NEW RESIDENTIAL WOOD BUILDING SYSTEMS IN SWITZERLAND

AND THEIR POTENTIAL TO MEET THE LOCAL REQUIREMENTS OF PLACE, PEOPLE AND PRODUCT WITHOUT COMPROMISING THE GLOBAL CONTEXT

by

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ABSTRACT

After a long dominance of brick masonry and concrete, wood, a traditional local building material, has had a remarkable revival in the single-family house market in Switzerland since the mid 1980s. Among the vast variety of new wood building systems, Swiss wood frames (SWF) and Ribbed panel system (RPS) are considered the most promising ones. Despite different construction principles both systems assist in achieving highly thermal-efficient buildings, and both are built in the factory. The panellised wall, floor and roof elements are assembled on-site in only one or two days.

In this thesis, I hypothesise that the success of a new wood building system depends on its ability to meet the local requirements of place, people and product (P-P-P concept) without compromising the global context). By conforming to the P-P-P concept, the success of the new wood building systems not only acquires a strong market share, but also conforms to the requirements of a more sustainable local building development. The investigation of the local building context reveals the characteristics of 'Swissness', the basis for the investigation of SWF and RPS. The characteristics of, and differences between, the two wood building systems are discussed according to their production and construction principles, where good thermal efficiency, vapour and air movement, differential movement, thermal and structural redundancy, maintenance work, indoor environment quality and sound protection are important characteristics of the wood building systems that allow them to achieve efficiently constructed, long-lasting and healthy housing.

In this thesis, I show that the two wood building systems, SWF and RPS, provide powerful strategies to achieve a more sustainable local building development. However, besides the strong marketing of the Minergie label that limits the use of non-renewable operational energy, political and institutional support as well as technical innovation, construction quality, design, comfort and financial benefits have also been necessary to turn the strategies into accepted buildings with the prospect of high asset values. Combining a broad range of requirements of place, people and product as well as key global needs, SWF and RPS are promising systems for a new and successful local building culture in Switzerland.

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1. INTRODUCTION

After the long-time dominance of brick masonry and concrete in the Swiss housing industry, wood - an almost-forgotten building material - has had a remarkable revival in the building market since the mid 1980s.

Within little more than a decade, the market share of single-family houses in wood has risen from about 2% to 10 - 12% (Germerott, 2002). Considering the fact that the total number of new single-family houses rose from 11,200 units in 1990 to 13,770 units in 2000, the number of new single-family houses in wood actually increased by a factor of 6 - 7, or from about 224 units (1990) to about 1,337 - 1,650 units (2001), a year. In comparison, during the same period of time the total number of new dwellings decreased from 39,980 to 32,210 units (SFSO, 2002:421). This is despite the fact that land is scarce and building is very expensive.

Whereas the market share of single-family houses in wood has considerably increased, multi-family residential buildings in wood are rarely built in Switzerland. There are still strict fire regulations applied to residential buildings with three or more storeys[1]. In these buildings all structural parts must provide a minimal fire resistance of 60 minutes and the use of combustible materials is not allowed (Lignum, 1998). These restrictions, rather than construction problems, may have kept the number of multi-residential buildings in wood negligible. However, this fact could change at the beginning of 2005, when new fire regulations will be put in place.

The fast-growing share of wooden single-family houses has coincided with the development of a great variety of new wood building systems relying on wood modules (manufactured elements) as well as on prefabricated (factory-built) wall, floor and roof elements (panellised components) or modular building components. Most of these new systems also comply with the advanced Swiss building standard for a minimized consumption of non-renewable operational energies, the Minergie standard, or they achieve the Passive House standard[2] defined by the Passive House Institute, Darmstadt (PHI). In keeping with the

[1] Exceptions to this regulation are made only in regions where multiple storey buildings in wood have traditionally existed, such as in the Valais.
[2] In Switzerland, the Minergie-P standard was launched in 2003 in addition to the Passive House standard. The new label basically adapts the European standard to the local settings and combines them with the requirement structure of the Minergie label.

current building-code requirements in Switzerland, Minergie and Passive houses achieve a reduction of the annual operational energy of about 50 % and 90 %, respectively (Architos, 2000).

The use of wood as a construction material, prefabrication as a production mode and operational energy efficiency as a characteristic of the modern house appears to satisfy the requirements and expectations of an increasing number of single-family house owners. A closer look at the building systems reveals that the two systems, *Swiss wood frame* (SWF) and *Ribbed panel system (RPS)*, might be of particular interest to the residential wood building market.

The SWF currently dominates the Swiss wood building market for single-family houses at about 30% (Germerott, 2002). This new system relies on the principles of the Canadian western platform frame. House-long and story-high or storey-wide wall, roof or floor elements finished to a high degree are produced in a factory. Relatively thin structural members (studs and plates) form the structural core of multi-layered wall elements; a sheathing applied on the interior side of the structure provides the frame rigidity. Hollow-core floor or roof modules often replace the joist or rafter construction of the original system. Notably, each carpentry firm has its own unique wood-frame system, varying in the material choice, the sequence and dimension of layers, the size of the structural members or the construction of the element joints. Besides its current success in the residential building market, it is highly-regarded for its flexibility, its constructive performance and its cost efficiency (Schöeb, 2002, and Renggli, 2002).

In contrast, RPS is a very new wood building system. Again, house-long and story-high or storey-wide wall, roof or floor elements finished to a high degree are produced in a factory; however glue-laminated block boards provide the wall, floor and roof elements with structural and lateral stability. Characteristic of the system is the rib construction of enclosure elements. A set of parallel ribs glued against the thin structural board provides it with additional support and prevent it from bending. Custom production allows matching the factory-produced block boards structurally and aesthetically to the specific requirements of a building. According to Deplazes, this factory-built system will become successful in Switzerland due to a simplified design and an easy construction (Deplazes, 2001). Germerott and Schuler share this opinion (Germerott, 2002, and Schuler, 2003).

1.1 Thesis interest

It is as yet undecided whether SWF and / or RPS will be successful over time. But the varied statements of different building professionals raise many questions: What does success mean? Will constructive advantages be enough to succeed in the local building market over time? Will the new building systems provide durable and long-lasting buildings? Will these new and operational energy-efficient houses in wood convince a growing number of clients? Are factory-produced houses accepted by the local population?

These questions indicate that the success of a building system will be a question of more than market share or construction advantages. In fact, the context of a specific place as well as the requirements and expectations of its people provide important clues as to how products are valued. Even more importantly, environmental problems will more and more change the mindset of future clients and influence the requirements and expectations of the local building market.

Therefore, in this thesis I am interested in how these promising new wood building systems, SWF and RPS, match the requirements and expectations of the local building market by asking:

How do the well-tried Swiss Wood Frame (SWF) and the newly-developed Ribbed Panel System (RPS) fulfil the requirements and expectations of the residential building market in Switzerland?

1.2 Methodology

1.2.1 Approach

Today, new residential wood building systems will be successful only if they support attempts to achieve more sustainable local building development and if they rely on a strong long-term market. As such, the new systems need to conform to local as well as to global requirements. Also, they need to be accepted and supported by the local population. This approach relies on the following definitions and the P-P-P concept.

Definitions

The Brundtlandt-Commission defines *sustainable development* as a process that meets the requirements of present generations without jeopardising the chances of future generations (Gotsch, 1999). Therefore, a sustainable development must be economically, ecologically and socio-culturally feasible.

Building development describes the production mode of a building type as well as the building type itself, while *building type* describes what a building is built for (use, function), how it is built (building system) and how it looks (design, architecture).

Kramel describes a local (traditional) *building type* as the result of local materials and means grown over generations. Popularity and cultural identity of a [wood] building type is necessary to achieve a [wood] building culture (Kramel, 1998: 18-20).

The P-P-P concept

The locally-bound definition as it is postulated by Kramel is no longer applicable to contemporary building types. Today, the coexistence of both local and global factors is a major criterion for the successful development of sustainable housing. The *P-P-P concept* (Fig. 1.1) states:

> *A contemporary building type is defined by the synthesis of present PLACE, PEOPLE and PRODUCT without compromising the global context.*

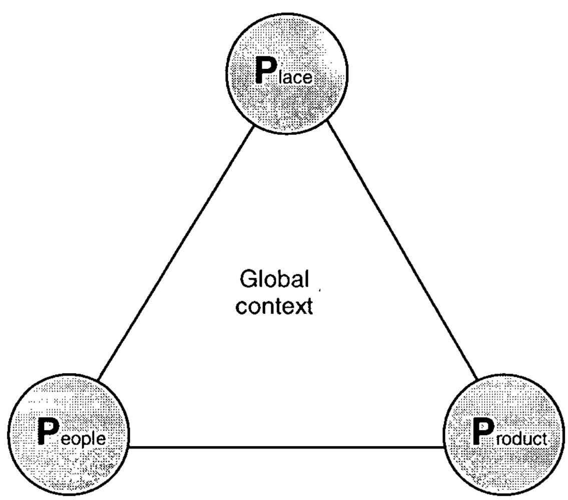

Fig. 1.1 The P-P-P concept

As such, a contemporary building type that relies on local and global factors best provides the base for sustainable housing. However, popularity and cultural identity of a contemporary building type is necessary to achieve a strong long-term market and a new wood building culture.

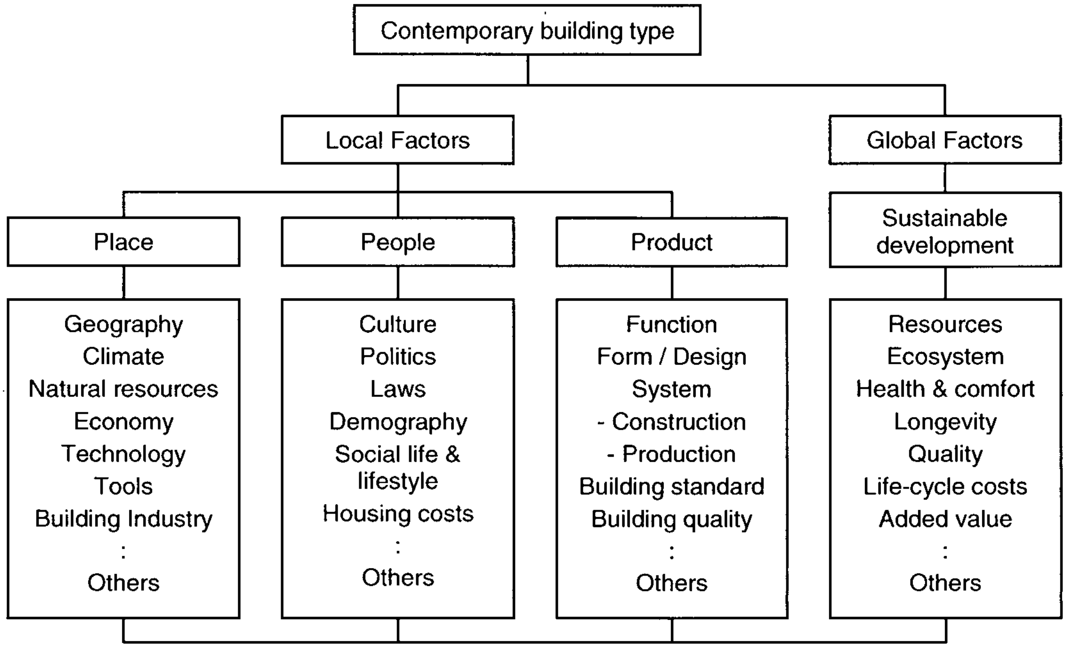

Fig. 1.2 Major local and global factors determining a contemporary building type

Figure 1.2 lists basic local and global factors that determine a contemporary building type. The synthesis of these factors forms the glocal (global and local) requirements and expectations of a specific building market. As the meaning behind the single factors as well as the weight awarded to them change from one location to another, the glocal factors will not be the same in different locations. As a consequence, a contemporary building type as well as a sustainable local building culture will be defined differently in different locations of the world.

Contemporary building types are not only place dependant; they also change over time. This is a result of changing local factors (e.g. technological development or policy) and global factors (e.g. new findings in environmental research) as well as of the weight assigned to the single factors at a given time. It is assumed that the need for more sustainable development will increasingly influence the building market over the coming years and decades. Therefore, a sustainable local building culture must not only rely on local or on global factors, but on glocal ones.

1.3 Aim of the Thesis

1.3.1 Thesis scope

The scope of this thesis is meant to go beyond general construction characteristics, such as flexibility, simplified design or easy construction, that are used to promote one or other system. Evaluation of the building context as well as the SWF and the RPS is necessary to evaluate how the two systems meet the requirements and expectations of the local building market. As well, this discussion allows an evaluation of the potential success of these new wood building systems and gives an insight into the "Swissness" of the systems. Moreover, this thesis may potentially identify factors or strategies that are necessary for a new or a foreign building system to adapt successfully to the (residential) building market in any country.

1.3.2 Thesis limitations

Residential buildings

In this thesis I have limited my investigations to residential buildings or houses. It does not focus on a specific group of residential buildings (e.g. multi-family residential houses, single-family houses or owner-occupied houses) even though the remarkable revival of wood is primarily in the construction of single-family houses, and detached single-family houses are preferred by new homeowners. The adoption of the new fire regulations at the beginning of 2005 will potentially increase the use of wood for multiple-storey buildings. Also, an upcoming limitation of urban growth might enforce the construction of denser housing systems. Governmental institutions are already discussing steps to stabilise the size of the urban space at a benchmark of 400 m^2 / capita; presently it has already reached 407 m^2 / capita (ARE, 2002: 24).

Form and design of the house

In this thesis I do not discuss the form and design of the house. This does not mean that the form and design of a building are not important in order for people to accept it, that the design of the house will be the same when using the different wood building systems or that any design may be applied to a specific building system. But it has been shown that the described building systems allow the building of houses that meet people's expectations in terms of architectural expression, form and floor plan.

Building system

In this thesis I limit the discussion to the building system, particularly to a regular enclosure section as well as to a vertical section of an enclosure-floor joint. Providing the interface between inhabitants and nature, the enclosure has to withstand wear and tear over time. In addition, joints are the critical part of factory-built systems. As such, the regular enclosure section and the enclosure-floor joint represent typical sections for the investigation of the constructive characteristics of building systems in terms of their local and global requirements and expectations.

New wood building systems

This thesis limits the discussion of the available wood building systems to SWF and RPS. This does not mean that none of the other systems has a chance to succeed in the local building market. But SWF is currently the leading wood building system for single-family houses and the system is strongly supported by carpenters; RPS is a very young building system whose value is strongly supported by engineers and architects. Furthermore, both systems rely on factory-built large wall, floor and roof elements that provide high construction quality and precision, as well as fast assembly on site. In addition, they are designed to achieve highly thermal-insulated enclosures with large heating-energy savings.

As well, in this thesis I assume that this production mode (factory production of panellised and individually-designed houses) is accepted by clients, as these houses achieve high-quality standards and showcase a new and fascinating way to build. Despite many similarities, the two wood building systems are very different in the way the buildings are constructed.

Global context

Over the last few years, the achievement of a more sustainable development relying on ecological, economic and socio-cultural factors has become one of the most urgent global problems of industrialised countries. In this thesis I limit the discussion of the global context to some key factors of sustainability that stand in close relationship with the new wood building systems, such as fossil-fuel consumption, CO_2 emission, longevity or health and comfort.

1.3.3 Thesis structure

Chapter 1 introduces the objective, the methodology and the structure of the thesis.

Chapter 2 investigates the building context in Switzerland, structured into the local factors of place, people and product as well as the global context focusing on sustainable development. This chapter provides an insight into the "Swissness" of the discussion and summarises the findings.

Chapter 3 discusses the production and construction principles of Swiss Wood Frame and Ribbed Panel System. It characterises principles, similarities and differences of the two systems.

Chapter 4 analyses the two wood building systems on their ability to achieve thermal-efficient, long-lasting and healthy houses and discusses the findings.

Chapter 5 summarises the findings of this thesis and gives an outlook on further work and potential implications of the study.

2. BUILDING CONTEXT IN SWITZERLAND

Local and global factors determine a contemporary local building type as discussed in Chapter 1.2, whereby place, people and product as well as global factors provide the basis of the P-P-P concept. In this chapter, I give the Swiss-related background information for the major aspects of each factor.

2.1 Place

The *place* is seen as the framework of a location in which people live and work. Geography, climate, natural resources and land use as well as energy consumption, economy, technology and tools are place-related key aspects for contemporary residential buildings in wood.

2.1.1 Geography

Location and size

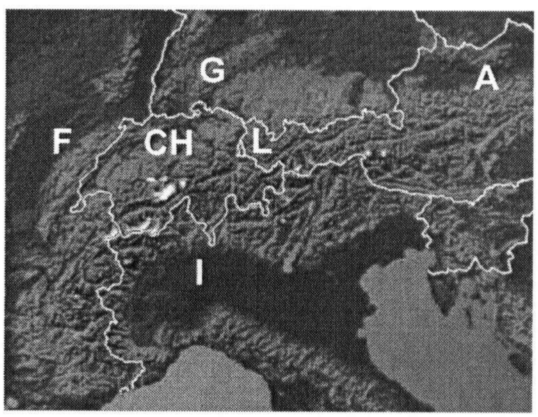

Fig. 2.1 Countries of central Europe (Alpentouren, 2002)

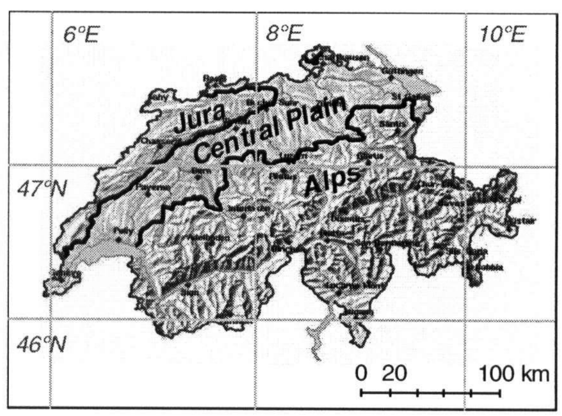

Fig. 2.2 Geographical regions in Switzerland (Source: Adapted from SFSO, 2001:2)

Switzerland (CH) is a small, landlocked and mountainous country in the centre of Western Europe located at latitudes between 45.5° and 47.5° North. Its area covers 41,285 km^2 with maximal extents of

220 km in the North-South and 348 km in the East-West directions[1]. Switzerland is surrounded by Germany (G), France (F), Italy (I), Liechtenstein (L) and Austria (A) (Fig. 2.1).

Geographical regions

Switzerland may be divided into three geological regions; 63% of the country belongs to the Alps, 27% to the Central Plain and 10% to the Jura (Fig. 2.2). All these regions show a great variety of different landscapes and habitats, varying with climate, topography and / or soil composition.

The Alps

The Alps, a large mountain chain, cross Austria, northern Italy, Switzerland and France in a Northeast-Southwest direction (Fig.2.1). They form a continental watershed as well as a major dividing line between cultural areas, climates and vegetation types. For hundreds of years major transit routes through the Swiss Alps have connected northern Europe with the Mediterranean.

Mountains, ice and rocks dominate the central part of the Alps (altitudes over 2,500 m / 8,202 ft). The highest point in Switzerland is the Dufour Peak with 4,634 m (15,203 ft). Climate and topography strongly restrict population and land use in the central Alps; only 11% of the population live in these areas. However, the Rhone and Rhine valleys, with their arable land and mild climate, are densely populated and intensely used for agriculture (grains, vegetables, fruits and grapes). Tourism (sport, health and recreational activities) is important for many remote municipalities of the central Alps.

Alpine meadows (about 1,800 m to 2,500 m) and coniferous forests (up to about 1,800 m) as well as scattered settlements prevail on the lower levels of the Northern part of the Alps (Bär, 1989: 49). But harvesting the forests in these areas are often very difficult due to the impassable terrain and the remoteness of the sites. The Southern part of the Alps is strongly affected by the Mediterranean climate. Deciduous forests (e.g. chestnut), rich agriculture (grains, vegetables, fruits and grapes) and Mediterranean vegetation dominate this area.

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[1] In comparison, Vancouver Island has more than three-fourth of the size of Switzerland. It covers 32,134 km^2 with maximal extents of 100 km in the East-West and 454 km in the North-South directions.

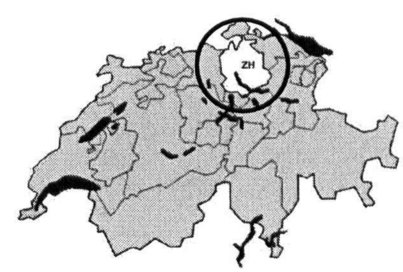
The Central Plain

The Central Plain with an average altitude of 580 m (1,903 ft.) above sea level is built up of layers of rock and covered with moraines of the Alpine glaciers. The undulating landscape of the Central Plain is characterised by rolling hills, plateaus and numerous lakes.

The relatively small strip of land (50 to 100 km, Fig. 2.2) between Lake Geneva and Lake Constance is predestined for conflicts in land use. The fairly flat and arable land is suitable for agriculture, but in addition it is the main source of gravel for the building industry, and it also contains most of the big cities and the majority of workplaces; two thirds of the 7.3 million inhabitants live and work in the Central Plain. With about 450 people / km^2 (1,165 people / sq mile), it is one of the most densely-populated areas in Europe (PRS, 1999: Landscape and habitat).

The canton of Zurich - with 666 inhabitants per km^2 - is the most densely-populated area in the central plain. The city of Zurich with about 364,000 inhabitants and a size of 92 km^2 is Switzerland's largest city as well as its economic centre (SOZ, 2002). Here, sustainable building development is most urgently needed. Table 2.1 provides selected data from the canton of Zurich and from Switzerland. Figure 2.3 shows the geographical location of the canton of Zurich.

Statistical figures	Canton Zurich	Switzerland (CH)
Size	1,792 km2	41,284 km2
% of country	4.34%	100%
urban area (1997)	20.1%	6.7%
agricultural area (1997)	43.4%	37.3%
Building zones (1999)	282.55 km2	...
unused building zones	16.80%	...
Population (end of 1999)	1,193,789	7,164,444
% of population	16.66%	100%
Population density	666 pers/km2	174 pers/km2
Dwellings (end of 1999)	588,145	3,582,171
% of dwellings in CH	16.42%	100%
in single-family houses	17.30%	...
empty dwellings	0.97%	1.66%
Number of new dwellings	6,520	33,108
% of new dwellings	19.69%	100%
Electricity use / inhabitant	6,247 kWh	7,148 kWh
Household waste / inhabitant	212 kg/a	363 kg/a
Average water use / inhabitant	340 l/d	409 l/d
Number of cars	577,236	3,467,275
% of cars	16.65%	100%



Tab. 2.1 Statistical data Canton of Zurich and Switzerland

Fig. 2.3 Location of the canton Zurich

(Source: SOZ, 2002: Canton Zurich in numbers: 2002; building and land costs in 2001).

The Jura

The Jura mountains consist of regular and parallel undulations built up by limestone folds and fairly flat plateaus. With an average altitude of about 700 m (2297 ft.) above sea level the mountain chain terminates the Central Plain towards the Northwest and West. Scattered settlements, meadows for livestock farming and coniferous forests dominate the Jura landscape (PRS, 1999: Landscape and habitat; Kümmerle+Frey, 2001:2-5). The Jura provides an important source of stone, limestone, chalk and clay. The large supply of chalk, a base material of cement, and clay, the base material of brick, has been very important for the widespread development of local concrete and brick masonry buildings.

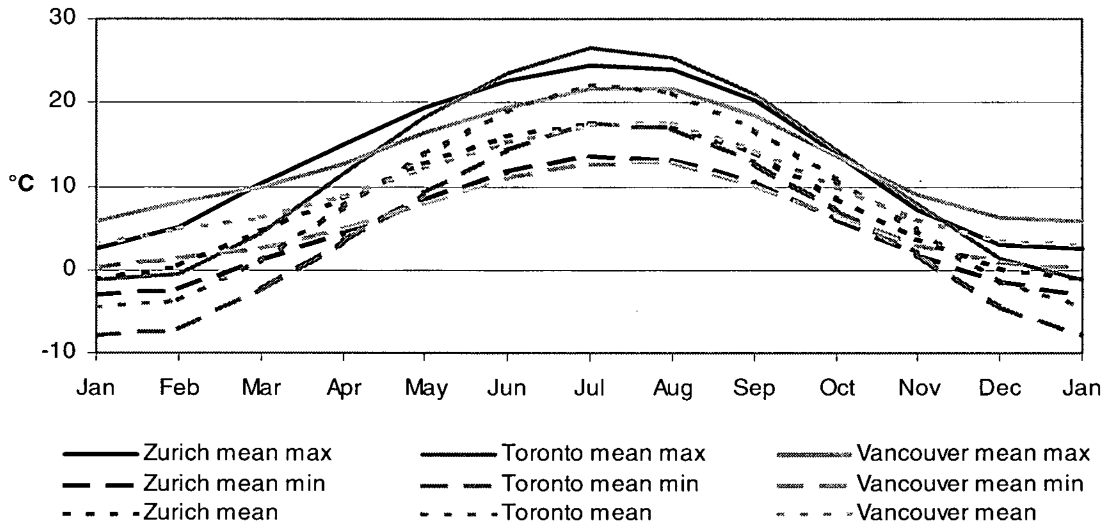
Climate

Switzerland has a temperate climate with four seasons: spring, summer, autumn and winter. The winters are cold and cloudy with rain and snow. The summers are cool to warm and humid to cloudy with occasional showers. However, considerable differences in local and regional microclimates exist due to the influence of four different air currents (Atlantic, Continental, Sub-polar and Mediterranean) and geographical characteristics of the location (elevation, exposure to sun or wind, or geographical location). Table 2.2 gives an idea of climate differences among major Swiss cities.

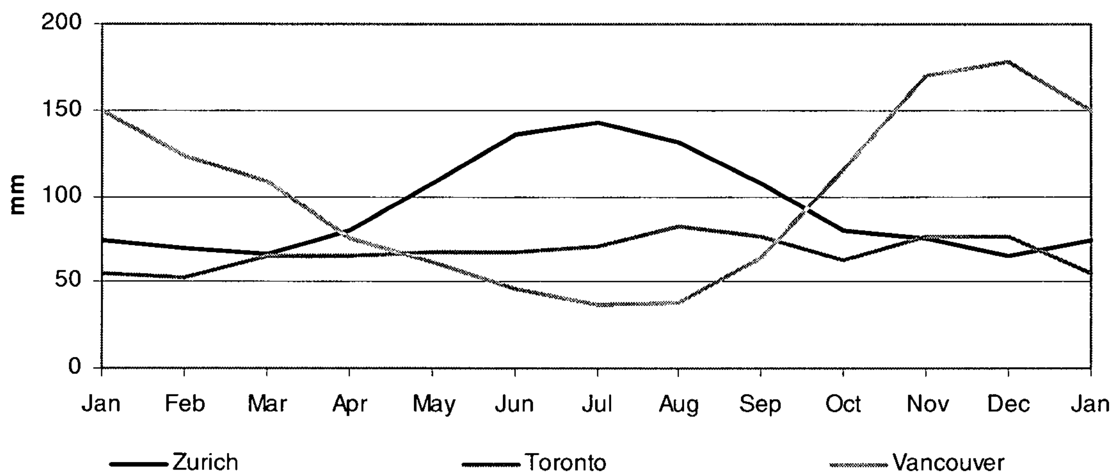
Area City	Elevation [m] o.s.l.	Mean temperatures High [°C]	 Low [°C]	Precipitation [mm]	Sunshine [h]
Jura					
La Chaux-de-Fonds	1,018	10.6	1.2	1,406	1,715
Central Plain					
Basel	316	14.1	5.6	778	1,599
San Gall	779	11.1	4.1	1,248	1,390
Zurich	556	12.7	4.9	1,086	1,482
Bern	565	12.9	4.2	1,028	1,638
Geneva	420	14.4	5.5	822	1,694
Alps					
Davos (central part)	1,590	7.9	-1.7	1,082	1,680
Samedan (central part)	1,705	8.2	-6.5	700	1,732
Sion (Rhone valley)	482	15.1	4.3	598	1,990
Lugano (southern part)	273	15.7	8.2	1,545	2,026

Tab. 2.2 Climate data of different Swiss Cities, 1961-1990 (MeteoSchweiz, 2003: actual climate).

As a reference to Canada, Figure 2.4 compares the mean temperature and mean precipitation data from Zurich (SMA), Vancouver (International airport) and Toronto. In all three cities the mean temperature gradients achieve the lowest level in winter and the highest in summer. While the seasonal temperature differences in Zurich are more distinct than those of Vancouver, they are less extreme than those in Toronto (Fig.2.4a). Major differences exist in the precipitation patterns. Toronto has an equally-distributed precipitation pattern throughout the year while Zurich shows a considerable peak in summer and Vancouver in winter (Fig.2.4a). Over all, precipitation in Zurich (1,136 mm) and Vancouver (1,167 mm) are much higher than in Toronto (819 mm).



a) Mean temperatures



b) Mean precipitation

Fig. 2.4 Climate data from Zurich SMA, Toronto and Vancouver Int. Airport (Source: MeteoSchweiz, 2003, and Environment Canada, 2003)

Land use

Switzerland consists of 30.8% forested area, 36.9% agricultural area, 6.8% settlement and urban areas and 25.5% unproductive area. Figure 2.5 shows examples of the landscape texture of each area.

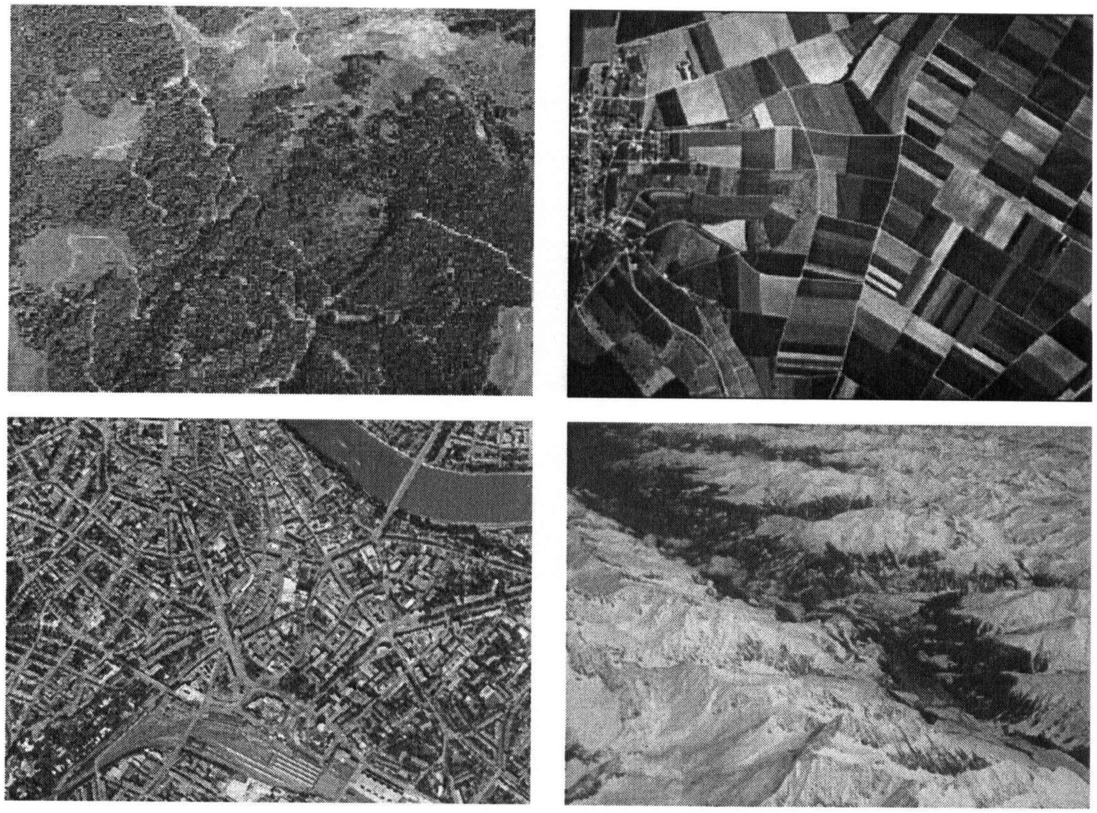


Fig. 2.5 *Landscape textures in Switzerland: forest area, agricultural land, urban area, and unproductive area (Alps) (Source: SFSO, 2001; RPS, 1999; and photos by author)*

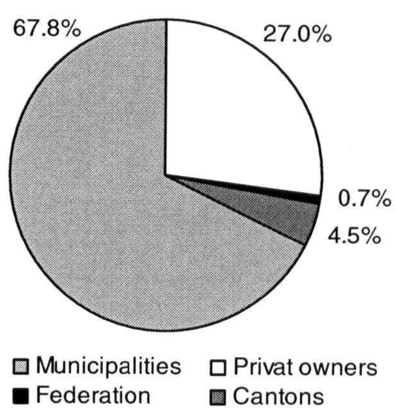
Forest area

The depletion of the forests for firewood, construction and industry resulted in repeated natural disasters with enormous damage throughout the 19th century. As a consequence, in 1876 Switzerland limited logging by law and ordered a large-scale reforestation of mountain areas to protect the country against natural disasters. Over the last century, the forested areas have recovered to an area of 12,716 km^2 or 30.8% (1992) of the country. 86.7% of the forested area consists of forests (without brush forests), 4.5% of brush forests and another 8.6% of other woods. However, at the beginning of the 1980s a widespread die-off of the local forests was observed. Investigations revealed that it was caused partly by the increasing air pollution, and partly by over-aged trees due to low logging rates. This worrying fact led to a first political campaign against air pollution in 1984 as well as to a growing environmental consciousness in the population in the second part of the 1980s. In 1991, a new forest law (see chapter 2.2.3: forest laws) was decreed.

Over the last twenty years, the forest composition has remained fairly constant at 26% deciduous to 74% coniferous trees (SFSO online, 2002: Agriculture and Forestry). More than 50% of the forests grow at an altitude of over 1,000 m (SFSO, 2001:20-24). The most frequent tree species in the Swiss forests are Norway spruce, silver fir and beech (Tab. 2.3). Satellite data from 1990 indicated that 43.7% of the forests consisted of conifers, 22.8% mixed conifers, 18% mixed deciduous and 15.5% deciduous forests. However, native deciduous forests tend to replace the (cultivated) conifers in the Central Plain.

Coniferous trees	**No. of stems %**	**Growing stock %**
Norway spruce	40	49
Silver fir	12	15
Pine	4	4
Larch	4	5
Swiss stone pine	1	1
Other conifers	0.4	0.3
Total conifers (12 species)	**61**	**74**
Deciduous trees	**No. of stems %**	**Growing stock %**
Beech	19	16
Maple	4	2
Ash	4	2
Oak	2	2
Sweet chestnut	2	1
Other broad-leaved trees	8	3
Total broad-leaved trees (over 40 species)	**39**	**26**

Tab. 2.3 Tree species in Swiss forests (SFSO online, 2002: agriculture and forestry)



Forest ownership and size

Privately owned forests 27%
belong to 2,500 owners
average area is 1.3 ha

Public forest 73%
are harvested by 3,500 enterprises
1/4 harvests areas > 200 ha
3/4 harvests areas < 200 ha

Total: 250,000 forest owners

Fig. 2.6 Forest ownership in Switzerland (SFSO, 2002: 342; Holzindustrie Schweiz, 2002)

Characteristic of the Swiss forests are small-scale forest stands that belong to a large and diverse ownership (Fig. 2.6). The high numbers of forest-owners and mixed or fragmented forest stands as well as high elevations makes efficient and economic forest harvesting very difficult.

Agricultural area

Since 1985, Switzerland has been losing about 11ha of agricultural land, or the area of a small farm, daily. Two thirds of this land loss is accounted for by settlement and urban areas within the fairly flat arable land within the Central Plain. The rest results from abandoned agricultural land in remote areas where new forest is growing (SFSO, 2001:7). Despite the vanishing agricultural areas, both the arable production of the Central Plain and the economic value of agricultural products, or the agricultural productivity, are decreasing. Moreover, low income forces farmers to stop farming. Since 1996, the focus of agricultural politics has changed from maximal productivity to high-quality products and sustainable land use. It is now realised that a decreasing number of farmers (about 5% of the population in 2002) are responsible for the health of more than one third of the country. As a consequence, nature-oriented farming has increasingly been supported with large amounts of governmental subsidies (SFSO, 2002:115, 341).

Settlement and urban areas

In 1997 settlement and urban areas accounted for 6.8% of the country, and about 28% of this area was occupied by residential areas (houses and surroundings). However, the fast increase in growth of residential areas between 1985 and 1997 (about 25.4%) by far outweighs the population growth (about 9%) as well as the average annual growth of the settlement and urban areas of 27.2 km^2 (about 13.3%) (SFSO, 2001:7, 14). It is assumed that this trend towards bigger living spaces has continued, even though after 1997 no new data have been published. Yet this trend strongly contrasts with the political will to limit the average settlement and urban area to 400 m^2 per capita, to slow down urban sprawl (see chapter 2.2.2. Policy).

Between the 1960s and 1980s, urban growth mainly affected urban centres in the Central Plain and villages adjacent to agglomerations, while the Jura and the Alps lost much of their population. In the last two decades, improved public transportation systems as well as higher mobility using affordable cars have increasingly allowed people to move to smaller cities and villages in remote areas. Today, the majority of the population lives in locations with less than 10,000 inhabitants, most of them in villages with 2,000 to 5,000 inhabitants (SFSO, 2002:33-34). Here, land for detached single-family houses is still available at reasonable prices.

Unproductive area

The unproductive area has remained fairly stable at 25.5% of the territory. This area consists of lakes (13.5%), rivers (3%), unproductive vegetation (25%), rock, sand and scree (45.7%) as well as glaciers and perpetual snow (12.8%). Despite being described as 'wasteland', these areas are intensively (economically and physically) used by tourism and for recreational purposes, as well as for the production of hydroelectricity. Also, biotopes and nature-conservation areas within unproductive and untouched zones are vital for the preservation of biodiversity (SFSO, 2001:24-25).

2.1.2 Natural Resources

Switzerland is a country with few 'valuable' natural resources and limited arable land. Traditionally, gold and other metals, coal, salt and asphalt were mined. Except for the three remaining salt mines that still cover the domestic demand, high mining costs and low outputs have not allowed these mines to keep up with the prices for imported products. Nonetheless, Switzerland relies on vast resources of mineral building materials, water and timber as well as a unique natural and cultural heritage. In the following sections, mineral building materials, water and wood are more closely discussed.

Mineral building materials

The vast resources of mineral building materials, such as limestone, granite, stone, brick, clay, chalk gravel, sand and gypsum provide important components for the building industry, so it is no surprise that today two thirds of building materials consist of concrete, stone and artificial stone, brick masonry and tiles (SFSO, 2000:6) Table 2.4 shows a comparison of annual consumption among the different building materials.

As only about 1% of the annual consumption of gravel is naturally built up, the vast resources are steadily decreasing in Switzerland (Wachter, 1995:52). Also, the substantial use of potable water in the making of cement together with the emission of CO_2 during the burning process of cement have thrown doubt on the sustainability of concrete.

Building materials	Amount	
Brick	851,000 m^3 *	
Gravel	32,000,000 tons	
Cement	3,540,000 tons *	
Concrete	3,500,000 tons	
Wood	800,000 tons *	
Bitumen	300,000 tons	* *data from 1996*
Glass	114,000 tons **	** *assumed use*

Tab. 2.4 Annual consumption of building materials (SFSO, 2000: 7).

Water

In contrast to many regions of the world, Switzerland has plenty of water that is regularly recharged by precipitation. Low costs and abundant supply lead to a comparatively high consumption of potable water (162 litres / person / day) of which only about 3% is used for drinking and cooking (EAWAG, 2002). As such, in the building industry (e.g. the cement industry) as well as in the operation of houses, the consumption of water has not yet become an important issue. Besides covering the domestic and industrial demand, water provides a great potential for hydropower. Also, lakes and rivers provide room for sports activities, recreation and health pursuits. Swiss mineral or hot springs are well known for their mineral water and their therapeutic benefits in spas.

Hydropower production

Hydropower is the largest domestic energy source in Switzerland. In 2000, turbine and storage power stations produced about 37.8 billion kWh of hydropower. This is about 65% of the annual electricity consumption of 58.2 billion kWh. Figure 2.7 shows hydropower production in relation to other domestic electricity sources. In total, 65.3 billion kWh electrical power were produced, including the export surplus of 7.1 billion kWh (SFSO online, 2002: Energy).

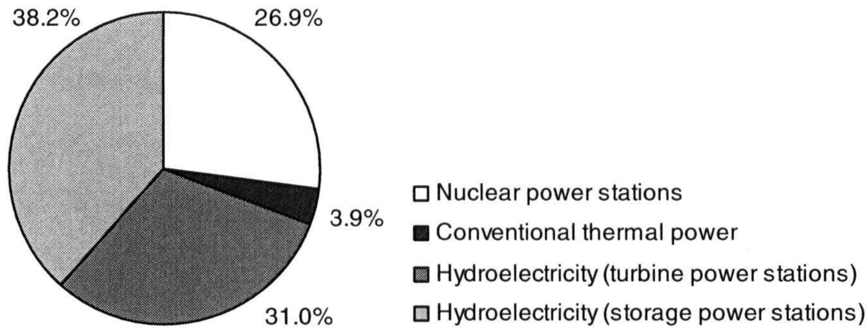


Fig. 2.7 Domestic electricity production in 2000 (SFSO leaflet, 2002: 15)

Wood

According to the National Forestry Inventory, Swiss forests contain a standing wood stock of 387 million m^3 or $362m^3$ / hectares. It is assumed that forests annually grow about 10 million m^3 of wood, of which 7.5 million m^3 of timber could be harvested. However, over the last twenty years on average only about 4.5 million m^3 have been felled. 69% of this amount consist of logs for the production of timber, lumber, veneers and plywood; 20% are used for fuel purposes; and 11% is industrial wood used for the production of particle- and fibreboard, paper and cardboard. However, Switzerland annually uses about 7.5 million m^3 of timber (log equivalents); 38% (about 2.8 million m^3) is used for construction, furniture and packaging materials; another 33% is used for paper and cardboard and the last 28% for fuel[2] (App. 1, App. 2) (SAEFL, 2003:41).

Currently, the domestic wood harvest is similar to the annual exports; the annual consumption roughly equals the imports. The export of wood is determined by about one-fourth of primary products, about one-fourth of semi-finished products and one-half of final products; the imports consist of about one-half of semi-finished products and about one half of final products (App. 2) (SAEFL, 2003:41). Almost 50% of the wood exports (without sawdust and paper) go to Italy, whereas almost 50% of the imports come from Germany (Tab. 2.5).

In 1995, the forest and timber industry consisted of 12,415 plants and employed 90,817 people. It achieved revenues of 10,317 million CHF. Together, the forest and timber industry have account for about

[2] Appendix 1 specifies the use of wood used for fuel purposes (energy-wood) between 1990 and 2001. Appendix 2 provides an overview of the average wood flow in Switzerland between 1995 and 1999.

1.5% of the GDP (SFSO online, 2002: Agriculture and Forestry). However, the economic situation in the Swiss forest and timber industry is difficult. The production of timber has shown economic deficits for years. Despite considerable federal subsidies of about 200,000 million CHF annually, in 2000 public forest enterprises lost 18 CHF per m^3 harvested wood (SFSO, 2002:343). Also, the recession throughout the 1990s caused many traditional sawmills and joiners to close down.

	Exports		Imports	
Country	tons	%	tons	%
Italy	1,080,579	47.7	42,347	2.9
Austria	470,186	20.8	204,005	13.4
France	266,126	11.7	401,017	27.0
Germany	240,910	10.6	668,050	45.0
Other EU countries	152,062	6.7	75,933	5.1
Non-EU countries	56,302	2.5	92,925	6.3
Total	2,266,165	100	1,484,277	100

Tab. 2.5 Import and export of wood (without sawdust and paper) in 2002 (SFSO, 2003: 116-117)

As yet, the situation has not changed. The delayed recovery of the building industry, increasing production costs (labour and machines), full wood-storage facilities due to Hurricane Lothar at the end of 1999, and the increasing market presence of European countries with lower wood prices are further putting the Swiss forest and timber industry under pressure (Holzindustrie Schweiz, 2002). This is despite the fact that the domestic timber harvest could be almost doubled, and an increased harvest would improve the health of the forests.

2.1.3 Energy consumption

Since 1950, energy consumption in Switzerland has multiplied by more than a factor of 5 (Fig. 2.8), while the population has increased by only 53%. In 2000, Switzerland used in total about 855,000 TJ of energy; about 35% was used by transport, about 27% by private households, about 20% by industry and about 16% by commerce and services (SFSO, 2002:381-382).

In the early 1970s, oil provided almost 80% of the total energy use. After the oil crisis in 1973 / 74, the country tried to limit its dependency on oil. While this strategy was first caused by concern about the limited resources of oil, the emission of greenhouse gases deriving from the burning of fossil fuels has now become a primary issue (SFSO, 2002:381). Commitments and strategies to reduce greenhouse gases (particularly CO_2) as well as federal subsidies have supported the development of renewable energies (wind, hydro, solar, bio-gas) over the last decade.

But still the most important energy sources are oil (60%), electricity (22%) and natural gas (11%). This is despite the fact that about three fourths of the materials (oil, natural gas and nuclear fuel rods) have to be imported from foreign countries; the use of renewable energies and the reduction of total energy consumption have become a political issue.

Important changes since early 1970s

After an enormous growth between the mid 1940s and the early 1970s, the rate increase of total energy consumption has diminished, even though the use of motor fuel, electricity and gas has considerably increased. The 25% decrease in heating-fuel consumption could balance total oil consumption over the last 30 years (Fig. 2.8). With reference to the user groups, the increased energy consumption was primarily in transportation, while that of private households, industry and services remained fairly small (SFSO, 2002:382).

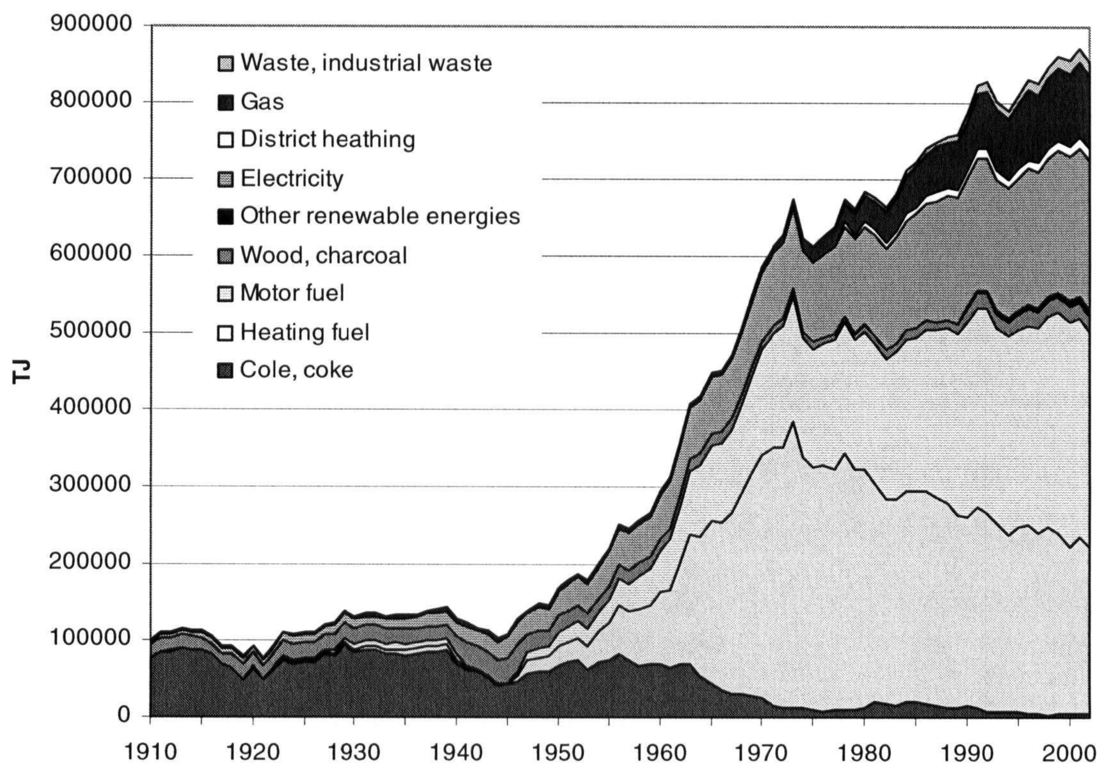


Fig. 2.8 Energy consumption by sources of energy since 1910 (Source: SFOE, 2002: 2)

Through the same period of time (1970 - 2000), the consumption of electricity more than doubled. In 2000, industry and trade used 34.5% of the electricity, private households 30%, commerce and services 25.6%, transport 8%, agricultural and gardening 1.9% of the total of 58.2 billion kWh (SFOE, 2001:4).

Renewable sources of energy account for about 17% of the total energy consumption, whereas hydroelectricity, with about 14%, is still the largest source of renewable energy in Switzerland. As well, wood, solar power, bio-energy and ground heat are becoming increasingly important. Between 2000 and 2001, the use of these energies grew by 12.3% to a total amount of 7,100 TJ or 0.8% of the total energy consumption (SFOE, 2002:7, 20). As yet, their full potential has not been tapped.

Private households

With a share of 27% (2000) the energy consumption of private households is considerable. But between 1980 and 2000 it increased by only 3% (223.8 to 230.6 TJ), while the population grew by 14% and the real Gross Domestic Product (GDP) increased by 33.9% (SFOE, 2002:22; SFSO, 2002:64; Furrer, 2001). The Swiss federal statistical office (SFSO) attributes the small size of this increase to the improved thermal insulation of building enclosures as well as to more efficient heating systems.

Although the overall consumption remained fairly stable, a strong shift from oil to gas (connection to international gas pipeline in the early 1970s) and electricity (construction of nuclear plants at the end of

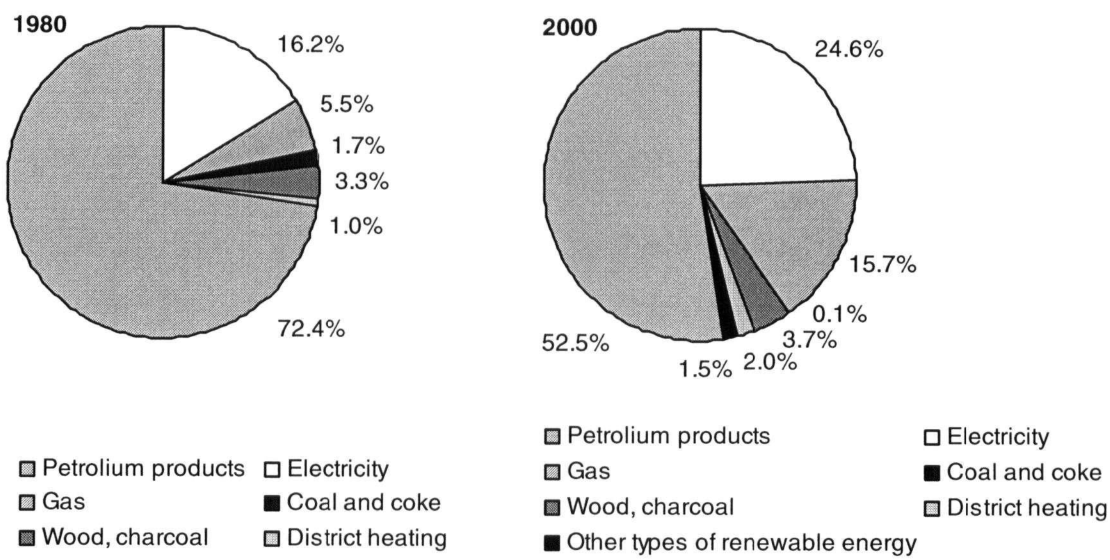


Fig. 2.9 Energy consumption of private households in 1980 and 2000 (SFOE, 2002: 23)

the 1960s) is observable (Fig. 2.9). While coal has almost disappeared, the use of wood, district heating and other renewable energies has strongly increased.

2.1.4 Economy

Despite its small size and few natural resources, Switzerland has had a flourishing economy for more than 150 years, relying on foreign trade with high-tech products and services. Switzerland's key trading partner is the European Union. In 2000, 58.9% of exports and 74.4% of imports (values) were achieved with the EU, 12.8% / 7.4% with the USA, 4.2% / 2.8% with Japan, and 24.1% / 15.4% with the remaining countries (SFSO, 2002:300).

Measured on its gross domestic product (GDP) of 404.4 million CHF and its export volume of almost 127 billion CHF in 2000, Switzerland achieves a middle position among the industrialised countries (OECD, 2002). Top-ten ranks are achieved with the GDP per capita, the high-tech goods exports (textile and machine-tools or precision instruments) and the financial market indices (Tab. 2.6). Switzerland's large import surpluses are due to agricultural and forestry products, textiles, clothing and shoes as well as vehicles. In contrast, chemical products, machines and electronic goods as well as precision instruments and watches achieve high export surpluses (Tab. 2.7).

	GDP [1] [billion US$]	Rank	GDP [1] / capita [US$]	Rank
USA	9,810	1	35,600	4
Japan	4,765	2	37,500	2
Germany	1,866	3	22,700	15
United Kingdom	1,427	4	23,900	10
France [2]	1,305	5	21,500	17
Italy	1,073	6	18,600	19
Canada	706	7	23,000	14
Switzerland	239	13	33,300	5
Sweden	229	14	25,800	8
Luxembourg	19	29	43,000	1
[1] at current prices and exchange rates				
[2] includes overseas departments				

Tab. 2.6 GDP 2000 of selected OECD countries (OECD, 2000)

Products	Import 1990	Import 2000	Import 2001	Export 1990	Export 2000	Export 2001
Total [million CHF]	96,611	128,615	130, 052	88,257	126,549	131,717
Product groups [% of annual total]						
Agricultural and forestry products	8.38	7.72	7.64	3.40	3.50	3.33
Textiles, clothing, shoes	9.11	6.92	6.91	5.65	3.07	2.99
Chemicals	11.00	17.03	20.19	20.88	28.36	31.76
Metals	9.34	8.35	7.94	8.54	8.61	7.94
Machines, electronic goods	20.49	24.56	22.75	28.92	29.35	27.35
Vehicles	10.59	11.59	10.89	1.68	2.41	2.31
Instruments, watches	5.99	6.24	6.28	15.10	16.21	16.43

Tab. 2.7 Foreign trade by product groups (SFSO online, 2002: Industry and Services)

Economic development over the last century

After World War II, Switzerland experienced a long phase of economic growth. Between 1960 and 1973, the annual average economic growth was more than 4%. Big investments, an increasing domestic workforce and a large number of temporary foreign guest workers brought prosperity and a high standard of living. Throughout that period of time, industry and trade (2nd sector) compensated for their decreasing workforce with automation and technological progress, achieving a strong increase in productivity.

The oil crisis in 1974 put an end to the long phase of economic growth. The immigration of foreign workers was stopped; economic problems made the dislike of foreigners grow. As well, the protection of the environment became a political issue; the former economic growth was revealed to be a major result of careless consumption of energy and wasteful use of natural resources. Since then, the environment has become a major factor in political, economic and social considerations.

Towards the end of the 1980s, after a phase of low economic growth, the labour market once more needed a large number of foreign workers. By that time, the price for real estate had climbed to the highest levels ever. But in 1990 the situation changed dramatically. The public deficit, subsequent expenditure cuts and a strong Swiss franc brought Swiss industries trouble. Switzerland lost its strong economic position, prices for real estate sank dramatically and the unemployment rate increased to a historical peak of more than 5% in 1996 - which, in comparison to the neighbouring countries, was still very low (SFSO, 2002:176). Even traditionally strong branches such as mechanical engineering or construction declined, while parts of the 3rd service sector (health, social work, education) grew. In 1999, this sector achieved more than 70% of the GDP in 1999 (SFSO, 2002:234).

Since 1994, the Swiss economy has slowly been recovering. The first notable signs of growth were seen in all branches in 2000. But the former strong economic growth has not yet returned.

2.1.5 Industry and trade

In Switzerland, small and medium-sized enterprises (SMEs) are important forces within the industry and trade. In 1998, 99.7% of companies had fewer than 250 full-time employees, employing about 69% of the total workforce. These companies have their markets mainly within the country; 86% of the SMEs do not export and 79% do not import. The Swiss federal statistical office attributes this to small outputs, missing distribution channels and the low level of name recognition (SFSO, 2002:300). The strength of these enterprises is their strong innovation potential and flexibility in their particular markets.

Most of the large industrial and trade companies concentrate on specialised high-quality and high-precision niche products. Internationally-standardised or mass products are rarely produced in Switzerland, as these products may not provide sufficiently for the high wage levels and for the strong Swiss franc. For example, about 95% of the 3.4 million Swiss watches were exported in 2000. Despite its price, the luxury Swiss watch is valued for its high-quality production, constant improvements in components and good customer service. These companies invest a large proportion of their turnover in research and development. They account for more than two-thirds of the research and development budget[3] and they reuse about three-fourths of it.

In Switzerland, economic crises and technological knowledge, together with a qualified workforce and the ideals of quality and precision have repeatedly developed to produce new ideas and products. Finding market niches, keeping organisation structures simple and promoting creativity and high product quality have been attempts to compensate for the high salary costs and the strong Swiss franc.

[3] In 2000, about 10.7 billion Swiss Francs or 2.7% of the GDP was spent towards research and development within the country. Considering the domestic R+D expenses per capita, Switzerland is ranked third after the USA and Sweden, followed by Japan in fourth position.

Building industry

The building industry is a key element of economic and social life. Despite the depression throughout the 1990s, in 1999 and 2000 this industry obtained about 10% of the GDP (SFSO leaflet, 2002:10). Between 1997 and 2000, the building industry showed the first signs of slowing, even though the top construction-expenditure levels were far below those of 1990. The total expenditure increase of 2,484 million CHF is mainly accounted for by public expenditures for underground engineering projects (+ 1,355 million CHF) and private expenditures other than housing (+ 1,098 million CHF), while private expenditures for housing increased by only 503 million CHF. Public expenditures for construction engineering (residential and non-residential constructions) decreased (Tab. 2.8).

	1980	1990	1997	1998	1999	2000
Total [million CHF]	**25,336**	**49,182**	**41,224**	**41,542**	**40,917**	**43,708**
Public expenditure	8,448	14,993	15,100	15,250	14,835	15,983
Underground engineering	5,037	7,999	8,705	8,516	8,616	10,060
of which roads	...	...	4,329	4,110	4,349	5,221
Construction engineering	*3,411*	*6,994*	*6,395*	*6,735*	*6,219*	*5,923*
Private expenditure	16,918	34,189	26,124	26,292	26,081	27,725
of which housing	...	...	*16,644*	*17,145*	*16,783*	*17,147*

Tab. 2.8 Construction expenditures between 1980 and 2000 (SFSO online, 2002: Construction and housing)

Wood building industry

The strongly-decreasing market share of wood as a construction and building material in the mid 1960s put an end to the fairly stable level of about 30% since the end of the 19th century. About twenty years later, the market share of wood achieved its lowest level at less than 10% (Winter, 1995). In the 1970s and early 1980s, wood - the traditional and natural building material - did not have a place in the promising future geared to the achievements of a flourishing economy and technological progress. Throughout that time, wood was used only for roof construction and houses in remote or traditional areas, or for non-residential buildings (Fig. 2.10).

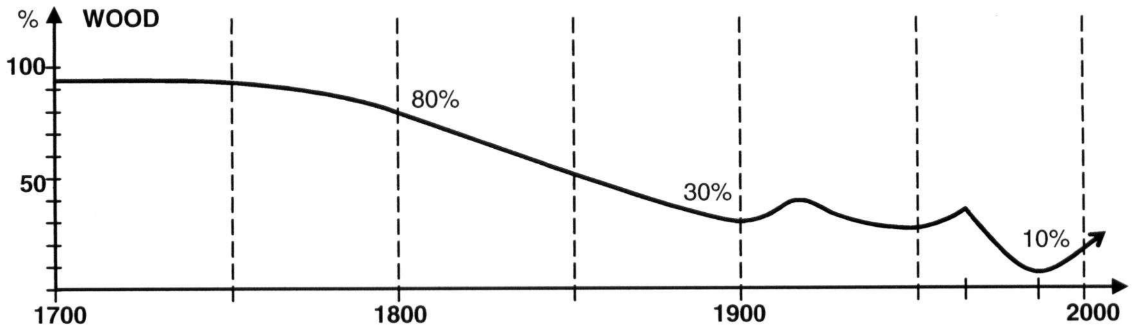


Fig. 2.10 Development and importance of wood as a work and building material in Switzerland (Source: Adapted from Winter, 1995:2)

Between 1991 and 1996, the consumption of wood increased by 8% to about 850,000 m^3 (SFSO 2000: 7). But according to the Swiss Association of Woodworking Industries (Lignum), the use of wood for construction purposes has still not tapped its full potential. Based on the availability of local wood and current demand, it is believed that the use of construction wood could be about ten times as high as it is now; the use of construction wood would increase from about 1,900 m^3 to 19,000 m^3 annually. As well, the use of wood for finishing materials, facades or insulation might also grow, while the use of wood in roof constructions and furnishing is believed to decrease (Fig. 2.11).

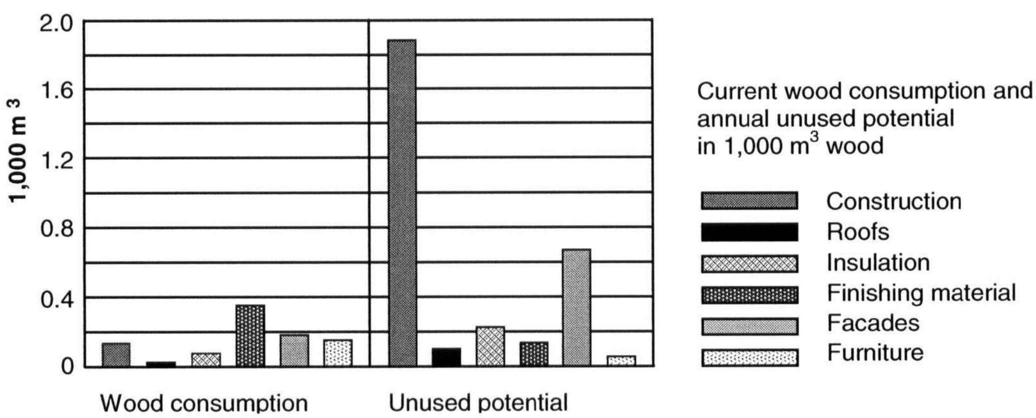


Fig. 2.11 Current wood consumption and annual unused potential *(Lignum online, 2002)*

Development since the mid 1980s

In contrast to the collapsing economy, the wood building industry was revitalised in the early 1990s. While many traditional sawmills and carpentry firms had to close down throughout the 1990s, many small new carpentry firms have been developing. The influence of telecommunication and computer technology has opened the stagnating traditional wood building industry and called for new products (factory production of houses, new joining techniques or new lumber norms) and services (consultancy, construction and maintenance) (Netzwerk Holz, 1999). Today, successful small or medium-sized carpentry firms are spread all over the country. Most of them (e.g. Renggli AG, or Schöeb AG) rely on highly industrialised and automated production processes implementing Computer Numerically Controlled (CNC) machines or CAD-CAM technology and, potentially soon, robots.

It is probable that the development of the new wood building industry in Switzerland has followed a similar path to that of the successful high-tech industries (see Chapter 2.1.5 Industry and trade). This means that the deep crisis within the timber and building industry, along with strong technical know-how and a qualified and motivated workforce, as well as ideals of quality and precision, may have evolved to produce quality niche products that accord with the contemporary spirit of the age. Produced as niche products, these new houses in wood are valued for their individuality, design, energy efficiency, health and comfort. For numerous clients these striking characteristics might count much more than a potentially lower price.

However, factory-built wooden houses imported from Austria and Germany are putting pressure on the residential wood building market. Between 1998 and 2001, the number of imported factory-built houses jumped from 159 to 279 houses (those from Austria increased from 14 to 76 and those from Germany increased from 145 to 203) and accounts for about 20% of the new wooden houses per year (VGQ, 2002). The benefits of these houses are low primary costs, short delivery times and their readiness for immediate occupation.

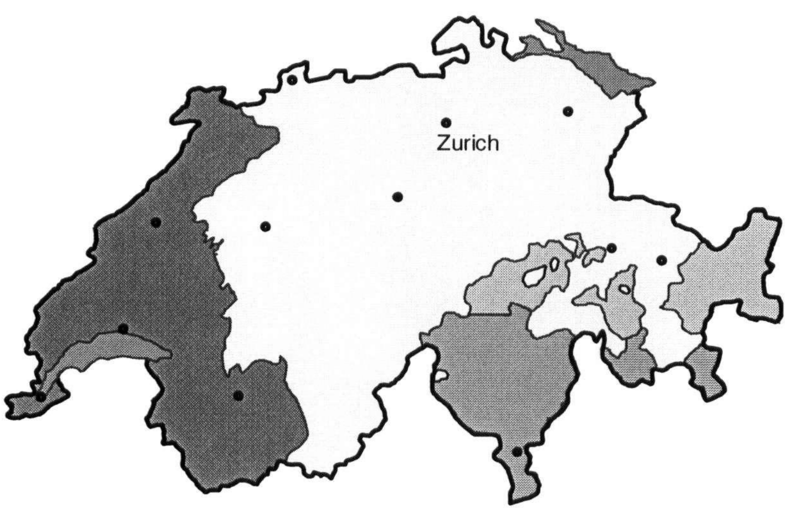
2.2 People

This chapter discusses aspects of culture, politics, population and demography, education and workforce, social life and lifestyle society, as well as wealth and housing.

2.2.1 Culture

Linguistic and ethnic development

The linguistic and ethnic character of today's Switzerland developed through the immigration and settlement of different population groups into the area of today's Switzerland, up to 900 A.D. Since then, the clear language regions have barely mixed; the four official languages, German, French, Italian and Romansh, are still spoken and written in Switzerland (Fig. 2.12). The language boundaries also indicate considerable differences in mentality; often, these differences are visible in the outcome of public votes. Whereas the Swiss Germans care about environmental issues and defend the independence of the country, the French and Italian parts of Switzerland are strongly associated with their neighbours in France and Italy, as well as with their lifestyles.



German (Heathen Allemannian tribes, region became German speaking by 900 A.D.)

French (Christian Burgundians, adopted the Latin Language of the resident Roman population)

Italian (Lombard tribes, kept their Gallo-Italian Lombard dialect)

Romansh (The Rhaeto-Romans, resisted the Allemannian immigrants and kept their language)

Fig. 2.12 Language boundaries in Switzerland (PRS, 2001: Federalism and multilingualism)

Conservation of cultural heritage

Aware of their cultural wealth, Switzerland started to support the preservation of monuments by federal grants[1] in 1886. Towards the end of the 19^{th} century, the increasing reconsideration on national traditional values (see chapter 2.3.1 Modern Architecture and Country-Style) also increased interest in vernacular buildings. As a result, numerous roman ruins, medieval castles, monasteries and churches, along with well-preserved old cities, villages and buildings (including many traditional buildings in wood) still showcase Switzerland's large cultural heritage all over the country. For 25 years, the open-air museum at Ballenberg (Bernese Oberland, central part of Switzerland) has exhibited a large collection of traditional Swiss farmhouses. In 1975, a collection of Swiss heritage sites was started. The inventory of Swiss heritage sites (ISOS) currently includes about 5,800 sites, among them many originating in the 20^{th} century (Heusser, 2004).

Customs and festivals (religious and seasonal traditions, popular music, folk dance or theatre) and other aspects of life (e.g. how people feed, clothe or amuse themselves) have been actively or passively preserved by various societies and foundations over the last century. Within the central and eastern part of the Alpine range (Switzerland, Northern Italy, Austria) the festival tradition has remained very rich. In addition, over the past few decades forgotten religious and seasonal customs have been revived and several new festivals have been created (Thüler, 1997:23). These cultural events belong to specific locations or certain regions more than they are determined by political boundaries.

2.2.2 Politics

In 1291 the first three cantons (Uri, Schwyz and Unterwalden) swore mutual aid and support. Other cantons soon joined the alliance to protect their autonomy and their own legal systems against the dominance of the Habsburg Empire. After centuries of internal disputes, the occupation by Napoleon, and religious and civil wars, the democratic 'Confederatio Helvetia' (CH) was founded in the middle of the restored European monarchies in 1848. The new state granted freedom of worship and press, and the

[1] In 1999, Switzerland spent about 37 million CHF on the preservation of natural heritages and monuments.

neutrality of the country was recognised internationally. Today, Switzerland still relies on the essential features of the first constitution, though they have been adapted to meet present-day demands.

Hierarchical structures

Switzerland's confederation consists of 26 autonomous cantons (20 full cantons and 6 half cantons) and 2,929 local municipalities. All divisions, the Confederation, the cantons and the municipalities, perform legislative, executive and judicial functions administered by different autonomous authorities. Each division has its own legislation as well as its own financial sources (taxes or charges). The interplay of the autonomous municipalities, cantons and federation is given by the hierarchical structure of the divisions.

The federation is in charge of interior and exterior security as well as economic development and general welfare. Cantons are responsible for education, police, health and cantonal roads. Municipalities provide local infrastructures such as the provision of water and energy, the disposal of waste, and local streets, as well as schools and social and cultural institutions. In addition, they are in charge of income taxes. Despite their autonomy, over the past few years a closer cooperation between the cantons has become necessary to master complex problems or duties efficiently (e.g. delinquency, medicine, higher education).

Administrative authorities

The organisation of the administrative authorities is similar to that of the divisions themselves. For example, the following sections describe the organisation of the administrative federal authorities.

Administrative federal authorities

The administrative authorities of the confederation consist of the *Federal Assembly* or parliament (legislative authority), the *Federal Council* or government (executive authority) and the *Federal Court* (judicial authority).

The Federal Assembly is made up of two chambers, the *National Council* or big chamber (200 seats) representing the population, and the *Council of States* or small chamber (46 seats) representing the cantons or states. Decisions taken in the two chambers have equal weight in order to balance the interests of the cantons. The seats in the National Council are distributed between the cantons in proportion to their populations. In contrast, in the Council of States each full canton is represented by two seats and each half canton by one seat. The members of both chambers do the job part-time, and they are elected or re-elected by the citizens every four years. They meet four times a year for 3 weeks at a time to approve federal laws and supervise the government. Each member of the two chambers is entitled to propose a new law or decree and put questions to the Federal Council about any matter concerning state affairs. The Federal Assembly comes together only once a year to elect or re-elect the councillors and the head of the Federal Council as well as other bodies and state officials.

The Federal Council consists of 7 councillors representing the major political parties of parliament (two central parties, the Radical Democratic Party (FDP) and the Christian Democratic Party (CVP); one left-wing party, the Social Democratic Party (SPS); and one right-wing party, the Swiss People's Party (SVP)) and the different regions. One of the councillors, annually elected by the Federal Assembly, heads the Federal Council for one year at a time. Each councillor presides over one of the seven Federal Departments: 1) foreign affairs; 2) home affairs; 3) justice and police; 4) defence, civil protection and sport; 5) finance; 6) economic affairs; and 7) environment, transport, energy and communications. According to the collegiate system the councillors are collectively responsible for the decisions taken within the Federal Council.

The Federal Court in Lausanne is the highest judicial institution in Switzerland. It protects the constitutional rights of the citizens against the arbitrariness of authorities and administrations (Ambühler, 2002).

Semi-direct Democracy and Federalism

The Swiss Democracy is unique in that the highest political authorities are the citizens themselves. Not only do they elect or re-elect the municipal and cantonal authorities (government and parliament) or the members of the federal assembly; but also four to six times a year all citizens over 18 years are asked to vote on municipal, cantonal and federal issues alike (e.g. changes of the constitution, new laws or approval of federal finances). Together with the right to make initiatives or referendums, citizens may take part actively in democratic aspects of public life or local affairs and themselves play the role of the opposition or the establishment.

Federalism has been a way to unite the dissimilitude of the country in terms of natural and geographical regions, cultural and political interests, and economic differences. However, inequality of rights (e.g. varying tax levels from municipality to municipality), inefficiency (e.g. different building laws in each canton), slowness (e.g. public referenda may take several years to go through) and big coordination efforts are strong disadvantages of the system; also, the need to accept a compromise rarely allows taking brave or seminal decisions. Nonetheless, the initiative of individuals has often led to seminal federal discussions or decisions. This has also been the case in initiatives concerning the environment, such as the demand for the abolition of nuclear power plants or the adoption of car-free Sundays.

Policy

Home policy

As a result of the semi-direct democracy and federalism described above, the political system in Switzerland is very stable; changes take place by a process of gradual changes rather than by sudden disruptions, and decisions are always based on compromises. Despite Switzerland being one of the oldest democracies, women only got the right to vote at the federal level in 1971. Most cantons followed the federal example in 1983, while a mandate of the federal court forced the last canton to change its practice in 1990. Since then, the influence of women in federal and cantonal governments and parliaments has slowly increased; in 1984 the first woman was elected to the Federal Council. However, the Federal Council still consists of one woman and six men.

Foreign Policy

Switzerland has actively taken part in many different international organisations (PFP, OSCE, FAO, ILO, UNESCO, WHO, UNHCR and several others) for many years. Recently, Switzerland's population agreed by public vote to join the United Nations Organisation (UNO), to which it has been affiliated since the end of 2002. Nonetheless, Switzerland is not part of the European Union (EU); the population rejected it by public vote in 1996. Still today, Switzerland is a political island in the middle of Europe with its own currency and policy, dealing with the EU through bilateral agreements in all sectors. However, the increasing dependency of different countries on each other and the growing importance of international cooperation require Switzerland's foreign policy - without a need to give up the commitment to neutrality - to be more targeted and internationally present. The basis for such actions (e.g. peacekeeping operations) has newly been included into the revision of the Federal Constitution (January, 2000).

Environmental concerns

Environmental concerns have become a strong influence on politics over the last thirty years. Prompted by the oil crisis in 1973 / 74 (see also chapter 2.1.3. Energy consumption) and the suspicion that the dying of the forests was a result of increasing air pollution (see also chapter 2.1.1 Land use, and chapter 2.2.2 Forest laws), Switzerland has enforced research into environmental problems such as air pollution, energy use and forest health. Since then, a reduction in fossil-energy consumption, the use of renewable energies and a limit on the emission of CO_2, as well as the health of the forests, have become key issues in the environmental debate.

Whereas Switzerland keeps an eye on global development and supports major environmental strategies, it does not often take an active part in the operations of international networks. It appears that Switzerland may not want to subordinate its own interests, and that it aims at being better than the others. As such, most of its environmental activities are based on federally, cantonally or municipally-launched programs and/or on eager individual initiatives (see also chapter 2.2.2 Semi-direct democracy and federalism), such as the Energy2000 or the 2,000-watt society.

The *Energy2000* program (1990-2000) was the first voluntary and federally-supported 10-year program to stabilise the increasing energy use and CO_2 emission by 2000, as well as to increase the use of renewable energies (SFOE, 2001). The goal of this program was to achieve a reduction in CO_2 emission of 10% between 2000 and 2010, as well as to limit the growth of electricity demand to 5% and to increase the share of renewable energies used to 1% of transport energy and to 3% of heating energy (SFOE, 2001). This national program has funded more than 3,500 research projects with a total of 64 million Swiss Francs (CHF). While the initial goal at the turn of the 1990s was to stimulate the building industry federally, on the initiative of Luzius Schmid, deputy head of the Swiss federal office of energy (SFOE), the subsidies were tied to environmental strategies connected with the content of the Kyoto protocol. In 2001, the program was succeeded by the 10-year *SwissEnergy* program, focusing on buildings, economy, mobility and renewable energies.

The idea of a '2000-watt society' was initiated by Dieter Imboden, a member of the council of the Swiss Federal Institute of Technology (ETH Rat) in 1998. The goal was to reduce worldwide energy consumption to a benchmark of 2,000 watts per person by 2050. The benchmark of 2,000 watts per person per year is based on the total global energy consumption in 1990. In that year, the worldwide average energy consumption per person was 17,500 kWh or 2,000 watts (about 45 kWh/d). However, with a consumption of 500 watts per person per year in Ethiopia, 10,000 watts in the USA and 6,000 watts in Switzerland, the regional differences are huge (Bueller, 2002). That means that Switzerland would have to reduce its energy consumption by two thirds. What started as the idea of an individual person is now seen as a long-term goal to comply with the Swiss energy and climate policy, and to become the successor to the SwissEnergy program in 2011. So far, an unused industrial area in Basel has already been redeveloped to become the first pilot project area (recreational use) for a 2,000-watt society, and others (workplaces and living areas) are yet to come.

Besides these specific endeavours to reduce the consumption of energy and the emission of CO_2, Switzerland anchored the protection of the environment into the revised Federal Constitution (January 1, 2000). This step represents a milestone for more sustainable development in Switzerland and has become a symbol of substantial and significant intentions for future changes (Federal Chancellery, 1999).

Also, at the Johannesburg conference in 2002, Switzerland presented a program containing 22 environmental strategies. They rely on the attempt to achieve a more sustainable economic, social and environmental development. Key strategies for the planning and building industry are (Swiss Federal Council, 2002):

- Environmental and incentive taxes on resources
- A (life) cycle evaluation policy for products and services
- The vision of a 2,000-watt society
- The limitation of the average urban area to 400 m^2 per capita
- The support of public transportation and sustainable mobility
- New forms of funding for sustainable developments
- Environmental education, monitoring and assessment of sustainable development

In the same year, the Federal council enacted a law to reduce CO_2 emission. It requires a 10% reduction in CO_2 emission towards the 1996 level by 2010, while the emissions caused by heating and transport fuels have to be reduced by 15% and 8%, respectively. The law includes a potential CO_2 tax in the case of non-achievement (Federal Chancellery, 2002). Early in 2003, the cement industry - most probably not voluntarily - signed a federal declaration to reduce its CO_2 emissions by 2010 to a level of 44% (fossil fuels) and 30.3% (production process) below the 1990 level, (Tages Anzeiger, 2003). Only shortly afterwards (July 2003), Switzerland ratified the Kyoto protocol.

The broad range of research activities and environmental programs over the last years has not only led to an increased sensibility within the population towards environmental problems, but has also led to the adoption of new laws and regulations within the building industry.

2.2.3 Legislation

Planning and building legislation

Planning and building legislation relies on a dense, hierarchical network of federal, cantonal and municipal laws and regulations. Those relevant to building practices are the use-zoning plans of municipalities or towns as well as the federal, cantonal and municipal planning and building laws and regulations. Together they define where, what and how to build by asking a specific goal or performance of a site, a building or a building part. Conformity to these requirements is necessary to obtain a building authorisation for the construction of a new building, major changes to an existing building or major changes of use.

Use-zoning plans

The federal use-zoning plans assign major use zones (agricultural zone, building or protected zones). While these plans are very general, they are further refined in those of the cantons and municipalities. The cantonal and municipal *use-zoning plans* assign the major use zones to single lots and give them specific uses and aspects (e.g. type of residential area, maximum number of storeys or maximum living area per lot size). This information is relevant for landowners. (Engeler 1992:15).

Planning and building laws

The federal planning and building laws provide the basic principles for planning and building practice in Switzerland. They consider general aspects such as energy, traffic, forestry, environment, water, air, soil, noise, radiation and waste.

The cantonal planning and building law contains fire regulations, regulations on thermal insulation and energy use and basic regulations of use, construction, form and size of a building, as well as distances from neighbouring lots, forests or water bodies and green spaces, or specific aspects of a building, such as minimum room height and size. Often, the cantonal legislation includes requirements for the conservation of nature, culture and heritage.

Building codes of municipalities or towns further refine the cantonal legislation, or define specific aspects of a building not considered by the canton, such as maximum height of a building, specific roof forms and exterior colours or materials, as well as distances from neighbouring buildings or streets. This may be important for the protection of historic sites or quarters of towns. However, building codes of municipalities and cities often include an 'aesthetics clause' that allows them – very much at the discretion of the local authorities - to deny building permission to buildings that fulfil all legal aspects except for the desired aesthetic value.

Energy performance of buildings

Since the oil crisis in 1973 / 74, the increasing requirements for thermal insulation of buildings have considerably reduced heating-energy use (seen section 2.1.2 and Fig. 2.5). By the end of June 2002, most cantons had decreed a new energy law for new buildings, relying on a standard (SIA 380/1, 2001) of the Swiss society of engineers and architects (SIA). In the canton of Zurich, the new energy law requires new buildings to reduce the use of non-renewable energy for heating and domestic hot water to 80% of the permitted energy consumption. Clients determine whether they will use non-renewable energies, waste heat or improved thermal insulation to compensate for the remaining 20% of energy (AWEL, 2002:5). The performance of the enclosure may be proven by the total heating energy need; U-value (thermal transfer of building elements in W/m^2K) calculations of single building elements are only tolerated if limited elements with low U-values are used (Tab. 2.9).

These new requirements considerably improve the energy performance of new buildings towards the goal of the 1997 legislation. In addition, they are about to change the element-related method using the U-values of single elements to a building-related performance evaluation of the building's overall consumption of energy for heating and domestic hot water and, they promote the use of renewable energies. As such, the new code requirements are adopting the practice defined by the advanced voluntary building standards (Minergie, Minergie-P and Passive House). However, the current code requirements are as yet far from reaching the Minergie or Minergie-P standards (see section 2.3 Advanced voluntary building standards).

	Requirements according to thermal insulation regulations		Solution A: Improved thermal insulation (minimum plus 30%)	
U-values for indoor air temperature of 20°C	Towards out-side climate	Towards non-heated rooms*	Towards out-side climate	Towards non-heated rooms
Roof, ceiling, wall, floor	0.30 W /m^2 K	0.40 W /m^2 K	0.21 W /m^2 K	0.28 W /m^2 K
- with integrated heating	0.25 W /m^2 K	0.30 W /m^2 K	0.17 W /m^2 K	0.21 W /m^2 K
Windows	1.70 W /m^2 K	2.00 W /m^2 K	1.19 W /m^2 K	1.40 W /m^2 K
- with adjacent radiator	1.20 W /m^2 K	1.60 W /m^2 K	0.84 W /m^2 K	1.12 W /m^2 K
Doors	2.00 W /m^2 K	2.0 W /m^2 K	1.40 W /m^2 K	1.40 W /m^2 K
Restrictions: - This energy efficiency standard is tolerated only if the total area of windows and doors accounts for less than 20% of the respective heating-energy relevant area. - Thermal bridges need to be considered according to SIA 180/1.				

Tab. 2.9 Thermal insulation regulation of the canton of Zurich (Source: AWEL, 2002).

Forest legislation

The prevailing forest legislation is important to the way the local forests can be harvested as well as to the amount, the quality and the costs of the resulting timber. The newest forest law (WaG, October 4, 1991) not only considers the quantitative aspects of forests (as did the previous ones), but also the qualitative ones. It requires (Article 1):

a) the preservation of the forest in area and spatial distribution
b) the protection of the forest as an ecosystem near to nature
c) the best possible ability of forests to fulfil their protective, social and commercial functions
d) the promotion and support of forestry

Here, protective functions include protection against natural disasters, such as avalanches, floods, landslides, erosion, falling rocks or storms. Social functions include the provision of natural habitats for plants and animals, recreation and activity space for people, the classification of landscape, the production of oxygen, the filtration and storage of water, the filtration of air, noise protection and the reduction of climate extremes. Commercial functions consider the use of timber as a renewable and domestic natural resource and energy source, as well as employment opportunities in forestry and associated trades for about 90,000 people, mainly in rural areas (Federal Chancellery, 2002: 921.0:1-16).

The adoption of the new forest law was an important step towards the re-evaluation of the local forests. The connecting of protective and social functions with commercial ones at once increased the importance of the forest, timber and wood building industry. Moreover, the forest and timber industry were given new arguments to emphasize the importance of a sustainable forest harvest as well as the need for an increased use of wood to limit the number of over-aged trees. Proof of this assumption was given in winter 1999, when hurricane Lothar felled 10 million trees in only few minutes. As well, the wood building industry strongly emphasises the benefits of wood in the CO_2 debate.

2.2.4 Population and demography

Since the beginning of the 20th century the population in Switzerland has more than doubled, reaching 7.2 million inhabitants in 2000. After a peak between 1950 and 1970, population growth has stabilized at an average rate of 0.6 - 0.7% (SFSO, 2002:32-33). Yet decreasing births rates since 1965 and increasing emigration of Swiss citizens after 1992 would have led to a negative population growth in Switzerland since 1994, if it were not for the foreign population. Birth excess of foreigners (since 1960) and migration (after 1980) have become the deciding factors for the slight population growth in Switzerland.

Like other industrialised countries, the age structure of the population in Switzerland has strongly changed over the last century as a consequence of higher life expectancy and lower birth rates. In 2000, the average life expectancy reached 82.6 years for women and 76.9 for men (SFSO, 2002:64). At the same time, the average birth rate of 1.46 children per woman is far below the critical 2.1 mark. The trend towards an increasing proportion of old people is expected to continue. However, the fast ageing process in Switzerland is reduced by the presence of the foreign population. First, young foreigners often come in for work. After retirement or upon finishing their job they move back to their family in the home country. Second, foreign women tend to have more children than Swiss ones. In 2000, the average birth rate per foreign woman was at 2.0 children versus 1.3 per Swiss woman. In 2000, 27% of the children born in Switzerland were of foreign nationality.

In Switzerland, foreigners account for almost 20% of the population as a result of outdated and restrictive immigration regulations. The majority of these people were born in Switzerland (almost 25%) or have been living here for more than 15 years (36%). Unlike other countries, babies born in Switzerland get a Swiss passport only if at least one of their parents has Swiss citizenship. The percentage of foreigners in Switzerland would decrease to less than 7% by counting only those people who have lived in Switzerland for a limited period of time (SFSO, 2002:33). But, simplified naturalisation of second-generation foreigners and automatic naturalisation of third-generation babies was again rejected by public vote in 2004; a majority of Swiss citizens (particularly in the German and Romansh-speaking part) does not want "to give the Swiss citizenship away". This is despite the fact that Switzerland strongly relies on the foreign workforce (compare to Chapter 2.2.5 Education and Workforce, and 2.3.1 Local building culture).

2.2.5 Education and workforce

Education

"Education, research and technology are Switzerland's most important resources" (SFSO, 2002:652 [translation]). As a consequence, the federation as well as the cantons and municipalities spend about 6% of the GDP or almost 15% of the total public expenses on education. With this expenditure volume, Switzerland ranks among the top OECD countries.

In Switzerland, compulsory school on average lasts 9 years, followed by several possibilities for post-compulsory education. Due to the cantonal responsibility for the education system, considerable regional differences arise in the length of study, teaching materials or salaries for teachers. Whereas reformations of the education system have created more equity among schools of different regions and eased the acceptance of different diplomas within Switzerland over the last 30 years, international exchanges are still difficult.

Vocational training is the most popular post-compulsory education in Switzerland. About three-fourths of young men and about two-thirds of young women choose to enter an apprenticeship (Tab. 2.10). In this form of education, the combination of hands-on training and theoretical education provides deep insight into the specific know-how of the future profession. Also, this education hands traditional knowledge down from generation to generation. This is a very important factor in the education of carpenters. Still today, the high levels of know-how in traditional wood building techniques are passed down to the new generation of carpenters.

Education level 2	total	[%]	men	[%]	women	[%]
(education determined)	1990/91	2000/01	1990/91	2000/01	1990/91	2000/01
Vocational training (2 to 4 years)	72	70	77	76	67	64
Gymnasium	13	18	13	16	13	20
Teaching schools (kindergarten, others)	2	1	1	0	3	2
Non post-compulsory or short-term educations	13	11	9	8	17	14

Tab. 2.10 Education of 20-year olds (Source: Adapted from OFS, 2001)

Workforce

Switzerland shows the characteristics of a service society that are common to all advanced industrial nations, due to technical progress (automation of fabrication) and globalisation such as outsourcing of production to low-wage countries (SFSO, 2002:166). Since 1900, employment in the 1st sector has dropped from about 36% to 4.5%. In the 2nd sector it has decreased from about 40% to about 26.5%, whereas the workforce of the 3rd sector has increased from about 24% to 69% (see also chapter 2.1.4. Economy). Women have profited from the increasing number of jobs (also part-time jobs) in the 3rd sector, where they account for 50.7% of the workforce. However, women depend on part-time jobs to be able to combine job and family. In contrast, the number of men in part-time jobs is low and only slowly increasing (Tab. 2.11).

Workers [% of population]	1970	1980	1991	1999	2000
Total	48.3	47.8	54.0	53.2	53.0
Women	32.9	34.1	43.2	44.4	44.6
Men	64.4	62.2	65.3	62.4	61.8
Foreigners	63.2	55.3	64.9	58.6	57.4
Swiss	45.5	46.5	51.8	51.9	52.0
Workers in sectors [%]	1970	1980	1991	1999	2000
Agriculture and forestry (1st)	8.5	6.9	4.2	4.7	4.5
Industry and trade (2nd)	46.2	38.1	31.0	25.9	26.4
Public and civil services (3rd)	45.3	55.0	64.7	69.4	69.1
Part-time workers [% of workforce]	1970	1980	1991	2000	2001
Total	...	...	20.6	25.6	26.9
Women	...	...	43.3	49.6	51.1
Men	...	...	5.7	8.3	9.2

Tab. 2.11 Workforce in percent of the respective population (Source: SFSO leaflet, 2002:8)

Within the European context, Switzerland's workplace is characterised by long working hours, high salaries, low unemployment rates and few strikes. In 2000, on average a full-time employee worked 41.8 hours a week or about 1,800 hours a year (Tab. 2.12) and earned 5,220 CHF a month or about 68,000 CHF (gross income) a year (Tab. 2.13). As yet, women's wages are lower than men's, even though a federal law was implemented two decades ago to address this (SFSO, 2002:172-173). After a rise in the unemployment rate to more than 5% in 1997 (up to 14% in EU countries) it sank to about 2% in 2000 (Kümmerle+Frey, 2001:28; SFSO leaflet, 2002:8, 16). Throughout the 1990s, strike losses only made up about 1.5 days per 1,000 workers per year. Since 1937 a 'peace agreement' between employers and major trade unions does not allow an employee to strike or to use other lockout practises.

The fear of attracting too many foreign workers due to the high salaries and the low unemployment rate (compare to Chapter 2.2.4 Population and demography) was a main reason why Switzerland hesitated to sign the bilateral negotiations on labour mobility with the EU[2]. On the other hand, high wage levels and expensive products strongly restrict the potential to export locally processed or produced goods.

	Net wage level [1]	Taxes [2] [%]	Annual working hours	Paid vacation days	Prices [3] (excl. rent)	Apartment rents [4] [USD]
Zurich	100 (index)	26.1	1,868	24.7	100 (index)	1,140
Geneva	90.2	31.6	1,842	24.4	94.4	780
Frankfurt	61.7	36.2	1,688	31	76.2	820
London	66.8	22.8	1,833	22.2	94.8	2,450
Milan	41.9	33.4	1,732	22.8	66.8	810
Paris	57.8	24.5	1,587	28.3	81.6	980
Toronto	61.0	28.8	1,967	11.7	74.9	820
New York	97.2	28.9	1,882	13.3	103.8	2,200
Tokyo	120.8	19.2	1,868	20.5	140.1	2,160
Moscow	5.9	13.4	1,824	21.4	59.1	1,510

[1] Actual hourly wages in 12 professions, after deduction of taxes and social contributions.
[2] Taxes and social contributions as a percentage of gross wages.
[3] Cost of a basket of 111 goods and services, weighted by consumer habits
[4] Medium price range of unfurnished 2-bedroom apartment in USD

Tab. 2.12 Prices and earnings of selected cities in 2000 (UBS, 2000: 6-8, 17,27)

[2] The Schengen-agreement was signed mid 2004; yet it has to be accepted by public vote in 2005.

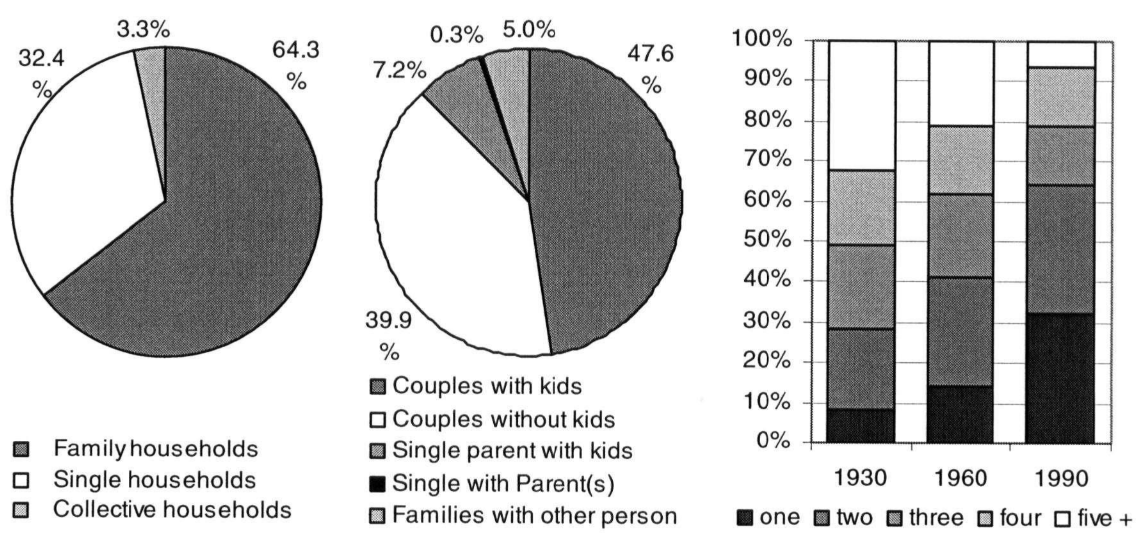
2.2.6 Social life and lifestyle

Social life

Private households

In 1990, 83% of the population lived in one of the various forms of family households, such as parents or common-law partners with children, couples without children, families with another person or singles with a parent. But private households are no longer dominated by traditional families. Single households account for 32.4% of private households, followed by traditional family households (parents with children) with 30.6% and couples without children with 25.6%. Single-parent families with children account for 4.6%, families with another person for 3.2% and singles with a parent for 0.2%. The majority of single households are accounted for by widowed women over 64 years (59%). Women often live longer than their husbands (higher life expectancy). In contrast, the majority of men in a single household are under 40 years old and divorced. They often live alone as the children generally live with their mothers. Indeed, 85% of single-parent families are women living with their children (SFSO 2002:37).

As a result of the growing number of single-parent family households, couples without children and single households (14% of the population), the average size of households has largely decreased (Fig. 2.13). Three-generation families virtually do not exist any more even though they were widely spread at the beginning of the last century (SFSO 2002:42).



a) Private households in 1990 *b) Family households in 1990* *c) Number of persons per household in 1930, 1960 and 1990*

Fig. 2.13 Structures of private households (Source: SFSO, 2002: 99).

Changes of the traditional family

The changing role of women is having a strong impact on the picture of the family. Better education and a changed workplace have increased job opportunities and economic independence for women. As a consequence, getting married and having children is postponed to a later age, and married women tend to keep on working. In contrast to most European countries, the marriage rate has remained fairly stable over the last two decades. This is a consequence of the unsatisfactory legal situation for common-law partners and parents with children. However, marriages no longer last for a lifetime, and children may only delay an upcoming divorce. Between 1950 and 2000, the divorce rate in Switzerland increased from 4% to 22% (SFSO 2002:40). Nonetheless, the traditional family - with women caring for children and household - is still central to a large percentage of Swiss people, as well as of political decisions.

Lifestyle

Income and expenditure of private households

Switzerland is a very wealthy country with a high wage level, and it is an expensive land to live in. In fact, 50% of the population earn less than 6,170 CHF a month (80,200 CHF a year), while the monthly expenditures for an average family (with an average of 2.4 persons) amount to 7,634 CHF. Notably, insurances, taxes, accommodation and energy make up 54.5% of the monthly expenditures (Tab. 2.13).

Between 1990 and 2000, most of the consumer expenditures (except for accommodation and energy, communication, entertainment, recreation and culture) decreased while major increases occurred in accommodation and energy (about 30%) as well as costs for health insurance (almost 50%). However, consumer prices (increase by 21.2%) and salaries rose in a similar range throughout the 1990s, keeping the purchasing power (prices / salaries) fairly stable.

In 1998, the expenditures of private Swiss households were 32% over the average expenditures of the 15 (old) EU countries. There are considerable differences in certain products such as food, medical expenses, accommodation and domestic water, and public transportation. Yet even though building in Switzerland is considered to be very expensive, expenditures for building construction, machines and equipment material appear to be only slightly above the average of the EU countries, while furniture and finish flooring are actually cheaper (Tab. 2.14).

Gross salaries		[CHF[2]]	**Expenditure structure**	[%]
Average annual gross income		**67,860**	(of total expenditure)	
			Consumer spending	**63.1**
Average monthly gross payment		5,220	Food, non-alcoholic beverages	8.3
(full-time job with 13 monthly salaries)			Alcoholic beverages and tobacco	1.3
10% of population		> 8,900	Clothing and footwear	3.3
80% of population	between	< 8,900	Accommodation and energy	17.6
	and	> 3,440	Furnishings	3.2
10% of population		< 3,440	Health	4.0
			Transport	7.5
Swiss men		5,900	Communications	1.8
Foreign men		4,700	Entertainment, recreation and culture	6.7
Swiss women		4,500	Education	0.4
Foreign women		3,700	Restaurants/hotels	6.5
			Other goods and services	2.5
Monthly gross income				
Average gross income		**5,655**	**Withholdings**	**36.9**
(full-time job distributed over 12 months)			Social security contributions	9.5
			Health insurance (basic insurance)	4.8
Monthly expenditure			Health insurance (supplements)	1.8
per household, relying on 2.4 persons		**7,634**	Other insurance payments	4.7
			Taxes and fees	13.6
[2] 1 CHF = 1 CAD (rate: July 1, 2002)			Contributions and other transfers	2.6

Tab. 2.13 Income and expenditure structure of private households in 2000 (Source: SFSO online, 2002: Industry and services, and SFSO, 2002: 172).

Food	129%	Individual transportation	89%
meat	172%	Individual vehicle	115%
milk, cheese, eggs	137%	Public transportation	146%
fruits, legumes, potatoes	132%	Hotels and Restaurants	129%
Tobacco	88%	Furniture and floor finishing	96%
Medical expenses	166%	Machines and equipment material	103%
Clothes and shoes	100%	Building construction	105%
Apartment (incl. domestic water)	181%	Mail and telecommunication	104%
Heating and light	92%	Books, magazines, newspapers	123%
Appliances	117%	Leisure articles and equipment	110%

Tab. 2.14 Expenditures for specific products in relation to the average of the 15 EU countries in 1998 (Source: SFSO, 2002: 274).

Social security

Switzerland has become the best-insured population in the world. Besides a broad range of voluntary and mandatory personal insurances (unemployment, health and accident, third party risk, legal protection, and many more) the pension scheme has become an important factor of the social security of the aging population. The pension scheme consists of three pillars: the national old-age, surviving dependant's and disability pension scheme (AHV/IV), the employer's staff pension scheme (BVG) and the private old-age saving insurance scheme (Kümmerle+Frey, 2002:54-55). As well, Swiss people spend a lot on insurance against potential loss or damage of possessions such as houses, household effects, cars or jewellery.

Waste and recycling

The amount of household waste has risen considerably since 1996. In 2000, a total of about 4.73 million tons of waste or 660 kg / inhabitant were produced. But Switzerland also is a nation of recyclers: In 2000, about 42.5% (2.01 million tons) of total household waste was recycled. The largest recycle figures were achieved in aluminium tins and glass, at more than 90%. Also, the recycling percentages of PET (over 80%), tinplate (over 65%), paper (almost 65%) and batteries (60%) were very high. The reasons for the high recycling numbers include taxes on household waste[3], frequent advertising and the comparatively small effort required to reach the goal. It appears that people support the strategies as long as little time and financial engagement are required.

Besides this, every year about 6.4 million tons of construction waste is produced. More than 50% is recycled; the remaining amount is burnt or put in waste-deposal sites. In total, about 1 million tons of construction waste have to be disposed of in hazardous-waste sites every year (SFSO, 2002:122). However, planning strategies for the waste generated by the demolishing of buildings are not (yet) common in Switzerland. Here, considerable amounts of material are used for the construction of buildings, and they are literally meant to last a lifetime.

[3] In Basel, a 35 litre waste bag currently costs about 1.90 CHF.

2.2.7 Housing aspects

Housing stock and occupancy

The housing market in Switzerland shows residential buildings of remarkable age (Fig. 2.14). Even though private investors build two-thirds of the new housing units, the majority of the dwellings are inhabited by tenants (67.8% in 1990); less than one-third of the units are occupied by the owners themselves. Despite a federal law that decrees the support of home ownership, the rate of housing owner-occupancy in Switzerland (31%) is very low (Fig. 2.15).

High initial costs for housing, an attractive stock of rental dwellings and a large proportion of (low-income) foreigners, as well as limited governmental support of home ownership, are seen as major reasons why Switzerland has remained a country of tenants (IFS, 2000).

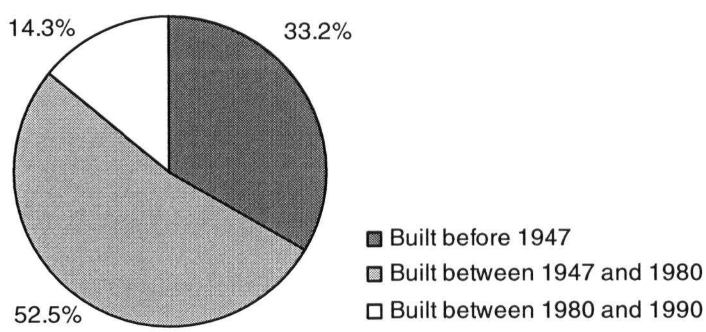
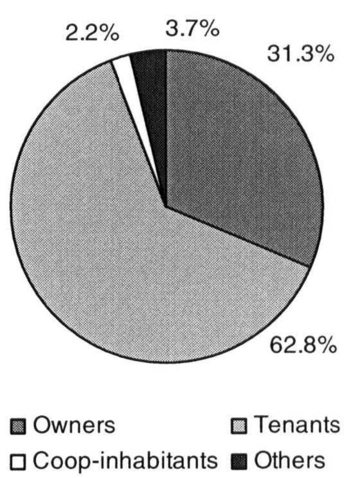
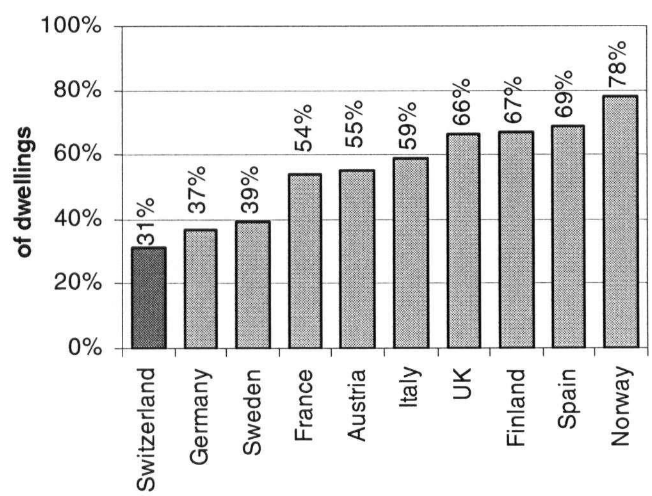


Fig. 2.14 Age of residential buildings in Switzerland (Source: Source: SFSO leaflet, 2002:20)





a) Inhabitant type of dwellings *b) Owner-occupancy of dwellings in Europe*

Fig. 2.15 Inhabitant type in Switzerland and owner-occupancy in Europe in 1990 (Source: SFSO, 2002: 399).

Housing situation

There is still a strong demand for single-family houses. Between 1980 and 1990, their share grew from 45% to 54% of the total building stock. While the number of multi-residential buildings remained fairly constant around 4,300 buildings per year, the number of single-family houses, as well as the number of dwellings in multi-residential buildings, altered considerably between 1975 and 2001. The strong decrease in the number of dwellings in multi-residential buildings since 1994 is remarkable. It appears that the high demand for single-family houses (between about 11,000 and 14,000 units) and the low requirement of multi-residential buildings (decline from 6,000 to almost 3,000 buildings) has had an influence on the size of multi-residential buildings. Within this period of time, the average number of dwellings in multi-residential buildings decreased from 6.1 to 5.5 units - the lowest number ever (Fig. 2.16).

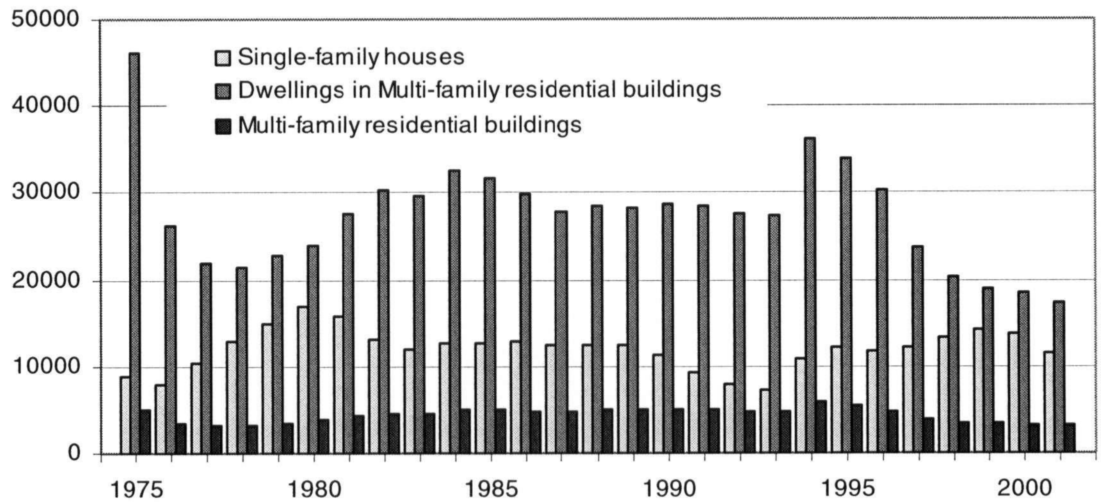


Fig. 2.16 Number of new dwellings in Single-family and multiple-residential buildings (Source: SFSO, 2002: 421).

In Switzerland, decreasing household size and an increase in the average living space have resulted in considerable growth of the urban space (see chapter 2.1.1: land use). As we have already seen in Figure 2.13c, the number of single households more than doubled between 1960 and 1990. As well, the number of apartments with 1 or 2 rooms (bachelors or one-bedrooms) clearly decreased while the number of dwellings with four and five rooms clearly increased. Between 1980 and 1990, the average number of people living in a dwelling decreased from 2.6 to 2.4, while the average living space increased from 34 m^2 to 39 m^2 per person. Today, singles want to live in a 3-room apartment (two-bedroom apartment).

Wuest & Partner predict that demographic ageing of the population and its growing wealth, along with globalisation, will determine the housing market over the next decade. Luxurious and easily-accessible dwellings are becoming more important for the growing number of wealthy elderly people. As well, fewer young people will inhabit the small and modest older apartments. The desire for bigger living spaces will continue despite a limited readiness to pay higher rents. Also, expensive urban regions with a broad range of workplaces, such as Zurich or Geneva, Basel or Berne, will continue to attract people (Fischer, 1999).

Housing costs

The initial costs for houses are very high in Switzerland. This is mainly due to fairly high land costs, whereas the average construction costs are comparable with those of the other EU countries. Land prices vary considerably within cantons as well as within different regions of a canton. Closeness to urban centres and urban infrastructure, view or orientation may considerably influence the price for undeveloped building land. However, spacious and flexible indoor and outdoor spaces and expensive interior finishing materials and appliances may considerably increase the construction costs.

Building in the canton of Zurich

After an enormous increase between the early 1980s and the early 1990s, land costs have remained fairly stable at an average of slightly above 600 CHF/m^2. But their variation has become enormous (Fig. 2.17). In Zurich city as well as in the adjacent 'gold coast' (Pfannenstil) undeveloped building land on average costs over 800 CHF/m^2, whereas for single lots up to 1,100 CHF are paid. In contrast, in remoter regions (e.g. in the Weinland) residential land may be found as low as about 220 CHF/m^2.

Considering average land costs of 550 CHF/m^2 and ordinary construction costs for architect-designed residential buildings[4] of 550 CHF/m^3 SIA[5], a detached single-family house (Fig. 2.18) costs

[4] Current construction costs for architect-designed residential buildings are within 1,500 and 2,500 CHF/m^2 net living and utility area or around 500 to 700 CHF/m^3 SIA. Luxurious villas may considerably spread the given boundaries.
[5] CHF/m^3 SIA is a measurement defined by the Swiss engineer and architect association (SIA) to allow a comparison of the costs for different houses.

about 650,000 CHF. In comparison with the average annual gross income of about 68,000 CHF in 2000 (Tab. 2.13), the expenditures for an ordinary house are almost 10 times the average annual gross salary.

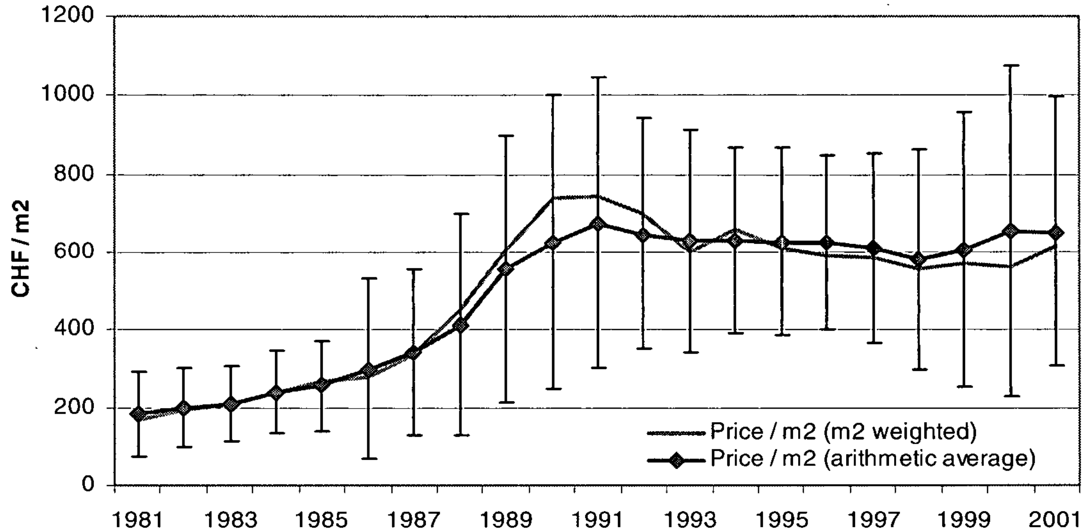
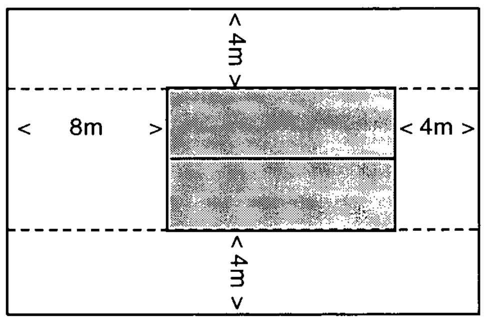


Fig. 2.17 Price development of residential land in the canton of Zurich (without city of Zurich) (Source: SOZ, 2002: Canton of Zurich in numbers: 2002; building and land costs in 2001).

Costs calculations of an ordinary detached single-family house in the canton of Zurich

Average land costs		550.-- CHF/m^2
Average construction costs		550.-- CHF/m^3
Minimal distances to boundary:		4 / 4 / 4 / 8m
Lot:	15.20 m x 23.30 m =	354 m^2
House:	2 storeys and cellar	
Size:	7.20 m x 11.30 m =	82 m^2
Net living area:	2 x 75 m^2 =	150 m^2
Volume SIA:	11 m x 82 m^2 ≈	900 m^3
Land costs:	354 m^2 x 550.-- ≈	200,000 CHF
House costs:	900 m^3 x 550.-- ≈	495,000 CHF



Total initial costs **695,000 CHF**

Fig. 2.18 Initial costs for an average detached single-family house in the canton of Zurich (Source: Reiners, 2002:158-196; SOZ, 2002: Building and land costs in the canton of Zurich in 2001).

According to the recommendations of a large Swiss bank, a client would need minimum available savings of 130,000 CHF to finance at least 20% (minimum) of the initial costs. In addition, he would need an annual gross income of about 125,000 CHF (or a monthly gross salary of about 9,600 CHF) to finance the single-family house in the previous example. On the basis of a 5% mortgage interest, the resulting monthly costs for mortgage interest, amortisation (about 1%) and incidental costs (about 1%) would be at about 3,150 CHF or almost one third of the gross salary (UBS, 2003).

Potential for reduced initial housing costs

In Switzerland, the high initial housing costs are influenced by three major factors; these are the costs for land, labour and building components or materials.

Land costs: The ongoing pressure on available land resources - especially in and around urban centres - will not allow land costs to decline. The only way to limit land costs is to limit the use of land by constructing denser housing systems. Considering the example in Figure 2.18, the cost difference between a detached single-family house and a row house would be around 100,000 CHF or about 15% of the initial costs.

Labour costs: In Switzerland, the labour costs will not decrease unless wages stop to increase, lower-educated (and lower-paid) people are employed, or the working hours during the planning and construction process are limited. Latter goals might be achieved by employing building contractors or constructing pre-designed and / or factory-built houses.

Building-component and material costs: Potential cost reductions of building components or materials will largely depend on the size of the dwelling, the building system, the construction material, the finishing materials and the infrastructure. Today, the desired living area per person is increasing. Also, increasing insulation and quality standards of enclosures do not allow reduction of the primary construction costs by much. Renggli has shown that the primary construction costs of a factory-built SWF (transport and erection not included) make up about 10% of the initial costs. Thus, considering a cost reduction in the primary construction of 10%, the initial building costs would be reduced by only 1% (Renggli, 2002). However, there is a potential saving in finishing material costs; using less expensive materials, avoiding finishing materials or applying them at a later stage has to be considered. Also, lower heat losses limit the initial costs of the heating system (smaller sized infrastructure).

To sum up, a considerable reduction in the initial housing costs could be achieved by limiting the land costs. Additional, but more cutting, savings might be achieved by limiting the costs of finishing materials and infrastructure or the volume of the dwelling, or by reducing the planning and construction time.

2.3 Product

The *product* describes the goods people produce in a certain place over time. In this chapter I discuss briefly local building culture, building materials, traditional and present-day wood building systems and the advanced voluntary building standards, as these product-related aspects are necessary for the evaluation of present-day wood building systems. Aspects of housing have already been discussed in the housing section (Chapter 2.2.6).

2.3.1 Local building culture

Representative aristocratic, religious or public buildings were mainly built in stone and designed according to the prevailing European style. In contrast, common houses, farms or workspaces were built in stone, wood or a combination of wood and stone depending on the locally-available natural resources. Generally, wood buildings with stone bases were prevalent in the Central Plain and most of the Alps (mainly German and Romansh speaking regions), while stone buildings dominated in the Jura (French speaking) and the

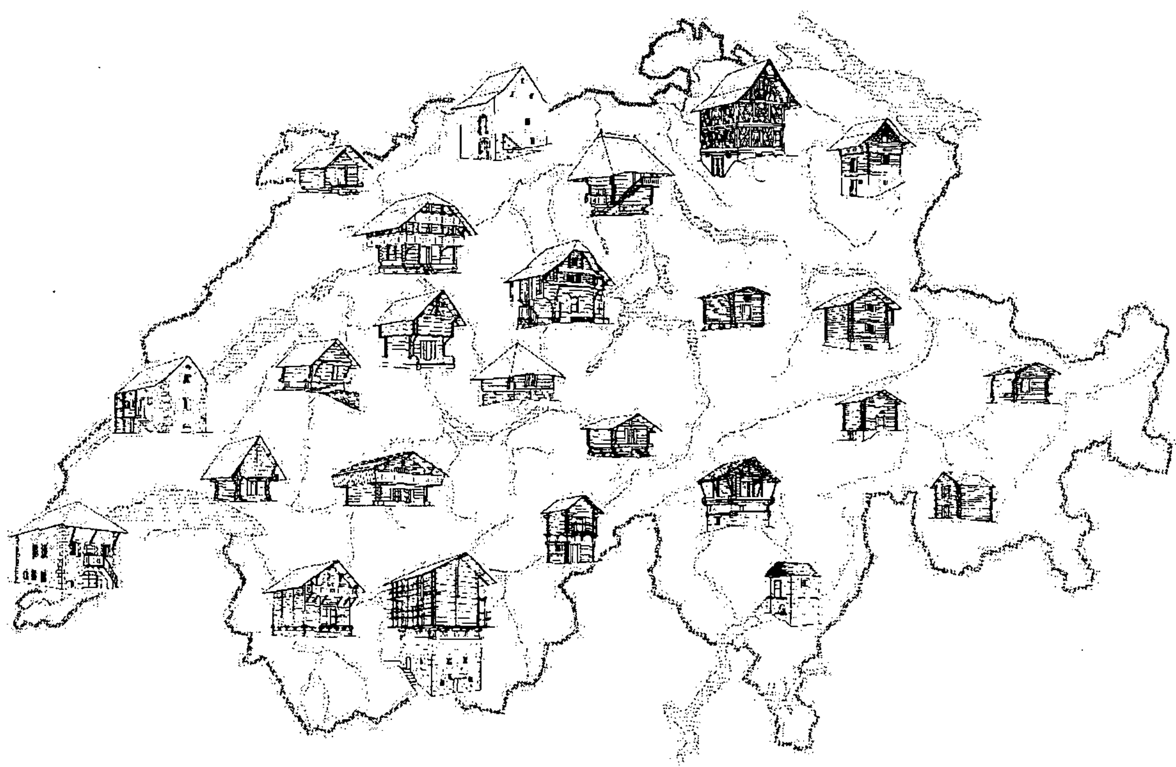
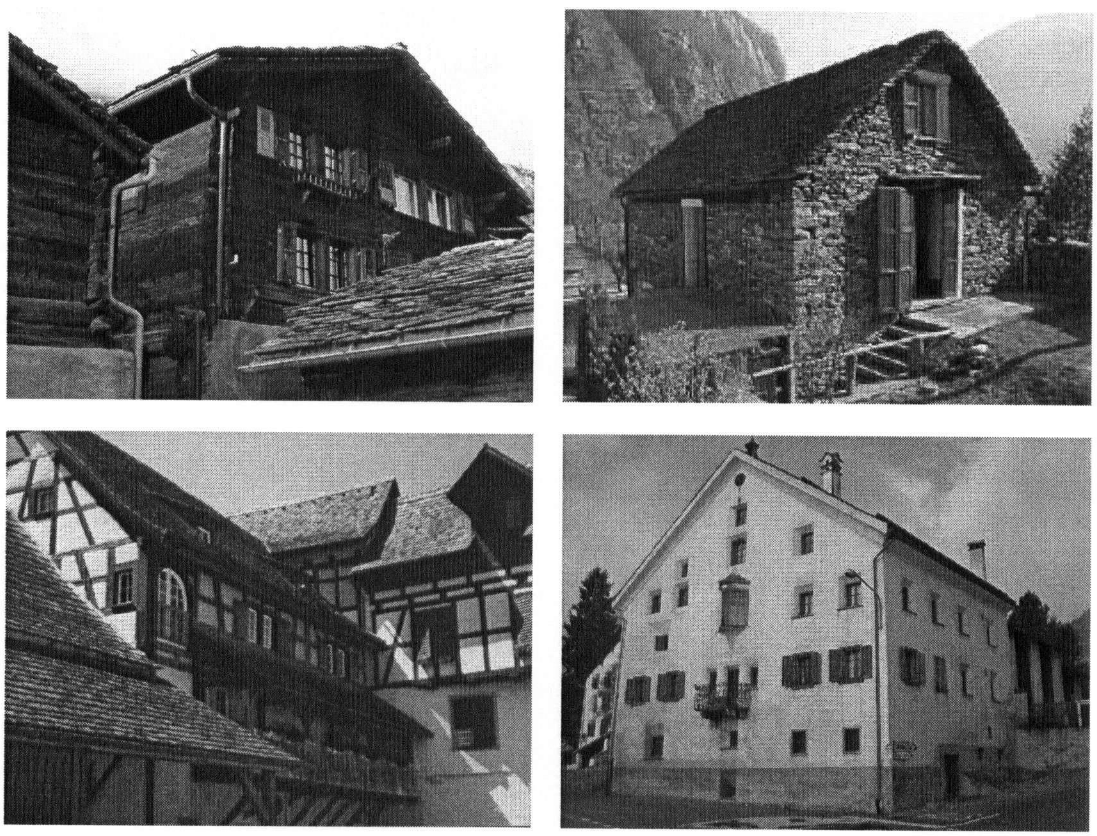


Fig. 2.19 Map of regional-traditional storage buildings in Switzerland (Gschwend, 1989:41).

most southern (Italian speaking) parts of the Alps (Fig. 2.19). These buildings were built by local builders using their passed-down skills. Both carpenters and masons were organized into guilds with monopolised skills and high social status.

Typical elements of vernacular residential buildings are stone bases, gable roofs and hipped or hipped gable roofs covered by stone slates or tiles, as well as exterior shutters. The stone bases were especially important to protect wood constructions against ascending water and deep snow covers in winter. In addition, they were used to adjust the building to the uneven lots. Often, these stone bases were the visible parts of cellars that provided important storage spaces. Tile roofs with large projections were ideal weather protection for wood buildings and exterior storage spaces. Shutters protected interior spaces against overheating in summer and excessive cooling in winter (Fig. 2.20).



a) Log house, Ausserberg, Valais *b) Traditional stone house in Cevio, Tessin*
c) Timber-frame buildings, Stein am Rhine *d) Traditional stone house, La Punt, Engadin*

Fig. 2.20 Traditional residential building types (Photos by author, 2002).

Today, the basement cellar is still an indispensable part of residential buildings, even though a storage space could also (sometimes more cheaply) be placed adjacent to the house. Also, tiled pitched roofs with dormer windows - in contrast to flat roofs - and shutters are important elements of residential buildings. Not only are they requested by the inhabitants; they are often indispensable elements required by local building codes (see chapter 2.2.2. Legislation). Moreover, in many places a predefined range of exterior colours, closely-spaced window muntins, specific roof tiles, given roof slopes, or defined form and size of dormers are meant to keep the appearance of new buildings within the rural-traditional settings. These restrictive building regulations (especially for residential buildings in remote areas) often do not allow the broad unfolding of the architectural potential of contemporary buildings.

Modern Architecture and Country-Style

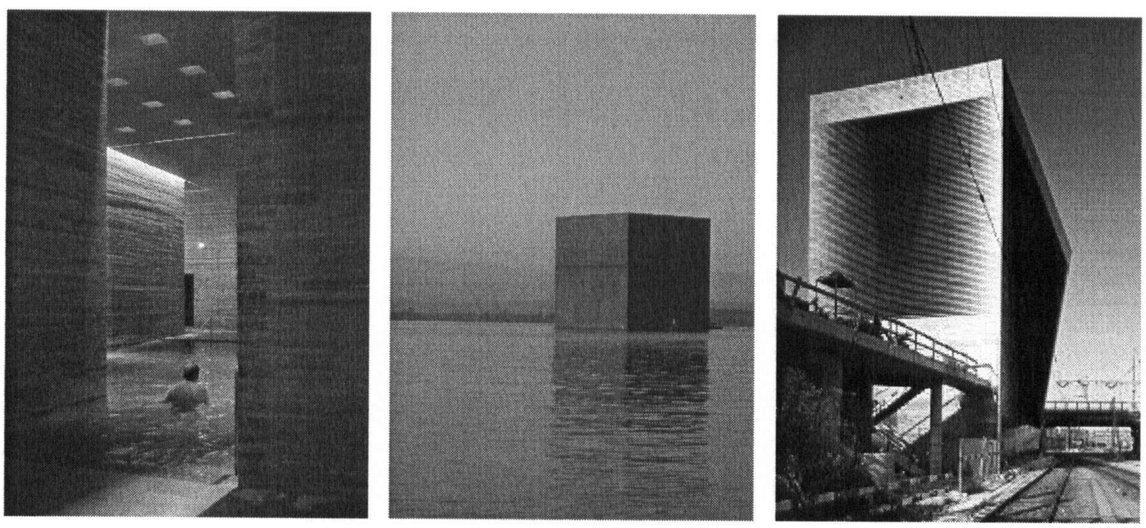
The social and technical effects of the industrialisation that affected Switzerland throughout the 19th century had considerably changed the traditional building culture in Switzerland by the turn of the 20th century. Increasing urbanisation and social changes as well as an increasing technical materialism and developing international trade quickened the ideas of architects that aspired to meet the needs of the new society with an adequately-built environment. This new approach was characterised by asymmetric forms and floating designs relying on new building materials, industrial production and various international mindsets (Amman, 1988:31). Various international styles or 'Modern architecture' without ornament or historical references developed likewise in different countries throughout the first two decades of the 20th century.

In contrast, the social and technical changes, the opening to trade outside the region, and the influence of new and 'foreign' ideas evoked an increasing reflection of national-traditional values (compare to Chapter 2.2.4 Population and demography). Within the population, regional-traditional, rural-looking buildings became a symbol for the lost local identity and for the 'good old times'. Typical vernacular elements, such as wooden balustrades, bull's-eye panes or barn doors were applied to any building, from houses to hotels to commercial and administration buildings. At the end of the 19th century, the Country Style was born.

In reaction to the threat of war and as a countermovement to the spreading modern architecture, the Country Style once more had a strong revival throughout the 1930s. During that time, the Swiss Chalet - an over-ornamented square-log building - became a symbol of Swiss cultural identity and traditional integrity. In the following decades, the Swiss Chalet became popular in any region and for any use (e.g. large hotels in a rustic Chalet style), even though it strongly opposed the ideas of modern architecture. As well, buildings in wood became a symbol of backwardness and regionalism for many architects.

Present trends in architecture

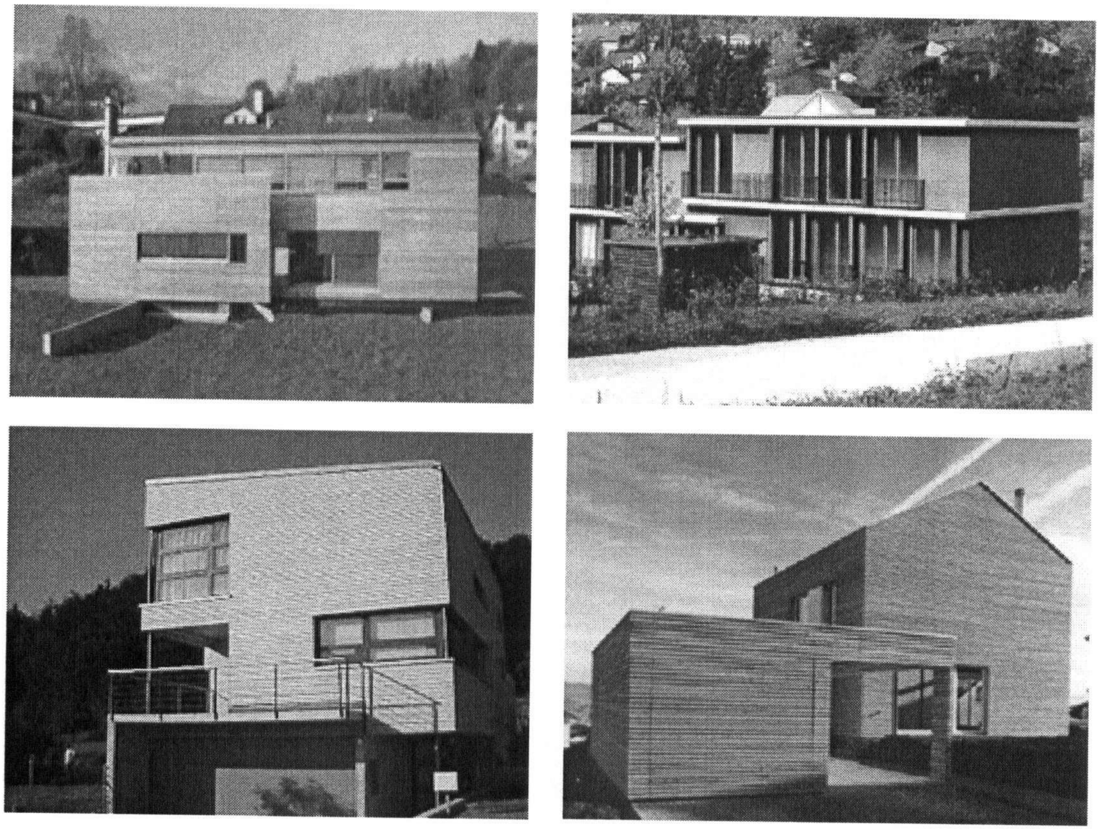
Switzerland's building culture is often equated with traditional rural buildings or the idea of the Swiss Chalet. However, recent buildings, such as the thermal bath in Vals by Peter Zumthor (1996), the central signal tower (1995), the soccer stadium (1999) or the Schaulager (2002) in Basel by Herzog & De Meuron as well as the Culture and Congress Centre in Lucerne (1999) or the Monolith for Expo 02 (2002) by Jean Nouvel, have been recognised by local and foreign press alike (Fig. 2.21). This recognition found its expression in the awarding of the Pritzker prize to Herzog & De Meuron in 2001. Characteristic of this present trend in non-residential architecture is the radical formal reduction.



a) Thermal bath, Vals, Peter Zumthor, 1996 — *b) Expo 02 monolith, Murten, Jean Nouvel, 2002* — *c) Central signal tower, Basel, Herzog & De Meuron, 1995*

Fig. 2.21 Contemporary non-residential architecture (Photos by the author).

The growing prestige and popularity of 'good design' is also strengthening the demand for architect-designed residential buildings, even though contractor- or factory-built houses are becoming more and more popular in Switzerland. Whereas contractor-built houses with guaranteed costs, short time frames, limited personal involvement and fixed moving-in dates do not exclude good architectural design or individual solutions, numerous architect-designed and factory-built wood houses demonstrate the strong architectural potential of recent developments in the wood building industry (Fig. 2.22).



a) House Trösch, Epalinges, Novello & Trösch, 1995

b) Estate Spittelhof, Biel-Benken, Peter Zumthor, 1999

c)House Plaschy, Wermatswil Werner Reichle, architect, 1999

d) House Lingg-Steger, Nottwil, Steger & Partner, 1999

Fig. 2.22 Architect designed new residential architecture in wood (Lignum, 2000).

2.3.2 Wood as a building material

In Europe, wood buildings are widely spread, from central and eastern Europe to Russia and from Scandinavia to the Balkans where vast timber resources were (or still are) available (Fig.2.23).

During the Middle Ages (mid 13th to 17th century), the fear of large city fires and the fashion of banning 'rural-looking' wooden buildings from the city resulted in a growing avoidance of wood towards the end of the 17th century. In the following centuries, residential buildings in wood increasingly lost their importance, while brick and concrete took over the leading roles in the residential-building industry. In the first half of the 20th century, the increased desire for protection against threat and / or war (World War I and World War II) have caused people in central Europe to prefer residential buildings with 'heavy' masonry or concrete walls (Winter, 1995). Even the booming economy between the 1960s and 1980s did not have an impact on the wood building industry. At that time, plastic was the progressive material that showcased belief in the technological progress.

While the central European countries stopped building in wood, the Scandinavian countries as well as Canada and the United States established a successful wood building culture throughout the 19th and 20th centuries.

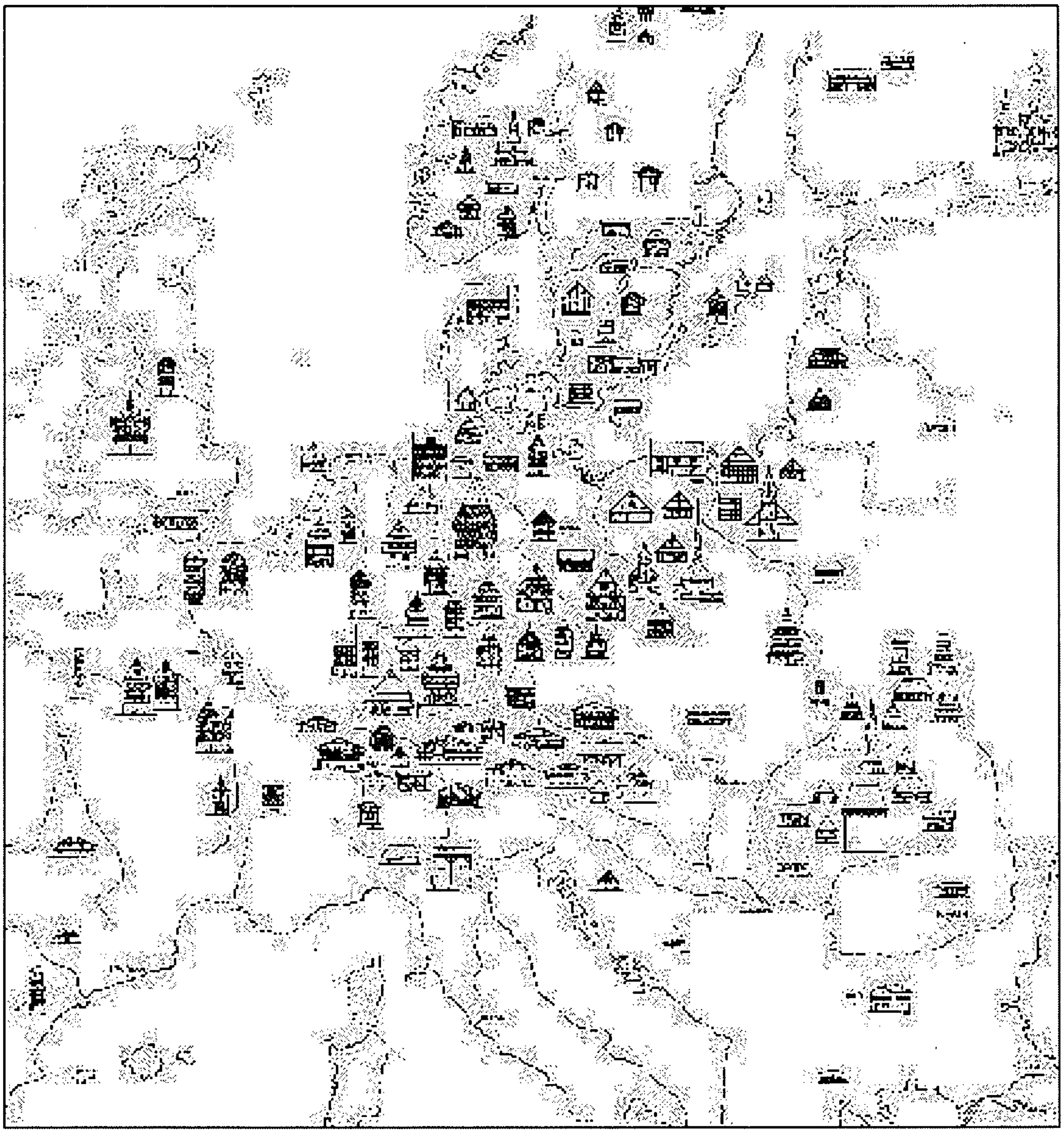


Fig. 2.23 Extent of wood buildings in Europe (Source: Phleps, 1983).

Revival of wood as a residential building material

Only at the end of the 1980s did young architects and engineers in Switzerland (as well as in Germany and Austria), together with innovative carpentry firms, start to rediscover the new values of wood. By that time, glue-laminated wood (gluelam) beams in combination with new joining techniques (metal fasteners and glue) had already succeeded in the construction of large roof constructions, such as those for sports halls or other large spaces without columns. In Switzerland, the roofing of the ice hockey hall in Davos (1981) was a first famous example where, instead of an expensive steel construction, a gluelam beam construction was built. Whereas first engineered wood products (EWP's), such as plywood, particleboard and fibreboard had been used since the first half of the last century, oriented strand board (OSB) and glue-laminated boards came up over the last decades. Since, the share of OSB and a growing number of glue-laminated boards has strongly increased in the residential building market in Switzerland[1].

The new joining techniques and the supply of new wood building materials challenged building practices in Switzerland, as did the fast development of information technology throughout the 1980s as well as increasing concerns about the health of the environment. At the end of the 1980s the first federal program, Energy 2000 (see Chapter 2.1.3), launched research into reducing consumption of fossil fuels and the use of renewable energies. Also, over-aged and dying forests became of political interest (see Chapter 2.2.3 Legislation). This initiative was very welcome to the wood building industry. After the long crisis (see Chapter 2.1.5 Industry and trade) that forced many carpentry firms to close down, it urgently needed new input as well as new self-confidence. Supported by Lignum, the Swiss Association of the Woodworking Industry, the wood building industry started to emphasize its advantages in relation to the cement industry. But even though a strong framework for the revival of wood was given, Kramel believes that knowledge of the Danish work of Niels Bohr and Jorn Utzon, relying on the translation of Japanese wood buildings, as well as the modern wood buildings by Richard Meier and Peter Eisenman must have given an important impetus to the idea of the new wood house in Switzerland (Kramel, 98:48-55).

Undoubtedly, the renewed interest in wood and the enormous choice of new wood building products and systems for residential (and non-residential) buildings is based on a broad range of technical, economic, ecological and political factors (discussed in various sections throughout this chapter) as well as the existence of a skilled workforce, and a new perception of houses in wood.

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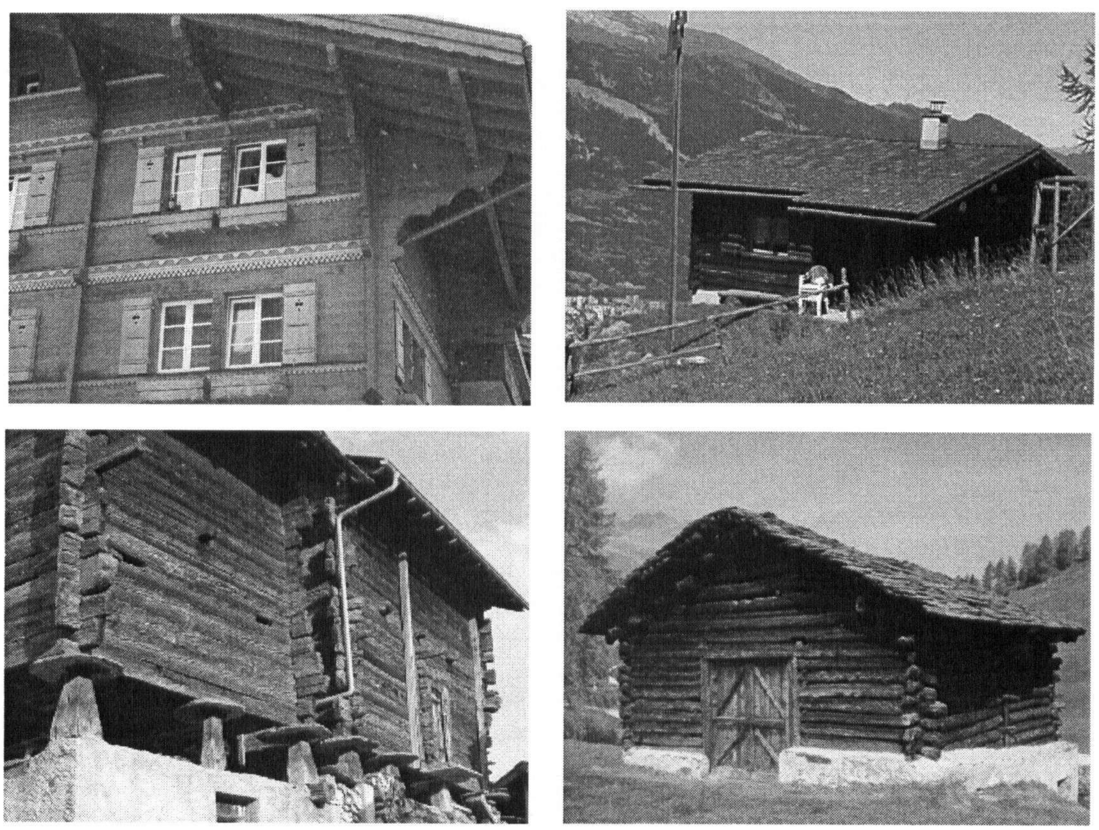
[1] Other EWP's, such as waferboard, laminated veneer lumber (LVL) or parallel strand lumber (PSL) are barely used.

2.3.3 Traditional wood building systems

Log and timber-frame construction used to be the leading residential wood building systems in Switzerland. They influenced the development of residential buildings up to the 20th century. Yet, over the last century, these traditional building systems have lost their importance in the residential building market.

Log construction

Log constructions were widely spread throughout the northern part of the Alps as well as the Rhine and Rhone valleys, where vast wood resources were available. Regional differences are showcased in the shape of the log and the joining and cornering techniques, as well as in the specific decorative carvings. Square logs and rich carvings are typical of houses in villages in the northern part of the Alps as well as



a) Square-log house (Chalet), Grindelwald *b) Round-log cabin, above Chur*
c) Square-log storage, Ausserberg *d) Round-log storage, Engadin*

Fig. 2.24 Traditional log construction (Photos by the author).

the Rhine and Rhone valleys (Fig. 2.24 a), whereas rough square-log and round-log constructions were mainly used for storage buildings, barns and cabins in areas in all parts of the Alps (Fig. 2.24 b - d).

Characteristic of log construction are walls of round or square logs laid horizontally on top of each other in courses. Structural strength and lateral support are achieved by fitting and interlocking the logs at the corners. Chinking of the gaps between the logs is necessary to achieve a weather-tight construction; traditionally, different chinking materials such as wood chips, stones, mud, grass, straw or moss were used. The simplicity of this construction method allows the erection of a building with just one tool, the axe (Phleps, 1983: 52).

Log construction embodies major disadvantages due to the horizontal layering of the logs. Firstly, the load-bearing capacity of wood across the grain is much lower than along the grain; log construction does not make use of the high vertical load-bearing capacity of wood. Secondly, the radial and tangential wood shrinkage are much higher than the longitudinal; as a result, settling, stability of the corners and tightness of walls are critical constructive aspects that need to be handled with special care. Thirdly, the length of the logs considerably constrains the flexibility of the floor plan.

In the Swiss Alps, rustic round-log cabins or restaurants are still popular. Also, traditional square-log buildings still dominate the local character of many settlements in the northern and central part of the Swiss Alps (e.g. Grindelwald, Vrin and Vals) as well as in the Rhone valley (e.g. Oberberg and Ernen). Yet log constructions are barely feasible for contemporary housing as they use a large amount of wood. In addition, traditional (insinuated) enclosure constructions no longer comply with the enclosure standards of current building codes. Additional insulation must be applied to the interior or exterior of the structure, thereby losing the typical appearance of log constructions. Today, manufactured layered log-like square elements (e.g. the *ISOX* system: Fig. 2.35, and chapter 2.3.4) often replace the traditional building system. These building systems visually imitate traditional log construction without disregarding present code requirements or making contemporary building structures impossible.

Timber-frame construction

By the end of the 17th century, the knowledge of timber-frame construction was almost standardised throughout Europe. Carpenters were organized into guilds with monopolized skills, and books in numerous languages taught common solutions for the problems of stresses and strains within a structure. Also, young carpenters who had completed an apprenticeship spread their know-how during their compulsory one-year travels all over Europe.

Timber-frame buildings consist of a basic load-bearing frame of square timbers, assembled as a set of horizontal and vertical structural members. The vertical (posts) and horizontal members (bottom-plates, plates, girts, summer and joists) are connected with mortise-and-tenon joints and locked with wooden pegs or, more recently, with screws (Fig. 2.25). Diagonal braces provide the frame rigidity. Wall infill and / or cladding is necessary to achieve a weather-tight enclosure. In most early European timber-frame constructions, the vertical members consisted of load-bearing primary and - often non load-bearing - secondary posts. The widely-spaced primary posts extended to the full height of the wall (Fig. 2.26). Storey-high secondary posts provided additional lateral support.

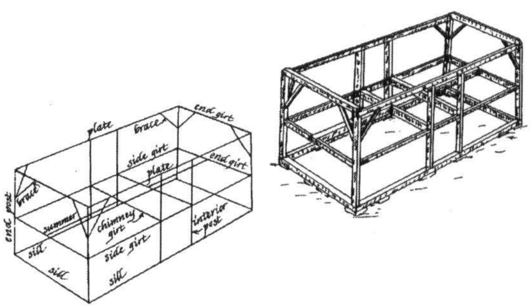


Fig. 2.25 Primary timber-frame construction (Source: Rempel, 1980).

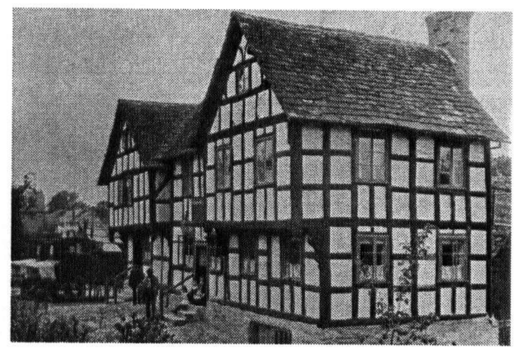


Fig. 2.26 Half-timbered house in Pembridge, UK (Source: Harris, 1980).

All over Europe, half-timbered constructions - exposed timber-frame constructions with wattle and daub, stone or brick infill - were widely employed until the mid 19th century. However, in towns they were often covered with plaster by the end of the 18th century. Plaster was meant to give the rural-looking timber-frame buildings an urban appearance by imitating stone and masonry facades and to protect them from fires. During the 19th century, this attitude was also adopted to farmhouses, as timber-frame construction was considered to be a poor rural construction mode.

In Switzerland, timber-frame buildings with wood board or plank infill were prevalent in the central and north-eastern parts of Switzerland. Around 1500, Southern German half-timbered buildings influenced framing techniques in Switzerland. By the end of the 18th century, particularly picturesque and decorative half-timbered buildings had developed in North-eastern Switzerland and Southern Germany. These buildings were built up floor-by-floor using pre-cut frame members and storey-high posts (Gschwend, 1989: 102-103). Typical of these buildings is the exposure of the floor joists in the facade as well as rich bracing patterns beneath the windows (Fig. 2.27, Fig. 2.28). Like those in the other European countries, many of these buildings were covered with plaster throughout the 19th century. However, efforts to preserve monuments and historic buildings (compare to Chapter 2.2.1 Culture) have unveiled the original beauty of half-timbered villages in Switzerland by giving them back their typical red and white coloration over the last century.

Fig. 2.27 Half-timbered house in Wigoltingen (Source: photo by the author)

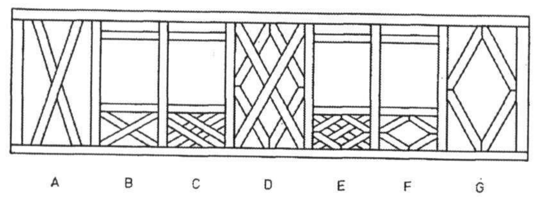


Fig. 2.28 Common bracing patterns in CH (Source: Kolb, 1998:24)

Today, timber frame construction is still used in Switzerland. Especially in remote areas, timber frame construction is appreciated as a fast building system at reasonable costs. On site, the pre-cut frame members are assembled to a rigid frame using floor-by-floor construction as well as wood-to-wood connections (Fig. 2.29, Fig. 2.30). The frame cavities are filled with insulation. If required, additional insulation may be applied on either side of the frame. Generally, cladding is applied to the structural frame even though an exterior exposure of the frame would still be technically possible. The most probable reasons are reduced maintenance work and / or conformity to present aesthetic values.

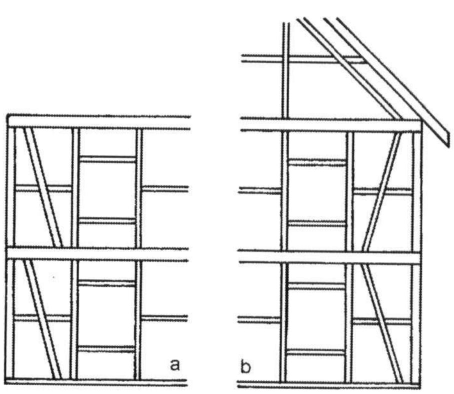


Fig. 2.29 Timber frame principle (Source: Kolb, 1998:67)

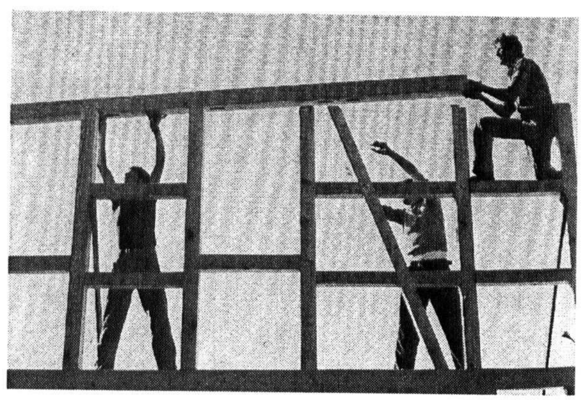


Fig. 2.30 On-site timber frame construction with pre-cut members (Source: Kolb, 1998:76)

2.3.4 New residential wood building systems

The following section gives an overview of the vast variety of the new wood building systems for load-bearing walls available for the construction of residential buildings in Switzerland. According to the characteristics of the load-bearing members I classify the systems into four different groups: *wood frame systems*, *wood panel systems*, *wood module systems* and *wood-lightweight-concrete*.

Wood frame systems

The structural frames of wood frame systems consist of lumber or timbers. Together with the structural sheathing, the structural frame forms a rigid wall element. In Switzerland, wood frames are generally processed to storey-high wall, storey-wide floor, and roof panels with maximal length and a considerable degree of finishing. On site, these panels are assembled in only one to two days. Modular elements are not common for residential buildings. This standard is most probably limited by the lack of availability of large storage spaces and the means of transport. Also, smaller elements are rare as they increase the number of joints.

The *Swiss wood frame (SWF)* represents a large number of different systems, each one varying in the material used, as well as the number and dimensions of layers. Even though the Swiss wood frame system is not (yet) standardised, it is very successful in the residential building market in Switzerland. As it is the leading wood building system at present, it requires a closer look at its specific characteristics (see chapter 5).

Wood panel systems

Wood panel systems rely on a structural board that provides vertical as well as lateral stability. Like wood frame systems, wood panel systems are processed into wall, floor and roof panels with maximum size and varying degrees of finishing for on-site assembly. Generally, insulation and cladding are applied to the exterior side of the structural board on site. For the interior, the exposed structural boards are painted or oiled. Unless an installation layer is needed, no interior finishing materials are required.

The structural board of wood panel systems consists of *particleboard* or *solid-wood board.* In Switzerland, Homogen 80 is the only system that employs a structural particleboard. In contrast, the choice of solid-wood panel systems relying on structural solid-wood boards is enormous. Due to the easy production process, carpenters may process low quality and waste wood into their own (non-standardised) solid-wood boards. As a consequence, the names given to these boards are very different and confusing. Table 2.15 lists major particleboard and solid-wood boards used for load-bearing walls of wood panel systems. Panels for other purposes, such as furniture or sheathing, are not included in this table.

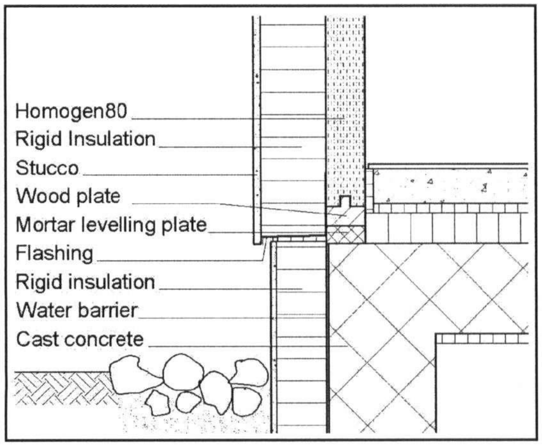
Particle-board systems	Brand name	Panel		Layers		
		Thickn. in [mm]	Size (w x l) in [m]	Num-ber	Section	Wood chips
Particle-boards	*Homogen 80*	80	2.03 x 5.37 / 2.65 grooved panel: 2 x 2.65	3	symmetric	Glued, pressed

Solid-wood panel systems	Brand name	Panel		Layers		
		Thickn. in [mm]	Size (w x l) in [m]	Num-ber	Section	Wood laths / boards
Dowelled boards	*Bresta*	80 - 247	up to 3.5 x 9	1	opt: diff. surface relief	dowelled top-on-top
	Optiholz	50 - 210	0.416 x 13 force-fit dowelled: multiple 0.416 x 13	1	(finger-jointed boards)	
Glue-laminated boards	*Rohrex*	35 - 80	1.25 x 5 max. 1.25 x 6	3 or 5	symmetric	glued side-by-side
	Wiehag-Profiplan	17 - 40	1 / 1.25 x 5 force-fit finger jointed: max 1.25 x 20	3	symmetric	
	Merk Dickholz	85 - 297	4.8 x 14.8 max. 4.8 x 20	odd, 5 to 17	symmetric, opt: curved panel, diff. surface materials (finger-jointed boards)	
Block boards (subgroup)	*Schuler*	30 - 140	max. 2.17 x 7.2	3 or 5	symmetric	glued top-on-top
		7 - 200	0.8 x 9	1	feasible for ribs	
	K1 Multiplan	20 - 75	2.015 x 5.03 / 6.03 force-fit finger jointed: max 2 x 24	3	symmetric (finger-jointed boards)	

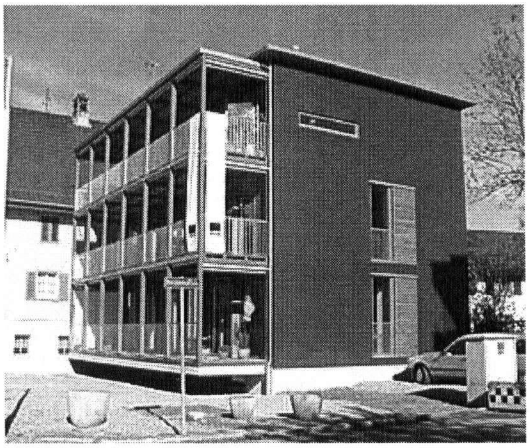
Tab. 2.15 Major structural boards used for wood panel systems (Source: Adapted from Lignum, 1999, and Lignum, 1997)

Particleboard systems

Homogen 80 relies on an 80 mm thick, three-layered particleboard. Two layers of fine particles enclose a central layer of rough particles. These boards are available with tongues and grooves for tongue-and-groove connections, as well as non-moulded for glued connections. They are applicable for structural walls, but not for the construction of floors or roofs. In the factory, particleboard wall panels including openings and ducts for wiring are prepared for on-site assembly. As insulation and cladding are applied only on site, protection of structural particleboards against weather influences has to be guaranteed (Fig. 2.31) (Lignum, 1999:38-39, and Clausen, 2004).



a) Enclosure-foundation section



b) House Baggenstoos & Hatt, Cham, by HWP architects AG, 2000.

Fig. 2.31 Homogen 80 (Source: Homogen 80, 2004, Bisang, 2004).

Solid-wood panel systems

Solid-wood panel systems consist of *dowelled boards* or *glue-laminated boards,* whereas *block boards* are specifically glue-laminated boards[1]. A minimum board depth of 7 cm is required for the construction of load-bearing walls to resist structural and lateral loads. All these boards also qualify for the construction of floor and roof elements. However, structural walls of glue-laminated boards, particularly block boards, often consist of thinner structural boards that are supported by a set of parallel ribs. This system also has a specific name; it is called the *Ribbed panel system* (RPS). It is discussed at the end of this section.

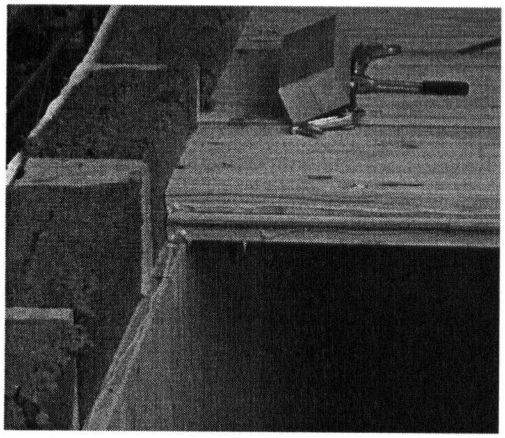
Structural *dowelled boards* mainly consist of sapwood boards of local wood, such as fir, Norway spruce, larch, Douglas fir or pine, dowelled on top of each other. The surface of the single-layered boards is determined by the depth of the basic boards; profiled edges allow the achievement of specific surfaces, such as for acoustic uses. Dowelled boards such as 'Bresta' and 'Optiholz' may be used for structural walls as well as for the construction of floors and roofs (Lignum, 1999:8-9, 12-13; Tschopp, 2004: Bresta, and Timbatec, 2004: Optiholz).

[1] Cerliani and Baggenstos only distinguish between *single-layer*ed glue-laminated boards (for non-structural use) and *multi-layered* glue-laminated boards (for structural use). They do not consider the different production processes (Cerliani, and Baggenstos, 2000:48-51).

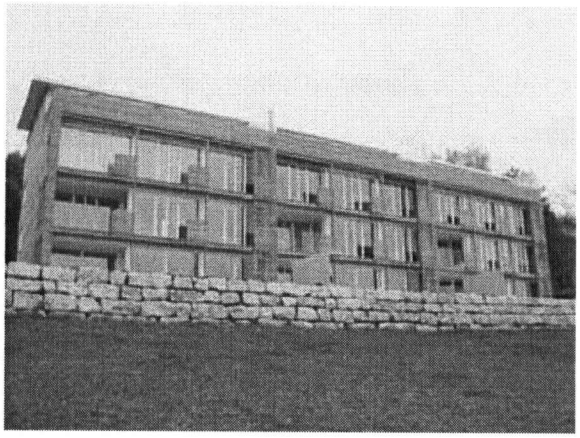
Structural *glue-laminated boards* consist of an odd number of layers (Tab. 2.16). Each layer consists of side-by-side glue-laminated sapwood boards of Spruce fir or Douglas fir. The required number of layers is glued on top of each other with alternate orientation. Variations in the dimensions or the wood quality of the basic boards and in the number or the material sequence of the layers result in a large variety of panels. As the wide side of the basic boards determines the surface of plank panels, they show a fairly uniform wood texture.

As for glue-laminated boards, structural *block boards* also consist of an odd number of layers, but the production process is different. Here, sapwood boards or laths of Spruce fir or Douglas fir are glue-laminated (side-by-side and top-on-top) to form a large block with equally-oriented boards. In a second step, the block is cut lengthwise into thin slices with the required thickness of the basic block board layers. Finally, the required number of basic layers is crosswise glued on top of each other. Variations in the dimension or the wood quality of the basic boards, the layer thickness, or the number of layers result in a large variety of block boards. As the depth of the basic boards or laths determines the surface of the block boards, they show a fairly irregular pattern of small wood stripes (Lignum, 1999:10-11, 14-15).

The *Ribbed panel system* was first presented by Schuler in 1997 (SAH conference, Weinfelden). The system consists of a load-bearing, 3-layered, 35-mm-thick block board. It is structurally supported by a set of parallel ribs glued against the structural board. This idea is strongly reminiscent of concrete slab constructions where secondary beams or ribs are an integral part of the slabs. Together, the thin structural board and the supporting ribs provide structural and lateral stability. In addition, the ribs keep the insulation in place and provide a nailing base for exterior layers (Fig. 2.32) (Schuler, 1997: 93-101).



a) House Bearth, enclosure - floor joint, Deplazes, 1998



b) Sunny woods (multiple-residential building), Zurich, Beat Kämpfen, architect, 2001.

Fig. 2.32 Ribbed panel system (Source: Deplazes, 2001, and Pius Schuler, 2004).

Wood module systems

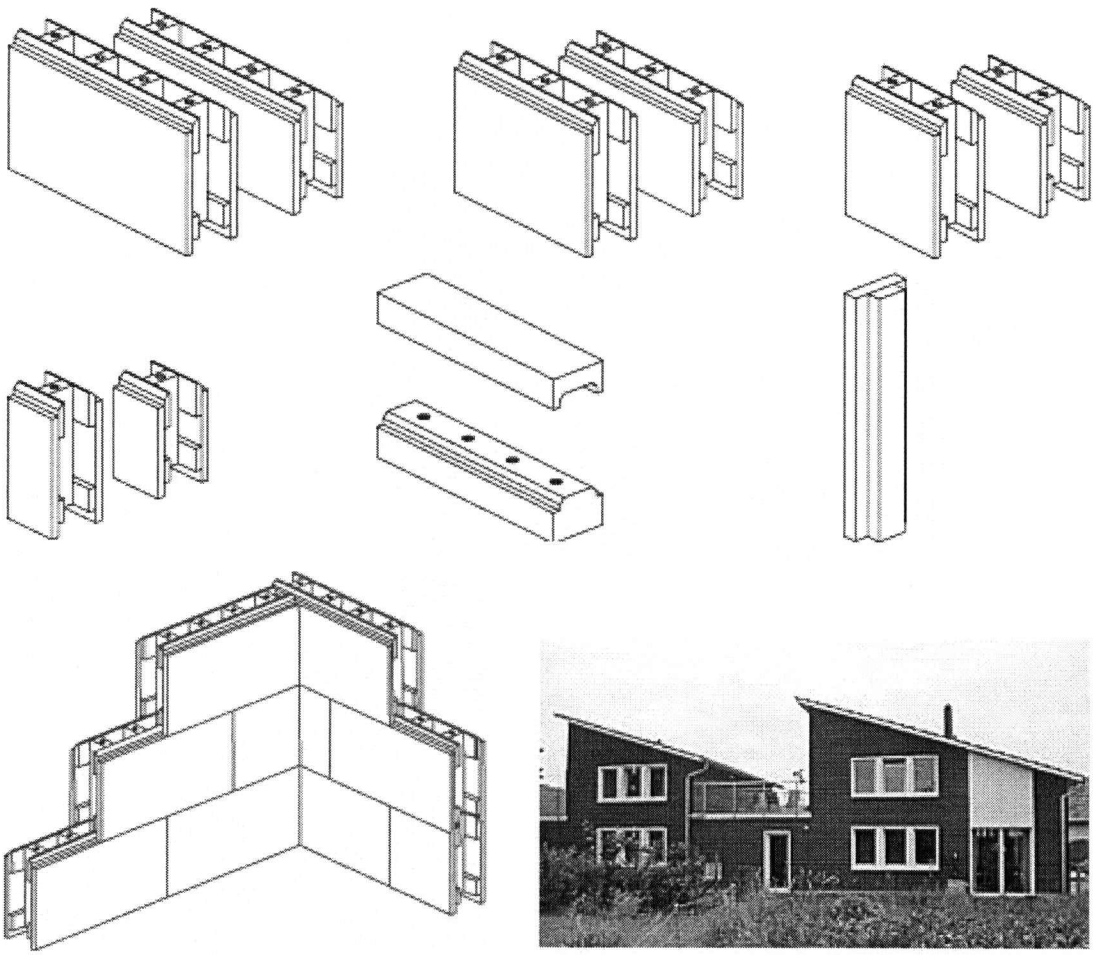
Wood module systems show a great diversity in layering, form and size of the elements, from multi-layered brick-like elements to large planar ones. Characteristic of these systems is the on-site assembly of walls using manufactured smaller or larger single elements or compounds of elements. Wood module systems consist of stick connections or tongue-and-groove joints that are fixed with mechanical fasteners or glues. Insulation, exterior cladding, installations and interior finishing are applied on site. Most of these systems are constructed in such a way that wiring can run through a conduit in the structural elements. Not all these systems qualify for the construction of floors or roofs. Table 2.16 gives an overview of the major wood module systems for load-bearing wall systems.

Wood module systems	Brand name	Panel			Layers		
		Thickn. in mm	Size (h x l) in cm	Orientation, Form	Num-ber	Section	Layer / modules
Masonry-like modules	*STEKO*	160	24 / 32 x 16 / 32 / 48 / 64	horizontal, small rectangle	5	symm. opt: surface choice	glued / stuck
Plank-like modules	Ligno-trend	70 / 90 / 110 / 150	250 / 300 x 37.5 / 50 / 62.5 / 75 / 87.5	vertical, linear - planar	3, 4, 5, 7	opt: choice of surface	glued / mech.
Beam-like modules	YSOX	12 - 20	0.14 x 200 - 500	horizontal, linear	3	insulated	glued / stuck
		10 - 20			1	non-insul.	
Hollow-core modules	Lignatur LKE	(8, 10), 12 - 32	19.5 x (up to) 1,200 opt: longer elements	horizontal, linear (planar)	3	symm. opt: core insulation	Glued / tongue& groove
	LFE	12 - 32	51.4 / 100 x max.1,600				
Web modules	WE-KA-element	19 – 51	1900 x 166.6	vertical, linear (planar)	3	symm.	glued / tie-bar
Stud modules	Brüggo Holes	60 - 260	30 – 800 x 30 – 100 length max. 1,200	vertical, linear (planar)	1, 3	symm. / asymm.	Dove-tailed / tongue& groove

Tab. 2.16 Major wood module systems for load-bearing walls (Source: Lignum, 1999 and, Lignatur, 2001, YSOX 2002)

Steko

Steko is a wood building system that is reminiscent of masonry construction (Fig. 2.33). The cubic elements consist of five layers of wood; these are central studs, with horizontal boards and a finishing layer on either side. The system consists of differently-sized modules as well as specific plates as base for the wall construction, as well as lintel, sill and reveal elements to frame openings. The central cavities may take up installation and insulation. On site, the manufactured wood modules are stuck side-by-side and top-on-top with differing joints. This wall construction system is combined with established floor and roof systems, such as solid-wood panel systems or joist and rafter construction. Installations as well as exterior insulation and cladding are applied to the basic structure. Finished surfaces or a specific top layer allow walls to remain visible on the inside (Lignum, 1999:44-45, Steko, 2004).



a) Steko elements (1/1 element, ¾ element, ½ element, ¼ element, plate and lintel, sill and reveal element)

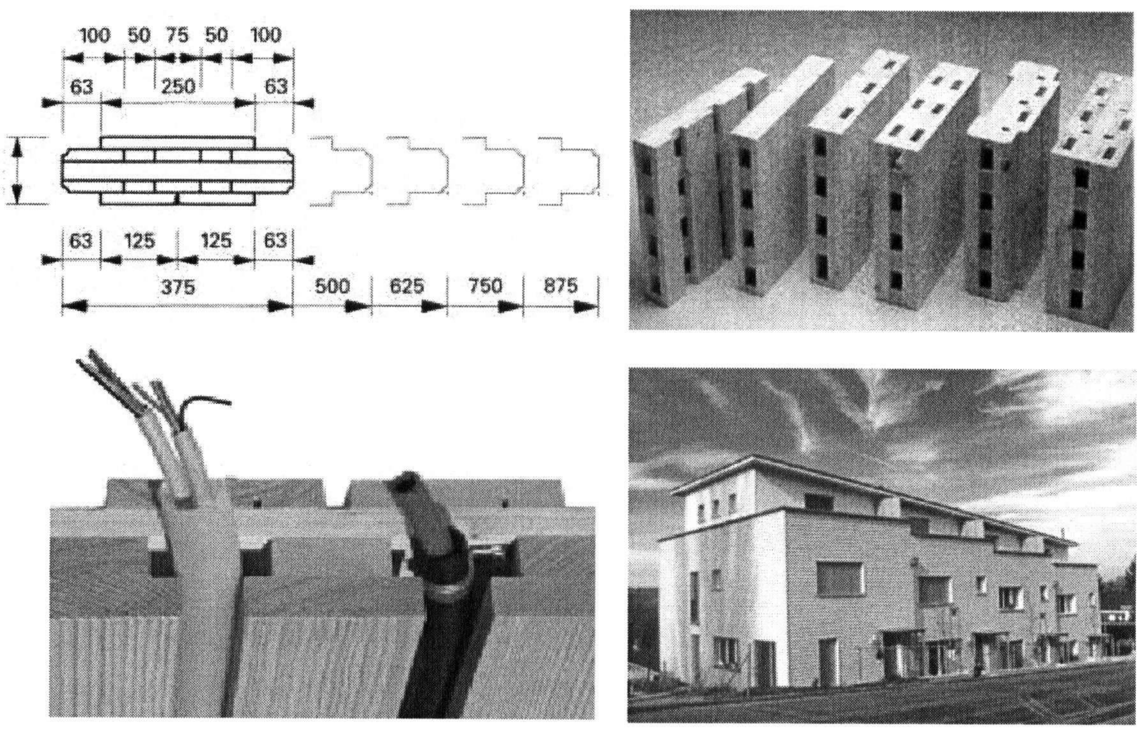
b) Assembly of wall, isometric corner section

c) Two Boxes, double house, Kümmertshausen, Ruth Schwarzenbach, 1999.

Fig. 2.33 Steko system (Source: Steko, 2004).

Lignotrend

Lignotrend is a planar module system of manufactured floor-high elements (Fig. 2.34). The basic elements consist of multiple layers of crosswise glue-laminated pieces of finger-jointed boards or laths of sapwood. Variations in the layering and the size and material of the boards or laths, as well as in the size and distribution of gaps, result in a large palette of systems for specific uses. Gaps of several centimetres between the lumber pieces of the interior layers provide space for installations as well as acoustic insulation. Single elements are stuck sidewise to larger wall elements. Specific top and bottom plates allow easy joining of the element compounds to other building parts. The joints between the single elements as well as with other building parts are fixed with mechanical fasteners. Air barrier, insulation and cladding are applied to the exterior side of the basic construction; this system is designed to work without a vapour barrier. According to the particular surface layer used, the structural elements may remain visible on the inside or be covered with finishing materials. A similar system is available for the construction of floors and roofs (Lignum, 1999:42-43).

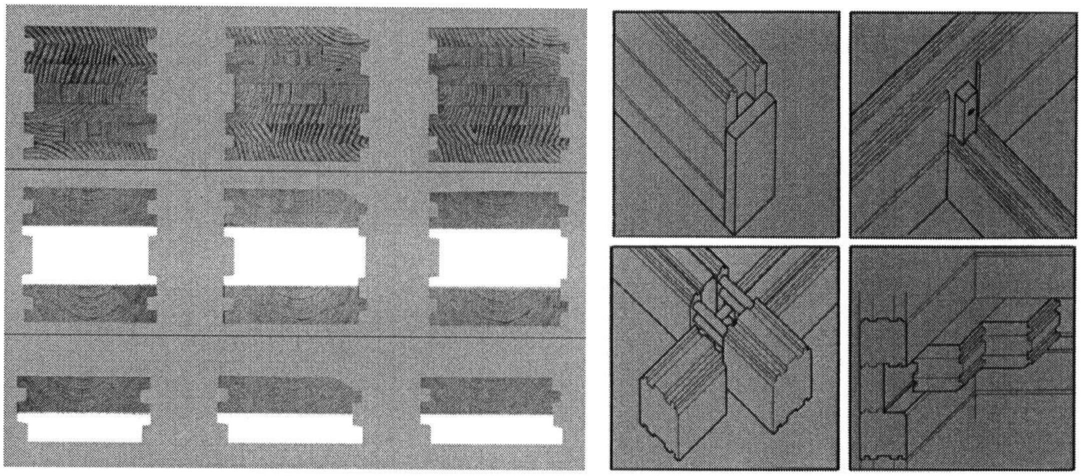


a) Single element with optional size *b) Selection of different element*
c) Installation cavities within element *d) Row houses, Winterthur, Bär & architects, 1996.*

Fig. 2.34 Lignotrend system (Source: Lignotrend, 2004).

YSOX

YSOX is a wood building system that is reminiscent of traditional log construction (compare to Chapter 2.3.3 Traditional wood building systems). It relies on manufactured linear elements laid on top of each other in courses and interlocked at the corners. The system consists of three basic elements: a structural non-insulated, a structural insulated and a non-structural insulated element. The structural non-insulated element is a (five to ten-layered) glue-lam beam with tongue-and-groove joints (Fig. 2.35). The structural insulated element contains a polystyrene centre with two-layered flanges to either side. The non-structural insulated element consists of one-half of the structural insulated one. On site, the elements are cut to the required length and assembled into walls, floors and roofs. The elements are interlocked at the corners and fixed with mechanical fasteners. (Samavaz, 1998).

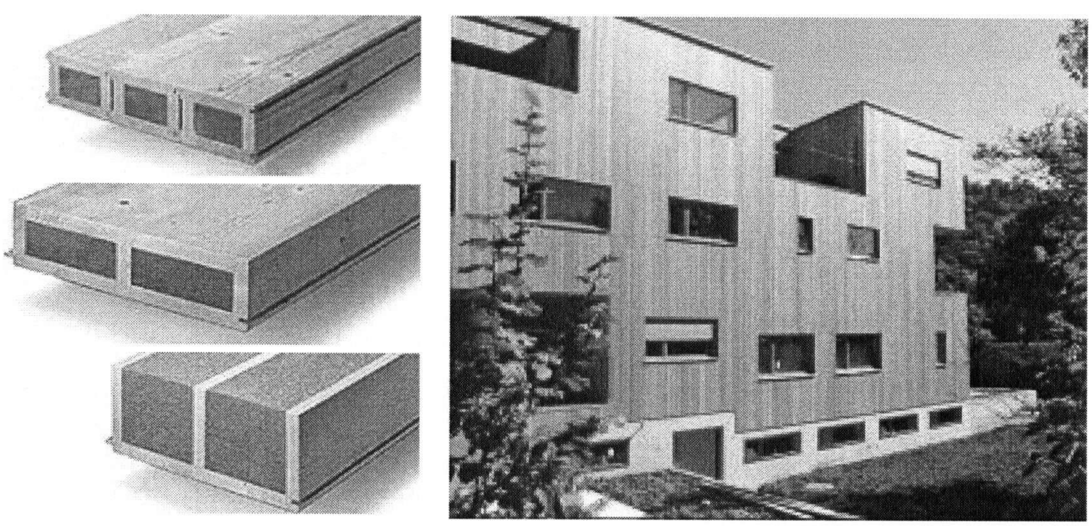


a) Selection of YSOX elements *b) Details at openings, joints and corners*

Fig. 2.35 Ysox system (Source: Samvaz, 1998).

Lignatur

Lignatur LKE (Lignatur Kasten Element (Lignatur case element)) and LFE (Lignatur Flächen Element (Lignatur planar element)) elements are manufactured hollow-core elements of Norway spruce boards, providing tongue-and-groove joints. LKE is a single case element; LFE is a planar (double or quadruple a



a) LKE (top), LFE (centre), LSE (bottom) *b) Multi-residential building Blümlimattweg, Thun, Architekturwerkstatt 90, 2002.*

Fig. 2.36 Lignatur system (Source: Lignum, 1999: 28-29, Lignatur, 2004).

case) element (Fig. 2.36). This system is generally used for floor constructions. As well, specific module, the LSE (Lignatur Schalen element (Lignatur shell element)), is also available for the construction of roofs. Upon request, elements with individual dimensions and optional core insulation are provided. (Lignum, 1999:4-5). Even though this system is meant for floor and roof constructions, it has also been used for the construction of load-bearing walls, where the elements are used in the vertical direction. Using these elements, curved roof and wall sections are easily achievable. Often, single elements are joined to form larger compounds. On site, the elements or element compounds are assembled into walls, floors and roofs and the construction is wrapped with insulation and cladding.

WE-KA-elements

Single WE-KA-elements (Wellsteg-Kammer-Element (corrugated web-chamber-element)) are similar to I-joists. A corrugated birch plywood web is glued into the grooves of the lateral flanges consisting of Norway spruce or fir. The two flanges with tongue-and-groove edges allow single elements to be assembled into large elements, kept together with internal wooden tie-bars. The resulting cores may be filled with thermal insulation or other infill (Fig. 2.37). These elements are used for the construction of walls (vertical cores), floors and roofs alike. The easily-varied depth of the panel allows highly-insulated structural panels. Enclosures of WE-KA-elements need only to be covered with cladding on the outside, along with a vapour barrier and finishing materials on the inside (Lignum, 1999:16-17).

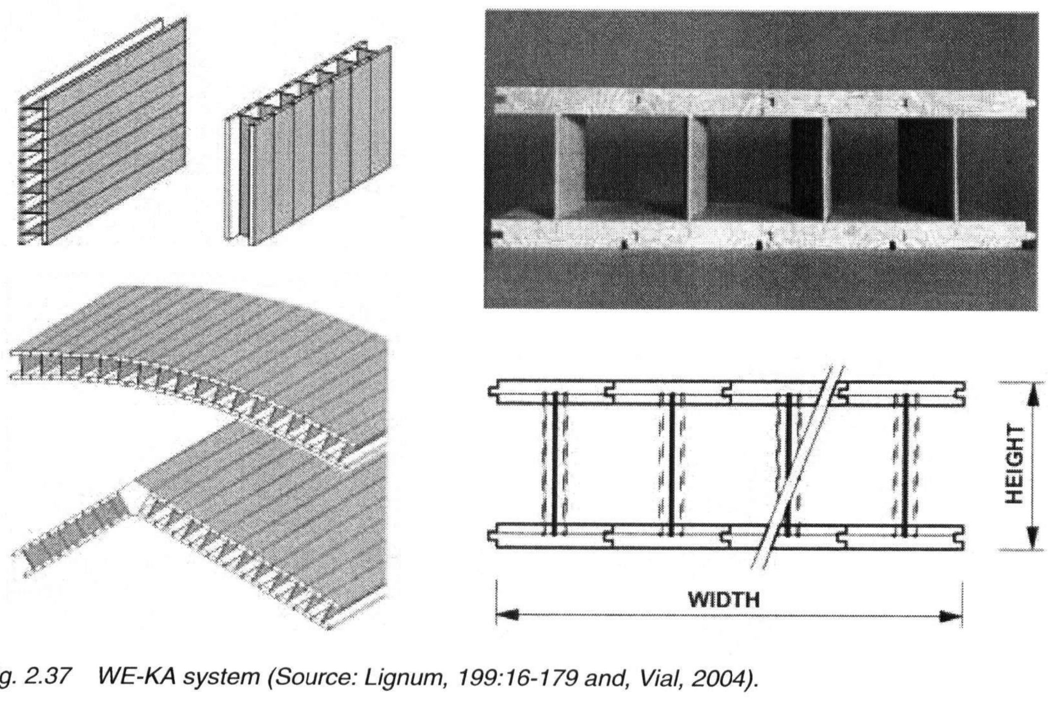


Fig. 2.37 WE-KA system (Source: Lignum, 199:16-179 and, Vial, 2004).

Brüggo Holes

The Brüggo Holes system relies on glue-laminated studs and sheathing boards with tongue-and-groove connections, both consisting of Norway spruce or fir sapwood boards. Instead of being applied to either side of the studs, one or two layers of sheathing are eccentrically fitted between the studs using a dovetail connection. Special plates are used to close the panel at the top and bottom. As such, this system allows the building of large wall, floor and roof elements. The single-sheathed system is generally used for enclosures, where the large spaces are filled with insulation, and the smaller ones work as installation cavities. Insulation and cladding are applied to the exterior side and finishing materials to the interior one. The double-sheeted system is often used for floor constructions. The three separated cavities allow great freedom in designing the performance of floors. The floor construction may for example contain an installation layer or a layer with crushed stones to achieve increased thermal mass and / or sound insulation, as well as a thermal insulation layer. The single- and double-sheathed system allows very flexible layering of walls, floors and roofs (Fig. 2.38) (Lignum, 1999:40-41).

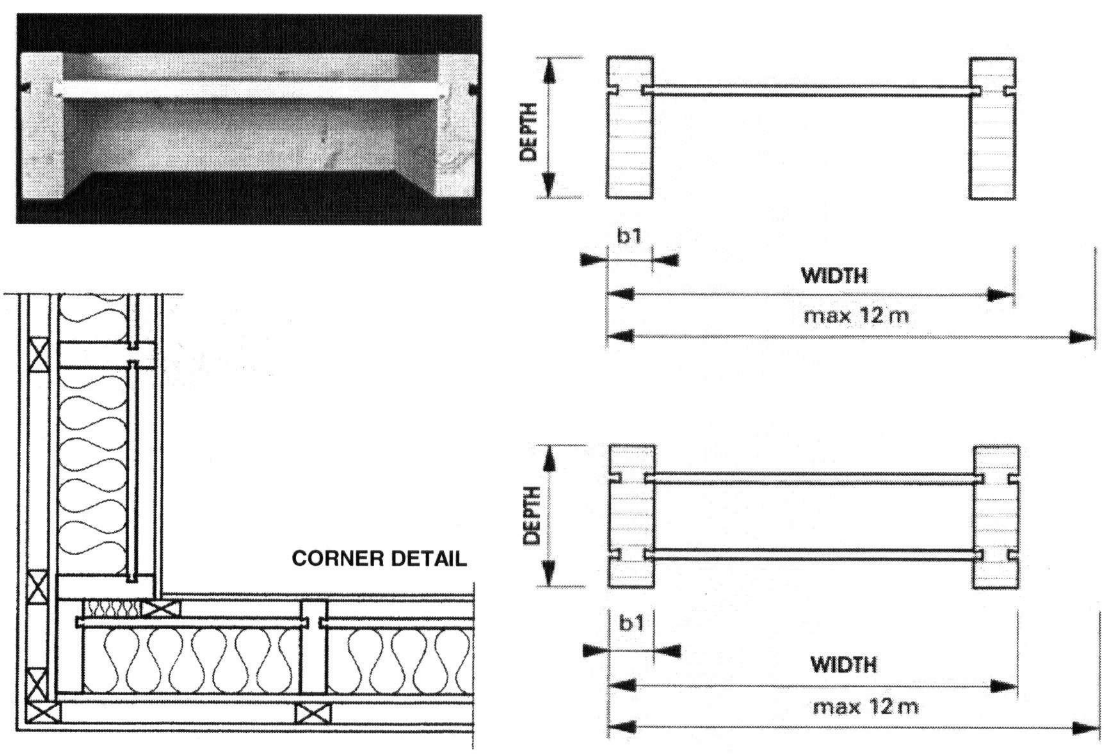


Fig. 2.38 Brüggo Holes (Source: Lignum, 1999; and Vial carpenters, 2004).

Wood-lightweight-concrete

Wood-lightweight-concrete is a new type of concrete, using wood fibre aggregates instead of sand and gravel. This new building material allows a cast-on-site construction as well as the use of manufactured modules (e.g. blocks) or factory-built elements (e.g. wall panels with high levels of prefabrication). Wood-lightweight-concrete combines the positive advantages of wood and concrete: It is seen as a potential material for the construction of multiple-storey buildings, as it provides better fire resistance than any other wood building system and, like concrete, it allows the construction of almost any form. In comparison to concrete, the new material is lighter; it has a better thermal performance (thermal conductivity of about 0.3 to 0.75 W/mK), and it provides good sound-insulation values (Gliniorz, 2001).

2.3.5 Advanced voluntary building standards

Encouraged by the Energy 2000 program (see 2.2.2 Politics), the wood building industry has strongly supported the federal attempts to reduce the consumption of non-renewable energies of buildings over the last ten years. Consequently, the new wood building practice in Switzerland is closely linked to the *Minergie*, the *Passive House* and the recently-developed *Minergie-P* standards. These three labels are meant to honour buildings with an operational energy use that is substantially lower than is required by the (enhanced) present building code. In addition, factory-built houses in wood that provide high economic, ecological and construction advantages may achieve the *label VGQ* (Swiss Union for Tested Quality Houses). As such, this label encourages carpenters to achieve high product and production standards. Also, it markets the idea that factory-built houses in wood are of high construction quality.

Minergie

Minergie is a label that may be assigned to buildings, tools, technical installations and machines alike. It stands for “more living quality” and “low energy consumption”. In 1998, the first Minergie label was given to three single-family houses in wood built by Renggli AG.

The Minergie label limits the consumption of operational energy as well as the initial building costs. The benchmark for the annual consumption of non-renewable operational energy is at 42 kWh/m^2 for new residential buildings and at 80 kWh/m^2 for old ones (built before 1990), whereas electricity used for heating purposes counts as double. In order to limit ventilation heat losses, tight enclosures (of $n_{50} \leq 1/h$) along with controlled ventilation with heat recovery are compulsory. Minergie buildings reduce the use of operational energy to about 40% of conventional ones. Despite, the initial building costs are not allowed to be more than 10% higher than those required for conventional buildings. (Minergie, 2004).

Passive House standard

The *Passive House* standard has mainly been defined by Dr. Wolfgang Feist of the Passive House Institute in Darmstadt, Germany, and is standardised for central Europe. The maximum annual heating energy of passive houses must be less than 15 kWh/m^2; the annual consumption of primary energy is limited to 120 kWh/m^2, and the tightness of the enclosure must limit the air exchange rate to $n_{50} \leq 0.6/h$. The heating energy mainly relies on passive energy sources such as passive solar heat, the inhabitants themselves, and appliances. Heat pumps or domestic hot-water systems may provide additional energy and / or hot water. High surface temperatures and controlled ventilation with heat recovery provide a high level of comfort. These compact, Southern-oriented buildings with airtight enclosures consume only about 10% of the operational energy used by conventional houses.

Minergie-P

In accordance with the European passive house standard, Switzerland launched the Minergie-P label in 2003. This label basically translates the benchmarks defined for central European countries and the European DIN-norms to the specific settings in Switzerland and the local SIA-norms relating them to the features of the Minergie label. The first Minergie-P label was assigned to the single-family house Setz built by Renggli AG in March 2003 (Fig. 3.1c).

Minergie-P limits the consumption of operational energy as well as the initial building costs. Minergie-P buildings limit the annual consumption of non-renewable energy for heating, domestic hot water and ventilation to 30 kWh/m^2, while renewable energies are desired, and energy-efficient appliances

(A or A^+ standard[1]) are required. Air-tight enclosures with a maximum air exchange rate of $n_{50} \leq 0.6/h$ and controlled ventilation with heat recovery are compulsory. The initial building costs must not be more than 15% higher than those for conventional buildings. Similar to Passive Houses, Minergie-P houses consume only about 10% of the operational energy used by conventional houses. Figure 2.39 gives an overview of annual operational energy consumption of different building standards in Switzerland (Minergie, 2004).

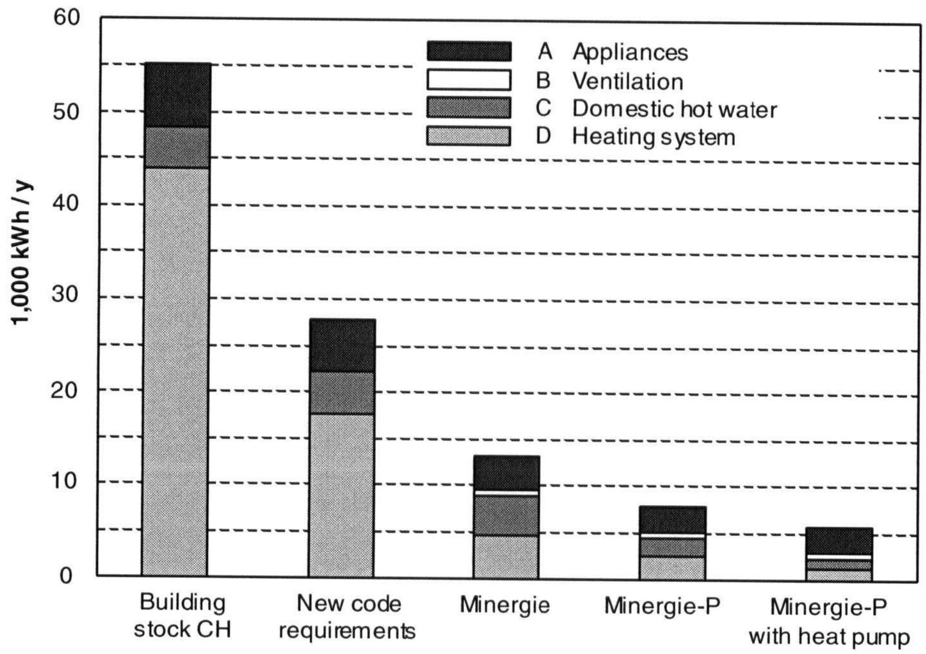


Fig. 2.39 Energy consumption of houses in Switzerland (Source: Frommelt, 2004).

Label VGQ

The *Quality Label VGQ* is assigned to factory-built houses in wood that meet the ecological and economic standards defined and controlled by the VGQ. In 2001, the label was set up by a group of carpenters and consultants (e.g. Renggli, Schöeb, Germerott) to strengthen and promote high product and production standards for factory-built houses in Switzerland. Neutral, external and internal tests, assessments and measurements evaluate the building system, the factory production process and the erection on site as well as the completed house. In 2001, the first labels VGQ were assigned to three carpentry firms honouring their production and erection processes; one of which was Renggli AG (VQG, 2001).

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[1] Classification of appliances according to the guidelines of the European Community. The classification defines 7 levels from G (energy inefficient appliances) to A (energy efficient appliances).

2.4 Global factors

Over the last three decades, in industrialised countries the achievement of a more sustainable development has become one of the most urging global problems to solve. In 1972 - shortly before the first oil crisis - the world was confronted with a report called "Limits of Growth" by the Club of Rome. It challenged the assumption that the Earth was infinite and would always provide the resources needed for human prosperity. It predicted a worldwide environmental crisis and a shortage of resources if the high population growth and the consumption patterns continued at the same high rates. The report based on research that used first computer modelling to invest the intricate problems. Even though it was very controversial and the predicted crisis in the early 1990s did not happen, the key message is still valid (Suter, 1999).

2.4.1. Sustainable Development

In 1987, the Brundtlandt-Commission defined sustainable development as a process that meets the requirements of present generations without jeopardising the chances of future generations (see also chapter 1.2. Definitions). This general principle was internationally recognised by most countries at the Earth Summit in Rio in 1992. Despite, the specification and the implementation of this basic concept appear to be very difficult. While it is agreed that all economic, ecologic and social components are an integral part of a sustainable development, disagreement exists on how much of one component might be given up in favour of another one. Also, there is an uncertainty in the rating of the rights and needs of future generations (Gotsch, 1999).

The Rio Declaration on Environment and Development (Agenda 21[1], UN, 2003) provides a comprehensive plan of action for the 21st century. Considering the broad field of environmental aspects, it provides an important tool for the implementation of environmental strategies. At this point, the cooperation of local, national and international partnerships (vertical networks) as well as those of local or national politicians, civil societies and industries (horizontal networks) is necessary to find the most appropriate level to approach the spatially and textually complex environmental problems.

[1] This document was adopted by 178 countries at the Earth Summit in Rio in 1992.

Figure 2.40 gives a scheme of interactions between global and local activities and responsibilities. Whereas the rule making (e.g. Agenda 21) as well as the generation of information and networks is very important on global level, on local level, the implementation of strategies or the distribution of knowledge is very important. Notably, the achievements on both global and local level depend on the commitment of local agents.

Global	-	**Local**
Rule making	-	Implementation
Structure	-	Function
Information	-	Knowledge
Top-down	-	Bottom-up
Networking	-	Partnerships

Fig. 2.40 Linking the global to the local activities and responsibilities (Source: Velasques, 2002: 11).

Sustainable Development in Switzerland

Since the early 1990s, the growing global concerns have enforced Switzerland's engagement for the environment. It actively supports various international activities considering the limitation of electromagnetic pollution, the protection of forests and water springs, the limitation of desert spread or the handling of hazardous goods. In 1992, it adopted the Agenda 21 and, in 2003 it ratified the Kyoto protocol (see also chapter 2.2.2 environmental concerns).

According to Agenda 21, Switzerland has started to convert the global requirements into local strategies. Currently, 17 cantons are in progress to set up a tool for environmental strategies on cantonal level, whereas 94 municipalities in 13 cantons have already implemented their 'local Agenda 21'. Even though the strategies are different from municipality to municipality, their goal is the same: they try to achieve an economically and ecologically sustainable as well as socially-just future (ARE, 2004). The development of environmental strategies by cantons and municipalities guarantees regionally-bound solutions, as well as an immediate information and communication process. Further more, thriving strategies might push the launch of tightened new laws and regulations.

Alongside, federally-funded programs, such as the Energy2000 or the 2,000-watt society (see chapter 2.2.2 environmental concerns), particularly focus the research on the reduction of the fossil fuel consumption and the CO_2 exhaustion as well as on the production of renewable energies. Thereby, the research of sustainable issues is seen as an 'innovation motor' (Zehnder, 2004) as well as a tool to establish partnerships. Again, a good example is the Energy2000 program. Whereas not all the goals were met (Tab. 2.17), the success of the program is seen in the establishment of partnerships between cantons, municipalities, non-governmental organisations, commercial enterprises and private partners. In addition, it generated new ideas or standards applicable to cities, buildings (enclosure, appliances), mobility issues (fuel, co-ops) or the production of renewable energies (wind, sun, water, ground, wood) (SFOE, 2001). Even more, the potential to test ideas or standards in pilot projects was an important step to transfer the new standards into feasible tools (Tab. 2.18). Since 1998, about 3,000 Minergie buildings as well as some Minergie-P buildings (Minergie, 2004) have been awarded. By the end of 2003, the "Energiestadt" label (EnergieSchweiz, 2004) was assigned to 102 cities hosting more than one-fourth of Switzerland's inhabitants. Since January 1, 2002, the declaration of the energy efficiency and the energy consumption of appliances with an "Energie Etikette" is mandatory in Switzerland (EnergieSchweiz, 2003). As we have already seen in Chapter 2.3.5 (Advanced voluntary building standards), the Minergie-P label requires the use of appliances rated with an A or higher (A^+ or A^{++}). As such, this energy and CO_2 focussed research has likewise influenced the building development in Switzerland.

	Goal (1990 – 1999)	*Result (1990 – 1998)*
Fossil energy use	Stabilisation	+ 6.1%
Electricity use	Increase < + 15%	+ 6.5%
Renewable energies - heating energy - electricity	 + 3% + 0.5%	 + 37.2% + 60%
Hydroelectricity	Increase + 15 %	+ 4.3%
Output existing nuclear stations	+ 10%	+ 6%
CO_2 exhaustion	Stabilisation	fairly stable at ± 40 million tons (light decrease 1990-96, light increase after 1996)
	- 10% (2000 - 2010)	?

Tab. 2.17 Goals and achievements of Energy 2000 (Source: Adapted from SFOE, 2001).

"Energiestadt" (energy-city)	Label rewarded to municipalities for complying with more than 50% of a total of 91 defined energy saving strategies.
"Minergie" (Minergie-P)	Label rewarded to buildings, cars, appliances and processes for lower energy use and higher living quality within a given economic frame
"Energie Etikette" (energy etiquette)	Rating of appliances or cars in terms of their energy use according to the directives of the EU (A = lowest energy consumption level, E = highest one)

Tab. 2.18 Standards generated during the Energy 2000 program (Source: Adapted from SFOE, 2001).

2.4.2 Sustainable building development

In near future, aspects such as healthy housing, longevity, natural resource efficiency, renewable energy, local and renewable building materials, operational energy consumption, greenhouse gas emission or recycled building content will become more important in the evaluation of a building or a building development. Also, they might increase the pressure on politicians, planners, builders and owners alike even though there is yet not much readiness to voluntarily adopt more sustainable building practises neither by the building industry nor by future owners. The expectation of higher costs, the loss of social image as well as a potential change of habits or personal comfort mostly seem to prevent the voluntary adoption of more sustainable building practices and, the adaptation of the local building codes takes time.

Over the last 15 years, many countries or regions have launched voluntary building standards or labels for a more sustainable building development. Among them are the BREEAM[2] (UK 1988, Canada 1998), the LEED[3] (USA 2000, Canada 2004), the Passive House standard (central Europe 1988) as well as the Minergie label (Switzerland 1998) and the Minergie-P label (Switzerland 2003) (see also chapter 2.3.5 Advanced voluntary building standards). Whereas the overall goal of all standards is the same, the approach differs from standard to standard as well as from region to region. As such, they differently

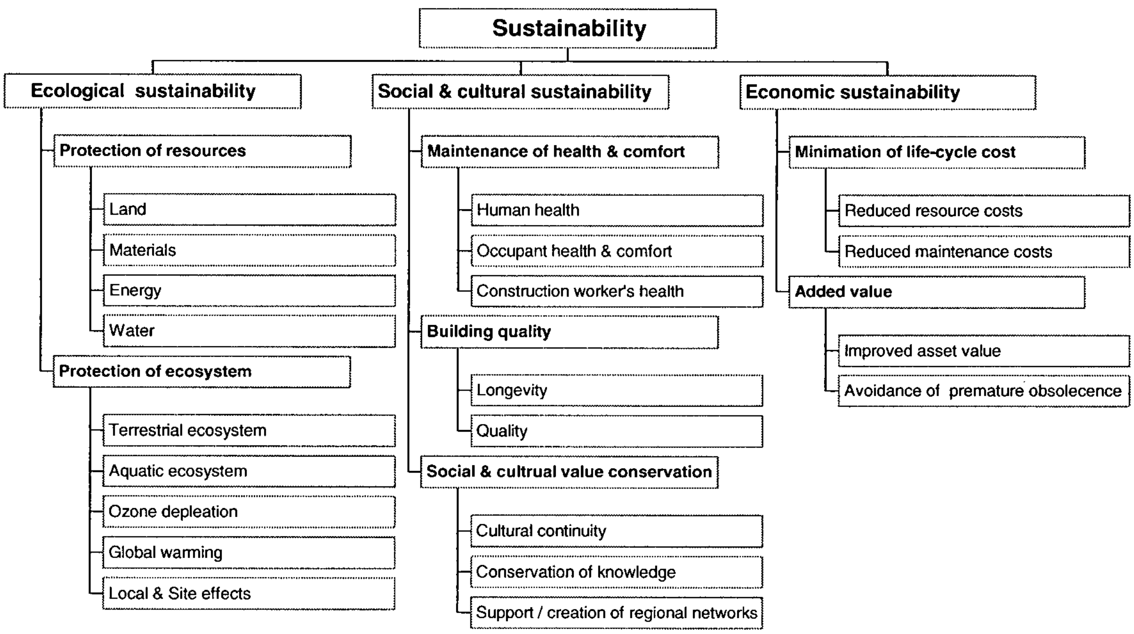

Fig. 2.41 Chart of basic factors of sustainability (Source: Cole, [2002?]).

[2] BREEAM stands for Building Research Establishment Environmental Assessment Method.
[3] LEED stands for Leadership in Energy and Environmental Design.

address and value the basic global factors of sustainability, as they are exemplary shown in the chart in Figure 2.41. Nonetheless, the successful implementation of sustainable strategies into the local building practise is a central problem that has yet to be solved in most countries.

Sustainable building development in Switzerland

Many global environmental concerns have not become priority issues in Switzerland. The large resources of wood, mineral deposits (lime, clay, sand and gravel) and water have not yet imposed major restrictions on the building practise. Also, the large stock of old buildings, the idea of 'ever lasting' buildings and a comparably small number of disposed buildings has not enforced steps for the reuse of building components or the use of recycled building materials. In contrary, problems of transportation, waste management, air pollution or site effects have gradually have been included into the building legislation. Today, issues such as waste-water management, on-site infiltration of storm-water, minimal size of green-space ratios, thermal insulation of enclosures, separation and recycling of building materials and components or the use of non-toxic building materials are ruled by federal, cantonal or municipal laws.

Despite a steady update of the building legislation, the attempts to reduce the CO_2 exhaustion (Kyoto Protocol, CO_2-law), to maintain the local forests (new forest law) and to reduce the dependency on fossil fuels have considerably changed the building context within only few years. And, these attempts have also had a strong impact in the building practise in Switzerland. In 1998, the launch of the Minergie label (chapter 2.3.5 Advanced building standard) has become a promising tool to achieving these goals. Minergie buildings reduce the consumption of operational energy to about 50% towards conventional buildings (Architos, 2000). And, the local wood building industry is strongly and successfully supporting this strategy.

As most of the new wood building systems rely on local wood and assist in providing thin enclosures with high thermal efficiency, they have a strong potential in meeting the new requirements. Thin enclosure save urban land or provide larger living spaces (better construction - living space ratio). As they are considerably lighter than concrete or brick masonry constructions, the new wood building systems require smaller foundations. Also, an increased use of wood assists in maintaining the health of the local forest as well as in limiting the CO_2 emission due to its CO_2 neutrality and limited transport emissions. Even more, wood is a fast renewable as well as a traditional building material. However, it is believed that not the environmental benefits but, that the marketing of the Minergie label, the federal funding and the reduced mortgage interests as well as the focussed content of the label have been important for the fast growing market share of the Minergie buildings.

Minergie houses are primarily marketed as houses with increased comfort and security at reasonable costs. These arguments consider aspects like fresh air without the need to open windows (controlled ventilation[4]), high surface temperature on the inside of the enclosure (thermal insulation), no drafts (air tight enclosure, controlled ventilation) as well as protection against allergenic particles (filtered air), noise and burglary (closed windows). All these arguments are becoming increasingly important as more and more people suffer from noise and allergic reactions. In addition, today more and more houses are unattended for most of the day as both men and women are at work (see also chapter 2.2.4 Education and workforce). The fact that these houses promise more comfort at little higher initial costs as well as a payout over the years due to reduced running costs is a weightily advantage of these houses towards conventional ones. Even more, saving fossil fuels and using renewable energies are supported by governmental subsidies and, some financial institutions support the construction of Minergie houses with lower mortgage interests[5]. Also, long lasting and healthy houses as well as houses that keep their value over time support the Swiss attitude to consider a home a provision for one's old age.

The clear focus on reducing the operational energy consumption allows architects and planners to acquire the specific know-how in little time or by employing the advice of a consultant. Even more, the easy achievement of a small goal may encourage planners and clients to go for another one.

Even though the growing local responsibility to implement the global requirements for a more sustainable building development will further challenge the building practise in Switzerland, Minergie (or Minergie-P) houses in wood provide a powerful package as long as they provide durable, long lasting and healthy houses. The longer these buildings last, the more the reduced energy costs pay out. Also, durable and long lasting buildings reduce the average live cycle costs as well as its material use. Whereas the local population requests durable and long lasting buildings, healthy houses will become increasingly important to maintain their value over time.

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[4] Building biologists consider the Minergie standard, particularly the mechanical ventilation, to be critical to the inhabitant's health.
[5] For example, the Raiffeisen banks (regional mutual saving banks) reward future owner of Minergie buildings a four-year reduction of 0.5% on the interests of primary mortgages up to 250,000 CHF.

2.5. Summary

The investigation of the building context in Switzerland (Tab. 2.19) revealed a “Swissness” that will be very important for the evaluation of the potential success of the two new wood building systems. The following section briefly summarizes and discusses the key aspects of the Swiss background as well as the local importance of Minergie houses in wood.

Place	Small, mountainous and landlocked country Four distinct seasons, temperate climate with considerable regional differences Few natural resources except of water, wood and mineral sediments (sand, gravel, ...) Increasing urbanisation of arable land within the Central Plain Dependency on foreign trade and currency exchange rates (High-tech) industry and trade with expensive, high-quality niche products / no standardized mass products Large percentage of small and medium sized companies
People	Political neutrality, political island within EU countries Federal system recognises cantonal diversities Four different languages, increasing percentage of foreign population Federal support for qualitative production methods in forestry and agriculture Performance oriented building codes and zone planes Federal priority to limit the use of fossil fuels and the exhaustion of CO_2 Research on renewable energies Ageing population, almost stagnating population growth Increasing percentage of women in work and politics Highly educated workforce (school, vocational training) Growing employment possibilities and part-time jobs in service sector High incomes and high expenditure levels with expensive insurances Increasing percentage of single households, growing dwelling size /person Old housing stock / country of tenants Buildings are expected to last more than a lifetime High building costs due to land costs, labour costs and building quality expectations
Product	Quality, perfection and reliability – like a Swiss watch Strong wood building culture Prevailing current brick masonry or concrete houses Minimal and clear forms prevail in present architecture Advanced voluntary building standards (Minergie, Passive House, Minergie-P, VGQ label)
Global context	Ecological development (Protection of resources and ecosystems) Social development (Building quality, health maintenance, social and cultural value conservation) Economic development (Minimisation of life-cycle costs, added value) - Glocal activities: Local agenda 21 Limiting the use of fossil fuels and the exhaustion of CO_2 Increase of renewable energies Improvement of forest health

Tab. 2.19 Key characteristics of the Swiss building context.

Switzerland is a small and densely populated country with vast resources of water, mineral sediments and timber as well as attractive natural and cultural sites. The lack of popular primary energy sources, such as oil, gas and uranium as well as the need for exterior trade (import of primary goods and export of processed ones) makes the country strongly dependent from foreign countries. Besides being landlocked within the heart of Europe, Switzerland has also become a political island that is not (yet) part of the EU. Yet, the ideal of being independent, the fear of loosing the high living standard, the difficulty to subordinate itself as well as the difficulty to unite the diverse interests within the country are potential reasons for this attitude. Within the country, differences between the four parts of the country (German, French, Italian and Romansh speaking part), urban and rural sites, cultural groups or political affiliations require strong efforts to take common decisions. Often, ordinary compromises more than brave decisions are the outcome of long debates. Or, decisions are only supported by certain regions. For example, saving energy, the construction of Minergie houses, or building in wood are issues that are mainly limited to the German and Romansh speaking part of Switzerland. Whereas the French part of Switzerland partially supports theses strategies, the Italian barely part does. They traditionally did not have wood buildings and, they do not care too much about saving energy.

"Quality instead of quantity" or "quality costs" are major credos that Swiss people use for aspects of live as well as to products, from agriculture and forestry to industrial products and buildings. High technology and production standards, high productivity as well as a workmanship with good practical and theoretical education assist in achieving these goals. In turn, innovation, quality and reliability are key characteristics of the expensive niche products produced by the large number of small and medium sized industry and trade enterprises. As such, expensive products, high salaries and high living costs make Switzerland another island within Europe.

The oil crisis and the dying of the local forests emerged political institutions to address environmental problems in the mid 1980s. Since, the increased use of local wood, the reduction of the consumption of fossil fuels and the CO_2 exhaustion have become key strategies of the local policy. And, the implementation of these strategies is becoming increasingly important in the building industry. Whereas brick masonry and concrete dominated the residential building market for many decades, the changed building context is more and more favouring low operational energy consuming houses in wood. These houses, particularly Minergie or Minergie-P houses in wood, address the key strategies of the federal policy and, the acceptance of operational energy-efficient houses in wood is slowly but steadily increasing. Important for this development was the marketing of the Minergie label, assisted by the attempts of the wood building industry to provide high quality houses.

Minergie houses promise high comfort and low consumption of operational energy at limited additional initial costs. Generally, people in Switzerland are ready to support environmental strategies as long as few time and financial engagement is required. And, they are ready to invest as long as they get security, material benefits or immaterial values out of it. Considering the housing issue, future clients accept the higher initial building costs in return for comfortable and long lasting houses that save energy and maintenance costs. Even more, federal subsidies and lower mortgage interests reduce the payback time. Minergie houses also promise to achieve high resale values.

Since the mid 1980s, the wood building industry is trying to get back to the market with innovative and high quality products that relay on the new wood building products and joining techniques as well as on high technology and production standards. By addressing the need for houses with high production and construction standards as well as by focussing on their advantage to provide enclosures with high thermal efficiency, the wood building industry has found a niche market that will promisingly grow over the next years and, that might exceed the single-family house market. Yet, whereas the overall goals are the same, there are big differences how they can be achieved.

A look at the sophisticated (or almost intricate) construction of the SWF still reveals the skilled craftsmanship of traditionally educated carpenters whereas the key details (e.g. joint details) are property of the firm. Latter might have been a strategy for innovative carpentry firms to survive in the small market or even a traditional relict of the carpenter guild where knowledge was monopolized. In any case, this habit strongly restricted the spread of standardised knowledge and, might be a reason why the construction principles of the SWF have not been standardised. On the other side, systems like the RPS do barely relate to the traditional craftsmanship. Glue-laminated boards are joined and glued as if it was cardboard. Even more, detailed information on the joining technique and the dimensioning of the basic boards invite for do-it-yourself experiences.

In the following chapters I will more closely investigate similarities and differences of SWF and RPS by discussing the construction principles and the production process, as well as critical aspects considering important issues of climate and inhabitant.

3. THE SWISS WOOD FRAME AND RIBBED PANEL SYSTEM

Both SWF and RPS are new in the Swiss building market. They support the construction of high thermal-insulated enclosures for residential houses, and they are factory-built and panellised constructions. However, they differ considerably in the way they achieve the goal. Major differences exist in the construction principles as well as in the planning and production processes. In this chapter I give background information for further investigations of the SWF and the RPS systems. As different types of SWF and RPS systems exist on the market, I have chosen the SWF system produced by Renggli AG and the RPS system developed by Pius Schuler AG.

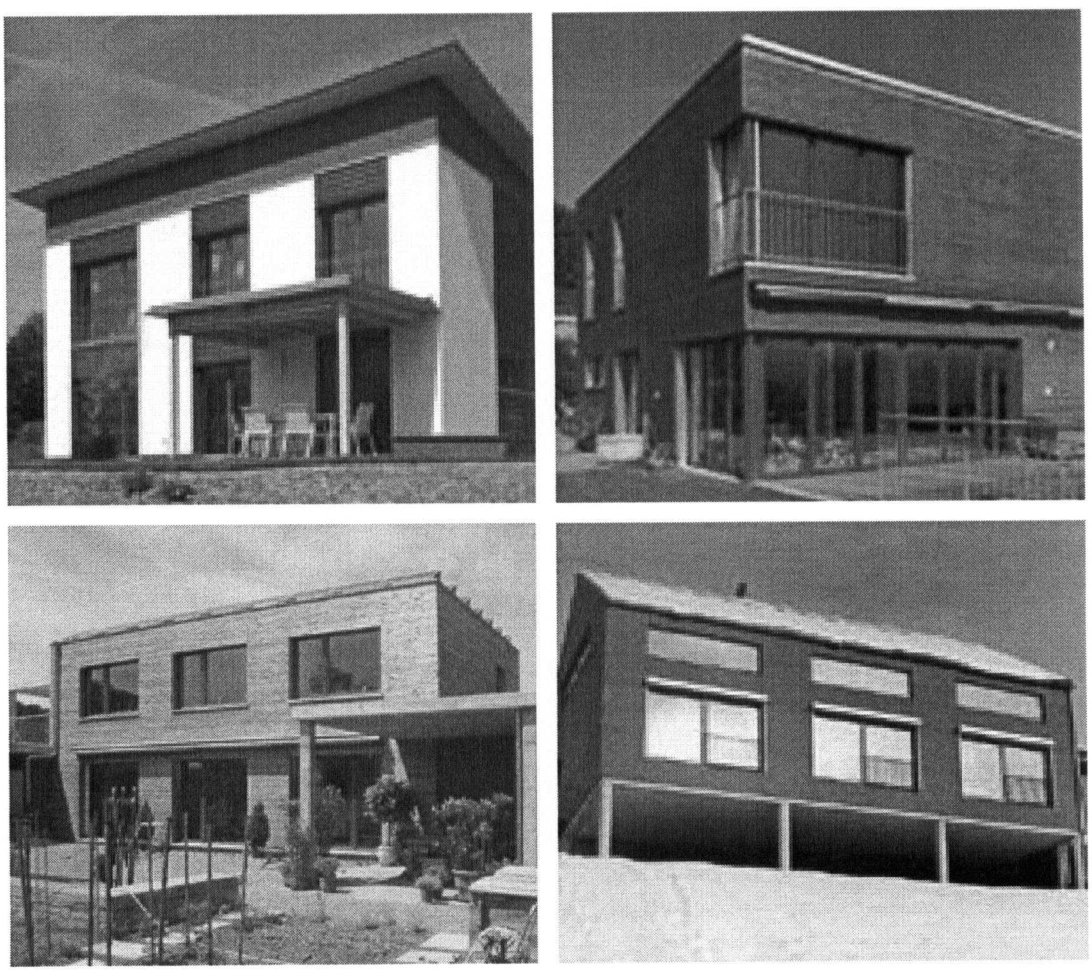
3.1. Swiss Wood Frame

In Switzerland - as well as in Germany and Austria - the Western platform frame as it is built in Canada and the United States has been known since the 1920s, but only a few houses were built in this foreign framing technique. For a second time, the Western platform frame was 'rediscovered' and transferred to the Central European building market in the mid 1980s. In Switzerland, the new framing technique (relying on the principles of the Western platform frame) was published under the title "Holzrahmenbau" (SIA, and Lignum, ed. 1989) in 1989. This document aimed to present anew wood building system that conformed to the present possibilities and requirements in terms of construction, performance and design (SIA, and Lignum, ed. 1989:1, 5), but once more this adapted system was never really accepted. Nonetheless, it was the basis for the development of the successful SWF within only a few years.

Within this thesis I use the term *Swiss Wood Frame* to refer to the specific factory-built wood frame system as it has been developed in Switzerland over the last ten years. This terminology contrasts the attitude to translate the German term *Holzrahmen*(bau) with *timber-frame*(construction), a term that relates to the traditional *timber-frame* construction (*Fachwerk*bau). In addition, the comparatively heavy new Swiss framing technique contrasts with the terms *Western platform frame* or *light-wood frame* as they are used in Canada and the United States.

The SWF generally relies on large wall, floor or roof elements that are produced in large production halls. The factory production makes use of CAD-CAM technology, transferring computer drawings directly to the respective machines. Means of transportation and storage space as well as the need for flexible floor arrangements in single-family houses might be key reasons why the panellised construction has been preferred to the modular one. Individual and modern design, scientifically-engineered building materials, highly-insulated enclosures and sophisticated construction details are characteristic of these buildings. Despite – or potentially also because of – the high levels of knowledge, technology and tools involved in the construction of these systems, each carpentry firm has its own unique system (see chapter 2.6. Summary).

Today, Renggli AG is the leading producer of residential and non-residential SWF buildings, as well as the leading producer of single-family houses in wood. With a current annual production of about



a) House Kiser, Hitzkirch, Concept house 'Futura' *b) House Boss, Baar, Custom designed*
c) House Setz, Dintikon, Werner Setz architect *d) House Brun, Geuensee, Custom designed*

Fig. 3.1 SWF houses built by the Renggli AG (Source: Renggli, 2004: References, Architos, 2004: References).

100 to 120 SWF single-family houses, Renggli AG accounts for about 1% of the total number of new dwellings or for about 12% of the new single-family houses in wood. Figure 3.1 illustrates a selection of SWF houses built by Renggli AG. This firm goes back to 1923 when it was founded as a carpentry firm with an affiliated sawmill. In 1991, the firm was handed over to the 4th generation. Four years later, in 1995, the first production hall was built.

Renggli AG has been involved in research on energy-efficient buildings as well as in the development and launch of the Minergie and the Minergie-P labels. In 1998, the first three Minergie labels were assigned to its concept houses 'Domino', 'Futura' (Fig.3.1a) and 'Familia' (Solar agency, 2003). In 2003, house Setz (Fig.3.1c) became its first Minergie-P house. Renggli AG is a member of Architos[1], and makes its technical know-how as well as its wood building system available to the association. In addition, it is a founding member of the VGQ (see chapter 2.3.5 Advanced voluntary building standards). In 2001, Renggli AG achieved one of the first three labels VGQ for its building system. In 2003, it also received a label VGQ for its concept houses. Latter rewards the high-quality standards of the entire building process of these ready-to-move-in houses, from the planning phase to the finishing of the house.

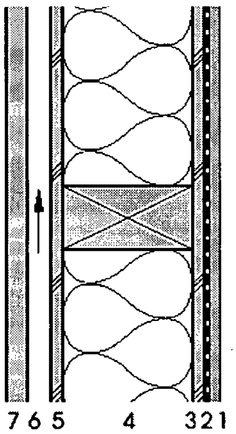
3.1.1 Construction principles of SWF

In its technical documentation, Architos (Architos, 2000) presents the three building standards of Renggli AG. The norm standard is used to achieve the code requirements. The Minergie and Passive house (or the Minergie-P) standards are used to promote the respective voluntary building standards. For each standard, a vertical scheme section 1:20 through a two storey house as well as regular sections 1:10 through the enclosure, the roof construction, the ceiling against an unheated roof space and the ground floor ceiling is given, together with information on the materials used (Fig.3.2).

As Minergie buildings have become a standard for SWF houses, in this thesis I investigate this building standard, though the norm standard shows the construction principles more clearly. Figure 3.2 shows the three thermal insulation standards, while Figure 3.3 shows the enclosure section as well as the roof, ceiling and floor constructions of the Minergie standard. Where no specific reference is given, the data refers to information provided by Renggli AG (Renggli, 2004), Architos (Architos, 2000), general

[1] Architos is an association of various experts that tries to develop new environmental strategies for buildings.

information on wood building systems published by Kolb (Kolb, 1998), and a personal interview with Max Renggli on the occasion of a visit to the firm (Renggli, 2002).

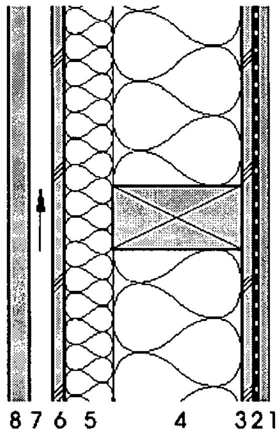


U-value [(1)] = 0.26 W/m²K
R'w [(2)] ≈ 46 dB

NORM STANDARD

1 Gypsum board 12,5 mm
2 Vapour retarder and air barrier
3 OSB 15 mm
4 Wood frame 80 / 160 mm
Mineral fibre boards 160 mm
5 OSB 15 mm
6 Air cavity 30 mm
7 Cladding variable

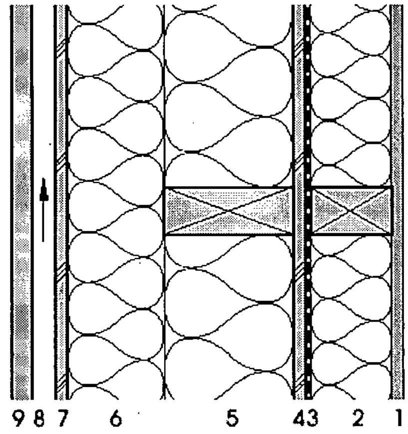
[1] *Heat transmission coefficient*
[2] *Airborne sound reduction index*



U-value = 0.19 W/m²K
R'w ≈ 50 dB

MINERGIE STANDARD

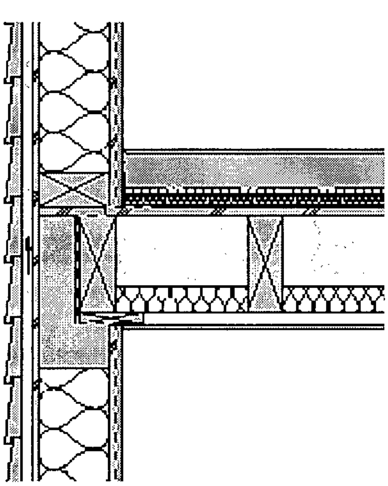
1 Gypsum board 12,5 mm
2 Vapour retarder and air barrier
3 OSB 15 mm
4 Wood frame 80 / 160 mm
Mineral fibre boards 160 mm
5 Furring 60 / 60 mm
Mineral fibre boards 60 mm
6 OSB 15 mm
7 Air cavity 30 mm
8 Cladding variable

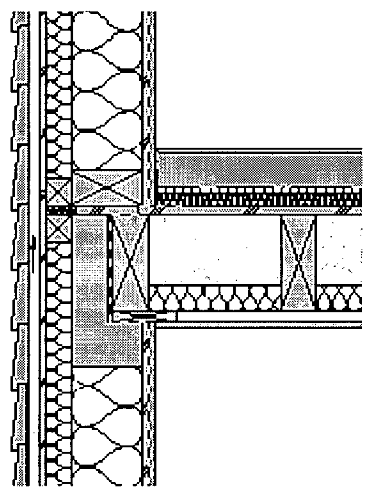


U-value = 0.105 W/m²K
R'w ≈ 50 dB

PASSIVE HOUSE STANDARD

1 Gypsum board 12,5 mm
2 Wood frame 60 / 100 mm
Mineral fibre boards 100 mm
3 Vapour retarder and air barrier
4 OSB 15 mm
5 Wood frame 60 / 160 mm
Mineral fibre boards 160 mm
6 Furring 40 / 120 mm
Mineral fibre boards 120 mm
7 OSB 15 mm
8 Air cavity 30 mm
9 Cladding variable





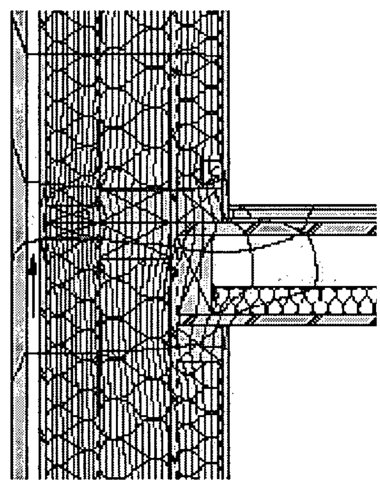
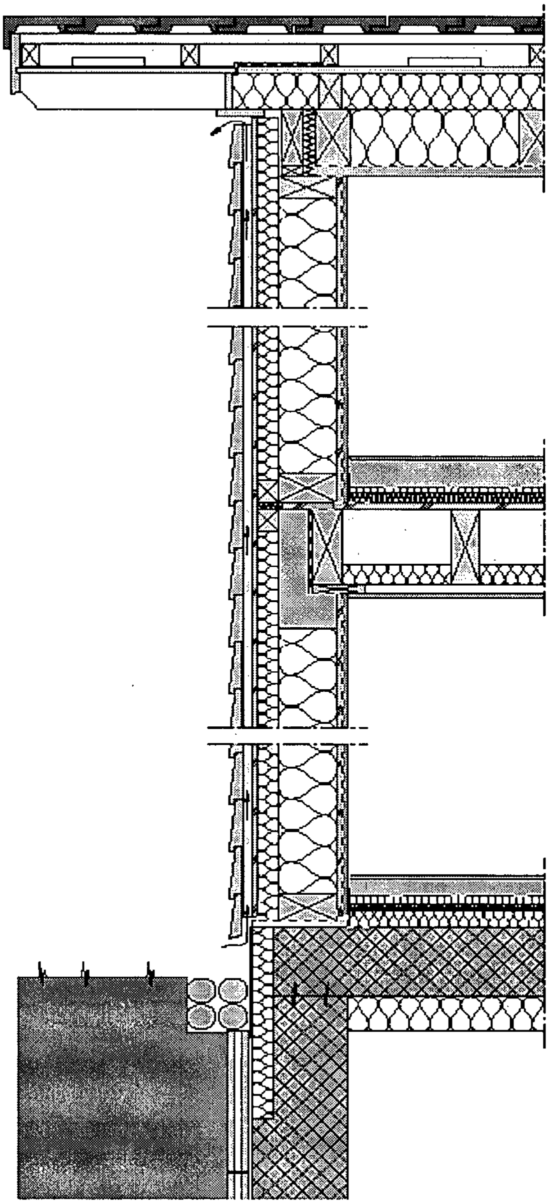
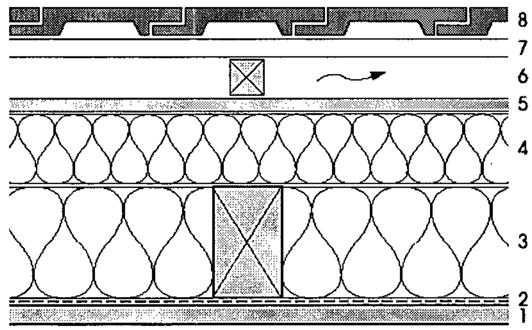


Fig. 3.2 Horizontal enclosure section and vertical joint section of the three thermal insulation standards of SWF (Architos, 2000).

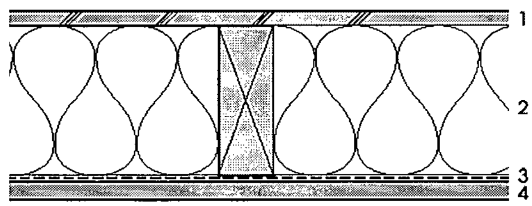




U-value = 0.17 W/m²K
R'w ≈ 50 dB

Roof construction

1 3-layered glue-laminated board 27 mm
2 Vapour retarder and air barrier
3 Rafters 100 / 160 mm, mineral fibre boards 160 mm
4 Furring 80 / 100 mm, mineral fibre boards 100 mm
5 Wood fibreboard 22 mm
6 Furring 40 / 50 mm and air cavity
7 Tile battens 24 / 48 mm
8 Roof tiles



U-value = 0.19 W/m²K
R'w ≈ 42 dB
L'n,w [(1)] ≈ 85 dB

Top floor ceiling (unheated roof space)

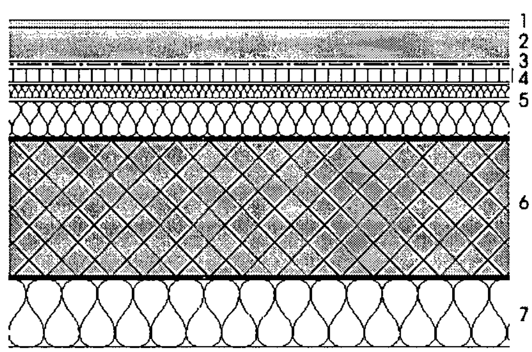
1 wood fibreboard 22 mm
2 Joists 80 / 220 mm, mineral fibre boards 220 mm
3 Vapour retarder and air barrier
4 3-layered glue-laminated board 27 mm

Ground floor (against cellar)

1 Finish flooring
2 Cement underlay floor 50 mm
3 Separating foil
4 Impact insulation 20 mm
ISOVER PS81 (glass fibre)
5 Expanded foamed plastic 20 + 50 mm
6 Cast concrete slab 200 mm
7 Mineral fibre boards 100 mm

L'n,w [(1)] ≈ 40 dB (Carpet)
L'n,w ≈ 40 dB (Hardwood)
L'n,w ≈ 40 dB (Tiles)

[1] *Weighted normalized impact noise level*



U-value = 0.17 W/m²K
R'w ≈ 56 dB

Fig. 3.3 Enclosure section and floor construction of SWF at the Minergie standard (Architos, 2000)

Structural core of wall and floor elements

In keeping with on-site-built frame constructions, the structural frame of wall elements consists of vertical (studs) and horizontal (top and bottom plates, lintels) members. The studs (80 x 160 mm), the bottom wall plates (80 x 160 mm) and the top plates (80 x 160 mm or L-shaped) are nailed against each other to form the structural frame (Fig. 3.4). In accordance with the available sizes of OSB sheathing (App. 4), the studs will be spaced at 625 mm on centre. As such, the studs support the joints of the sheathing boards. Supported by jack studs, lintels span openings of doors and windows. OSB sheathing nailed to the inside of the structural frame provides the frame rigidity; application on the exterior side of the frame is not possible, as additional thermal insulation is necessary to achieve the Minergie standard.

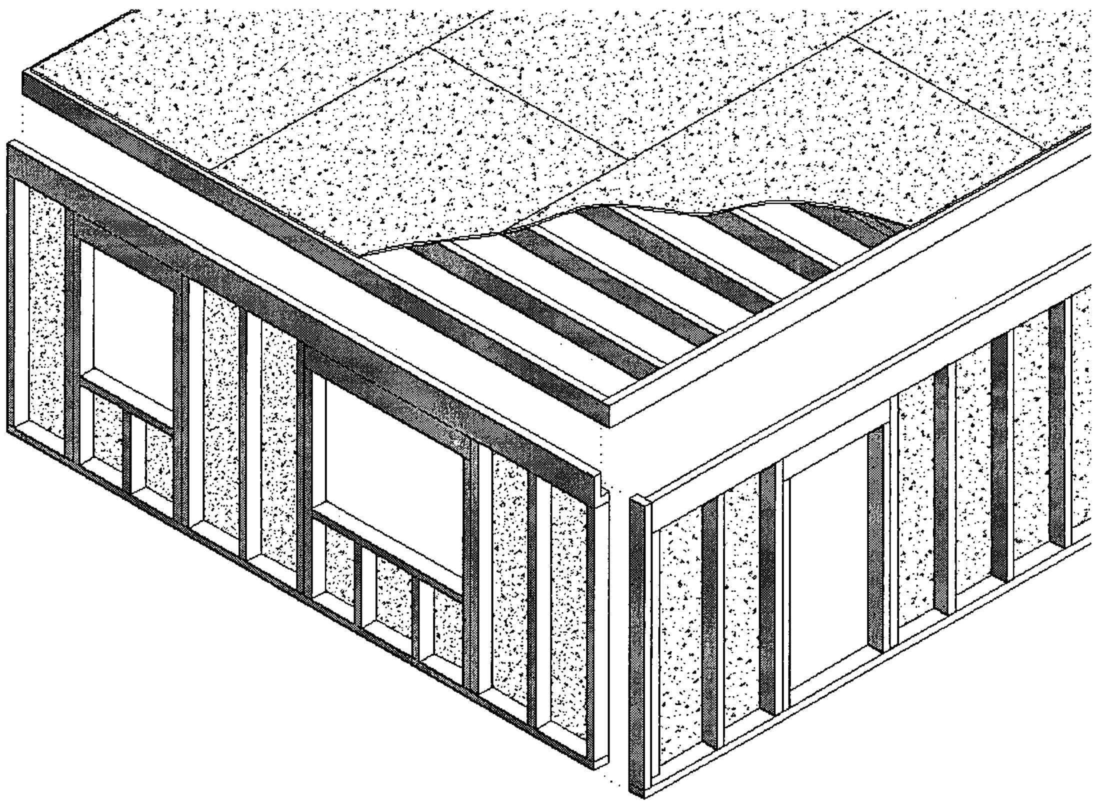


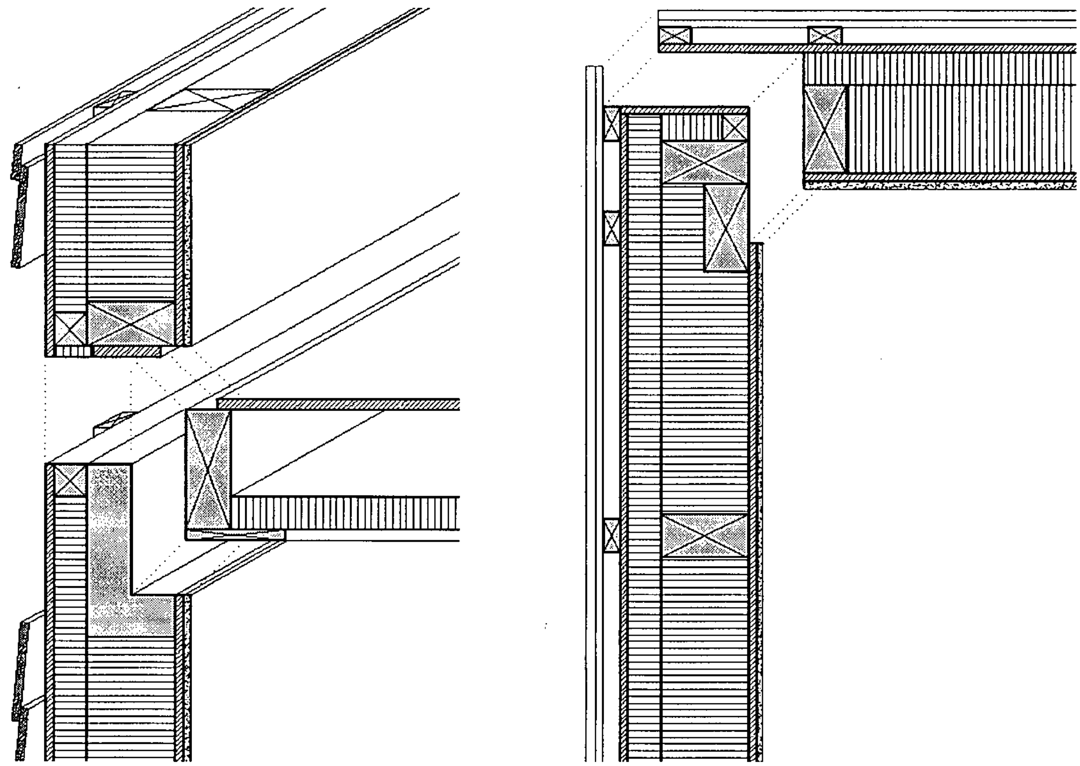
Fig. 3.4 Scheme of the structural wall and floor frame of SWF

As in the wall frame, joists and headers of 80 x 220 mm are nailed together to form the floor frame (Fig. 3.4). A wood fibreboard subfloor with tongue-and-groove joints is applied on top of the frame to provide the frame rigidity. It is assumed that the subfloor is glued and nailed on top of the floor frame, as the use of glue may substantially improve the stiffness of the floor. Due to the (most probably glued) tongue-and-groove connections and a crosswise orientation of the boards and studs, the spacing of the studs is independent from the subfloor material; it depends solely on the expected load as well as on the strength of the subfloor material. According to a rule of thumb, joists (80 x 220 mm) with a maximum spacing of 65 mm on centre may span approximately 4.40 m ($h \approx l / 20$ and $b = h / 2$). As $b / h \leq 2.5$, no bridging is needed to prevent the joists from twisting (Kolb, 1998:92, 149). The joists may be spaced more closely if larger loads are expected. Often, hollow-core elements replace the joist construction if heavier loads or larger spans occur.

The frame members of SWF consist of coniferous construction wood (e.g. Douglas fir or Norway spruce) of regular strength (FK II) and a maximum moisture content of 16% (SIA norm 164). The square sections of 80 x 160 mm and 80 x 220 mm are standardised dimensions of construction wood that that are readily available in Switzerland (App. 3). The structural wall sheathing consists of 15 mm OSB board with standardized sizes (App. 4). If alternative boards such as 12 mm plywood or 22 mm wood fibreboard sheathing are used, the spacing of the studs must be altered accordingly. The subfloor consists of 22 mm wood fibreboard with tongue-and-groove joints. Alternatively, OSB boards with tongue and groove joints are used.

Joints

As the representative for all the joints (enclosure / ground floor slab, enclosure / first floor ceiling and enclosure / roof), in this section I will investigate specifically the joint of the enclosure with the first floor ceiling, which is the most difficult one as three different elements meet along this line; it is also characteristic of this type of construction. According to the information published (Fig. 3.3) it is assumed that the elements of this enclosure / floor joint are partitioned as shown in Figure 3.5a. The floor element constructively interlocks with the L-shaped top plate of the lower wall. In contrast, the upper wall panel stands on top of the L-shaped top plate and the floor element. Mechanical fasteners are needed to connect the upper wall panel with the elements beneath. As the floor construction (impact insulation, cement underlay and finish flooring) as well as the cladding along the horizontal enclosure / floor joints are applied on site, the fit of the joints can be easily controlled and properly fastened and sealed.



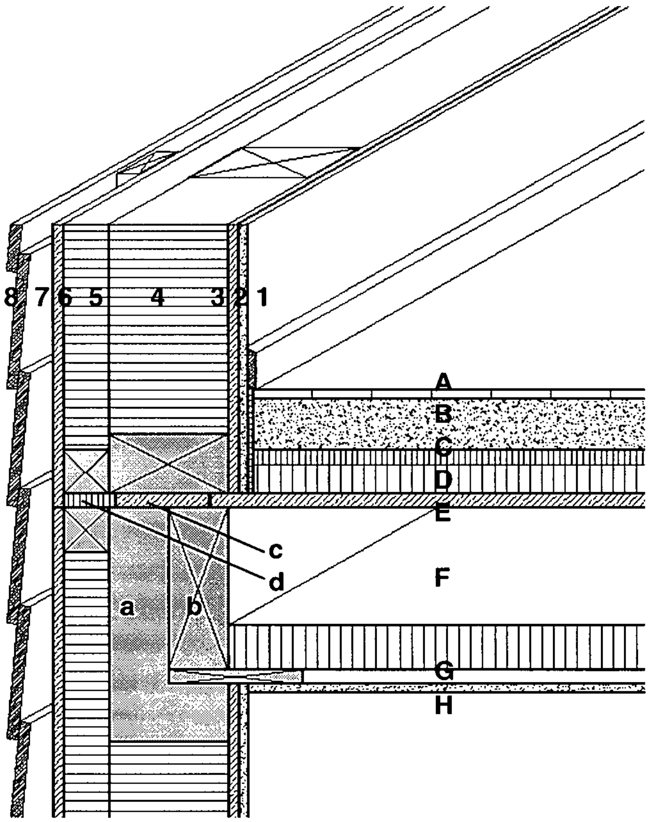
a) Vertical joint at the first floor ceiling *b) Horizontal joint at the building corner*

Fig. 3.5 Vertical and horizontal element joint of SWF

It is assumed that the enclosure overlaps as shown in Figure 3.5b. This constructively interlocking joint allows proper fitting of the elements during the assembly process. The enclosure elements can easily be fixed with long screws from either exterior side of the corner at the top and bottom part of the element (top and bottom plates), as the cladding in the joint area is completed on site.

Layering of enclosure and floor elements

Figure 3.6 shows a magnification of the enclosure / floor joint shown in Figure 3.3 and specifies the material layering of the regular enclosure and floor sections as well as the specific materials and elements within the joint. This detail will be the basis for further discussion in the following chapter.



Enclosure layering (inside to outside):
1 12.5 mm Gypsum board
2 PE air and vapour barrier
3 15 mm OSB sheathing
5 80 x 160 mm frame
at 625 mm on centre
160 mm mineral fibre insulation boards
4 60 x 60 mm horizontal furring
60 mm mineral fibre insulation boards
6 15 mm OSB sheathing
7 30 mm air cavity
8 Horizontal hardboard siding

Floor layering (top to bottom):
A 11 mm hardwood finish flooring
B 70 mm cement underlay floor
C Separating foil
D 40 mm impact insulation
15 mm ISOVER PS81 (glass fibre)
25 mm expanded foamed plastic
E 22 mm wood fibreboard subfloor
F 80 x 220 mm joists
at 625 mm on centre
160 mm air cavity
60 mm mineral fibre insulation boards
G 24 mm furring and installation cavity
H 12.5 mm Gypsum board ceiling

Specific joint elements
a L-shaped top plate
b End joist
c 22 mm wood fibreboard underlay (assumption)
d Foam gasket (assumption)

Fig. 3.6 Layering of enclosure and floor elements of SWF at the enclosure-floor joint

3.1.2 Planning and building process

The planning and building process of a SWF house may generally be split into three phases: the planning process, the factory production of the elements, and the on-site construction. All in all, the planning and building process may take up to one-and-a-half years, despite the fact that the production and assembly of the house only takes about two weeks. Even though the phases are well defined and coordinated in one location, the planning phase is very long. Also, the finishing work requires a considerable amount of time.

As a general contractor, Renggli AG takes responsibility for all stages from the planning to the handing over of the finished building, even though it outsources the on-site finishing work and potentially also the design to tradesmen and architects that work for the firm on a regular basis. As such, clients not only have a single negotiation partner, they also profit from a holistic service during the planning and construction phase, as well as the straightforward replacement of any guaranteed work during the first ten years of occupation.

Planning process

The planning process of a factory-built house may take from several months up to one year. Within this time, the house is designed according to the client's needs and expectations. By the time the factory production starts, every detail, such as the number and position of all electrical outlets, is defined. This is a critical aspect of individually-designed and / or factory-produced houses. Even clients without any building experience have to decide on every detail in advance.

Renggli AG offers three different design principles, the architect-designed house, the custom-designed house and the concept house. All rely on the standardised principles and details of the building system (system houses). The architect-designed house is the result of the co-operation of an architect (e.g. chosen by the client) and Renggli AG. The custom-designed house is custom-designed by the firm, and the concept house is a pre-designed house. This concept house consists of a basic house design with basic outfitting (e.g. kitchen, appliances, materials) and an estimation of the costs. Still, clients can take various individual decisions, such as minor changes in the floor-plan arrangement, the size or the location of openings or the distribution of electrical outlets, as well as materials and colours. The cost estimation is adjusted according to the chosen outfitting and the appliances. The purchase of a concept house may considerably simplify the planning process, as clients may visit a model house or those of former clients.

Factory-production

The production process of a factory-built single-family house takes one to two weeks, where the single steps are as precisely defined as in a script. The enclosure panels generally reach a high degree of finish; they include wiring, cladding (with basic paint coat), interior finishing materials (e.g. gypsum board), windows and doors. The finishing of rooms with tiles or plaster and paint, as well as the final paint coat of the cladding, are applied on site. In contrast, floor and roof panels consist only of the structural core; the upper floor construction (impact insulation, underlay floor, finish flooring) and the suspended ceiling, as well as the exterior roof construction (water barrier, air cavity, tiles), are applied only on site.

Top and bottom plates as well as end studs are particularly important to the erection process on site. The wall panels are carried on hooks attached to the top plate. Top and bottom plates are the bases for the attachment of vertical connectors. Similarly, the end studs provide a base for lateral connections.

The construction process of an enclosure element depends on the building standard (Norm, Minergie or Passive house) and on the finishing degree. Generally, it takes about five steps to complete a Minergie enclosure element with a high degree of finish. After every step the element is lifted to another construction table and put down on the reverse side; the last step is completed in an upright position. The following section gives examples to describe the production process of a Minergie enclosure panel.

1. According to the specifications provided by the construction drawings, the structural frame members are sawn to the required size.
2. The structural frame is arranged on a construction table and stapled together. The interior sheathing is nailed to the frame, and openings for doors, windows and installations are sawn out.
3. The wiring (where necessary) is applied and the cavities between the studs are filled with insulation (Fig. 3.7a). Then the furring layer is nailed to the studs and the cavities are again filled with insulation. Finally, the exterior sheathing is nailed to the furring and the required openings are sawn out.
4. Door and window frames are attached to the panel (Fig. 3.7b). The vapour barrier is applied. All joints are sealed to achieve a proper vapour barrier. Finally, a gypsum board (with or without installation cavity) is applied to the interior wall panel to provide a basis for additional finishing coatings (Fig. 3.7c).
5. The air cavity is prepared and the cladding is applied. Generally, the cladding at the top and bottom edges of the panel is not yet applied. This allows tightly screwing the panels against each other from the outside during the assembly process.
6. The panel is lifted up and moved to a special site. Exterior door and window frames and sills are applied to the upright standing panel (Fig. 3.7d). After completion, the finished enclosure panel is wrapped, together with other elements. The packages are ready to be trucked to the erection site.

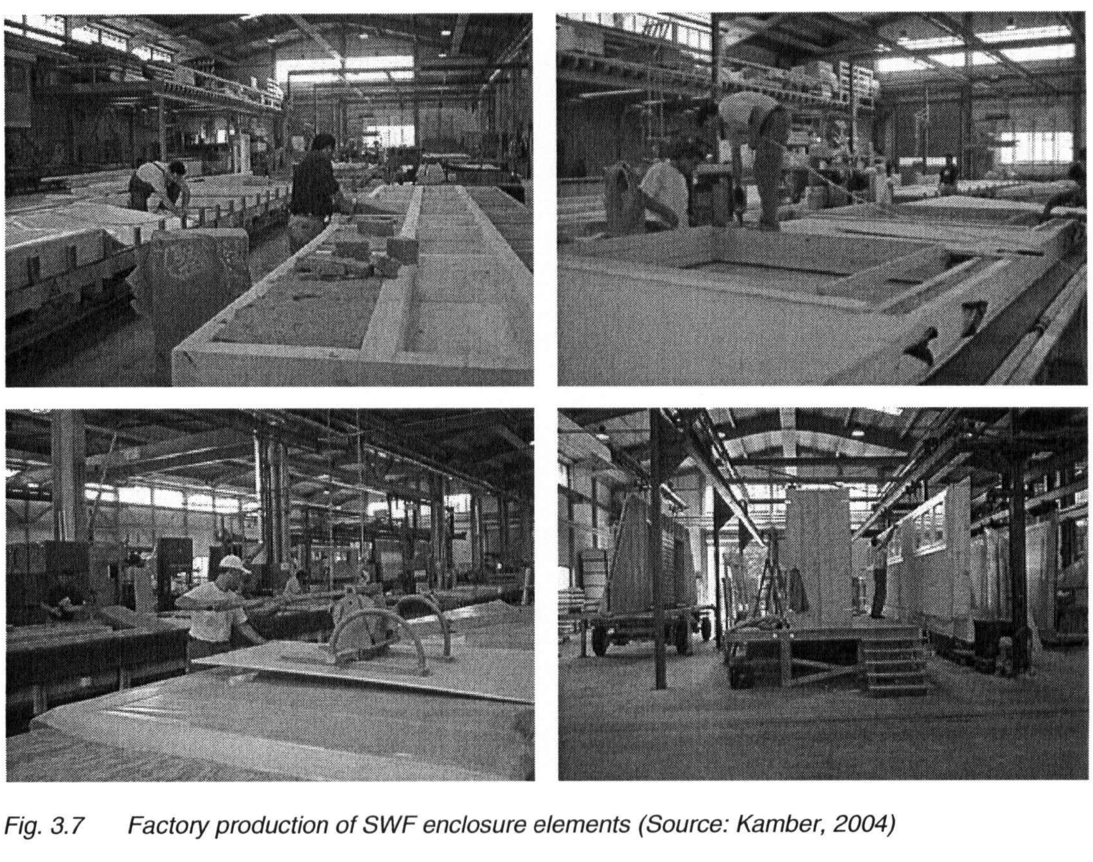


Fig. 3.7 Factory production of SWF enclosure elements (Source: Kamber, 2004)

On-site construction

The on-site construction work is divided into three phases, the on-site preparation work, the on-site assembly of the building and the finishing work.

The on-site preparation work starts with ground excavation for the cast-concrete foundation or cellar (Fig. 3.8a); cast-concrete cellars are usual in Swiss houses. The excavation (about 2.50 to 3 meters), along with the construction of the cellar and the installation of wiring and pipes takes some weeks (Fig. 3.8b and c). The concrete slab (ground floor ceiling) provides the base for the assembly of the first floor, where the electrical wiring and water pipes are already at the right positions. Before the assembly starts, a scaffold is assembled around the future building. It assists the assembly team during the erection process and for the completion of the exterior finishing works. As soon as everything is ready and the weather forecast is good, the elements are delivered to the construction site (Fig. 3.8d).

Fig. 3.8 On-site preparation works (Source: Kamber, 2004)

The assembly process only takes one day. Critical for a smooth assembly process are a proper foundation and the availability, chronological ordering (Fig. 3.9a) and precise fit of all elements (Fig. 3.9b), as well as a well-experienced team that works precisely and reliably, and good weather. A team of seven experienced workers is involved in the floor-by-floor assembly of the single elements[2]. The assembly starts with the fit of the first wall panel and ends with the last roof element (Fig. 3.9c). One element after the other is craned to the right position, manually adjusted and fixed with mechanical fasteners. As they occur, joints of the vapour retarder foil along the top plate of the wall panels are taped before the floor elements are put in place.

After the assembly of the building, the exterior finishing work such as the sealing of the roof with roofing paper, and air cavities and tiles (Fig. 3.9d), as well as the installation of PV panels or the final paint coat of the cladding, have to be done as soon as possible to get the building ready to withstand the climate, as well as to enable the removal of the scaffold. On the inside, technical installations such as plumbing, heating and electrical services are installed. Afterwards, plaster coatings, impact insulation and underlay floors as well as built-in cabinets, kitchen and bath are added. The finishing work includes the installation of finish floorings, tiles, final paint coatings and baseboards. The time taken may vary between a few weeks and several months, depending on the remaining finishing work.

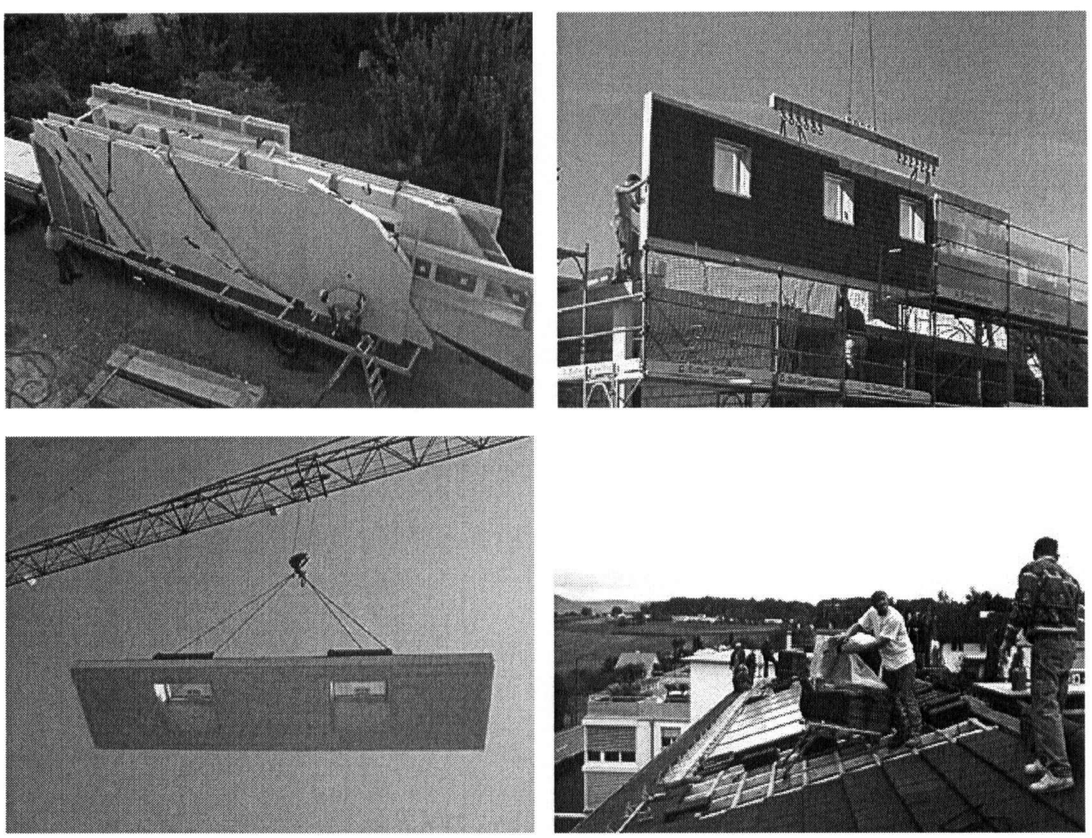


Fig. 3.9 On-site assembly and exterior finishing works (Source: Kamber, 2004)

[2] A single-family house consists of about 30 elements (Renggli, 2003).

3.2 Ribbed Panel System

The structural use of multi-layered glue-laminated boards (e.g. block boards) has a very young history in Switzerland as well as in Germany and Austria. They were first used for load-bearing walls around 1995. By that time, engineered wood products such as OSB or plywood for sheathing purposes, structural particleboards such as Homogen80 for the construction of load-bearing walls, as well as glue-lam beams and manufactured wood elements for floor or roof construction (e.g. Lignatur), were already known.

In 1997, Pius Schuler first presented the Ribbed Panel System (RPS), the 'Rippenbau' as it is named in German, at the 29th conference of the Swiss committee for wood research (SAH) in Weinfelden (Schuler, 1997:93-101). This system gets its name from a set of parallel ribs glued against the structural board of enclosure elements, where the structural board consists of a custom-produced block board (see chapter 2.3.4 Wood panel systems).

a) House Sägesser, Willisau, BAUREAG architects

b) House Schudel, Feldis, OOS architects AG

c) House Schilling, Hägendorf Schilling + Partner

d) House Meier, Bukten, Peter Gühther architecture AG

Fig. 3.10 New Ribbed Panel System (RPS) houses (Source: Pius Schuler AG, 2004: References; Schilling +Partner, 2004: Individuality).

Like SWF, RPS relies on large wall, floor and roof elements that are factory-produced. Engineered building materials and components as well as appropriate construction methods allow the construction of individual, modern houses (Fig. 3.10) with high thermal-efficient building enclosures. However, it appears that no carpentry firm has yet specialized in the factory production of RPS buildings. The production of panellised (residential and non-residential) buildings is only one sector of the firm (Kählin, 2004; Gfeller, 2004). Even though CNC (Computerized Numerical Control) machines and construction tables are employed, the production process is not yet standardised. Also, the realisation of these houses still relies on the co-operation of architects with consultants (e.g. energy, engineering), suppliers and tradesmen, as is generally the case for residential constructions in Switzerland. However, not the lack of standardisation or experience but the means of transport, the storage space required and the need for flexible ground floor arrangements will be reasons why panellised construction is favoured over modular.

Today, Pius Schuler AG is a leading supplier of single- or multi-layered block boards and block-board products (Fig. 3.11). As well, they give information on the use of block boards for the construction of walls, floors and roofs. Their spin-off firm, 'AG für Holzbauplanung', consults with carpenters and architects on specific aspects of building construction such as structure, thermal insulation, vapour balance and infrastructure. In particular, they do structural framework planning for RPS buildings. Pius Schuler AG was founded in 1946. Within a few years, they were a leading producer of wood-core plywood for furniture and casings; in the early 1970s, they started the production of doors. In the early 1990s, Pius Schuler AG, together with the University of Architecture, Building and Wood, HSB in Biel, developed the block board. Since then, they have conducted research into new approaches to building with block boards and have taken part in research projects by the ETH and the HSB. As such, the Pius Schuler AG not only

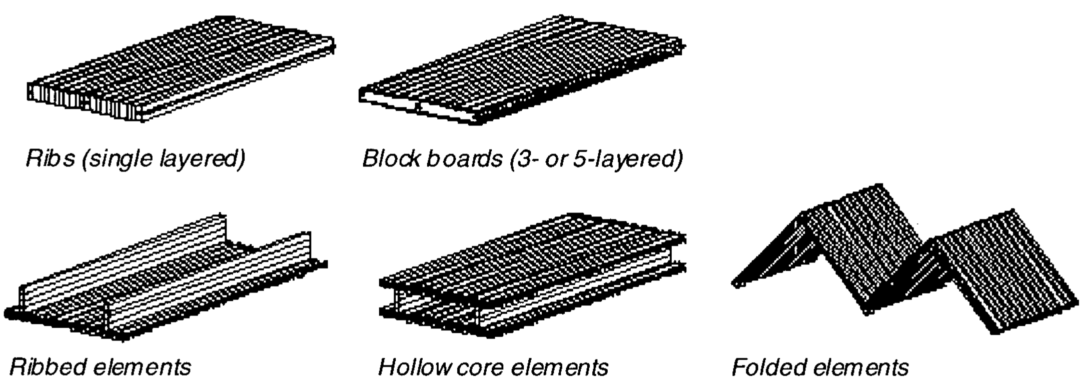


Fig. 3.11 Block boards and block board products (Source: Schuler, 2004: Block board products)

supplies building materials; it is also active in the generation of knowledge and the provision of know-how. But, it does not produce buildings itself.

There are no numbers on how many RPS buildings have been realised over the last seven years. Between 1996 and 1998, Deplazes (architect and design professor at ETH) planned and built one of the first RPS single-family houses (Fig. 3.12); Deplazes expects RPS to become the most important system in Switzerland (Deplazes, 2000). Also, Germerott (professor at HSB, and business manager VGQ) and Pius Schuler (head of the Pius Schuler AG) strongly support this seminal opinion.

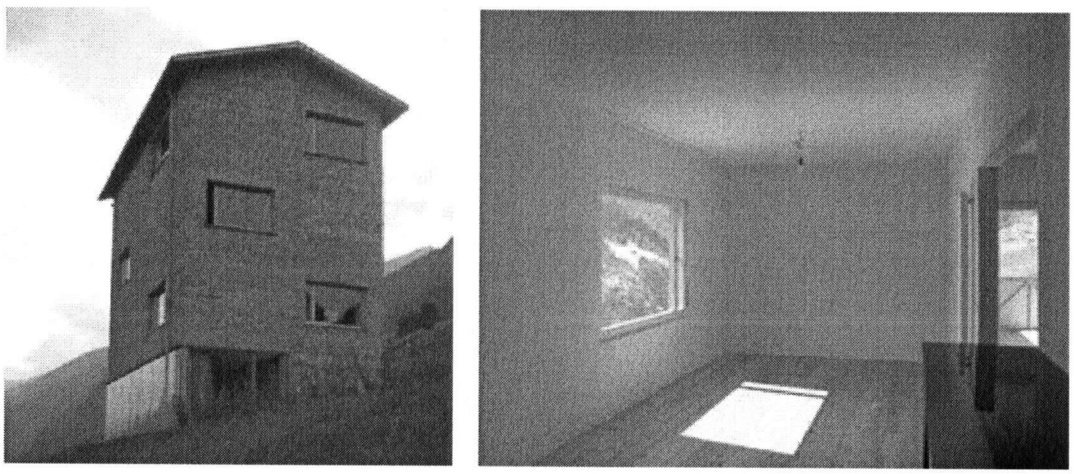


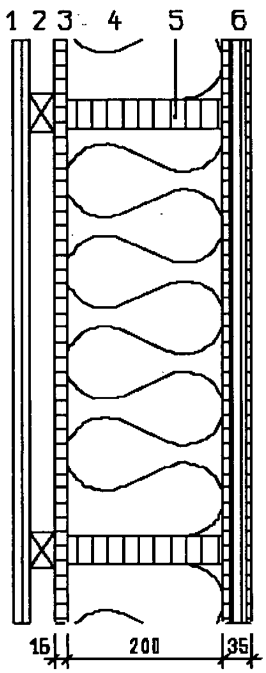
Fig. 3.12 House Bearth-Candinas, Sumvitg, Pilot Project 1996-98, designed by Deplazes (Source: Deplazes, 2004: Research, Prefabricated enclosures).

3.2.1 Construction principles of RPS

In their documentation (Pius Schuler AG, 2004), Pius Schuler AG show examples of scheme sections at 1:10 of thirty construction principles for elements that may be used for the construction of enclosures, walls, floors and roofs; all of these elements are described in terms of materials and dimensions, the relevant physical factors and the costs. In addition, he gives a vertical scheme section through the upper part of a building as well as a section through a building corner. Figure 3.13 shows three examples of enclosure elements. Figure 3.14 provides four possibilities for the floor construction as well as two roof elements, and Figure 3.15 shows the vertical scheme section, the building corner as well as a rib extender.

Where no other reference is given, the information refers to the publications of Deplazes (Deplazes, 2000), Pius Schuler (Schuler, 1997:93-101) and Pius Schuler AG (Pius Schuler AG, 2004), and a personal interview with Pius Schuler, head of Pius Schuler AG, at a house-building fair in Bern (Schuler, 2003).

Enclosure elements

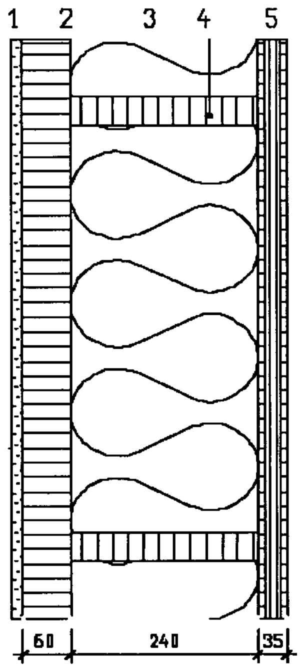


20 cm insulation

1 Cladding (e.g. fir coarse)
2 Air cavity 30 mm
3 Wood fibreboard 16 mm, bitumised, joints glued
4 Block board ribs 40 x 160 mm Mineral fibre boards 160 mm
5 3-layered block board 35 mm

U =	0.18 W/m^{2}K
R'w =	49 dB
q_{zul} =	140 kN/m^1
g =	45 kg/m^2

Cost material	105.- CHF
Cost processing	82.- CHF
Total costs	187.- CHF

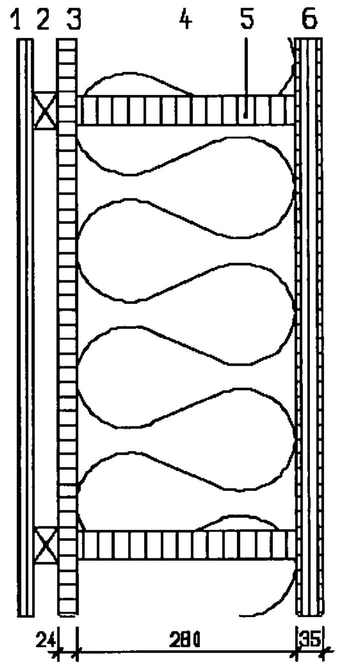


24 + 6 cm insulation

1 Mineral plaster 10 - 15 mm
2 Wood fibreboard 60 mm (e.g. Pavatex Diffutherm)
3 Block board ribs 40 x 240 mm Mineral fibre boards 240 mm
4 3-layered block board 35 mm

U =	0.14 W/m^{2}K
R'w =	57 dB
q_{zul} =	150 kN/m^1
g =	62 kg/m^2

Cost material	114.- CHF
Cost processing	48.- CHF
Total costs	228.- CHF



28 cm insulation

1 Cladding (e.g. fir coarse)
2 Air cavity 30 mm
3 Wood fibreboard 24 mm, bitumised, joints glued
4 Block board ribs 40 x 280 mm Mineral fibre boards 280 mm
5 3-layered block board 35 mm

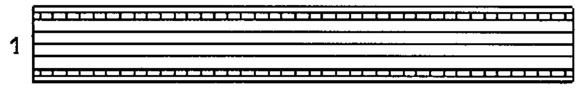
U =	0.13 W/m^{2}K
R'w =	54 dB
q_{zul} =	150 kN/m^1
g =	50 kg/m^2

Cost material	121.- CHF
Cost processing	90.- CHF
Total costs	211.- CHF

Whereas, *U = heat transmission coefficient*
R'w = airborne sound reduction index
qzul = maximally allowed buckling load
Total costs include all work, also the on-sit one

Fig. 3.13 Selection of three different enclosure elements of RPS (Source: Pius Schuler AG, 2004: Elements)

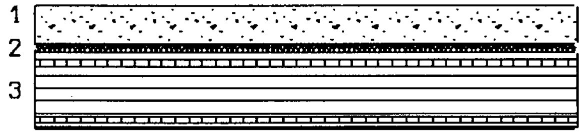
Floor Elements



1 Block board 120 mm (1-/ 3- or 5-layered)

U = 0.97 W/m^{2}K R'w = 37 dB
g = 54 kg/m^2 L'n,w = 88 dB

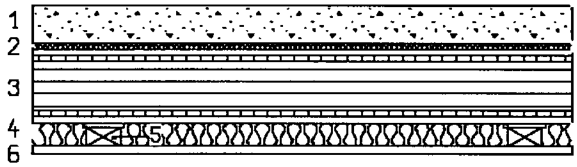
Cost material 135.- CHF
Cost processing 15.- CHF
Total costs 150.- CHF



1 Cement underlay floor 60 mm
2 Mineral fibre boards 12 mm (impact noise)
3 Block board 120 mm (1-/ 3- or 5-layered)

U = 0.71 W/m^{2}K R'w = 53 dB
g = 188 kg/m^2 L'n,w = 66 dB

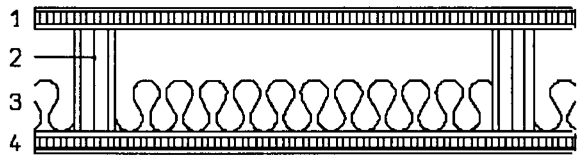
Cost material 135.- CHF
Cost processing 15.- CHF
Total costs 176.- CHF



1 Cement underlay floor 60 mm
2 Mineral fibre insulation 12 mm (impact noise)
3 Block board 120 mm (1-/ 3- or 5-layered)
4 Mineral fibre boards 30 mm
5 Furring (springy attachment)
6 Gipsum board 18 mm

U = 0.45 W/m^{2}K R'w = 65 dB
g = 210 kg/m^2 L'n,w = 56 dB

Cost material 98.- CHF
Cost processing 30.- CHF
Total costs 128.- CHF

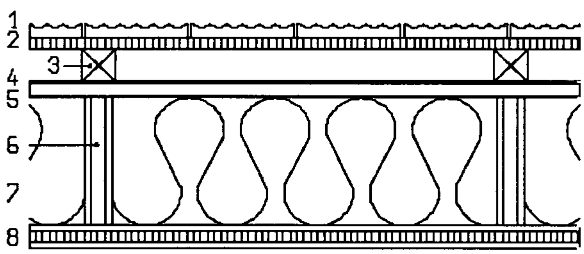


1 3-layered block board 30 mm
2 Block board ribs 40 x 160 mm
3 Mineral fibre boards 100 mm
4 3-layered block board 30 mm

U = 0.33 W/m^{2}K R'w = 44 dB
g = 35 kg/m^2 L'n,w = 85 dB

Cost material 98.- CHF
Cost processing 30.- CHF
Total costs 128.- CHF

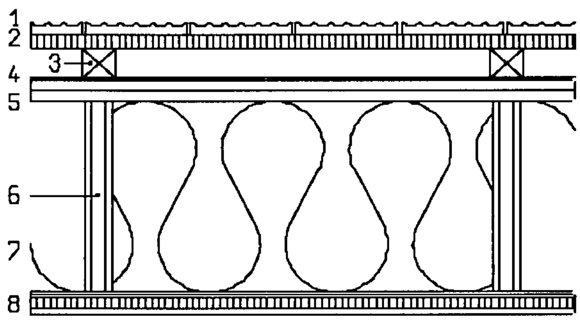
Roof Elements



1 Tiles
2 Tile battens 24 x 48 mm
3 Furring 50 mm (air cavity)
4 Water foil (open to diffusion)
5 Wood fibreboard 24 mm
6 Block board ribs 40 x 200 mm
7 Mineral fibre boards 200 mm
8 3-layered block board 35 mm

U = 0.18 W/m^{2}K
R'w = 50 dB
g = 37 kg/m^2

Cost material 106.- CHF
Cost processing 35.- CHF
Total costs 141.- CHF

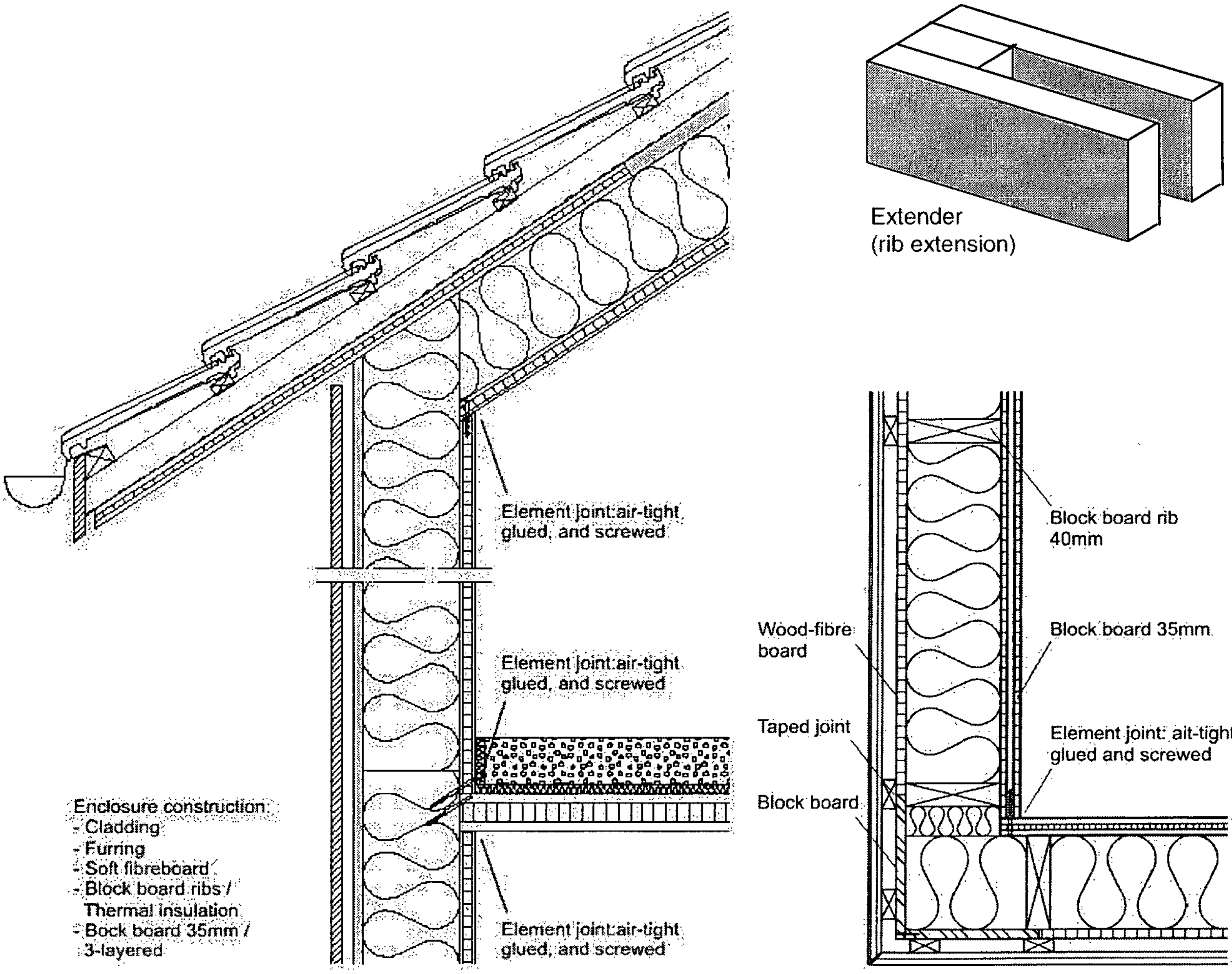


1 Tiles
2 Tile battens 24 x 48 mm
3 Furring 50 mm (air cavity)
4 Water foil (open to diffusion)
5 Wood fibreboard 35 mm
6 Block board ribs 40 x 300 mm
7 Mineral fibre boards 300 mm
8 3-layered block board 35 mm

U = 0.12 W/m^{2}K
R'w = 55 dB
g = 45 kg/m^2

Cost material 132.- CHF
Cost processing 35.- CHF
Total costs 167.- CHF

Fig. 3.14 Selection of four different floor and two roof elements of RPS (Source: Pius Schuler AG, 2004: Elements)



a) Vertical enclosure section

b) Extender [1]
c) Horizontal enclosure section

Fig. 3.15 Vertical and horizontal enclosure sections, and rib extender (Source: Pius Schuler AG, 2004: Detail; Schuler, 1997: 97; and Schuler, 2003)

Structural core of wall and floor elements

The structural cores of both the wall and floor elements consist of block boards. The structural core of an enclosure element consists of structural block boards (35mm thick) as well as a set of supporting ribs (40mm x 220mm) that are glued against the structural board. The ribs are spaced at 630mm on centre to friction fit the semi-rigid mineral fibre insulation boards (600mm). Openings are feasible at any place

[1] Extenders are used to extend the depth of the insulation without the need to change the depth of the ribs.

without considering the arrangement of the ribs; they are sawn out of the board and framed with lintel-like ribs to distribute the load. In addition, they give a base for the installation of the window and they close the insulation cavity. Where large openings are required, the stresses have to be calculated. The floors consist of block board panels with a thickness of about 90 to 120mm. These block boards are economically feasible for spans up to about 5.5m. If larger loads occur or larger spans are required, ribbed panels or hollow-core elements (see also Fig. 3.11) could replace the block boards. These elements can span up to about 7m and 10m, respectively (Pius Schuler AG, 2004). Figure 3.16 shows schematically the structural cores of RPS enclosures and floor elements.

Ribbed enclosure elements generally consist of 3-layered block boards, where ribs are single layered, and floor elements consist of 3- or 5-layered block boards. Block boards are available in sizes up to 2.18 by 7.20 m and a thickness between 24 and 140 mm, with or without with tongue-and-groove joints (Schuler, 2000). The block boards have a moisture content of 10% ± 2%. They are custom produced by Pius Schuler AG in terms of dimensions, number of layers, materials and surface (App. 5).

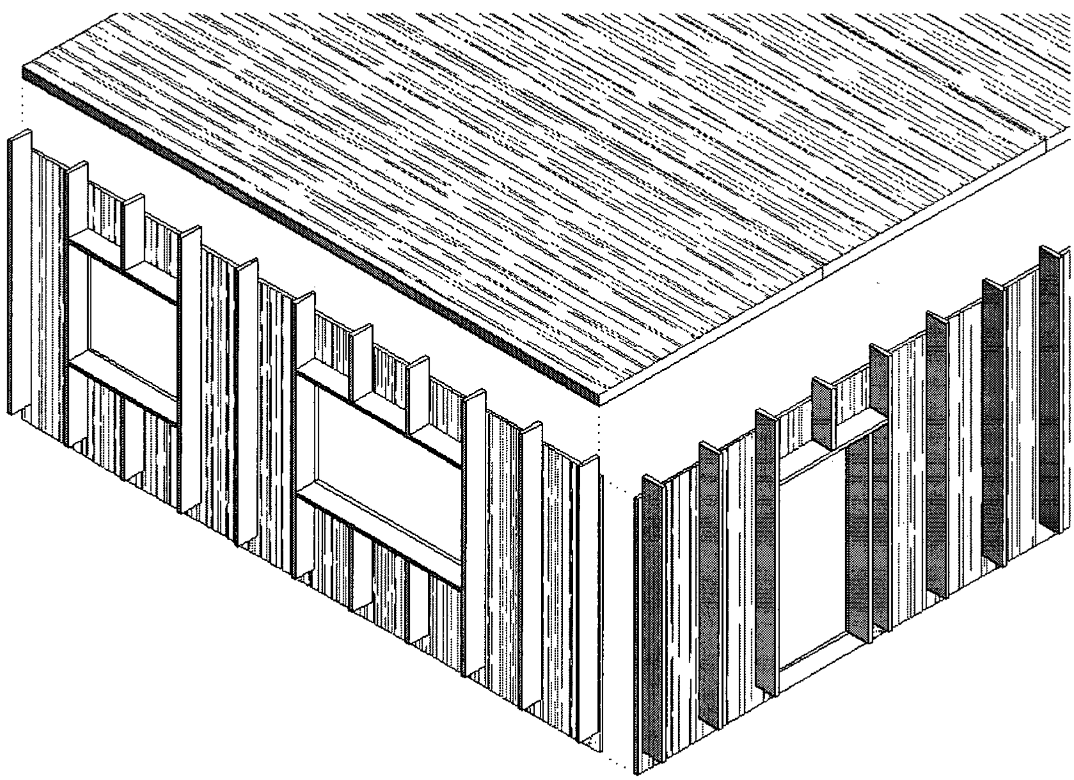
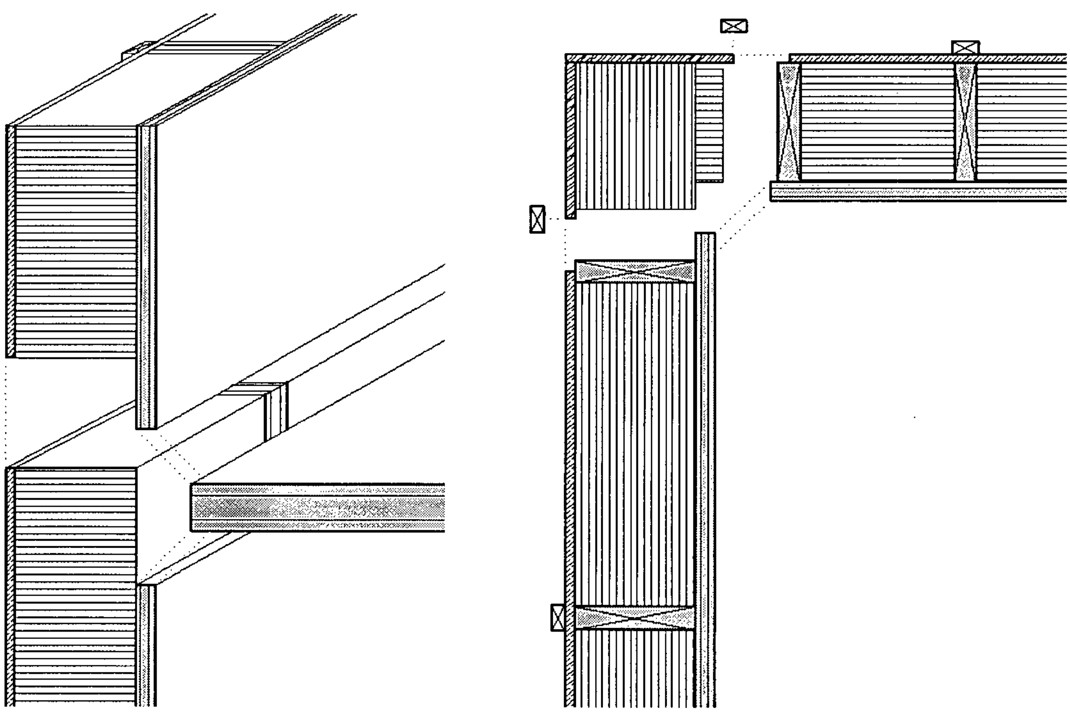


Fig. 3.16 Scheme of the structural enclosure and floor elements of RPS

Joints

To illustrate the specifications of RPS, Figure 3.17a shows a horizontal enclosure / floor joint at the first floor ceiling, as well as a vertical one at the building corner. As shown in Figure 3.15, the floor panel and the structural board of the upper enclosure constructively interlock with the ribs of the lower enclosure panel, whereas the floor element rests on the structural board of the lower enclosure element and the structural board of the upper element is put down on the floor element. Due to the small support precise work is required during the assembly process, but as the cladding as well as the floor construction (impact insulation, cement underlay and finish flooring) are applied only on site, the joints may easily be controlled, filled with gap-filling glue and additionally fixed with screws.

Again, the fit of the enclosure elements at the corners requires full attention, due to the thinness of the common joint along the enclosure panels. As seen in Figure 3.15c, the corner is built up by the enclosure element and an additional corner element (Fig. 3.17b). In the first step, the thin vertical joints along the enclosure panels need to be precisely fitted, glued and fixed with screws. In the second step, the corner element, consisting of insulation and sheathing, is installed in the corner section. The cladding is applied afterwards. This construction principle allows proper sealing and fixing of the joints.

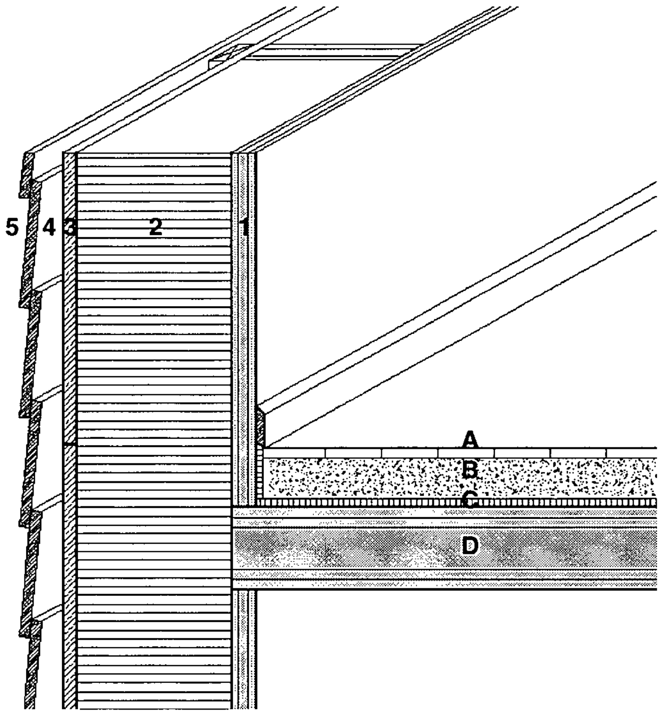


a) Vertical joint at the first floor ceiling *b) Horizontal joint at the building corner*

Fig. 3.17 Vertical and horizontal element joint of RPS

Layering of enclosure and floor elements

Figure 3.18 shows a magnification of the enclosure / floor joint shown in Figure 3.15a. This detail is appropriate for further investigation, because it wraps up the materials and dimensions as well as the layering and the joints. To be able to compare to SWF, this detail relies on 220mm thick thermal insulation of the enclosure.



Wall - floor of the RPS

Enclosure (inside to outside):

1 35 mm block board
2 220 mm ribs
at 630 mm on centre
220 mm mineral fibre insulation boards
3 16 mm wood fibreboard sheathing, bitumised
4 24 mm furring / air cavity
5 20 mm hardwood siding

Floor (top to bottom):

A 13 mm hardwood finish flooring
B. 60 mm cement underlay floor
C 12 mm impact insulation
D 120 mm block board

Fig. 3.18 Layering of enclosure and floor elements of RPS at the enclosure-floor joint

3.2.2 Planning and building process

As in SWF, the planning and building process of a factory-produced RPS house is split into three phases: the planning, the factory production of the elements, and the construction work on site. Altogether, these phases may take well over a year. Again, while the production of the elements takes a few weeks and the assembly on site only one or two days, the planning phase is very long. Also, the finishing work may take some months.

It is assumed that the planning and building process works in a similar fashion to that of conventional on-site-built houses, where architects supported by a team of consultants, such as energy, engineering or process consultants, lead through all the stages. Also, the problems of responsibility and co-operation will still be the same. The tradesmen involved in the building process are basically chosen by the client according to criteria like know-how, price offer or personal relationship. Acting as a trustee, the architect assists in concluding the contracts for work labour between the client and the tradesmen. Thus, the client has many negotiation partners, and the length of the planning and building processes depends considerably on the ease of co-operation and the progress of the work. As well, the client risks long delays in the completion of guaranteed work, as 'someone else' is always responsible for the failure.

Planning process

The planning process of a factory-built RPS house may take up to one year. This stage includes the individual design of the house up to the point where the element plans for factory production are finished. It is assumed that in most cases a consultant (such as the 'AG für Holzbauplanung') is required to develop the project plans of the architect to the final element plans. However, little experience in the planning of RPS houses, along with loose and temporary co-operation between the building professionals, means that vigorous planning and communication efforts are needed. As well, future clients of a RPS house have to invest time and uncertainty. They are not able to base their decisions on the nature of similar houses, nor on a fixed move-in date, nor on precise cost estimates. Even more, future clients are required to make decisions on the plans, and once the decisions have been made they will be unchangeable (or expensive to change) after the production process has started.

Factory-production

The production process of a RPS house consists of two stages, the production of the structural boards and the production of the wall, floor and roof panels.

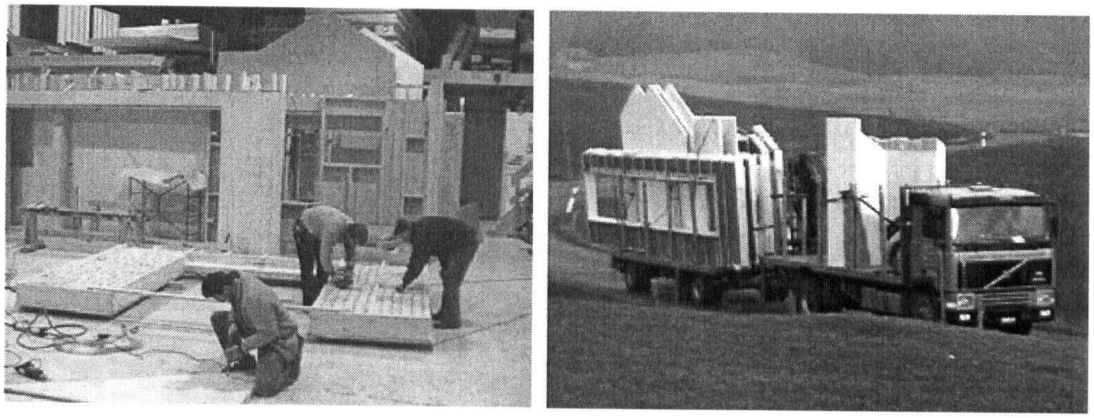
Pius Schuler AG produces the block boards for RPS houses upon specific orders. As such, the composition (number and material sequence of layers) and the surface quality of the boards (e.g. swan or ground, spruce / fir or larch) may be matched to the size of the project as well as to the requested constructive and / or visible uses. Unless otherwise ordered, the individually produced block boards are delivered to the carpentry firm in standardised sizes (App. 5). On request, the boards are processed to ribbed panels or delivered in the required size (Pius Schuler AG, 2004).

The production of the wall, floor and roof elements is expected to last some weeks, depending on the capacity of the carpentry firm. Carpenters process the block boards to enclosure, floor and roof elements; maximum-sized elements are desired to reduce the number of joints (Schuler, 1997: 99). The enclosure elements of RPS generally have a low degree of finish; they consist of only the structural ribbed panel, the insulation, the exterior sheathing and the furring for the on-site application of the cladding. Wiring and ducts are incorporated into enclosure elements only where they are indispensable; ducts for wiring are preferably included into interior walls, or they run within an installation cavity in front of the structural panel. The corner element, the cladding and the roof construction, as well as windows and doors, are applied on site. The floor elements consist of only the structural board: the floor construction with impact insulation and sand or cement underlay is built-in on site. The finishing of rooms with plaster, wall paint or tiles, a finish flooring and built in cabinets determines the interior work.

The production process of a RPS enclosure element does not depend on the thermal-insulation standard; the construction differs only in the depth of the ribs. Theoretically, an enclosure element can be produced on one production table without being turned over; at all stages the inside of the panel is turned downward. As yet there has no firm specialised in the production of RPS, there will most probably be different production modes, and there will be only limited infrastructure involved. But it is assumed that a construction table and a CNC machine have become standard. The following section describes a possible production process of an enclosure panel.

1. The basic block boards with tongue-and-groove joints are glued to large sheets.
2. Panels and ribs are cut to the required sizes. The openings for windows and doors are sawn out of the structural panels (or, the openings are sawn out before the ribs are applied).
3. Ribs and frames around openings are glued against the structural panel. Wiring (where required) is applied, and the cavities between the ribs are filled with insulation (Fig. 3.19a). Finally, the exterior sheathing and the furring are nailed against the ribs. After completion, the enclosure panels are put aside; they are ready to be trucked to the erection site (Fig. 3.19b).

A further production step could improve the low degree of finish of the enclosure panel as it is generally produced. This step would include the attachment of windows, doors, frames and sills as well as parts of the cladding (compare to chapter 3.1 Production process).



a) Production of a RPS element

b) Transport to the construction site

Fig. 3.19 Production and transport of a RPS house (Kälin, 2004: Beda Kälin house)

On-site construction

The on-site construction process of a ribbed panel house is similar to that of SWF. Therefore, this section will mention only the most important issues, similarities or differences.

The on-site construction process is also divided into three phases: preparation of the site, assembly of the building, and finishing work. However, because of the specific setting of each building, the single steps are not as standardized as for SWF.

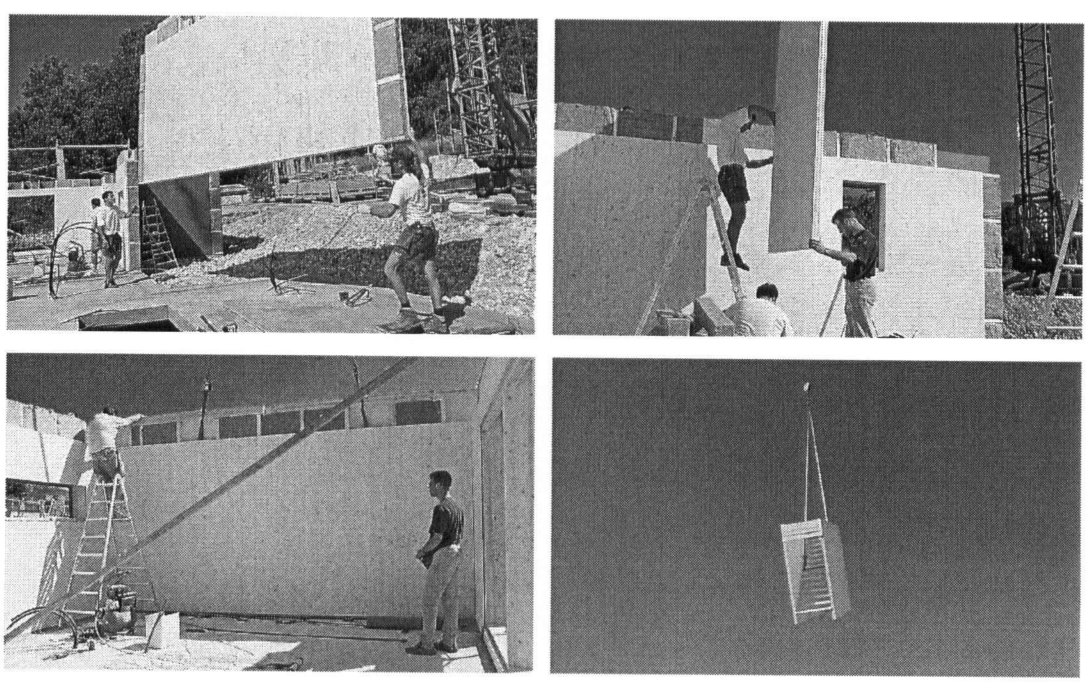


Fig. 3.20 On-site assembly of a RPS house (Kälin, 2004: Beda Kälin house)

A precisely-prepared concrete foundation or cellar is important for the assembly of the building. It also includes the necessary ducts, wiring and pipes (Fig. 3.20a). Generally, a scaffold surrounding the future house assists the workers during the assembly process and the finishing phase of the house.

The assembly of a RPS house takes about 1 to 2 days. The factory-built elements are put in place floor-by-floor (Fig. 3.20b,c,d). The precise fit of wall and floor elements is important, as their joints, which are very small, coincide with the structural supports, and they control air and vapour migration.

After the assembly process, priority is given to the finishing of the exterior shell (roof construction, windows, doors, cladding). On the inside, plumbing, heating and electrical services are installed as well as floor constructions and built-in cabinets, and wall coatings are applied. The finishing phase may take from a few weeks to several months, depending on the required finishing work.

3.3 Summary

The discussion throughout this chapter of the two wood building systems has made it clear that there are major differences in the construction and production of the two systems. The structural frame of SWF consists of linear elements; it gets its rigidity from a structural sheathing (planar element). Relying on mechanical fasteners and dimensional lumber, SWF adopts a wood building technique that has been known in Canada and the United States since the latter part of the 19th century. But it has also adopted a high level of technology, along with a highly-standardised production process that is led by one firm. The wall, floor and roof elements with a high degree of finish are factory-built, and they rely on CAD-CAM technology. Despite a script-like production process, each carpentry firm has its own construction principles. In contrast, RPS is strongly reminiscent of concrete constructions. The structural core of an enclosure element consists of a structural board (planar element) that is supported by ribs (linear elements). Relying on glue and glue-laminated boards, this building system is a new approach in building in wood. But, whereas the construction principles are standardised, the production process of the factory-built elements employs comparably low technology, and the full production process involves a team of building professionals, as is common in Switzerland.

Because of the different production principles, the two wood building systems rely on different client groups. Whereas SWF houses from Renggli AG primarily consider clients, RPS provides only a construction principle that addresses carpenters and architects. How many architects consider SWF constructions is not known; but it is assumed that architects are more likely to decide on RPS construction. This is due to their interest in exploring the new wood building materials, their knowledge of designing in concrete, and their being accustomed to leading the production process together with a team of building professionals from beginning to end, as well as the fear of the increasing concurrence of carpenters working as general contractors, such as Renggli AG.

	SWF	RPS
Background	Western Platform Frame	Concrete constructions
'discovered' in	Mid 1980s	Mid 1990s
built by	Carpenter working as general contractor	Team of building professionals
product type	Ready-to-move-in house	Construction principle
provided for	Clients (architects)	Carpenters, architects
General publications	Framing principles	-
Specific publications	Principles of 3 standards	Selection of standards
details	Few details	Basic details
further information	Basic element values	Detailed values
Construction principles	Sophisticated and partially concealed	Easy and disclosed
Wall, roof, floor	Large elements	Large elements
degree of finish	High	Low
Structural core of enclosure	Frame with structural sheathing	Structural board with supporting ribs
Structural core of floor	Frame and subfloor	Structural board
Joints	Intricate, interlocking	Simple, interlock partially
Layering of enclosure	Many layers	Few layers
principle	One function per layer	Many function per layer
Planning and building process	'Scripted'	Open, varying
led by	General contractor	Architect with team of building professionals
Planning	Up to 1 year	Up to 1 year
design	Architect, custom or pre-designed	Architect-designed
Production	1 to 2 weeks	1 to 2 weeks (assumed)
production place	CAD-CAM, series of production tables	Partially NCS machines, single production tables
Assembly	1 to 2 days	1 to 2 days
infrastructure	Scaffold, mobile crane	Scaffold, mobile crane
site preparation	concrete cellar with wiring and ducts in place	concrete cellar with wiring and ducts in place
Finishing work	Some months	Some months
on the outside	Roof construction, completion of cladding, final paint	Roof construction, completion of corners, cladding, sills, final paint
on the inside	E.g. plaster, paint, tiles, finish flooring, electrical and sanitary equipment	E.g. windows, doors, paint, tiles, finish flooring, electrical and sanitary equipment

Tab. 3.1 Summary of the characteristics of SWF and RPS.

4. CRITICAL ANALYSIS

The new wood building systems, SWF and RPS, rely on local wood as well as on factory-built wall, floor and roof elements with high production and construction quality, as shown in Chapter 3. Also, they achieve high savings in heating energy, they consider initial cost limits, and they promise comfort and safety to the inhabitants (Chapter 2). Thus, they conform strongly to many of the present basic needs of place, people and product, as well as to global requirements. But the efficiency with which it achieves these goals is crucial for the potential success of a new wood building system, as well as whether it fills the need for long-lasting and healthy houses.

The efficiency of a building system considers the effort to achieve a given goal. In Switzerland, a high level of thermal insulation is a key aspect of building. As such, building systems that provide enclosures with high thermal efficiency, employing limited material and labour costs as well as limited resource use (land, material, energy), are more likely to succeed. While the initial building costs and the operational energy consumption are limited by the Minergie and the Minergie-P labels, the depth and weight of the enclosure as well as potential heat bridges are important characteristics of a thermally-efficient building system.

Longevity is a key issue for the acceptance of a new wood building type as well as for the achievement of sustainable housing. People in Switzerland expect buildings to last literally a lifetime or longer. This is despite the fact that acquiring one's own house or condominium is very expensive and often requires future homeowners to cut down on other expenses. Nonetheless, people in Switzerland acknowledge that "good quality has its price" (Renggli, 2003) as long as the investment is beneficial and pays out over time. Therefore homeowners honour high production and construction quality (given by both systems), as well as durable buildings that are easily adaptable to new needs and require low and easily-performed maintenance work. As a consequence, they save on material and labour costs throughout the entire lifetime of the building. Moreover, new wooden buildings that are designed to limit the use of operational energy profit strongly from longevity; not only do they pay out the additional initial costs[1], but the financial benefits increase more the longer they survive. As a consequence, longevity enhances the

[1] Minergie buildings pay out the additional costs within about 7 years (SF DRS, 2004).

strong performance of these buildings by limiting the initial consumption of energy and materials as well as the costs for energy, materials and labour over a long lifespan. As such, building systems that avoid construction failure due to vapour and air movement or differential forces, and buildings that are adaptable to new requirements (thermal insulation, structure, infrastructure) and allow low and easily-carried maintenance costs are more likely to succeed in the local building market.

Also, health and comfort are becoming more and more important for houses in Switzerland, where the proportion of elderly people is growing, where people care about their personal health, and where an increasing number of people is ready to invest in their personal health and comfort. This is even more important for houses where tight enclosures impede a natural air exchange through the enclosure fabric, synthetic materials or material components are omnipresent, and the need for noiseless spaces is of increasing importance. Today, comfortable air and radiant temperatures with limited drafts, good indoor air quality, low-emission materials and sound control are important aspects of maintaining the inhabitant's health, well-being and comfort. Moreover, it is assumed that buildings that conform to higher standards of health and comfort will last longer and achieve higher asset values than others.

In summary, to succeed in the Swiss building market, the eight criteria listed in Table 4.1 are very important. In this chapter, I analyse the two building systems, SWF and RPS, in light of these criteria; all numerical values have been calculated from published raw data. Where no specific reference is given, the data rely on publications made by Renggli AG (Renggli, 2004), Architos (Architos, 2000), Kolb (Kolb, 1998) and SIA (norm SIA 380/1, SIA 381, SIA bulletin 2001).

CRITERIA		SWF	RPS
Efficiency	Thermal efficiency		
Longevity	Vapour and air movement		
	Differential forces		
	Thermal redundancy		
	Structural redundancy		
	Maintainability		
Health	Indoor air quality		
	Sound insulation		

Tab. 4.1 Criteria for the evaluation of SWF and RPS

4.1 Thermal efficiency

In Switzerland the new building codes, the Minergie and the Minergie-P standards, give benchmarks for annual heating-energy consumption (see also chapter 2.2.3 Legislation, and 2.3.5 Advanced voluntary building standards). As a rule of thumb, Minergie buildings require the opaque parts of the enclosure to achieve U-values < 0.20 W/m^2K [2]. But, increasing thermal insulation standards influence the construction of enclosures. Therefore, thermal efficiency considers the depth, weight and thermal bridges of enclosures.

4.1.1 Swiss Wood Frame

Renggli AG suggests a SWF construction with an insulation depth of 22 cm to meet the Minergie standard (Fig. 4.1a). It achieves a U-value of 0.194 W/m^2K using semi-rigid mineral fibre insulation boards. The regular section of the enclosure core[3] has a thickness of 26.25 cm and weighs about 58 kg/m^2, whereas the structure / insulation core[4] of a regular wall section consists of 83% insulation. Considering the entire enclosure, the insulation share decreases to an average of 73.7%, due to the irregularities in the enclosure / floor joint section (Tab. 4.2), and the U-value increases to about 0.233 W/m^2K.

Rigid insulation boards with higher thermal resistance are not feasible for this construction. They could not respond to the dimensional changes of the structure, leading to gaps between the structure and the insulation. But basically any other type of semi-rigid insulation boards, insulation batts or loose-fill insulation (e.g. cellulose fibre) could be used. However, these materials have thermal conductivities (λ-value) that are $\geq$ 0.044 W/mK, or a thermal transmittance (RSI-value) of $\leq$ 22.7 [mK/W]; therefore, this construction would no longer meet the Minergie requirement. As a consequence, the use of mineral fibre boards with $\lambda \approx 0.036$ W/mK (RSI $\approx$ 27.8) provides a good cost / value ratio.

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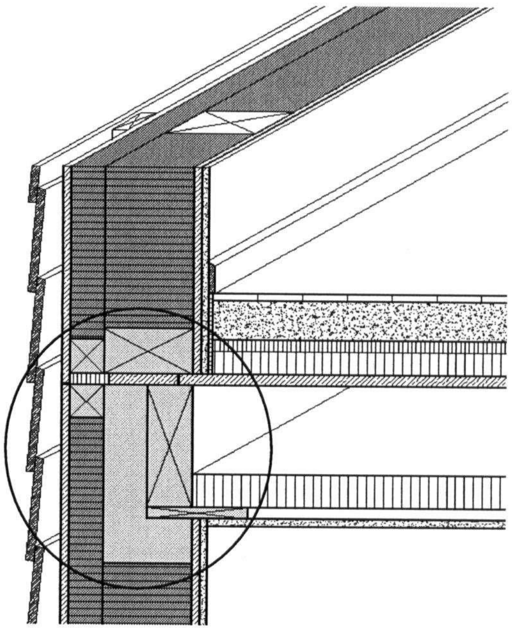
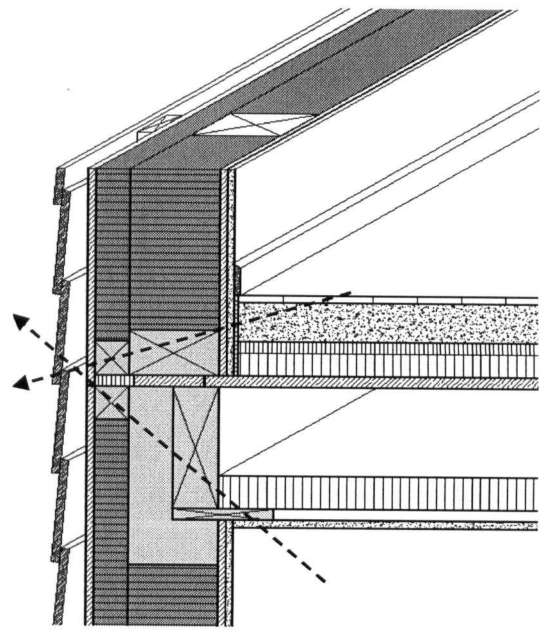
[2] In comparison, code requirements and Minergie-P houses require opaque parts of the enclosure to achieve U-values of < 0.30 W/m^2K and < 0.15 W/m^2K, respectively.
[3] The enclosure core corresponds to the enclosure without the exterior shell (cladding and air cavity). As the cladding is variable for both systems, it is not taken into consideration here.
[4] The structure / insulation core corresponds to the structurally-necessary parts (frame and sheathing / structural board and ribs) as well as the insulation layer(s), including the necessary support. It does not include non-structural sheathings, finishing elements or cladding.

Despite the considerable irregularities in the enclosure / floor joint area, this SWF construction has few heat bridges. There are only two linear horizontal heat bridges (furring strips) following the enclosure / floor joint (Fig. 4.1b), as well as points at the intersections of the three furring strips in the central part of the element with the studs (not shown in Fig. 4.1b).



a) *Thermal insulation layer and irregularities*



b) *Thermal bridges in the joint area*

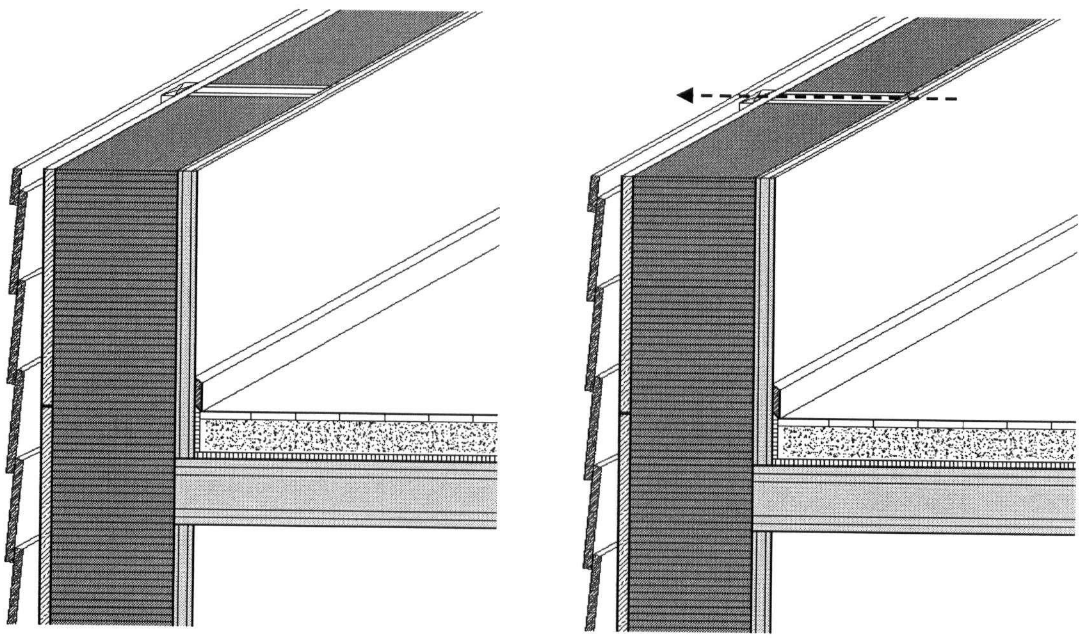
Fig. 4.1 Thermal efficiency of SWF

4.1.2 Ribbed Panel System

Pius Schuler AG provide a range of RPS enclosures with insulation depths starting from 16 cm; generally, the insulation consists of semi-rigid mineral fibre boards. To match the SWF, I will look at a RPS with an insulation depth of 22 cm (Fig. 4.2a), even though 19 cm would be enough to meet the Minergie standard. This construction achieves a U-value of 0.167 W/m^2K with a depth of the enclosure core of 27.1 cm and a weight of about 34 kg/m^2. Over the entire enclosure, 80.8% of the structure / insulation core of the RPS consists of insulation (Tab. 4.2). There is no irregularity of the thermal insulation; the layering remains the same from the bottom to the top of the house even in the enclosure / floor joint area.

As with SWF, rigid insulation boards are not feasible in RPS. But many other types of semi-rigid insulation boards, insulation batts or loose fill insulations (e.g. cellulose fibre) can be used. Despite their higher thermal conductivities, the Minergie requirement is met as long as the insulation material has a λ-value that is less than 0.046 W/mK.

As the ribs connect the interior shell with the exterior sheathing, linear heat bridges run along the ribs in the vertical direction (Fig. 4.2b). However, the wood fibreboard sheathing reduces the thermal bridges, due to its relatively high thermal resistance (λ = 0.06 W/mK or RSI = 16.7).



a) Thermal insulation layer and irregularities *b) Thermal bridges within the enclosure*

Fig. 4.2 Thermal efficiency of RPS

4.1.3 Summary

Both SWF and RPS provide high thermal-efficient enclosures with few thermal bridges; but the remarkable advantages of RPS are the light and thin enclosure as well as the very simple and consistent construction of the enclosure.

The new wood building systems reveal their thermal efficiency in comparison to a standard concrete construction (16 to 20cm depth) with exterior insulation and plaster cladding (Tab. 4.2). Concrete buildings achieve similar thermal values only with enclosures that are more than 10 cm thicker and 5 to 12 times heavier than SWF and RPS.

On the other hand, a comparison with an equivalent, highly-insulated Western platform frame construction as it would be built in Canada and the USA, using 2 x 6 in. (38 x 140mm) studs spaced at 24 in. (600mm) on centre (Allen, 1998:220) and an additional insulation layer with 2 x 4 in. (38 x 89mm) furring, shows a comparatively heavy SWF construction, whereas RPS shows similar values in weight as well as in thermal efficiency (Tab. 4.2).

Summary of characteristics	**SWF**	**RPS**	**Concrete**	**WPF**
Enclosure core depth [cm]	26.25	27.1	43	24.92
Storey height [cm]	279.95	260.5	265	≈274
Enclosure weight * (insulation 60kg/m^3) [kg/m] (insulation 30kg/m^3)	198 (184) [(1)]	(139) [(1)] 123	1,100-1,400	140 124
Enclosure core weight (ins. 60kg/m^3) [kg/m] (ins. 30kg/m^3)	162 (148)	(104) 88	1,000-1,300	103 87
Enclosure core weight (ins. 60kg/m^3) [kg/m^2] (ins. 30kg/m^3)	58 (53)	(40) 34	400-500	38 32
Thermal bridges [% of enclosure surface]	5.11	6.35	0	0.44
Insulation share [% of structure - insulation core] Regular wall section	73.7 83.0	80.8	51-56	87.0 91.3
U-value: [W/m^{2}K] mineral fibre insulation (0.036 W/mK)	0.195	0.169	0.152	0.172
Minimal mineral fibre insulation depth to meet Minergie standard [(plain) cm] Respective enclosure core depth [cm]	22 26.25	19 24.1	17 38	20 21.52
U-value: cellulose fibre (0.44 W/m^{2}K) [W/m^{2}K]	0.207	0.194	-	0.201
[(1)] SWF employs insulation with 60kg/m^3, RPS has insulation with 30kg/m^3				

Tab. 4.2 Thermal efficiency of SWF and RPS

4.2 Vapour and air movement

Pressure differences between the exterior and the interior side of the enclosure cause vapour and air to move through the construction. In Switzerland, the situation is critical in winter when temperature differences and vapour loads between heated rooms and the outside are high. Controlling the vapour and air movement through the enclosure (from the inside to the outside) is a key requirement to limit the migration of vapour by vapour diffusion as well as the migration of vapour and the loss of heat by travelling air. As well, a wind-proof layer on the exterior side of the insulation is required to reduce air currents within the insulation.

Important for a proper control of migrating vapour by vapour diffusion is the occurrence of an uninterrupted vapour retarder layer (properly sealed, no holes) on the warm side of the insulation. A rule of thumb suggests that one layer (e.g. a vapour-retarder foil) on the warm side of the insulation must be at least 10 times less vapour permeable than the least permeable one on the cold side. And, maximally one-third of the insulation may be on the warm side of the vapour retarder layer. These principles prevent vapour being trapped and condensing into the construction.

In Switzerland, the diffusion resistance of vapour retarders[5] is characterised by the diffusion equivalent air layer (s_D). Starting from s_D-values of ≥ 1.3 m (vapour permeability[6] ≤ 136 ng/m^2sPa), foils or other materials are considered vapour retarders (SIA norm 232). Vapour retarders with s_D-values < 20 m (vapour permeability > 9 ng/m^2sPa) are considered to be open to diffusion (Ampack, 2000). Ampack, a leading producer of vapour-retarder foils recommends s_D-values between 2 and 23 m (vapour permeability between about 90 and 8 ng/m^2sPa) for framed constructions with air cavities, while in constructions with low-value vapour-permeable claddings s_D-values > 1800 m (vapour permeability < 0.1 ng/m^2sPa) are recommended (Ampack, 2000).

An uninterrupted vapour-retarder layer always works as air barriers, as air particles are larger than vapour particles. As a consequence, the air barrier often coincides with the vapour-retarder layer. However, the abscence of holes that permit unimpeded migration of air is crucial to prevent moisture damages within the construction as well as to limit heat losses. "Air leakage can transport upwards of 30 times as much vapour as vapour diffusion, depositing water within the building assembly [...]" (CMHC, 1998:215). Moreover, the better the thermal insulation of an enclosure is, the more migrating air accounts for the fabric heat losses. In contrast to the vapour-retarder layer, the position of the air barrier within the enclosure is free.

Minergie houses require enclosures with air-exchanges rates of $n_{L,50} < 1\ h^{-1}$. This means that at a pressure difference of 50 Pa the air within a building would exchange less than once an hour. In comparison, building codes and Minergie-P houses require air exchange rates of $n_{L,50} \approx 3\ h^{-1}$ and $n_{L,50} < 0.6\ h^{-1}$, respectively. Critical for the achievement of this high level of air-tightness is not the air barrier (or the vapour retarder) itself, but the occurrence of properly sealed joints and the omission of holes.

[5] In Switzerland, the two terms 'vapour barrier' and 'vapour retarder' have been replaced by - strong or weak - 'vapour retarder' (SIA Norm 232).
[6] The relationship between the two values: vapour permeability [$ng/m^2s\ Pa$] = 177.92 / s_D-value [m].

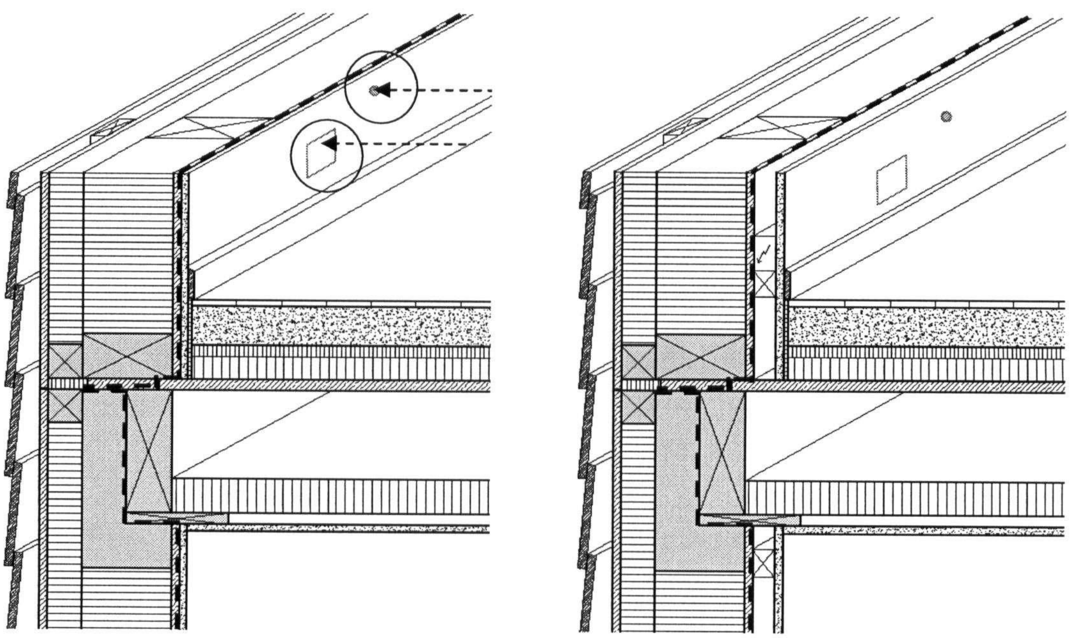
4.2.1 Swiss Wood Frame

SWF stops pressure-driven vapour and air movement through the enclosure with a vapour-retarder foil. This construction may properly control migrating air as long as the vapour barrier is properly sealed and free of wholes. As well, the exterior OSB sheathing (behind the air cavity) protects the insulation layer from exterior wind. Here, sufficient tightness against wind is given by the furring within the air cavity covering the sheathing joints.

SWF employs a transparent polyethylene vapour-retarder foil with a s_D-value between 40 and 159 m or a vapour permeability between 4.44 and 1.12 ng/m^{2}sPa; by definition, this foil is no longer considered to be open to vapour diffusion. However, it is necessary to provide the required vapour permeability difference towards the exterior OSB sheathing. According to the rule of thumb, OSB sheathing with a s_D-value between 5 and 7 m (vapour permeability between 35 and 25 ng/m^{2}sPa) requires the use of a vapour-retarder foil with a s_D-value between about 50 and 70 m. Only the replacement of the exterior OSB with another sheathing such as wood fibreboard (e.g. Pavatex UD KN) would change the situation. Having a s_D-value of about 0.11 m (vapour permeability of about 1,600 ng/m^{2}sPa) at a depth of 21 mm it would be about 10 times as open to vapour diffusion as the mineral fibre insulation (s_D-value of between about 1 and 2 m), as well as about 50 times as open as the structural OSB sheathing on the interior side of the insulation. As a consequence, SWF could be built as a system that is open to vapour diffusion. Moreover, the use of exterior wood fibreboard sheathing would also improve the U-value of the enclosure from 0.194 to 0.183 W/m^{2}K, and it would reduce the existing heat bridges. But, using the structural OSB sheathing as vapour barrier requires special care of the joints to achieve an uninterrupted and air-tight layer.

Within the wall section, the vapour barrier is well embedded between the structural OSB sheathing and the interior finishing element consisting of a 12.5 mm gypsum board. In the wall / floor joint, the vapour barrier runs along the enclosure / floor joint. Thus, the vulnerable foil is well protected against decay caused by light exposure and deformations due to pressure differences. It appears that the vapour-retarder foils of the upper and lower enclosure elements overlap in the enclosure / floor joint (Fig. 4.3a). It is assumed that these joints are tight, the vertical joints within the elements are reliably and durably sealed (high quality of product, production and construction), potential holes resulting form transport or on-site adjustment are sealed during the assembly process, and breaking seals will not be a issue for unwanted vapour and air migration. In doing so, the air-tightness of the system is given unless the vapour retarder foil will be damaged over time.

The position of the vapour retarder foil right behind the thin gypsum board makes it vulnerable to wear and tear caused by the inhabitants. An ordinary picture nail may already perforate the foil and generate a permanent outlet for migrating vapour and air. Also, the installation of a concealed electrical duct is difficult if not impossible (Fig. 4.3a). The use of a thicker gypsum board or another finishing material (e.g. block boards), or more likely the application of an installation cavity (Fig. 4.3b) could solve this problem. Moreover, an installation cavity would increase considerably the adaptability of the enclosure to the future needs of the inhabitants.



a) Run of the vapour-retarder foil *b) Installation cavity*

Fig. 4.3 Control of vapour and air movement in SWF

4.2.2 Ribbed Panel System

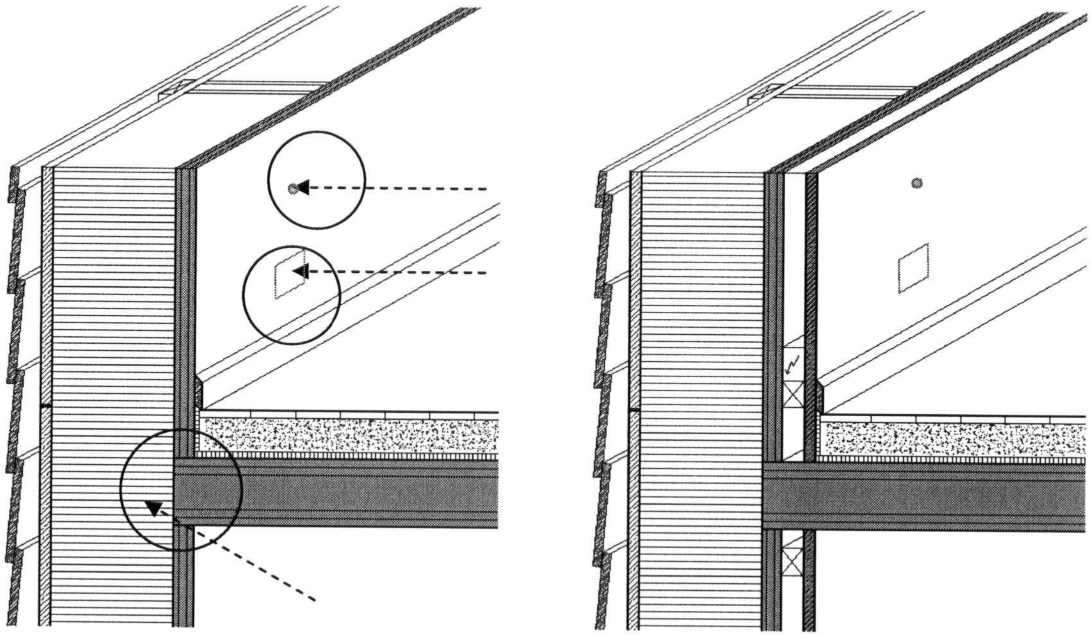
RPS does not employ a specific vapour-retarder layer. The structural board controls vapour and air movement through the enclosure. Gap-filling glues connect the single elements to an uninterrupted shell. On the exterior side of the insulation, wood fibreboard sheathing with tongue-and-groove joints protects the insulation layer against the circulation air within the air cavity.

With a s_D-value of about 2.8m (vapour permeability of about 63.5 ng/m^2sPa) at a moisture content between 6% and 12% (Schuler, 2003), the block board is considered a low-value vapour retarder that is considered to be open to vapour diffusion. Also, it has the highest vapour-diffusion resistance of all enclosure layers. Calculations show that this enclosure construction will be free of condensation in winter (App. 7). Moreover, observations made by Pius Schuler AG allow the assumption that a block board with a thickness of 35mm stores the migrating vapour and gives it back to the indoor air at a later stage (Pius Schuler AG, 2004).

During assembly, the element joints are filled with gap-filling glue and fixed with screws. The possibility to control all the joints lets assume that they are properly sealed (production and construction quality). As such, the air tightness of the system is given, as long as the employed glue may withstand the differential forces and the exposed wall panels are not perforated.

Changes in indoor air temperature and humidity evoke differential forces within the exposed structural board as well as along the joints. However, cracks within the block board are not considered critical, as they are temporary, they remain small due to low dimensional changes of the block boards (see chapter 4.3 Differential movement), and they are limited to the top layer (Deplazes, 2001). Also, joints are not considered vulnerable, as multi-layered block boards have small and isotropic shrinkage and swelling rates in length and width. Potential differential forces are assumed to be taken up by the boards as well as by the screws and the gap-filling glue. Nonetheless, a closer investigation of the joints will be necessary to secure vapour and air tighness over time. Also, the type of gap-filling glue may be critical to a proper and durable sealing of the enclosure-floor joints (Fig. 4.4a). Potentially, the application of a tape covering the enclosure-floor joint on the exterior side might eliminate this deficiency and help achieving a durably sealed and air-tight layer.

The exposed position of the block-board walls is not considered to make them vulnerable to wear and tear caused by the inhabitants; a thickness of 3.5 cm will be enough to resist perforation by ordinary picture nails (Fig. 4.4b). In contrast, bigger interruptions such as the installation of an electrical duct are perilous. While potential perforations could be eliminated by using a thicker structural board, the installation of an electrical duct requires the application of an installation layer and an additional interior finishing material, such as a gypsum board or a thin block board (Fig. 4.4b). However, this strategy may change the architectural expression of the wall.



a) Critical zones *b) Protective installation cavity*

Fig. 4.4 Control of vapour and air tightness in RPS

4.2.3 Summary

Highly-insulated buildings require enclosures with limited vapour and air movement controlling vapour migration caused by diffusion as well as thermal losses and vapour migration caused by travelling air. SWF employs a specific vapour-retarder foil to control of the occurring vapour and air movement; RPS embodies its control into the structural board.

SWF represents an enclosure that is fairly tight to vapour diffusion. Its vapour retarder foil is 14 to 56 times tighter than the appropriate block board of RPS (App. 8). In contrast, the enclosure of RPS may be considered to be open to diffusion or 'breathable'. Moreover, it appears to have the potential to balance the indoor-air humidity, a characteristic that will be beneficial to the indoor-air climate. However, changes in the material choice may also make SWF a system that is open to vapour diffusion.

The occurrence of an uninterrupted and properly sealed vapour retarder layer provides both systems with the required air-tightness. However, the position of the vapour retarder foil of SWF, as well as the durability of the joints of RPS are critical for a proper performance over time. Adaptations to the interior finishing layer in SWF, the application of an additional sealing tape in RPS or the use of an installation cavity in both systems may make the systems more resistant to wear and tear over time, as well as more flexible to the changing needs of the inhabitants.

4.3 Differential movement

Temperature and humidity differences result in strong differential forces within the building materials and their joints, as well as between different building materials and layers. Sun-exposed claddings may heat up far above the maximum outside temperature in summer and cool down to minus temperatures in winter. In contrast, within a building, temperature differences vary by only a few degrees throughout the year. In Zurich, air temperatures generally vary between up to + 33°C in summer and about - 10°C in winter, while indoor air temperatures between 18 and 24 °C, and humidity ranges between 35% and 70% are considered to be comfortable for living spaces (Neufert, 1996:30).

Major dimensional changes are expected within the exterior layers of the enclosure. Nonetheless, the entire enclosure is required to fulfil its duties over time and to withstand the recurring differential forces. Thus, the choice of materials and the way materials are joined are crucial, whether structural damage occurs over time or not.

4.3.1 Swiss Wood Frame

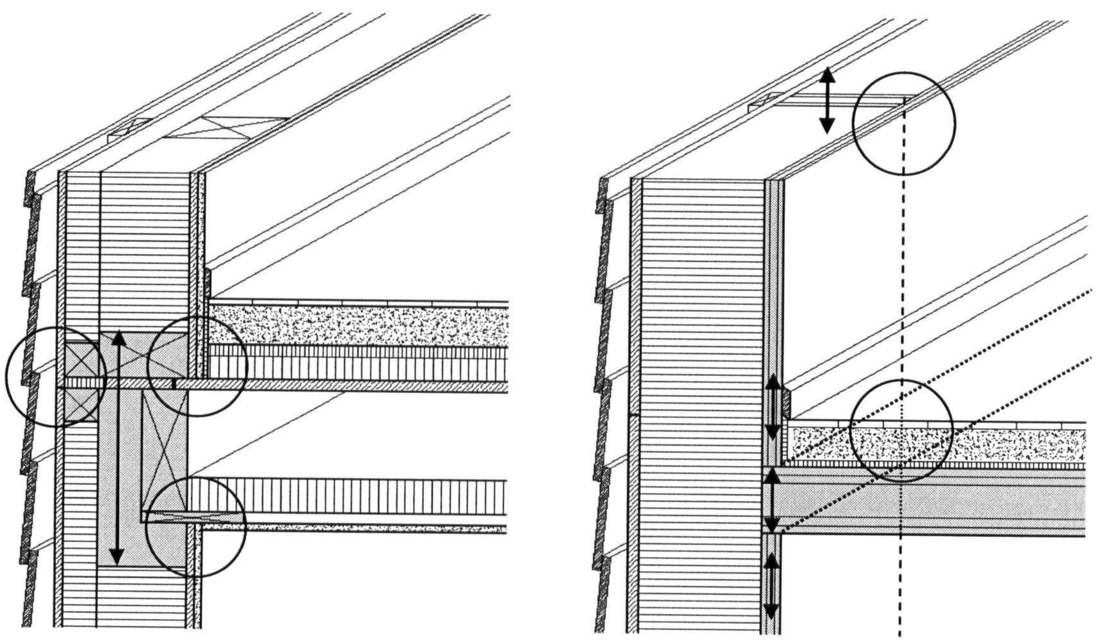
Under the influence of the local climate, major shrinkage and swelling is expected in the horizontal hardwood siding. In this construction, the overlapping boards are nailed against the flashing within the air cavity. Whereas the single boards have room to move in the vertical direction, they are fixed in the horizontal direction as well as in the layer depth at the nailing points. Considering shrinkage and swelling rates of 0.01% per % humidity change in the longitudinal direction and an assumed humidity range of 15% ± 5% for exposed wood (Maissen, 1985:94), the length of Norway spruce siding boards varies by about ± 0.31 mm within a single section (62.5 cm) of the enclosure. Also, considering radial shrinkage and swelling rates of 0.16% per % humidity change, boards with a thickness of 21 mm change their dimensions by about ± 0.33 mm in depth. Together, the ongoing longitudinal and radial movement will loosen the nails over time, and result in opening and closing gaps between the siding boards. Nonetheless, the central core of the construction will not be endangered as long as basic maintenance is done. The furring within the air cavity works like a flexible joint between the enclosure core and the cladding. In addition, this well-ventilated cavity allows any water to drain out and moisture to dry out again.

Considering a maximal initial moisture content of the construction wood of < 16% as well as a moisture balance at 9% ± 3% within warm and dry rooms over time (Kolb, 1998:81,147), on average the structure will shrink about 9.1 mm per storey, due to a decreasing moisture content from 16 to 9%. Over time, the dimensional changes due to the changing moisture content of the structure will be about ± 3.91 mm per storey, most of it (± 3.20 mm) accounted for by the horizontal wood in the joints (Tab. 4.3). Nailed connections between the exterior sheathing, the furring layer, the structural frame and the interior structural sheathing allow differential movements of the members. Gaps between the sheathing panels are necessary to take up the dimensional changes of the frame (Fig. 4.5a). Still, the tightness of the joints is maintained, as the joints run along flashing strips, studs or plates. Where gaps are needed between sheathing panels, the initial shrinkage of the frame will release potential tensions of the vapour retarder.

4.3.2 Ribbed Panel System

As in SWF, the nailed connections and the intermediary furring take up the dimensional changes of the siding. Nailed to the ribs, the exterior wood fibreboard with tongue-and-groove joints allows differential movement without losing its wind tightness.

Considering an initial moisture content of 10% ± 2% of the 3-layered block board as well as a moisture balance at 9% ± 3% within warm and dry rooms over time (Kolb, 1998:81,147), the structure will shrink about 0.65 mm, due to a decrease of the moisture content from ± 10 to ± 9%. Over time, the dimensional changes of the structure will be about ± 1.95 mm per storey, where about ± 1.19 mm is accounted for by dimensional changes in the floor elements (Tab. 4.3). As the small differential changes in the wall and floor boards are the same in length and width (isotropic characteristic) there is no problem in using fixed connections along the element joints provided by screws and gap-filling glue. Nonetheless, different dimensional changes exist between the single-layered ribs and three-layered structural block boards of the enclosure (along the grain) and the five-layered block-board elements of the floor (against the grain). Glued connections will impede differential movement at the contact area between the ribs and the structural wall board. Also, screwed and glued connections between ribs of the lower element and the structural enclosure board of the upper element, as well as between the ribs of the lower element and the floor element, will impede differential movement. As a consequence, the differential movement has to be taken up by the material; small cracks are expected along the rib / wall board joint line (Fig. 4.4b), due to strong strains.



a) Critical zones within SWF *b) Critical zones within RPS*

Fig. 4.5 Differential movement within the enclosure core of SWF and RPS

4.3.3 Summary

Within the structural core, SWF faces dimensional changes that are considerably larger than those of RPS. Most of them are a result of the higher initial moisture content as well as the large proportion of horizontal wood. However, nail connections and gaps between the sheathing panels that may take up the differential movement of the structural core will prevent structural damage. In contrast, the initial moisture content of the block boards already lies within the moisture balance zone, and the dimensional changes of the RPS are relatively small as well as isotropic in the length and width of the boards. As a consequence, major differential forces occur only along the joints between ribs and structural wall and floor boards; it is assumed that the stresses are taken up by the material, resulting in small cracks that are continuously opening and closing over time.

Shrinkage and dimensional changes over time	**SWF**	**RPS**
Changes along the grain [% per %]	0.01	0.016 0.012 (ribs)
Changes across the grain [% per %]	0.25	0.21
Initial wood moisture content [%]	<16	10 ± 2
Indoor wood moisture balance [%]	9 ± 3	9 ± 3
Storey height [cm] Vertical wood [cm] Horizontal wood [m]	279.95 237.35 42.60	258.5 246.5 12.00
Average initial shrinkage in height [mm] Vertical wood Horizontal wood	9.12 1.66 7.46	0.65 0.40 0.25
Average initial shrinkage of ribs [mm]	-	0.31
Average dimensional changes in height over time [mm] Vertical wood Horizontal wood Ribs	± 3.91 ± 0.71 ± 3.20 -	± 1.95 ± 1.19 ± 0.76 ± 0.94

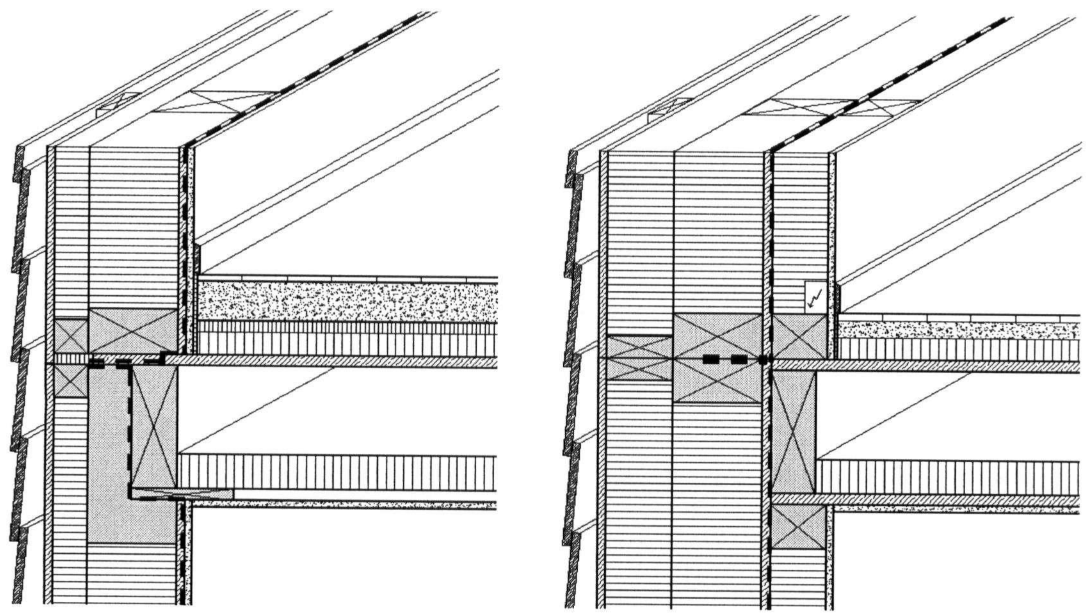
Tab. 4.3 Thermal irregularities and thermal bridges of SWF

4.4 Thermal redundancy

Over the last 20 years, thermal insulation requirements for building enclosures have considerably increased. Along with the increase in thermal insulation depth, new materials and building components (e.g. windows) have changed the construction principles of buildings. As a consequence, building systems as well as existing buildings that may be easily adapted to increased standards will be more successful in future. In this section, the two building systems will be evaluated on their flexibility in adapting to new insulation standards during the planning phase as well as after construction.

4.4.1 The Swiss Wood Frame

As we have already seen in chapter 3 (Fig. 3.2), Renggli AG suggests three enclosure constructions to meet code requirements, the Minergie standard and the Passive House standard. While the upgrade from the code requirements to the Minergie standard is achieved with an additional insulation layer on the exterior side of the structural core (Fig. 4.6a), a further upgrade to the Passive House standard goes along with a change in construction (Fig. 4.6b).



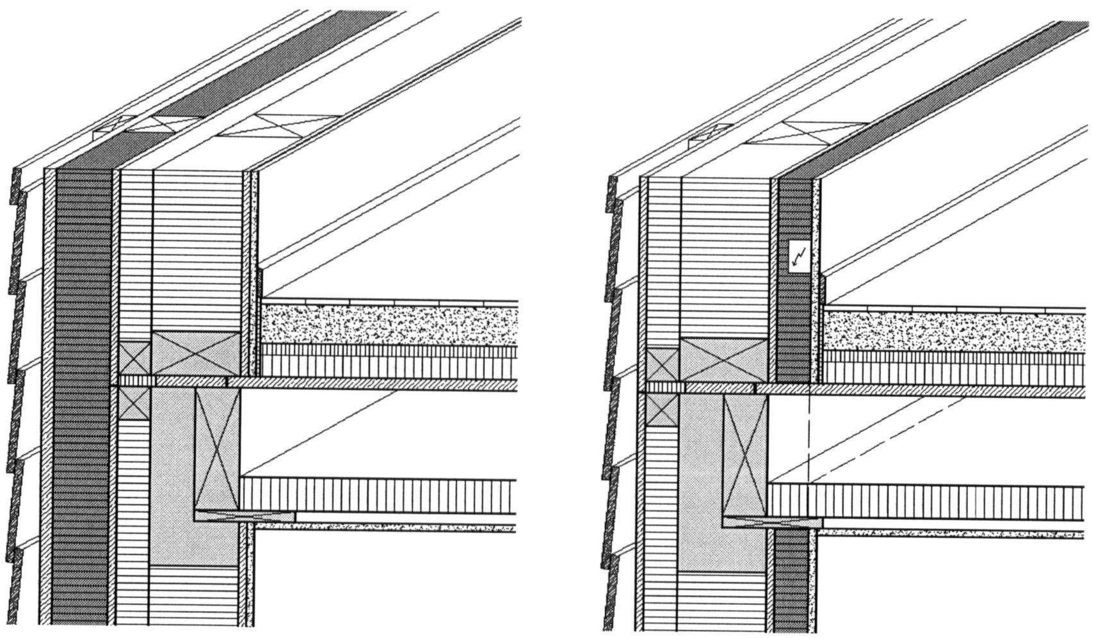
Minergie Standard
22 cm insulation, U = 0.194 W/m²K

Passive House / Minergie-P standard
38 cm insulation, U = 0.105 W/m²K

Fig. 4.6 Suggested insulation standards of SWF

Even though this upgrade is feasible only in the planning stages of the building, it embodies major advantages. Firstly, the vapour-retarder foil has moved behind the interior insulation layer, where it is protected against wear and tear caused by the inhabitants. Secondly, the vapour-retarder foil now runs straight through the enclosure. Thirdly, the complexity of the enclosure / floor joint and the proportion of wood have considerably decreased. Fourthly, the interior insulation layer may be used as an installation layer without the risk of losing its air and vapour tightness.

At a later stage, an additional insulation layer might be applied to the exterior side of the central core (Fig. 4.7a). This addition considerably improves the thermal insulation standard and reduces the thermal bridges. However, expanded or extruded foamed plastic insulation with plaster cladding may not be applied, due to its low vapour permeability (d_s-value between 200 and 3,000m). The application of an interior insulation layer is critical unless major renovations are done (Fig. 4.7b). Firstly, the additional insulation layer is applied on the warm side of the vapour-retarder foil. To avoid vapour-diffusion problems, the depth of the insulation is limited to about 7 cm; as a rule of thumb it may be one-fourth to one-third of the insulation depth. Secondly, this insulation layer is never continuous. Between the enclosure and the partition wall, as well as within the enclosure / floor joint, it is not possible to fit additional insulation, or it is very costly. Thirdly, with this strategy the rooms are getting smaller. Finally, the strategy is very expensive, as all rooms are affected and finishing materials have to be adapted. However, an additional insulation layer would protect the vapour-retarder foil and provide an installation cavity.



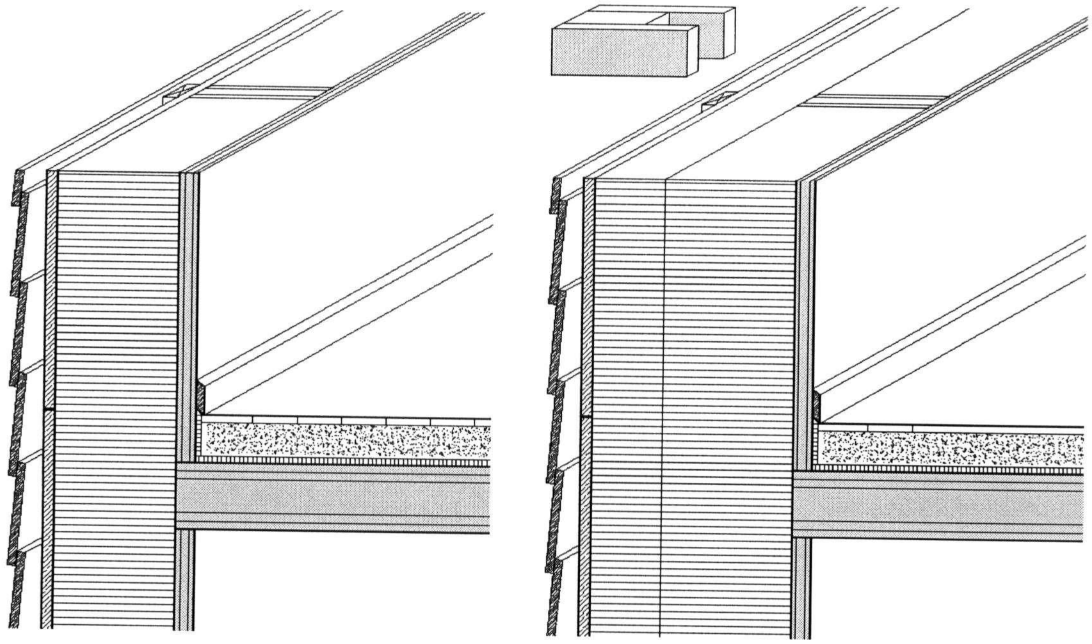
Additional exterior layer
22 + 10 cm insulation, U = 0.130 W/m²K

Additional interior layer
22 + 6 cm insulation, U = 0.155 W/m²K

Fig. 4.7 Possible insulation upgrades of SWF

4.4.2 The Ribbed Panel System

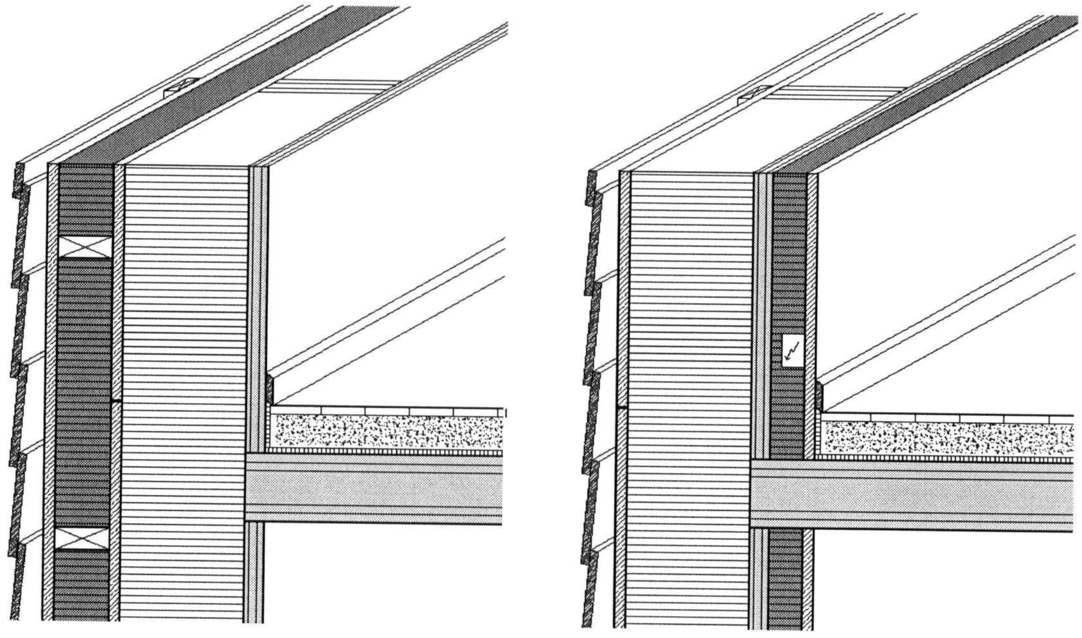
Pius Schuler AG suggest a range of enclosure principles relying on a depth of the ribs between 160 mm and 280 mm (Fig. 4.8a), but virtually any insulation standard is possible either by increasing the depth of the ribs or by using extenders (Fig. 3.13, Fig. 3.15b). As an increase in the thermal insulation affects only the depth of the ribs, thermal upgrades may easily be achieved without changing the construction principles. Moreover, the use of extenders considerably reduces the thermal bridges by reducing the linear thermal bridges to punctuate ones at the joints between the extenders and the exterior sheathing. As such, this system allows an easy and flexible thermal upgrade of the basic system in the planning stage as well as at the beginning of the factory production (Fig. 4.8b).



a) 16 to 28 cm insulation
$U \approx 0.22$ to 0.134 W/m^{2}K

b) 38 cm insulation
$U \approx 0.096$ W/m^{2}K

Fig. 4.8 *Thermal insulation standards of RPS (Source: adapted from Schuler, 2003).*



a) Additional exterior layer
22 + 10 cm insulation, $U \approx 0.119$ W/m^{2}K

b) Additional interior layer
22 + 6 cm insulation, $U \approx 0.137$ W/m^{2}K

Fig. 4.9 *Possible insulation upgrades of RPS (Source: adapted from Schuler, 2003).*

Also at a later stage, the application of extenders and a further insulation layer as shown in Figure 4.8b is possible. A less-costly alternative is the application of an additional insulation layer on top of the central core (Fig. 4.9a). Given the fact that the block board may take up all the migrating vapour, expanded or extruded foamed plastic insulation with plaster cladding could theoretically be applied; practically, this is not recommended as failures of the block board (joints or holes) may occur. The application of an interior insulation layer is also possible (Fig. 4.9b), even though it is more costly and decreases the size of the rooms. No vapour-diffusion problems are expected as long as the vapour taken up by the block board can be given up to either side at a later stage. Also, due to the regular distribution of insulation on the outside (especially in the enclosure / floor area) of the structural board, the irregularities on the inside are acceptable. Once more, this strategy changes the architectural expression of the wall.

4.4.3 Summary

Both SWF and RPS allow for a considerable increase in the insulation standard. Where SWF employs a different construction principle for highly-insulated buildings, the construction of RPS remains the same whatever standard it is designed for. On site, improvement to the thermal insulation preferably occurs on the exterior side of the enclosure. Thus, the new shell is uninterrupted, decreases existing thermal bridges and does not affect rooms and interior finishing materials. Vapour-diffusion problems are avoided as long as the additional layers respect the vapour-diffusion requirements. On the inside, the application of additional insulation will most probably be done along with major renovation work, or in response to a need for an installation cavity.

4.5 Structural redundancy

Structural elements that may bear larger loads than originally planned have a greater potential to be adapted to the changing needs over time. These needs include changes in use as well as the need for larger or more living space. The latter is especially true in Switzerland, where land is scarce and the densification of residential estates is being discussed. Thus, a building system that can potentially withstand the forces of an additional storey may assist in achieving long-lasting buildings. Also, changes in the fire regulations make multi-residential buildings in wood with up to five storeys feasible. This section investigates the load-bearing capacity of SWF and RPS enclosures where the load influence zone of the floors is 2.20m[7].

4.5.1 Swiss Wood Frame

A stud in a SWF building with 2.40m height and a cross-section of 80 x 160 mm can resist buckling loads of up to 6.2 N/mm^2. Calculations (App. 4) show that the loads of a five-storey building are not critical (Tab. 4.4), but the pressure at the intersection of studs and plates limits the number of storeys. Norway spruce and fir can only resist stresses of 1.6 N/mm^2 against the grain. Stresses of 2 N/mm^2 are allowed only if deformations do not endanger the stability of the construction. Thus, stresses against the grain limit the construction of SWF to three storeys (resulting in stresses of 1.68 N/mm^2). To be adaptable to a multi-storey building with four (2.28 N/mm^2) or five (2.89 N/mm^2) storeys, a reduction in the stresses against the grain in the top and bottom plates of lower floors is necessary.

The replacement of softwood plates with hardwood plates allows an increase in the critical stresses in plates from 1.6 N/mm^2 to 4.5 N/mm^2 against the grain. While an increase of the stud area would also reduce the stresses, changed dimensions in width and depth bear major disadvantages. An increase of the stud width is not feasible, as it would change the construction grid of the entire construction. Moreover, the respective buckling loads do not require increased width of the studs. Considering an insulation depth of 22 cm needed to achieve the Minergie standard, studs with square sections of 8 x 22 cm could replace the two insulation layers. Thus, the construction would be according to the basic standard. As a result, a four-storey building with assumed stresses of 1.66 N/mm^2 becomes feasible. But, the use of 8 x 22 studs would increase the thermal bridges of the enclosure. However, this square section is not (yet) readily available in the local market.

A look at the floor construction reveals that replacing the 7 cm concrete underlay floor with a 2.5 cm wood fibreboard would reduce the dead load of the floor by about 55%, or the total load of a storey (dead load and life load) by a remarkable 30%. As a result, a four-storey building with an assumed load of 1.73 N/mm^2 would still be feasible without considering any other changes in the construction. Moreover, if

[7] According to the rule of thumb, the joists of the SWF (8 x 22 mm) are feasible for spans of 4.40m.

hardwood plates are additionally used in lower storeys, theoretically this system could bear the loads of a then-storey building.

4.5.2 Ribbed Panel System

Ribbed panel enclosures with an insulation depth of 22cm, a height of the structural board of 2.50m and a thickness of 35mm can resist buckling loads of about 145 kN/m' (Pius Schuler AG, 2004: Elements) or 91.5 kN per enclosure section (63cm). This construction could therefore resist the buckling load of buildings way higher than five storeys (App. 4, Tab. 4.4). However, at the enclosure / floor joints the pressure against the grain is limited to 1.2 to 2.5 N/mm^2. This means that a four-storey building with assumed stresses of 1.02 N/mm^2 (without rib areas) is feasible without any further considerations, while a nine-storey building with 2.41 N/mm^2 still lies within the given range for maximum stress against the grain.

Considering buildings higher than four storeys, an increase of the thickness of the structural board from 35 mm to 45 mm could reduce the stresses by 28%. This strategy is easily achievable, as it does not affect the grid of the enclosure. Also, thicker block boards could be used in lower storeys only, where larger loads are expected. Alternatively, the use of hardwood block boards for floors could eliminate the stress problem. Both strategies are practicable, as the structural boards are produced only on demand.

As with SWF, replacing the 5 cm concrete underlay floor with a 2.5 wood fibreboard would result in a 45% reduction of the dead load of the floors as well as a 25% reduction of the total load per storey, so that a five-storey building (1.03 N/mm^2) would still be under the lower stress benchmark for maximum stresses against the grain. Theoretically, a twelve-storey building (2.49 N/mm^2) would still be feasible.

4.5.3 Summary

Both SWF and RPS are feasible for houses up to five storeys. While buckling loads are not a problem in either system, an increase in the number of floors results in critical stresses against the grain in both systems. Considering the basic construction, SWF is limited to two to three storeys while at least four storeys are feasible for RPS. The use of hardwood sills in lower storeys gives a considerable increase in the stress resistance in SWF and allows the construction of five-storey buildings. Also, the elimination of the heavy concrete underlay floor would considerably reduce the occurring loads. Therefore, structural redundancy for five-storey buildings is most easily achieved by changes in the materials. An increased depth of the structural board is also feasible for RPS.

	SWF	RPS
Loads per load influence zone and storey [kN/section] (load influence zone 2.2m x structural grid)	7.7	4.6
Structural grid [m] Enclosure [kN/section] Floor (life load 2 kN/m^2) [kN/section] Roof (life load 1 kN/m^2) [kN/section]	0.625 1.3 6.4 4.8	0.63 0.75 3.85 4.15
Maximum buckling load [kN/section]	79.5	91.5
Maximum storeys due to buckling load	10	19
Maximum stresses against the grain Softwood [N/mm^2] Hardwood [N/mm^2]	 1.6 - 2.0 (1) 4.5	 1.2 - 2.5 (2)
Maximum storeys due to stresses against the grain Softwood sills Resulting stresses against the grain [N/mm^2] Hardwood sills Resulting stresses against the grain [N/mm^2]	 2 - 3 1.08 - 1.68 7 4.09	4 - 9 1.02 - 2.41
Wood fibreboard underlay floor Maximum storeys due to stresses against the grain Resulting stresses against the grain [N/mm^2]	 3 - 4 1.30 - 1.72	 5 - 12 1.02 - 2.49
(1) Deformations must be tolerated at stresses of 2 N/mm^2 against the grain (2) This wide range most probably considers the use of different woods		

Tab. 4.4 Load-bearing capacity of SWF and RPS.

4.6 Maintainability

Over time, building materials and building components wear away, due to climate influences as well as the wear and tear caused by the inhabitants; however, durable materials and constructions achieve longer life spans and reduce the frequency of maintenance work. As well, exposed components or components with shorter lifespan (e.g. finishing materials) must permit easy replacement without affecting other building parts. Moreover, it is assumed that maintenance work that is easily and cheaply done is more likely to be done, which prevents the premature obsolescence of the entire building and thus saves resources and costs, increases the lifetime of a building, and is beneficial to the inhabitants' health. Generally, the interior and exterior surface layers are the components that suffer the most wear. This section looks at the ease and frequency of maintenance work.

4.6.1 Swiss Wood Frame

On the outside, a renewal of the paint on the horizontal wooden siding and driving nails back into the furring are maintenance work that may become necessary once in a while; also, the replacement of a single board or the entire siding may become necessary. Whether single boards or entire sidings are replaced, the maintenance work is limited to the parts requiring it without affecting the adjacent ones. Replacing the siding also allows easy examination and potential maintenance of the exterior sheathing.

On the inside, renewing the paint, along with a potential patch-up of the plaster or the application of another wall finishing such as wallpaper or wooden panels, is easily done; generally, these procedures are more likely to be requested by the inhabitants than to be technically necessary. However, problems with the vapour-retarder foil may require the removal of the gypsum board. Indeed, the vapour-retarder foil in SWF, being right behind the thin gypsum board (see also chapter 4.2 Vapour and air movement), is predestined to be perforated. The sealing of the holes is difficult and costly, even though in this construction it is necessary to limit the number of permanent outlets for vapour and air. This weakness of SWF may be solved by considering an installation cavity or a thicker finishing material during construction.

4.6.2 Ribbed Panel System

On the outside, maintenance of the wooden siding corresponds to that of SWF. The use of an air cavity is central to both constructions; the furring within the air cavity separates and links the exposed building components, which have more frequent maintenance needs, with the central core that is expected to last.

On the inside, the oiled or painted surface of the block board can be renewed once in a while. Like hardwood floors, the surface can be sanded; cracks and holes (even large ones) can be filled with a mixture of wood dust and glue. Thus, the control of vapour and air movement may be maintained with low and easily performed measures. If the inhabitants request it, the application of paint or another surface material (e.g. gypsum board with plaster and final paint coat) is generally feasible. But the application of vapour-diffusion resistant layers impedes the ability of the block board to balance the indoor air humidity. Therefore, the application of additional layers is beneficial only if there is a need for an installation cavity.

4.6.3 Summary

Both SWF and RPS provide outdoor layers that allow easy maintenance or the replacement of single boards or entire sidings without affecting the adjacent parts. Indoor maintenance of SWF is easily performed and most probably requested by the inhabitants. But, the maintenance of the indoor layers of SWF can become very costly if holes in the vapour-retarder foil have to be sealed to prevent structural damage due to moving air and vapour. In this system, the use of an installation cavity is urgently recommended. Indoor maintenance of RPS is occasional and easily performed.

4.7 Indoor environmental quality

Adhesives, sealants, paints, composite products and carpets may emit contaminants such as volatile organic compounds (VOCs) that are odorous, irritating or even dangerous to the inhabitants' health Moreover, the construction of air-tight enclosures as required for highly-insulated buildings (Minergie, Minergie-P or Passive Houses) prevent air from naturally exchanging. Therefore, mechanical or natural strategies (e.g. mechanical ventilation or controlled window ventilation) are required to provide a healthy and comfortable indoor air quality (i.e. CO_2 concentration, relative air humidity and pollutants). As well, the prevention of drafts and the provision of high radiant temperatures that limit the risk of moulds and mildew, enhance the well-being of the inhabitants. This section looks at how the building systems support the need for good indoor environmental quality (e.g. air exchange, air humidity control and the use of low-emission materials), few drafts and high radiant temperatures.

4.7.1 Swiss Wood Frame

As we have seen in the previous sections, SWF relies on an enclosure with a U-value of 0.194 W/m^2K, a vapour-retarder foil that is not considered to be open to diffusion (d_s-value between 40 and 150m), a maximum natural air-exchange rate of $n_{L50} < 1$, and necessary mechanical ventilation that is commonly called 'comfort ventilation'. Gypsum boards with gypsum-based plaster and water-based paint, as well as a hardwood floor (oiled or vanished), are commonly-used indoor finishing materials.

Since SWF is highly air and vapour-tight, mechanical ventilation is needed as a controllable method to secure the provision of fresh air (oxygen), and to renew the indoor air in such a way that high levels of humidity and potential pollutants or allergens (e.g. smoke, VOC's) in the indoor air are prevented. As well, this construction allows rooms to be fitted with indoor finishing materials (e.g. omission of solvent-based paint, timber preservatives) that have minimal health (and environmental) impact. Unnecessary drafts are prevented by air-tight enclosures and radiant temperatures of exterior walls are only slightly under the room temperature, due to good thermal insulation. For an assumed outside temperature of -10°C and an indoor air temperature of 21°C, the radiant temperature of the SWF construction is about 20.25°C. This means that SWF works perfectly as long as one can count on the successful operation of the mechanical ventilation. However, this is a factor that is strongly criticised by opponents; they mention aspects such as the risk of insufficient maintenance of filters and the considerable risk of moulds growing in the ducts of mechanical ventilation systems, as well as hygienic problems due to planning errors, and a potential ionisation of the air. These potential risks are contrasted by 'measurable' advantages such as fresh air all day long even if nobody is home, protection against pollution and traffic noise or protection against burglary due to open windows as they have been mentioned in chapter 2.4.

4.7.2 Ribbed Panel System

The RPS relies on an enclosure with an U-value of 0.179 W/m^{2}K, a maximum natural air exchange rate of $n_{L50} < 1$ and required mechanical ventilation. The structural block board of the enclosure and floor elements is air tight but open to diffusion (d_s-value around 2.8m), and / or it is able to balance the indoor air humidity. Therefore, generally no finishing materials are applied on the walls and ceilings; the surfaces are treated with oil or paint. On the floors, hardwood (oiled or vanished), stone or any other finish flooring is possible.

The mechanical ventilation system used in RPS has the same advantages and disadvantages as discussed for SWF. Also, unnecessary drafts are prevented by air-tight enclosures. Radiant temperatures of exterior walls are only slightly under the room temperature, due to good thermal insulation. For an outside temperature of -10°C and an indoor air temperature of 21°C, the radiant temperature of RPS construction is about 20.35°C. But in contrast to SWF, the enclosure is open to vapour diffusion and / or has the ability to balance the indoor air humidity. Thus, it has the potential to improve the well-being of the inhabitants considerably. But block boards, like many other engineered wood products, embody large amounts of urea-formaldehyde (UF) glues, and formaldehyde may harm the health of the inhabitants. Even though the block boards employed conform to the lowest emission class (E1) that requires a maximum emission of formaldehyde < 0.1ppm (maximum formaldehyde concentration of the indoor air < 12µg/m^3) and therefore also comply with legal requirements, sensitive persons may still perceive irritation or a nuisance smell. Also, the WHO suggests that formaldehyde emissions should be limited to < 0.05ppm (concentration < 6µg/m^3). Considering a natural formaldehyde concentration of 1µg/m^3 to 20µg/m^3 (WHO, 2004: WHO 5.8) or exposure to tobacco smoke with concentrations of 50 to 350µg/m^3, the concentrations resulting from the block boards are not exceptional, but they are added to the total of the daily exposure. Furthermore, the inhabitants' exposure may last for many years. Here, major improvements have to be made to achieve a healthier building system.

4.7.3 Summary

Both SWF and RPS are building systems that work only in combination with a reliable ventilation system. As long as mechanical ventilation systems are considered present-day benefit without major health disadvantages, the synthesis of both SWF and RPS with mechanical ventilation has great potential for success in the local market. However, alternatives to the use of mechanical ventilation systems should be tested, and improvements in the composition of glues in EWP's have to be made.

4.8 Noise protection

Good sound insulation against exterior and interior noise is necessary for the maintenance of the inhabitants' health and comfort. In Switzerland, norm SIA 181 defines the noise control requirements. Table 4.5 summarizes the required benchmarks for different noise immissions and sensitivity levels in living spaces. In this thesis, I investigate the enclosure with respect to exterior noise, as well as the suggested floors regarding interior airborne and impact noise. The benchmarks are set at 45 dB for exterior airborne noise, 52 dB for indoor airborne noise through floors, and 55 dB for impact noises through floors (bold numbers in Tab. 4.5).

The values $D_{nt,w}$ and $L'_{nT,w}$ describe the weighted standard sound level difference (airborne noise) and the weighted standard impact sound level (impact noise) in a room, respectively. The relationship between the $D_{nt,w}$-value and the R'_w-value (weighted standard sound reduction index of a building element) is given by a correction factor C that considers the room volume, the exposed area (wall or floor), and the reverberation time. Similarly, the relationship between the $L'_{nT,w}$-value and the $L'_{n,w}$-value (weighted standard impact noise level index of a building element) is given by a correction factor B that considers the room volume as well as the reverberation time (SIA 181:25,34).

Bold numbers: code requirements			Sensitivity	
	impact	value	normal	increased
Exterior noise	strong	$D_{nt,w}$ [dB]	≥ 40	**≥ 45**
	very strong	$D_{nt,w}$ [dB]	**≥ 45**	≥ 50
Interior noise	average	$D_{nt,w}$ [dB]	**≥ 52**	≥ 57
	strong	$D_{nt,w}$ [dB]	≥ 57	≥ 62
Impact noise	average	$L'_{nT,w}$ [dB]	**≤ 55**	≤ 50
	strong	$L'_{nT,w}$ [dB]	≤ 50	≤ 45

Tab. 4.5 Sound insulation requirements for living spaces according to SIA 181 (Source: SIA 181)

4.8.1 Swiss Wood Frame

According to Renggli AG, the sound insulation value (R'_w-value) of the SWF enclosure is about 50 dB (exterior noise). A comparison with Kolb (Kolb, 1998: 428-435) allows the assumption that the R'_w-value of the floor with hardwood finish flooring is about 63 dB (interior noise), and the $L'_{n,w}$-value (impact noise) is about 50 dB. Sound insulation calculations for differently sized and exposed rooms show that the given SWF construction achieves very good sound insulation values against exterior and interior airborne noise, as well as good insulation values against impact noises (Tab 4.6).

Using the described strategy to reduce the load of floors by replacing the 7cm cement underlay floor with a 2.5cm wood fibreboard (see Chapter 4.5.1), the sound insulation values for airborne and impact noise would decrease slightly, but they would still meet the given benchmarks (Tab. 4.6).

4.8.2 Ribbed Panel System

Pius Schuler AG provides an R'_w-value (exterior noise) for the RPS enclosure of 49 dB as well as an R'_w-value (interior airborne noise) of 53 dB and an $L'_{n,w}$-value (impact noise) of 66 dB for the floor without floor finishing material. A comparison with Kolb (Kolb, 1998: 428-435) shows that the R'_w-value remains at 53 dB for a floor with hardwood finish flooring, whereas the $L'_{n,w}$-value increases to about 62 dB. Sound insulation calculations for differently sized and exposed rooms show that the given RPS construction achieves very good insulation values against exterior noises. The protection against interior (airborne) noise is sufficient, while the impact insulation of floors, particularly for large rooms, is insufficient (Tab 4.6). However, a suspended ceiling (e.g. gypsum board ceiling with flexible connections) could improve the airborne sound insulation by about 12 dB and the impact insulation by about 9 dB. As such, the floor construction of RPS could also achieve good to very good results.

If the 5cm cement underlay floor is replaced with a 2.5cm wood fibreboard (see Chapter 4.5.2), the sound insulation of the floor is insufficient for both airborne and impact noise (Tab 4.6). In this construction, replacing the underlay floor is not recommended or necessitates the application of a suspended ceiling.

4.8.3 Summary

Sound insulation values		SWF		RPS		Goal
	Room size	100 m2	10 m2	100 m2	10 m2	
Enclosure: exterior airborne noise	$D_{nt,w}$ [dB] (1)					≥ 45
1 exterior wall		54	51	54	51	
2 exterior walls		50	47	50	47	
Floor: interior airborne noise	$D_{nt,w}$ [dB] (1)	60	65	50	55	≥ 52
Suspended ceiling		-	-	62	67	
Wood fibreboard underlay floor		53	58	46	51	
Suspended ceiling		-	-	58	63	
Floor: impact noise	$L'_{nT,w}$ [dB] (2)	43	51	55	63	≤55
Suspended ceiling		-	-	45	53	
Wood fibreboard underlay floor		47	55	56	64	
Suspended ceiling		-	-	46	54	

(1) $D_{nt,w}$ is the weighted standard sound level difference where $D_{nt,w} = R'_w - C$ (SIA 181:25)
(2) $L'_{nT,w}$ is the weighted standard impact sound level where $L'_{nT,w} = L'_{n,w} - B$ (SIA 181:34)

Tab. 4.6 Sound level difference and impact sound level of SWF and RPS

While SWF achieves very good sound insulation values for exterior and interior noise as well as for impact noise control, RPS achieves very good values only for exterior sound protection. Improvements in the impact sound insulation are strongly required for small rooms. This is even more important in multi- family residential constructions, where good sound insulation will be necessary to avoid noise disturbances by neighbours, as well as to promote the acceptance of multi-storey buildings in wood.

4.9 Summary

The key findings of the investigation in this section are summarized in Table 4.7. Both systems achieve good to very good results in most aspects of the analysis on efficiency, longevity and health. Generally, potential deficiencies can generally be solved with easily-achievable strategies. An important feature of both systems is the strong dependence on the mechanical ventilation systems.

SWF provides a comparatively sturdy and intricate solution to realise highly energy-efficient wooden houses; this construction principle achieves good to very good scores for most requirements, and where the requirements are not met, there are easy strategies available to improve the system. SWF only faces major difficulties with regard to the position of the vapour barrier and the structural redundancy. However, the application of an installation cavity to protect the air barrier, and the use of hardwood sills to increase the structural redundancy, are improvements that are easy to achieve. As such, the system becomes very adaptable to infrastructure upgrades and allows considerable improvements in the frequency and ease of maintenance work.

RPS provides an elegant solution to achieve highly efficient wooden houses. It relies on a very simple and clear geometry, few layers and few geometrical dependencies, which allows changing single parts without affecting others. However, major criticisms are the low noise-protection values of floors, and the formaldehyde content of the block boards. While the sound insulation may be much improved by using a suspended ceiling, the off-gassing of the block boards is a problem that is faced by most engineered wood products. A decrease in health-harming components (e.g. avoidance of formaldehyde) of the glue employed in block boards is essential for RPS to achieve a top score.

	SWF	RPS
Thermal efficiency	Good	Very good
Thermal insulation depth	22cm	22cm
Enclosure core depth	26.25cm	27.10cm
Weight / enclosure section	58kg (62.5cm)	34kg (63cm)
U-value	0.194 W/m2K	0.169
Minimum insulation for Minergie label	22 cm	19 cm
Vapour and air movement	Good control	Good control
Controlled by	PE-foil	Block board
Diffusion equivalent air layer (s_D)	40-159m	2.8 m
Position in relation to insulation	Warm side	Warm side
Joint connections	Overlapping, taped	Screwed, glued
Vapour diffusion	Not open to vapour diffusion	Open to vapour diffusion
Strategy for open construction	Exterior fibreboard sheathing	-
Characteristics	-	Humidity balancing
Air movement	Air tight	Air tight
Critical issues	Foil perforation	Joints (gap-filling glue)
Improvements	Protection of foil	Durably sealed joints
For example	Installation cavity	Use of additional tapes
Differential movement	Not a problem	Not a problem
Cladding	Detached	Detached
Structure: initial shrinkage / storey height	9.1mm	0.65mm
dimensional changes over time	± 3.91mm	± 1.95mm
Difficult parts	Sheathing joints	Rib-wall joint line
Thermal redundancy	Good	Very good
Increase during planning	Change of system	Same system
Variety of possibilities	Standards	Any level possible
Thermal increase on site	Preferably exterior	Exterior and interior
Structural redundancy	Achievable	Given
Maximum number of storeys	2 - 3	4 - 7
Adaptations	Hardwood sills	Not necessary
Theoretically-achievable storeys	7	-
Maintenance work	Easy to costly	Easy
Cladding	Easy	Easy
Interior shell	Costly	Easy
Difficult parts	Vapour retarder foil	-
Possible strategy	Use of installation cavity	-
Indoor air quality	Good	Critical
Fresh air and air exchange	Mechanical ventilation	Mechanical ventilation
Critical issues	Filters and ducts	Filters and ducts
Positive issues	Safety, avoidance of polls, noise, drafts	Safety, avoidance of polls, noise, drafts
Radiant temperature	Very good	Very good
Out-gassing materials	Avoidable	Inherent
Criticisms	-	Formaldehyde in glue
Noise protection	Good to very good	Fair to good
Exterior noise (enclosure)	47 - 54 dB	47 - 54 dB
Interior noise (floor)	60 - 65 dB	50 - 55 dB
Impact noise (floor)	51 - 43 dB	63 - 53 dB
Improvements	Not necessary	Suspended ceiling
Interior noise (floor)	-	62 - 67 dB
Impact noise (floor)	-	53 - 45 dB

Tab. 4.7 Summary of characteristics of SWF and RP

5. CONCLUSION

This investigation of the local building context in Switzerland and the two new wood building systems, SWF and RPS, has revealed that these systems provide powerful strategies to meet the present needs of the residential building market by using local wood and achieving high thermal efficiency. However, the fact that they consider important environmental strategies per se is not relevant to an assumed success in the local building market. Political decisions and federal subsidies, along with innovations in the wood building industry and the strong marketing strategies of the Minergie label, were necessary to push the new ideas. Today, new wood building systems match the principles of 'Swissness' by relying on high quality and technology standards and modern and individual design, by providing comfort and safety, and by offering financial benefits, high asset values and social status.

The provision of distinctive, high-quality products has been shown to be a good strategy for success in the stagnating residential building market in Switzerland. Following the credo 'quality costs', the new factory-built houses benefit from individual design, high construction quality and precision rather than from mass production, standardisation or major cost reductions. Moreover, the assembly of the factory-built houses in wood in only one or two days evokes a strong fascination and high expectations within the population.

These arguments demonstrate that SWF and RPS are products that skilfully connect present needs of place with people's expectations, as well as with global issues, using present day technology and tools. Furthermore, it is assumed that the two building systems will be able to adapt to the changing local and global needs, even though these investigations consider only a few criteria and reflect only a short time period of an ongoing process. Evidence for this assumption is provided by the facts that the wood building industry in general is heavily involved in research into more sustainable development, and that the two wood building systems in particular need to increase their shares within a tight market and a changing building context. As well, the investigation of key construction principles has shown that the two systems are also capable of adapting to further changes and needs. In doing so, both systems will have a strong potential to achieve a new and successful wood building culture that is locally bound and considers the principles of the global context. This goal will be reached in spite of the considerable idiosyncrasies of the producers, the planning and building process as well as the systems.

Renggli and Schöeb, the advocates of SWF, are carpenters with traditional education. Reliability is a key characteristic of their building system as well as of the planning, production, assembly and finishing processes. In contrast, Deplazes, Germerott and Schuler, the advocates of RPS, are involved in research on wood and wood buildings. With their curiosity to push the envelope they prefer systems with potential for innovation and experiments. Considering the different backgrounds, it is clear that SWF and RPS not only cover different ideas and niches on the supplier side but they also serve different client groups.

Whereas the planning and building process of SWF is script-like determined and supervised by one firm, RPS still relay on the co-operation of teams of building professionals as it is common in Switzerland. And, as different as the planning and building context differs the building system itself. While SWF uses a structural frame of studs and plates that gets its rigidity from a structural sheathing, RPS reverses the system: a thin structural board supported by a set of ribs provides structural and lateral stability. In this way, RPS shifts the idea of a traditional wood building system; loads are no longer conducted through linear members, but through a planar one. In other words, the linear members of SWF that already works as a planar system are physically amalgamated into a planar member. The development of this wood building system in central Europe most probably did not happen accidentally; the details of RPS are too reminiscent of those found in concrete construction. It is also assumed that this construction especially will attract the attention of architects; being skilled in designing in concrete, they value RPS in terms of easy details, grid independency, neglectable shrinkage rates and room-side exposed structural boards. Potentially, RPS may become an attractive alternative to residential buildings in concrete over time, whereas SWF provides a present-day interpretation of the traditional wood building culture.

Despite the simultaneous success stories of the two building systems and the Minergie label, further work should be conducted to investigate critically the dependence of these wood building systems on the Minergie requirements, in terms of mechanical ventilation, enclosure performance and initial building costs. Also, the consumption of wood as well as the potential harmful effects of glue on the health of the inhabitants should be investigated.

In accordance with the need to reduce the heating energy consumed by buildings, the Minergie label not only requires an increased thermal insulation standard of the enclosures, but also limits the ventilation heat loss through fabric and windows by demanding fairly air-tight enclosures and mechanical ventilation with heat recovery. But so far it is not known to what degree mechanical ventilation systems create a risk of health problems; researching the potential harm would provide more certainty on this issue. Furthermore, the certainty that mechanical ventilation systems do not harm the inhabitants' health would increase the credibility of Minergie houses, as well as new wood houses, in terms of health, longevity and asset value. Considering the large number of Minergie houses built over the last few years, this investigation is not only important but also feasible.

Today, Minergie buildings rely on the fact that mechanical ventilation systems are installed, and that they work. Thus, building enclosures are no longer required to take care of the control of the air and vapour exchange between the building and the environment. But longevity of an enclosure is not secured by responding to a defined and unquestioned requirement. The new generation of enclosures should be researched on their potential to work without mechanical ventilation systems, as breathable enclosures do. The investigation of SWF showed that its enclosure is fairly tight to air and vapour movement, although variations of the materials will allow optimisation of this system. While RPS provides an enclosure that is fairly open to vapour diffusion, it is assumed that the block board takes up the migrating vapour. This building system can most probably provide an enclosure that is not dependant on mechanical ventilation systems.

Currently, the initial costs of Minergie buildings are limited to 10% over those of conventional ones, yet the costs for houses vary considerably from less than 400,-- CHF/m^3 to well over 600.-- CHF/m^3. This makes an objective evaluation of the tolerable additional initial building costs very difficult. The investigation and classification of building costs by building parts, such as foundation, primary structure, finishing materials or appliances would help to achieve more transparency; and it could help to optimise the relation between construction quality standards and costs.

In Switzerland, buildings are currently not valued on the consumption of primary energies and resources. On the contrary, the performance of buildings relies on long life cycles and a low consumption of operational energies and resources. However, the consumption of wood could become important for obtaining a maximum market share, as wood is a renewable local building material that is still plentifully available, and an increased use of local wood is still desirable to increase the health of the local forests. These conditions may change with an increase in the demand on wooden buildings; therefore, an optimisation of the amount and the quality of wood used for the construction of buildings might become necessary.

The health problem posed by glues, particularly formaldehyde-containing glues, is inherent to all engineered wood products. Even though most products have reduced the emissions below the requested benchmarks, further research on glues is essential to make RPS a building system that does not impose harm on the inhabitants' health.

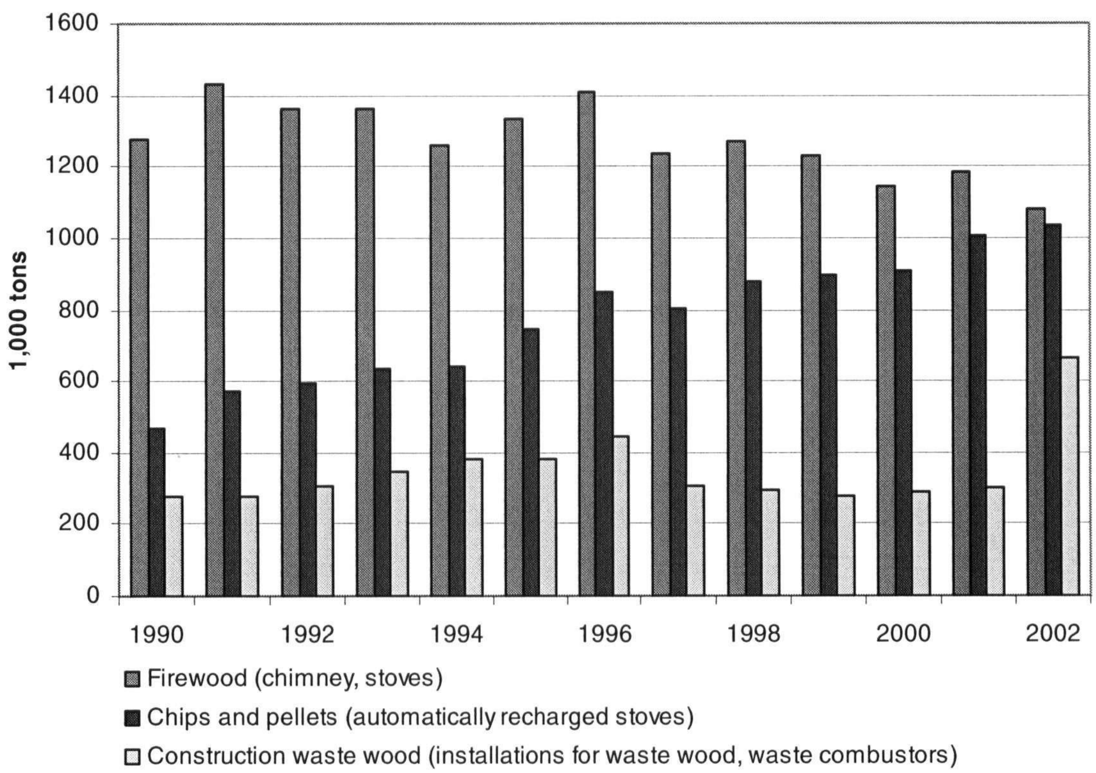
While the investigation and findings of this study are limited to the Swiss context, the structure of the investigation may be applied to the residential building market of any country, where the P-P-P concept will be determined by the specific local key factors of place, people and product, as well as by the locally relevant global factors. As such, the P-P-P concept is not only a tool to evaluate market opportunities from within a country, but house-exporting countries may also gain better insight into the requirements and expectations of the relevant country or region. In general, the success of a building system or building type relies on its ability to adapt to local and global needs, or to conform to the specific glocal factors.

APPENDICIES

Appendix 1 **Use of wood for fuel purposes between 1990 and 2001**
(Source: SAEFL: 2003:108)

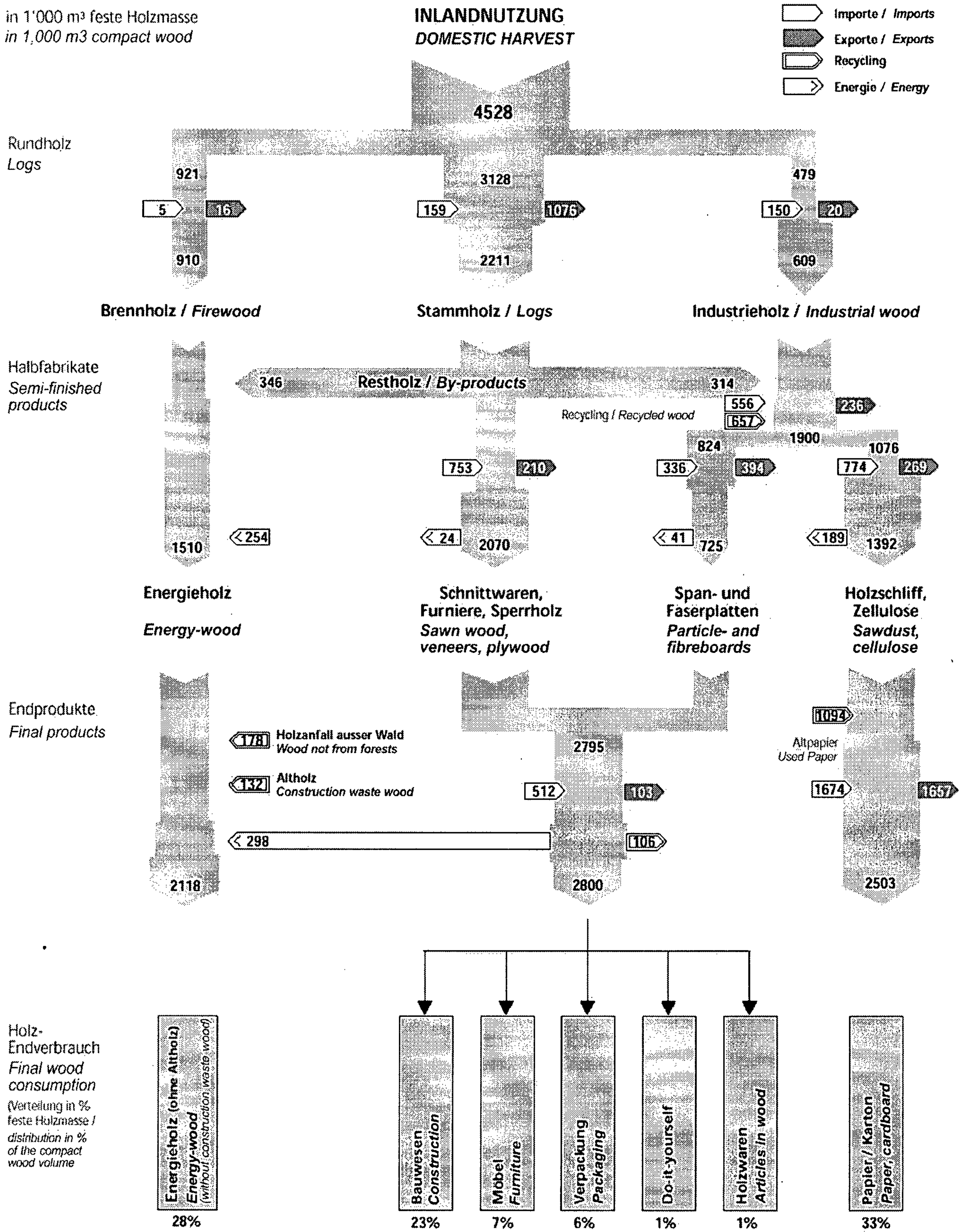
In 2001, about 54% of the wood used for fuel (2.2 million m^3) consisted of firewood for domestic uses (manual recharge) and 46% consisted of wood chips and pellets for residential and non-residential stoves with automatic recharge (compare to Appendix 1). Between 1990 and 2001, the use of firewood slightly decreased from 1.3 to 1.2 million tons, whereas the use of wood chips and pellets more than doubled from 0.47 to 1.0 million tons *(SAEFL, 2003: 108)*. Throughout these years, the use of wood chips and pellets was strongly supported by the Energy2000 program (see also Chapter 2.2.2 Politics).

These numbers do not contain the amount of construction waste wood of around 0.3 million tons that were burnt in waste combustors or specific stoves resulting in district heating energy.



Appendix 2 **Overview of the average wood flow in Switzerland between 1995 and 1999**

(Source: SAEFL: 2003:41, translation by author)



Appendix 3 Ready available timber sections in Switzerland

In Switzerland, construction wood is standardised on a 20 mm grid for widths and depths between 60 mm and 300 mm. Yet, only those square sections marked with an **X** are readily available.

[cm]	6	8	10	12	14	16	18	20	22	24	26	28	30
6	X	X		X									
8		X	X	X	X	X							
10			X	X									
12								X					
14					X	X							
16						X	X	X					
18									X				
20										X			
22									X				
24													
26													
28													
30													

Readily available square sections of timbers in Switzerland. (Source: Natterer, et al., 1994:46)

Appendix 4 Available dimensions of OSB in Switzerland

The square sections marked with an **X** are readily available dimensions of OSB boards in Switzerland.

EUROSTRAND® OSB Standard					12, 15, 18 mm: recommended for wall constructions						
Depths [m] / Dimensions	8	9	10	11	12	15	18	22	25	30	40
1.25 x 2.50	X	X	X	X	X	X	X	X	X	X	X
1.25 x 2.65					X	X					
1.25 x 2.80					X	X	X				
1.25 x 3.00					X	X					
1.25 x 5.00						X	X	X			
2.07 x 2.80					X	X	X	X			
2.50 x 5.00					X						
EUROSTRAND® OSB (Tongue&Groove)					18, 22 mm: recommended for subfloors (spaced at max. 65 cm on centre						
2.50 x 1.25						X	X	X	X		
2.50 x 6.75						X	X	X	X		

Readily available OSB boards in Switzerland.
(Source: Available: http://www.baudas.de/52.html [May 12, 2004].

Appendix 5 Technical data of block boards produced by Pius Schuler AG

<table>
<tr><td colspan="31">Material and surface treatment</td></tr>
<tr><td>Type</td><td colspan="30">1-, 3-, and 5-layered block boards (other surfaces on demand)</td></tr>
<tr><td>Surface
Material</td><td colspan="6">standard</td><td colspan="6">industry</td><td colspan="6">lath</td><td colspan="6">board</td><td colspan="6">veneer</td></tr>
<tr><td>Fir</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td></tr>
<tr><td>Norway Spruce</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td></tr>
<tr><td>Pine</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td><td colspan="6">x</td></tr>
<tr><td colspan="31">Dimensions</td></tr>
<tr><td>Type
Dimensions</td><td colspan="15">1-layered block boards (ribs)
economic spans < 5.0 – 5.5 m</td><td colspan="15">3- / 5- layered block boards
economic spans < 4.5 – 5.5 m</td></tr>
<tr><td>depth [mm]</td><td colspan="5">8</td><td colspan="5">to</td><td colspan="5">220</td><td colspan="5">24</td><td colspan="5">to</td><td colspan="5">140</td></tr>
<tr><td>width [mm]</td><td colspan="5">75</td><td colspan="5">to</td><td colspan="5">800</td><td colspan="5">-</td><td colspan="5">up to</td><td colspan="5">2,180</td></tr>
<tr><td>length [mm]</td><td colspan="5"></td><td colspan="5">up to</td><td colspan="5">8,000</td><td colspan="5"></td><td colspan="5">up to</td><td colspan="5">7,200</td></tr>
<tr><td colspan="31">Characteristics</td></tr>
<tr><td rowspan="2">Block boards</td><td colspan="10">Moisture content</td><td colspan="10">Glue</td><td colspan="10">Emission class</td></tr>
<tr><td colspan="10">10% ± 2%</td><td colspan="10">Urea (UF)</td><td colspan="10">E1</td></tr>
</table>

Technical data of block boards produced by the Pius Schuler AG (Source: Available: http://www.pius-schuler.ch [November 18, 2003]).

Appendix 6 Stress calculation of SWF and RPS

Swiss wood frame

Resulting loads:	Snow load (up to 800 m o.s.l.)		1 kN/m^2
	Life load / storey	≈	2 kN/m^2
	Roof	≈	2.5 kN/m^2
	Wall	≈	1.3 kN/section
	Floor	≈	2.66 kN/m^2
Effective floor area:	0.625 m x 2.2 m	=	1.375 m^2

A) Vertical loads relevant for stresses against the grain

Residential building	1 storey =	2.5 + 1.375 x 8.0	≈	13.5 kN/stud
	2 storeys =	5.0 + 1.375 x 12.5	≈	22.2 kN/stud
	3 storeys =	7.5 + 1.375 x 17.0	≈	30.9 kN/stud
	4 storeys =	10.0 + 1.375 x 21.5	≈	39.6 kN/stud
	5 storeys =	12.5 + 1.375 x 26.0	≈	48.3 kN/stud
	6 storeys =	15.0 + 1.375 x 30.5	≈	56.9 kN/stud
	7 storeys =	17.5 + 1.375 x 35.0	≈	65.6 kN/stud
	8 storeys =	20.0 + 1.375 x 39.5	≈	74.3 kN/stud

B) Maximal buckling loads of the studs

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{ba3}{12}}{ab}} = \sqrt{\frac{a2}{12}} = \frac{a}{\sqrt{12}} = \frac{16}{\sqrt{12}} = 46 \text{ mm}$$

Due to the structural sheathing, the depth (a) is relevant for the calculation of λ_K.

$$\lambda_K = \frac{l_K}{i} = \frac{2{,}400}{46} = 52$$

$$\kappa_K = 1.2 - 0.009 \ \lambda_K = 0.732$$

$$\overline{\sigma}_{K\text{II}} = \kappa_K \ \sigma_{d\perp} \times 1 \times 1 = 0.732 \times 8.5 = 6.22 \text{ N/mm}^2$$

$$F_{K\text{II}} = 6.22 \text{ N/mm}^2 \times 12{,}800 = 79{,}616 \text{ N} = 79.6 \text{ kN}$$

Ribbed panel system

Resulting loads:	Snow load (up to 800 m o.s.l.)		1 kN/m^2
	Life load / storey	≈	2 kN/m^2
	Roof	≈	2 kN/m^2
	Wall	≈	0.76 kN/section
	Floor	≈	1.87 kN/m^2
Effective floor area:	0.63 m x 2.2 m	=	1.386 m^2

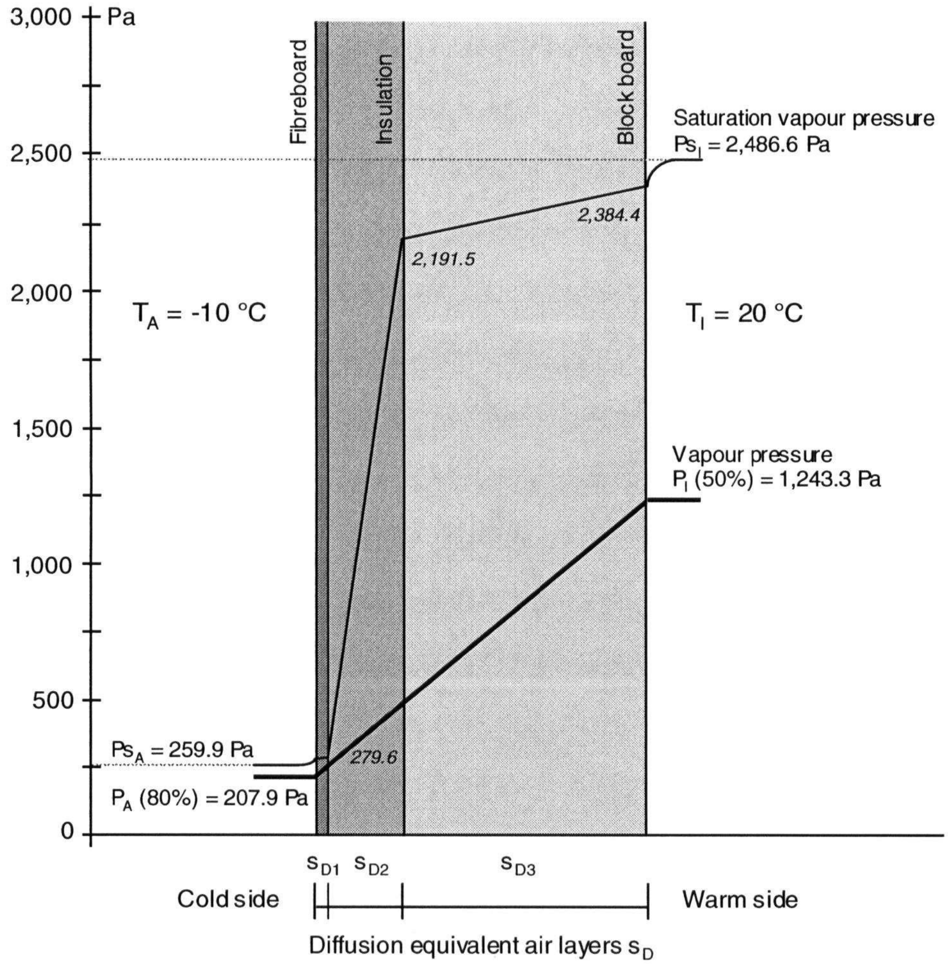
A) Vertical loads relevant for stresses against the grain:

Residential building	1 storey =	0 + 1.386 x 3.0	≈	4.16 kN/section	0.189 N/mm^2
	2 storeys =	0.76 + 1.386 x 6.87	≈	10.29 kN/section	0.466 N/mm^2
	3 storeys =	1.53 + 1.386 x 10.74	≈	16.41 kN/section	0.744 N/mm^2
	4 storeys =	2.29 + 1.386 x 14.61	≈	22.54 kN/section	1.022 N/mm^2
	5 storeys =	3.06 + 1.386 x 18.48	≈	28.67 kN/section	1.300 N/mm^2
	6 storeys =	3.82 + 1.386 x 22.35	≈	34.80 kN/section	1.578 N/mm^2
	7 storeys =	4.58 + 1.386 x 26.22	≈	40.93 kN/section	1.856 N/mm^2
	8 storeys =	5.35 + 1.386 x 30.09	≈	47.05 kN/section	2.134 N/mm^2
	9 storeys =	6.11 + 1.386 x 33.96	≈	53.18 kN/section	2.412 N/mm^2
	10 storeys =	6.88 + 1.386 x 37.83	≈	59.31 kN/section	2.690 N/mm^2
	11 storeys =	7.64 + 1.386 x 41.70	≈	65.44 kN/section	2.968 N/mm^2
	12 storeys =	8.41 + 1.386 x 45.57	≈	71.57 kN/section	3.246 N/mm^2
	13 storeys =	9.17 + 1.386 x 49.44	≈	77.69 kN/section	3.524 N/mm^2
	14 storeys =	9.93 + 1.386 x 53.31	≈	83.82 kN/section	3.801 N/mm^2
	15 storeys =	10.7 + 1.386 x 57.18	≈	89.95 kN/section	4.079 N/mm^2

B) Maximal buckling load of the wall element (Pius Schuler AG, 2004)

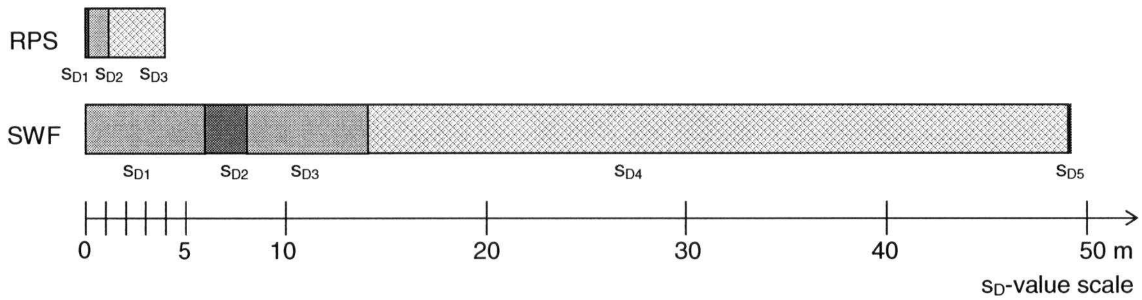
Enclosure with	20 cm rib depth	140 kN/m	88.2 kN/section	
	24 cm rib depth	150 kN/m	94.5 kN/section	
	22 cm rib depth	ca. 145 kN/m	91.35 kN/section	4.14 N/mm^2

Appendix 7 Condensation within the RPS



Vapour pressure within RPS enclosure: Calculation according to Keller, 2004: Building physics: vapour pressure in enclosures)

Appendix 8 Comparison of diffusion equivalent air layers of SWF and RPS[6]



System	s_D-layer depth		material	layer depth
RPS	s_{D1}	0.16 m	Wood fibreboard sheathing bitumised	16 mm
	s_{D2}	0.97 m	Ribs with mineral fibre insulation	220 mm
	s_{D3}	2.80 m	Block board	35 mm
total	$\mathbf{s_D}$	**3.93 m**	Enclosure depth	271 mm
SWF	s_{D1}	6.00 m	OSB sheathing	15 mm
	s_{D2}	2.11 m	Studs with mineral fibre insulation	220 mm
	s_{D3}	6.00 m	OSB sheathing	15 mm
	s_{D4}	35.00 m	Vapour barrier (PE-foil)	0.2 mm
	s_{D5}	0.09 m	Gypsum board	12.5 mm
total	$\mathbf{s_D}$	**49.20 m**	Enclosure depth	262.7 mm

[6] Diffusion equivalent air layers of RPS correspond to the ones shown in Appendix 7.

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