Retrofit of a century old land-house to a low-energy house

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Abstract: Converting a low-quality brick construction into a low-energy solar house takes five steps. First, avoid spillage by optimal space allocation. Second, apply natural and/or somatic energy wherever and whenever possible. Third, integrate passive and semi-passive solutions. Fourth, harvest renewable commodity energy. Fifth, efficiently complement previous steps with commercial energy. Twelve percentage of the retrofit budget made the house largely independent from commercial supplies (energy, water, sanitation). Benefits exceed costs several times. Thermal and living comfort levels are exceptionally high. The owner-occupier was intensely involved, adapting designs and solutions to personal preference while gaining understanding, familiarity and security with the house.

Keywords: sustainable house; energy efficiency; rooftop solar energy (PV and hot water); solar space heating; universal design; investing in passive energy components; retrofit of single family house; housing services and amenities; housing functions and activities.

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1 Introduction

The retrofit started in 1996 but was retarded by regulatory mess-ups and stretched till Christmas 2004. This allowed high involvement of the owner and many subsequent adaptations to the first layouts. The services and amenities obtained were excellent, partly due to the pleasant environment. The investment was affordable, while occupancy and maintenance costs are low.

2 Setting the case study

The single-family house is the third complete overhaul of a dwelling occupied before the 20th century. Initially, there was a small house with clay-walls and a straw-roof. After WWI the owners built a rectangle brick house incorporating the common design of Kempen land-houses. Half of the house was human living space and half was used for animal elevation and storage of feeder and agricultural equipment. The 30 cm thick brick walls had no foundations but were erected on tightened soil. Water supply and sanitary facilities in the house were missing. Water was taken from an outside well in buckets. After WWII, grid electricity was supplied and cooking in open fire places was complemented by a bottled gas range. Coal/wood stoves were added for heating. Such houses, occupied by people in the low-income group were located in inferior neighbourhoods of woods and less fertile land, which in the present, are appreciated as natural environments.

Since the 1970s interest for this housing stock has grown. Depending on the location (in/outside natural preservations) and on the budget of the (mostly new) owners, the houses are either upgraded to acceptable comfort levels (e.g., adding sanitary comfort, central heating, etc.), or retrofitted completely, or demolished and replaced by new constructions in the typical Flemish style. The Flemish laws on urban planning determined the future of a part of this housing stock. The regulatory changes were unpredictable, unstable and not based on comprehensive urban planning or architectural concepts and practices. On neighbouring lots one owner got the permit to demolish and build, the other was not allowed to replace the roof. But what was allowed or not has changed continuously. The case study house became the unfortunate victim of the regulatory arbitrariness in Flanders. The plan, conceived in 1996, could not be finalised till 2004, after costly court suits.

2.1 The 1996 plan

When bought in January 1996, the house was under reconstruction (added were a double garage, a new roof with two chapel extensions, etc.). In contrast, the new owner with a background in alternative energy policy, planned for a low-energy solar house, with:

- high-comfort, superior quality, life-long living space for a household of 1à2 to 4à6 persons
- energy efficient house: thermal integrity of K20 or less, application of passive concepts, efficient equipment and appliances
- maximum use of natural ambient energy and resources
- low occupancy and maintenance costs
- the size, height, external format (roof angle, window and door openings) of the construction had to be maintained.

The investment budget available was above average but the high-quality goals still required the contribution of the owner and the owner's family labour (six persons with three skilled).

3 Analytical framework of energy use

3.1 Energy from the user's point-of-view

In science and in daily life energy has many names, depending on the perspective of the analyst or craftsman. For a more sustainable use of energy, the concepts such as natural energy, somatic energy, commodity energy and commercial energy are helpful.

Natural energy. This is the energy directly supplied by the ambient nature that can be acquired for people's benefit. Natural energy is free for all of us to take when we let her serve us and do not obstruct her access and utility. To benefit from her availability, natural energy deserves a more prominent place in our energy economy, requiring more awareness, intelligence and the *redirection* of technical solutions and investments.

Examples: *Daylight* (can be used more when buildings are designed to maximise the capturing of useful daylight). *Ventilation* (in many climate belts, aeration and cooling of a well-constructed building can be met by using natural energy flows). *Drying* food, clothes, wood, etc with the sun and the wind. *Water* supplied by gravity and rainfall. 'Passive' solar concepts target an enhanced use of natural energy in buildings. Because natural energy is free, it is not metered and not recognised in our statistics and studies as a major supplier of our energy needs. However, the sun and earth provide us with more light, heat, breeze for free than the energy companies do for a good share of our budget.

Somatic energy. Energy delivered by the human body is almost free (if you walk a lot, you eat a little more). At the cradle of human history somatic energy was the important source of controlled energy. Examples: *Body heat* (sleeping under a cover allows to withstand the coldest ambient temperatures). *Body power* (lifting goods, walking; the reach and effect are enlarged by using levers, bicycles).

Commodity energy. This energy is available in natural flows or taken out from the stores of nature and converted into tradable products. The conversion of wind energy into power delivers electricity as commodity energy. In the actual energy economy, the dominant share of commodity energy is from the fossil fuel resource base. Examples: all oil products, natural gas, coal, electricity, but also chunked wood and solar hot water. Commodity energy requires the allocation of production factors such as capital, labour, designated land, and mostly, a significant quantity of commodity energy.

Commercial energy. This is the predominant part of the commodity energy being traded and priced. Examples: oil products, coal, gas, electricity sold by the grid. Locally generated and used commodity energy is often not commercialised. This occurs e.g., in the biomass market. In Belgium people may harvest wood in their neighbourhood for heating their house, without passing the commercial circuit (and the official statistics). In the developing world, local biomass is the main fuel for more than 2 billion people, also largely bypassing the commercial trade channels and official statistics.

In industrialised nations, natural and somatic energy use is overridden by commercial energy. We built our cities with their backs to the sun, also making human body contributions to transport difficult and not exciting. Because enjoyment of natural energy is often accompanied by a lot of other welcome factors (e.g., the tender breeze of a summer night), people pay money and consume lots of commercial energy to get access to natural and somatic energy during holidays (bikes are loaded on the car to reach the week-end biking excursion, while daily short distances near the home are covered by car).

A sustainable energy future must reconsider the priorities and assign a central place to natural and somatic energy. Commodity and commercial energy should support natural and somatic energy use by filling the gaps between our needs and the available natural and somatic energy. Such a change is what a sustainable development implies.

3.2 From technologies to housing services and amenities

Housing is meant to provide services and amenities to its occupants and visitors (Chappells and Shove, 2005). A catalogue of services and amenities can be listed under headings such as comfort, health, safety and security, aesthetics, authenticity encompassing autonomy, involvement, expression of personality, status, success, etc., (Buys et al., 2004). To obtain services and amenities, residents perform a variety of functions/activities in/around the house such as the construction and furnishing of the house that provides space and accommodation. Other functions are nurture, sanitation and caring, recreation, working. The intensity (capacity) and frequency (duration) of performing the various functions at home are highly relevant when assessing the efficiency of a house (Olofsson et al., 2004). Table 1 offers more details on the main functions.

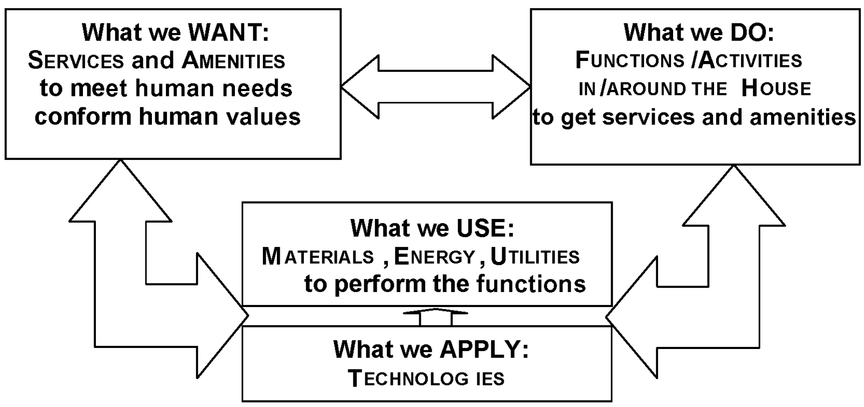
Table 1 Functions/activities performed in/around the house

1	Sheltered dwelling	Constructing/retrofitting/maintaining the building
		Accommodating objects (furniture, appliances, arts, …)
		Meeting and Interacting among occupants and with visitors
		Resting during day and at night (sleeping)
		Providing space for performing the other functions (see 2–5)
2	Nurture	Private supplies (growing, harvesting, cleaning, processing… vegetables, fruits, meat, …)
		Storage: dry (cereals, wine, …), cooled (drinks, fruits, …), frozen (meat, vegetables, …)
		Food preparation (grinding, cooking, baking, steaming, …)
		Washing and cleaning (utensils, dishes, table cloths, …)
3	Sanitation and caring	Personal care (bathing, showering, teeth brushing)
		Cloths washing/drying/ironing
		Cleaning the living area (floor, windows, appliances)
		Cleaning outdoors, Car washing
4	Recreation	Intellectual recreation: TV, audio, home movies, library, music playing (piano, cello, etc.)
		Indoor sports: fitness, sauna, relax tubes, billiards
		Outdoor sports: swimming, tennis, bicycling
		Gardening and outdoor hobbies
5	Work	Desk work (computer, printer, copier, fax, …)
		Small group meetings (therapy, social events, …)
		Health care (physician, dentist, …)

Some of the listed activities take place at home or outside the home. Clear examples are hot meals (there may be a difference of several hundreds hot meals per year prepared at home between one and the other family of the same size), cloths washing/drying/ironing (processing at home a 5 kg laundry may consume around 10 kWh electricity and 30 l water), working at home can be full-time or occasional, requiring basic desk infrastructure or specialised equipment (with widely diverging energy and other utilities consumption).

Performing functions requires space and materials, energy, water and utilities (e.g., waste storage and processing). For getting the inputs and for performing functions people apply a wide range of software and hardware technologies that range from personally directed to automatic. Mostly, industrialised societies have substituted automated solutions for personal driven ones at the cost of higher material and energy intensities. Figure 1 shows the separate components with their impact on the overall outcomes and inputs performance of a house.

Figure 1 Interaction between what we want, do, use and apply



3.3 *Reaching low-energy housing in five steps*

Five steps in realising low-energy solutions, particularly in housing projects, are:

- *Avoid spillage*. E.g., maximise the comfort and service level of the available area by a functional layout (Friedman and Sheppard 2004), sizing (optimal spaciousness), connectivity (short distances, un-jammed course ways), allocation (food storage in a cool cellar), combining (utilities' ducts in storage rooms), separation (do not heat where it should be cool). E.g., provide utility supplies at the command of the users (lights, heating, shower) by simple operating controls (switches, temperature regulated valves).
- *Apply natural and/or somatic energy wherever and whenever it makes sense,* because such energy is free or almost free when available. E.g., use daylight efficiently when it is available (Schuster and Jellinghaus, 2004), make use of natural breeze and shadowing, use gravity to avoid pumping, dry clothes outdoors.

- *Integrate 'passive' or 'semi-passive' solutions*. E.g., optimal location, compactness and orientation of the house (Friedman and Sheppard, 2004), roof overarching for optimal shadowing and rain protection, greenhouse extensions, screens with multiple uses (security, cooling in summer, insulation in winter), and most important, insulation and air-tightness of walls and roofs.
- *Integrate renewable commodity (non-commercial) energy.* Such as solar hot water for sanitary and heating purposes (Schmidt, 2004), PV solar power, biomass (digested organic waste as fertiliser; recovered wood for heating), collect rain water for toilet flushing, gardening, cleaning purposes, apply reed for waste water treatment.
- *Add on to the previous four steps, commercial energy in the most efficient way*. Instead of crowding out natural and somatic energy, passive solutions, local commodity energy and the like, commercial energy should only complement such supplies. When this philosophy is adopted, commercial energy is converted and transferred efficiently. E.g., space heating with water at 30–35°C allows for the maximum use of solar heat and it makes sense to insert a high-efficiency condensing gas heating boiler for complementing the solar supplies (Schmidt, 2004). E.g., natural light is complemented by efficient well controlled electric light. E.g., the laundry machine takes hot water from the solar/gas add-on boiler and cold water from the rain water storage tank, drive power from PV cells with add-on commercial power from the grid.

4 Integrated retrofit concept

4.1 Design and construction

Within the severe limitations of the brick house size of 7×20.5 m + 7×4 m added-on side construction at the West side, under a 40° roof at 3.5 m cornice and 6.8 m ridge height, and with given door and window openings, it was necessary to fully optimise the layout of the functional space inside (twice 6.40×10 m in order to retain an inner dividing wall). The basic principles of Universal Design

> "that suit people with varying abilities, such as step-free thresholds, open-plan rooms with flat non-slip flooring and wider hall and entrances that increase movement and safety," (Buys et al., 2004)

were intuitively followed. Flat access is guaranteed by equal flooring in natural stone all over the ground floor, both inside and outside. The stone floor is heated in winter and stays cool in summer.

Connectivity and separation of rooms go hand in hand. The bathroom downstairs (with flat shower access) is attached to the parents' sleeping room. The kitchen is open to the dining-living room. The veranda joins the living room through a wide entrance. The double spaced office is separated. Rooms requiring privacy (toilets, sleeping rooms, bathrooms) have solid wooden doors. The other doors are of stained glass, and transmit daylight and increase the connectivity, while providing sufficient separation. Connectivity is further enhanced by two passages between the eastern and western halves of the stretched house, offering smooth circulation for residents. All passages and entrances inside are wide 1 m or more, permitting wheelchairs on the entirely flat floor space without thresholds.

The wet functions are assembled at the north side of the house. There is a compact technical room upstairs with a 600 l solar hot water storage at a short distance from the panels, from the heating gas unit and from the end-users in the kitchen, washing room and bathrooms upstairs and downstairs. Because the standing walls of the long sides upstairs are but 0.45–0.75 m above floor level, the two sides have a 0.9 m deep attic space all along. In this attic the ventilation ducts and other utility pipes and wires are assembled, allowing permanent access at all times. The left-over width of the upstairs floor is but 4.60 m, leaving space for three rooms and a spacious bathroom that includes a sauna (to be installed).

The old brick construction is entirely preserved (Vincent and John, 2004). New foundations are added with 4 cm foam glass inserted joining the outer wall 12 (8 + 4 interlaced) cm mineral wool plates at the 10 (5 + 5 interlaced) cm polystyrene plates insulating the inner concrete tub completely for placing the floor heating pipes. Outside, a new brick façade conforming to the old style of the house is added. The roof construction is rebuilt, partly to secure the 30–50 cm (under the ridge) mineral wool insulation and the tight joining of wall and roof insulations. The new roof overarches 40 cm at the south side and 90 cm at the north side for shading and rainfall protection. On the south side 22 m^2 solar hot water panels are installed.

The 0.5 m thick walls (30 cm brick + 12 cm insulation + 8 cm brick façade) have aluminium windows and doors of 11 cm depth (five separate chambers) with (in 1998) high performance glass panes ($k = 1.1$, ZTA = 59%, LTA = 76%). All the windows on the ground floor have electric screens for providing shade in summer and insulation during winter. They also enhance privacy and security. The 7 m width of the house and the many glass doors provide all the passages and rooms, except one toilet, with daylight.

The garage is a separate 6.8 × 6.8 m building at about 10 m distance from the house. The floor plan is the old one, but it was allowed to install a 2.2 m deep waterproof cellar for storing food (2 × 500 l freezer capacity + cool place for beverages, fruits, vegetables, etc.,). On the 30° south roof 28 m^2 PV panels (2.4 kW peak) supply 2064 kWh/year (average of first two operating years).

An underground 10 m^3 storage tank collects the rainwater from the house and garage roofs, and supplies toilets, laundry machine and garden taps. Toilet water is collected in a digester tank and its overflow joined to other waste water flows for sanitation in a percolation reed pond. By making use of gravity forces, one small pump a few minutes per day suffices for driving the plant.

4.2 Use of the house

The occupants are a couple of adults (age: mid 50), one working at a distance of 55 km in Brussels, one at 45 km in Antwerp. One works halftime from home (standard desk job). The youngest adult son is a member of the household but lives most of the time as a student in Antwerp. With the visits and stay-over of two more sons, laundry, family dinners, etc., the mean occupancy rate is 2.5 adult persons.

The house is used intensively. In particular, above 70% of food is private supply (meat, vegetables, some fruit), processed and stored at home, and around 900 hot meals per year are served. Above 80% of the laundry is homework (washing, drying, ironing).

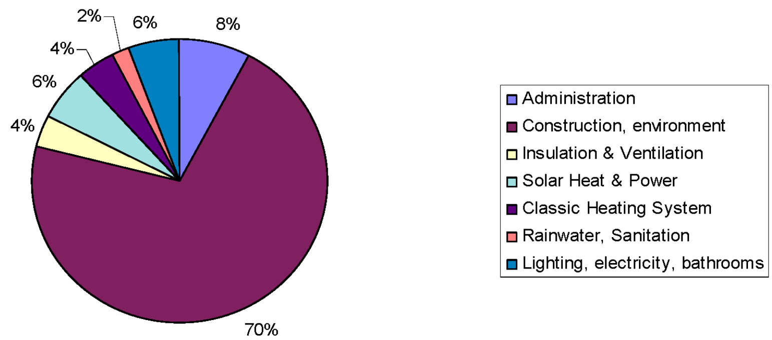
Gardening in this country house is above average. Recreation is not water or energy intensive because chatting-reading are preferred pastimes.

5 Evaluation

5.1 Costs

Figure 2 shows the construction cost breakdown. Administration (8%) covers lawyers' expenses to fight the Flemish regulatory arbitrariness; the retrofit was designed and monitored by the owner with support on technical issues by PHP and CENERGIE (Mlecnik, 2002). Family members contributed significantly to all retrofit works except the 'classic heating system' (4%) and 'solar heat and power' (6%). The latter component is the net cost to the owner after capital subsidies. Insulation material was purchased in bulk, a part was provided for free by KnaufAlcopor in 1998 and most of it was installed by the owner. The construction and surrounding works took up 70% of the budget, partly due to the high quality of materials used (inland natural blue stone, solid inland/French oak wood finishing, etc.). About 12% of the costs are related to the sustainable options (4% insulation and ventilation + 6% solar heat and power + 2% rainwater, sanitation). Although it forms a significant share, this investment provides high returns in services and amenities, in contrast to the 8% waste of money for addressing the regulatory mess.

Figure 2 Shares of main cost categories in construction budget (see online version for colours)



5.2 Benefits

The benefits offered by a more sustainable house consist of some easy to quantify returns, and of services and amenities not easy to express in monetary terms.

The monetary benefits are low energy, water and maintenance costs. Due to efficient equipment and appliances, overall daylight access and careful control, the annual electricity consumption is less than 3000 kWh while more than 2000 kWh is PV generated, leaving less than 1000 kWh/year to be purchased from the grid. Compared to US homes (Olofsson, 2004), the use of electricity at < 14 kWh/m^2 is very low for an intensively occupied and fully equipped 220 m^2 house, excluding the area of garage (45 m^2), cellar (28 m^2), veranda (25 m^2). In addition, self-sufficiency is high in water sanitation (100%), water supply (50%), food storage (70%), laundry (80%), while continuous forced ventilation (with heat recovery) takes place. With the €150/MWh-PV subsidy, the net annual electricity bill is negative. The non-discounted pay-back of the PV installation after capital subsidies equals ten years.

Ventilation is needed because of the high insulation thickness and tightness of the house (standard K20.4 (Mlecnik, 2004)). Space heating and hot water energy are, in order of priority, solar with LPG add-on and in winter the pleasure of a fireplace. LPG consumption (heating, hot water, cooking) was about 1250 l (8875 kWh or 40 kWh/m² floor-space) during the first occupancy year (while the plaster walls were still drying), but should be lower than 1000 l (7000 kWh) in a standard year. The thermal inertia of the house is high. E.g., when the outside temperature overnight is just below 0°C, the inside temperature decreases from 21°C to around 19°C (from 11 pm to 7 am). Air-conditioning in summer is not required because natural morning ventilation and shading with the window screens keeps the indoor temperature below 26°C even when the outside temperatures are above 35°C for several days. From a comfort and financial point of view, insulation pays off well. The air comfort temperature in winter is 21°C, the wall temperatures are 18–20°C and thermal inertia is high. The LPG consumption is still (too) high and it will be monitored to decrease it to approach the lower standard. Solar panels for hot water supply make sense but extending the system to supply space heating is financially not attractive because solar heat is only sufficiently available during half (of the least heat demand) of the 7–8 heating months in Belgium.

Grid water consumption at 60 l /person-day is about half the Flemish domestic average. In addition, the private water sanitation exempts payment of contributions for the communal sewerage system. At the present water price, paying-back the rainwater system takes 20 years. The private treatment plant pay-back would take longer, but avoiding pollution is a duty while polluting is not a right.

It is early days to assess the maintenance costs of the house. Due to the design and choice of materials, maintenance is expected to be minimal, e.g., because there is no need for painting outdoor parts, and due to the robust and compact construction.

The financial balance of investing in renewable energy and in sustainable solutions is, in the short-run, not exciting in a society where prices of resources and of nature stimulate overspending and waste, because these prices fall short in internalising the huge externalities of climate change and of nuclear risks. But the non-financial rewards in services and amenities are numerous and worth the investment and effort.

All of the objectives stated at the start of the project were attained:

- The *comfort level of the house is exceptionally high*. Thermal comfort is the result of investing in passive solutions and components (insulation, buffering brick walls, overarching roof, greenhouse attached) and in adapted active systems (low-temperature floor heating, window screens) controllable by room. Most of the year the daytime indoor temperature is stable at 21–23°C. Living comfort is high due to state-of-the-art luxury (avoiding overload), spaciousness, connectivity, flat access, natural light exposure, design details, natural materials, pleasant outdoor views and the availability of a garden and a natural environment.

- Indoor and outdoor air qualities are high and the house is almost free of outside noise thanks to the thickness of walls and roof, and thanks to the tightness of windows. Two caveats related to the ventilation system are that the ducts transmit human voice and sounds all through the house and the fact that air moisture is extracted by the heat exchanger in winter. Ventilation requires further research and experience.

- The house meets the seven criteria of Universal Design. It is not high-tech with sophisticated domotics, but requires monitoring and controlling by the occupants, responding to the ambience of the house. The safety and security standards are high. The risks of natural hazards (fire, inundation, storms), criminal acts (theft, robbery, vandalism) or black-outs in utility supplies are minimised.
- It is low-energy and energy efficient, gives priority to natural energy, allows for somatic energy, adds first local commodity energy (solar heat and power, rainwater and processed waste) and fills the gaps with small amounts of commercial energy.
- Despite the short observation period, occupancy and maintenance costs in energy, water, cleaning and repairs are below best practice levels.

One particular amenity this project offers the owner is the authenticity obtained by the involvement in the layout, realisation and functioning of the house (Thomas and Hall, 2004), by the high level of autonomy in organising one's own living conditions (reacting to what nature offers that day), by the growing familiarity with the house and the neighbourhood. Such authenticity values keep modern psychological illnesses at bay.

When asked if investing in higher sustainability is worth the effort, the true answer is that the incredibly high service and amenity levels set aside all cost-benefit calculations. Instead of wasting time and capability on valuing in an incomplete and inaccurate way the benefits of the many amenities and services supplied, one should adopt maximum sustainability goals and exert careful cost-effectiveness in realising the goals.

When asked about the extent of the investment cost in higher sustainability, the answer is: look at the car on the drive-way of the house. Investing in sustainability is the price of such a car, with the caveat that the car is depreciated in ten years, costs lots of money, causes pollution and risks also, to the owner's life. Mostly, small houses have standard cars on the drive-way, middle-class houses have large cars and expensive mansions have exclusive cars. Making the various houses sustainable will cost one of the various cars each.

5.3 Retrofit rather than Demolish and new-build?

The project shows that low-energy, high-efficiency, more sustainable retrofits are very well feasible, even when loaded with tight constraints, but one must convert threats into opportunities, and take advantage of all the latter. At the start, the long-shape and given window and door openings were considered as significant impediments. It took many hours of layout puzzling to optimise connectivity and separation, respecting also wet functions assembling and the like. The traditional long-shape also has many advantages such as daylight access everywhere (when glass doors are installed) and a 20 m long roof that can accept solar panels. Keeping the 30 cm thick outer brick walls as inside walls raises the thermal capacity of the house (Vincent and John, 2004). This recycling required hard work in putting new foundations with inserted insulation. Flanders' regulatory mess delayed this demo project by five years, but slow progress gives time for thinking and adapting. Careful design cannot avoid the fact that, in practice, several important changes during construction are necessary for adapting the house to the needs and wishes of later occupants (Thomas and Hall, 2004). The involvement, time and effort spending by the owner were larger, but such meaningful use of somatic energy provides many amenities for the rest of one's life, e.g., the familiarity with the construction, the better understanding of the living house, the safe feeling because of such knowing.

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