmission) have been reduced to minimum static necessity.

It is evident that this construction method reduces costs in a double way: On the one hand, about 50% 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. 15% less insulation and wall thickness (see Figure 4).

6.2 Improved airtightning technique

There is a completely new idea in the wood construction system we used: The stiffening plywood panel is fastened to the inside of the loadbearing structure. Thus, all statically necessary 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 airtightning of the building envelope (a big problem in many of the German light built dwellings) can be done in a rather simple way. This does not only prevent unwelcome heat losses, but it is also a secure protection against moisture damage by vapour convection.[5] Hereby, different measures are cooperating, securing against and completing each other:

- Avoiding problematic points already while planning the details (e.g. penetrations or changing of the position of the tightning layer between inside and outside of the structure). The windows are sealed by an overlapping fold surrounding the frame.

- 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

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

- Blower door testing has shown, that draft at "forgotten" spots can also be eliminated by the relatively high airflow resistance of the applied cellulose fiber insulation. Its treatment ("insitu" insulation process , jointfree blown into the ready cavity) protects also against convective loops between warm and cold side of the structure.

In the daily building practice the advantage of these easy to handle airtightning 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 selfevident 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 %. (Walther 1992)

6.3. More improvements for a long durability

These advantages of the timber construction system we used do not increase the building costs. So there is still money left for further improvements in the TRIPLE E HOUSE:

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

- On the inside of the plywood boards a thick lathing (with a 2nd layer of 6 cm insulation between them) carries the internal facing. These laths have a different modular grid, so a slightly further reduction of thermal bridges can be achieved. The much more important reason for this double leaf

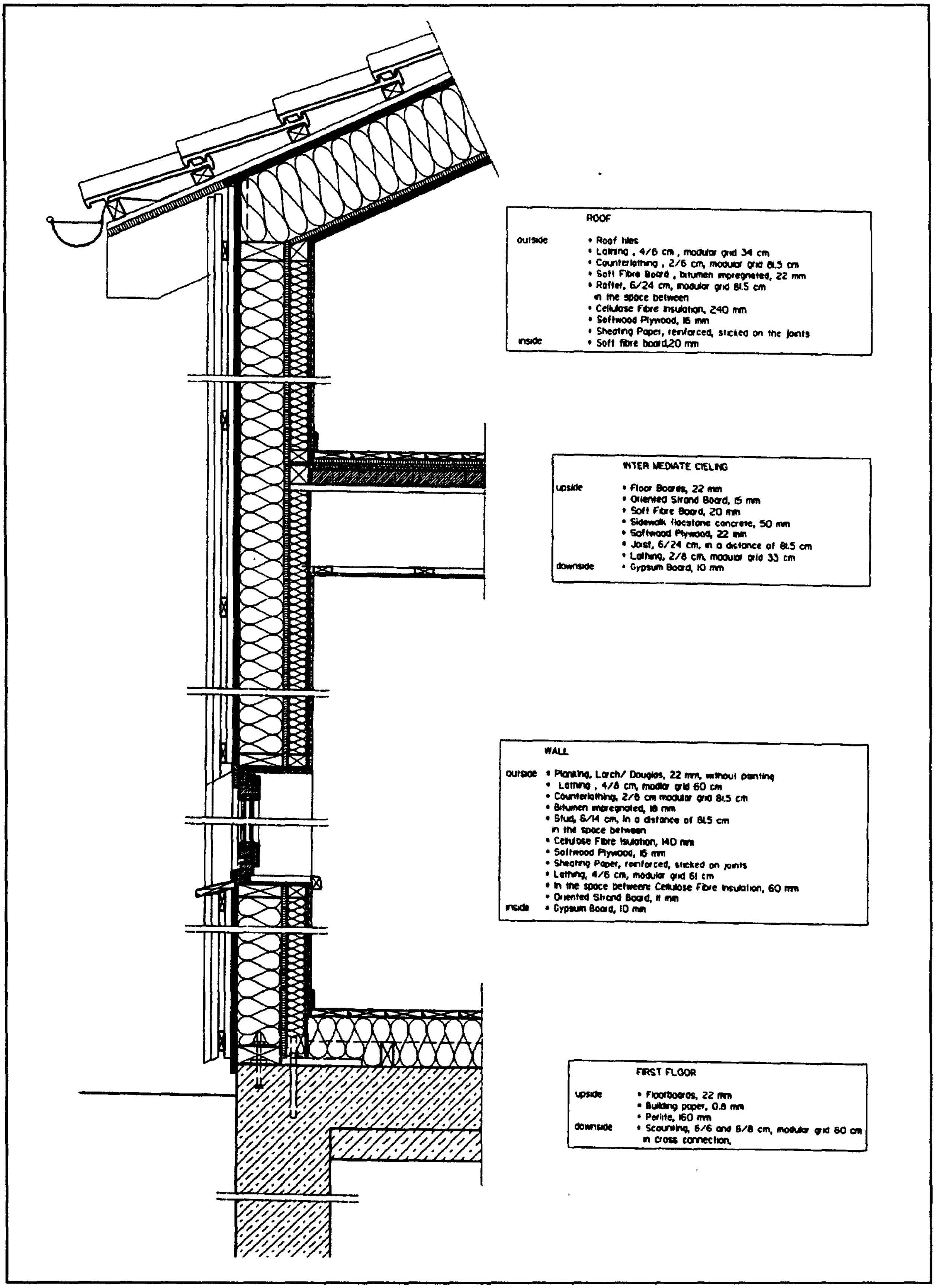

Figure 5. *Vertical section of the TRIPLE-E-HOUSE*

construction is to create a space for service installations (electrical wires, outlets, plumbing etc.) without any danger to hurt the airtightness level on the plywood. Unavoidable penetrations for ventilation system, outside lights, supply lines to service extension etc. can be taped invisible inside this extra space. Moreover static loadbearings 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 and so on are not required. Therefore, we use a 20 mm soft board as sheathing directly fixed on the (taped) plywood surface (see Figure 5). 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. On ground level, below the floorboards, we find a perlite insulation (16 cm) between scantlings in cross connection The consequent light-buildt construction avoids nearly all thermal bridges between the heated rooms and the foundation slab (see Figure 5).

A conclusive view at the construction system shows that its low U-values (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 compared to a reference German low-e-house of the same size and shape. (see Table 2, chapter 5.) [6] The construction costs of this type of wood framing are only about 5.000 ECU higher than those we would have to pay for a system with only one layer of insulation between 14 cm studs, 16 cm rafters, and 10 cm floor scantling.[2]

7. 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 usally they do not save enough money to pay the interest rates for their installation costs.(Borsch-Laaks et al. 1993) But, there are a lot of different other reasons to install them. Some examples: A mechanical ventilation improves the indoor airquality 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, but looking at the thermometer of your solar collector, reading 50° C ... and then start 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 brandnew 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 heatlosses. 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 at first do our energy conservation homework before we go to the hightec playground. But if we follow the suggestions to reduce building cost by a compact design we made before, then there is enough money left to install some energy efficient mechanical service systems.

7.1. 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 at least by some of the local craftsmen:

- Exhaust ventilation system for bath, 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 (Werner in EUZ 1992). Extra cost: ca. 2.500 ECU.[7]

- Condensing gas furnace (optional with cushion storage) with microprocessor control. Improvement of the annual effiency 5-8%. Extra cost: ca. 1.-2.000 ECU. [7]

- 5 m^2 solar collector with 300 l well insulated tank. 60% covering of the annual domestic hot water need. Primary energy savings: 3.100 kWh/yr. Additional costs: 6.000 ECU.[7]

- 6 m³ rainwater cistern with compressor pump. Saves about 38.000 l/yr for toilett flushing, (car)cleaning, and garden irrigation. Costs: 3.000 ECU.[7]

These four alternative service systems lead to extra costs of about 13.000 ECU. This is about the same amount that we have saved by designing a compact building shape.

7.2. Conservation first!

But 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:

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

- Think of distribution losses in the pipe grid also inside the heated area. Scandinavian resarch has shown that a high thermal output of uninsulated <u>interior</u> distribution lines impairs the ability of the system to react properly 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.

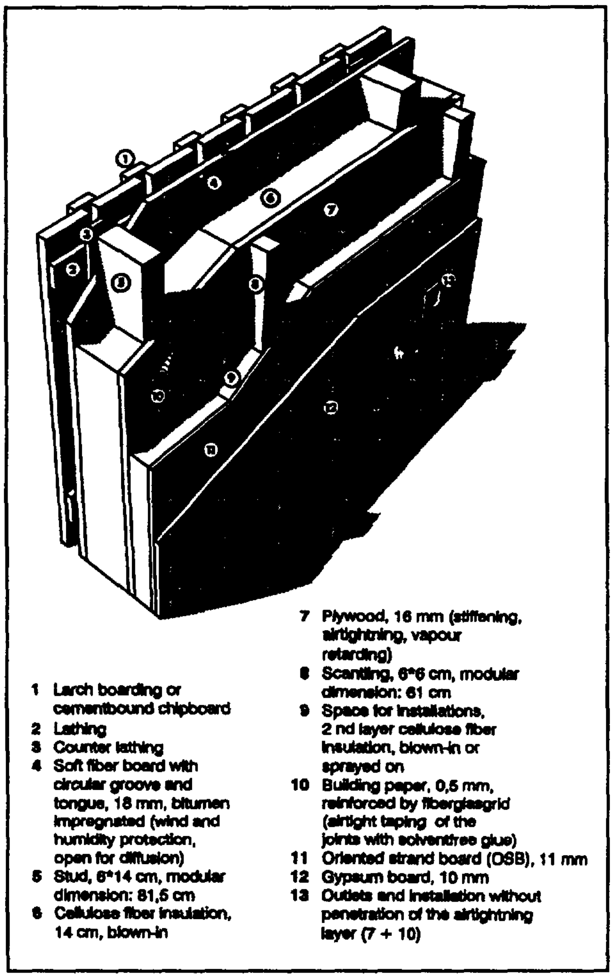

Figure 6. *The wall of the TRIPLE-E-HOUSE*

- Looking at the domestic hot and cold water supply, the environmental sources (solar and rain) will only get a chance to deliver a mayor part of the need, when water saving measures have been done before. Low flow taps and showerheads, toilets with 6 l per flush and stop-and-go function do their job with 30-50% less water use. Installing this equipment is much cheeper 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 effectiveness and energy efficiency can meet. The high insulation standard of walls and windows make the uncomfortably cold air drop on freezy winterdays to an experience of the past. From the thermal comfort view point it is now allowed to place radiators nearly everywhere in the rooms. In the TRIPLE E HOUSE the radiators are placed on internal walls. This helps to reduce installation costs (shorter lines), thermal losses, and electricity use 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 corner of the house and situate the service room next to it. Reduction of installation costs <u>and</u> energy consumption is the profit for this designing discipline. This concerns 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 fitting for a comfortable airflow.

8. 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 Figure 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

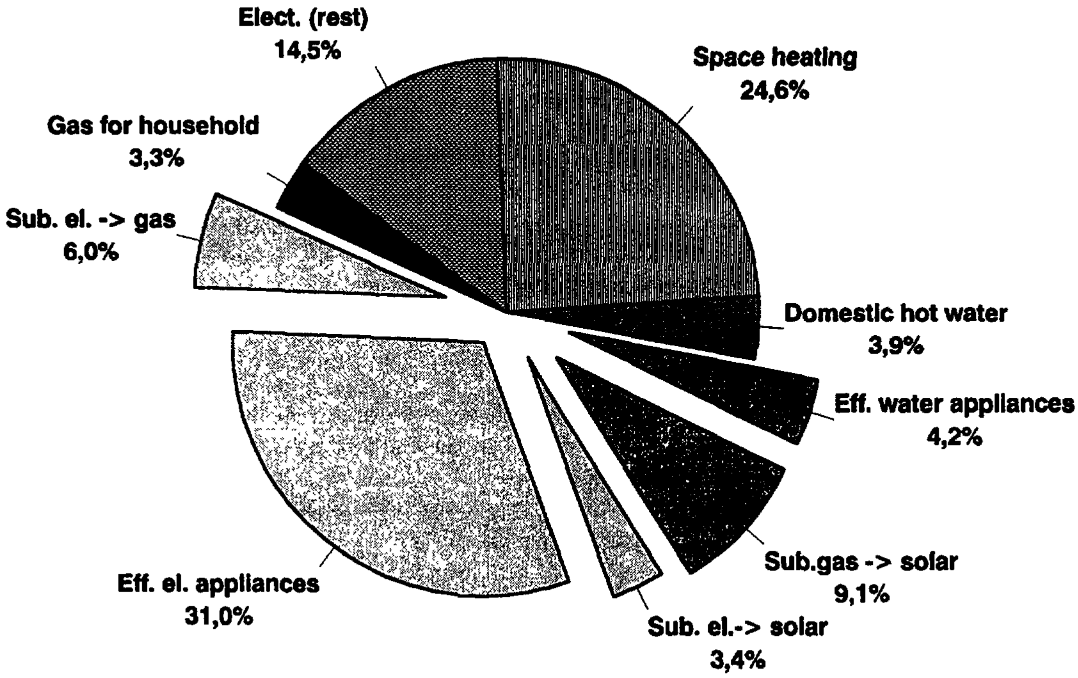

Figure 7. ***Primary energy use in the TRIPLE-E-HOUSE. Savings by efficient service systems ("cut" sectors) and remaining demand (100% = 24.500 kWh/yr)***

effect on the other side. And this should be the scale for saving our limited resources and for being careful to our environment. But, even if we only refer to end-use electrical energy, the standard amount of 4.-5.000 kWh/yr is approximately as high as the total space heating energy demand for the TRIPLE E HOUSE.

In chapter 7.2., 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 top of the iceberg. We think, in contrary to the customary opinion, that house design can provide many improvements for a higher efficiency of the household. Some examples from the TRIPLE E HOUSE:

- The generous dimensions of window areas (also for rooms on the northern side of the house) replace artifical by daylighting.

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

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

- With a short duct to the fan box in the service extension, a cabinet clothes dryer can replace an electrically heated tumbler.

- 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 1992). Some examples:

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 ECU 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 comsumption, without being forced to renounce reasonable electrical devices.

9. 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 environmetal compatibility. These criteria forced us to think over aspects like:

- Primary energy need for manufacturing of the materials

- Use of limited, non-renewable raw materials

- Waste disposal, recyclability, reusability

- 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 by calculations based on scientific data (e.g. primary energy use for the construction). In all other cases, environmetally concerned, qualitative assumptions were the only things we could do. The following examples may show the direction of the way we try to go:

- The primary energy use for the building materials in 1 m^2 outer wall of the TRIPLE E HOUSE is 50-75% lower than in masonry constructions with the same U-value (see Table 3).

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

- The special kind of on all sides planked, but diffusion-open wood costruction makes it possible to

Table 3. ***Primary energy use for manufacturing the building materials for 1 m^2 wall (U-value ca. 0,20 W/m^2K)***

	Wall thickness (cm)	Primary energy (kWh/m^2)	Index*) (-)
Masonry, double clay brick wall, 15 cm mineral fiber cavity insulation	58	355	185
Masonry, lime-sand brick, 18 cm polystyrene, synthetic resin plaster	40	191	100
Prefabricated wall, 18 cm mineral fibre + 4 cm polystyrene, synthetic resin plaster	27	125	65
TRIPLE E HOUSE, 20 cm cellulose fiber insulation, larch boarding	33	96	50

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

avoid preservatives for nearly all of the timber (Schulze 1992). The interior surfaces can be coated with solventfree natural paints.

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

- Instead of possibly harmful isocyanate foam, impregnated polyurethan, and buthyl-rubber tapes airtightning is done with jute felts, reinforced building papers, and solventfree latex or acrylic glue.

- In the service systems, environmental compatible, chloridefree polyethylen, and polypropylen pipes are used (no PVC anywhere).

- 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 recycable, because you can separate the different layers. By this we give future generations a chance of dismounting instead of destroying, and help already now to prevent the origin of future building waste.

10. CONCLUSIONS

The concept of the TRIPLE-E-HOUSE offers a new approach to energy and cost effiency 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 ground plan, replacement of the basement by an extension 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 comsumption costs based on todays purchase prices for energy and water can be reduced from 160 ECU/month in an average new home to 75 ECU/month in the TRIPLE-E-HOME (Borsch-Laaks and Pohlmann 1993).

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ENDNOTES

1. For the following comparision between average German low-e-houses and the TRIPLE-E-HOUSE, we will refer to a fuel use of 70 kWh/m^2/yr that has been reached by a lot of single family houses in the promotion programms, and which is in accordance to internationally tuned maximum levels.

2. 1 ECU = 2 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. Comparably detailled costs for standard low-e-houses in masonry construction were not available. If the reference house is to be built in the typical German timber frame work that is mentioned in chapter 6), the shape and floor area related cost differences may be estimated 10% lower.

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

4. In contradiction to the opinion of many architects that increasing the window area has always a positive influence on the final account of the energy balance, we found it (slightly) negative because of three often underestimated reasons:
(1) Thermal bridges of the window frames and the glas edges lead to an $U_{w,m}$ of only 1,52 W/m^{2}K.
(2) Radiant losses in the panes (38%) plus shadowing by the frames give an over all radiant transmissivity of only 47%.
(3) The typical Mid-European climate has mayor sunshine only in Sep./Oct. and Mar./Apr.. At that time, temperatures are rather moderate. Thus, the internal gains often are high enough to cover the little heat losses of a well insulated house. While increasing the glazed area, about 50% of the extra insolation only lead to room temperatures that are higher than necessary. That's fine and comfortable but no improvement of the energy balance.

5. Basic information about the typical problems and possible solutions in the field of airtightning in light-build constructions of Germany and Switzerland can be found in: Borsch-Laaks 1990, Borsch-Laaks in EUZ 1992, Eike and Feist 1990, and Zumoberhaus 1990.

6. <u>All</u> amounts in Table 2 are calculated with a mean internal gain load of 610 W, because of comparability to the reference low-e-house. This is--considering the usable part of the additional

solar gains--a worse case study for the improved constructions. But the total heating demand of the "real" TRIPLE E HOUSE (only 396 W internal gains because of lower electricity consumption) is of course higher than in Table 2 (about 20%).

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

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