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Pekka Leppänen, Sakari Pulakka, Mikko Saari &
Hannu Viitanen

Life-cycle-cost optimised wooden multi-storey apartment building

Nordic Wood

TECHNICAL RESEARCH CENTRE OF FINLAND

ESPOO 1999

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Nordic Wood, Phase 2, Project P-2
Final Report

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Cover photo

Wooden multi-storey apartment house Porvoon Aleksanterinkatu 29, Porvoo, Finland, under construction. Architect Aarne Launos. Contractor Porvoon Puurakennus Oy. The Kerava pilot building (Chapter 6) will be made by the same architect and contractor. Photographed by Pekka Leppänen.

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Abstract

The aim of this project was to develop a concept of a wooden multi-storey apartment building which is competitive with equivalent buildings made of other materials. The point of view has been that of the house owner, the investor. He is interested not only in the investment costs but also in the operating costs as well as in the resale price of the building. In this research, the life span of the building is limited to 50 years.

The wooden multi-storey apartment building has to be not only competitive to build but especially clearly cheaper to operate. The Finnish statistics show that about 2/3 of the operating costs come from energy, management, water and annual repairs. The major components, about 3/4 of the annual repairs are exterior surfaces, mechanical systems and interior surfaces and structures.

Thus, the research has concentrated on developing and analyse long-lasting wooden facades and life-cycle cost optimised envelope structures. Simplifying and decreasing the number of various components has proved in other industries to be an effective way of decreasing the investment and operating costs, and this is true also in the construction industry. And last but not least, the overall quality of the wooden multi-storey apartment building should transmit a positive image to the owner and the tenants of a better product than that of the competitors.

The results of this research work show that the main properties of a life-cycle-cost optimised wooden multi-storey apartment building are as follows:

- The investment costs of a wooden multi-storey low-energy apartment building are some 4 % higher than those of the present building practise. Due to lower energy costs, the payback time of extra investment costs is only 15 years when calculated using present energy prices

- The "high performance" facade is more profitable than a "normal" one. There are various alternatives for "high performance" facades. The main factor for the durability of the wooden facade is "wood-paint-structure-environment-manufacture". When all these factors are optimised, a long lifetime can be achieved

- The improved thermal insulation capacity of the envelope allows simplified mechanical (HVAC) and electrical systems. This results in a more effective use of space, lower investment and running costs

- The danger of water leakages decreases when the number of water system components decreases. The remaining components are gathered up in watertight units as far as possible and installed so that a possible leakage can be rapidly and easily noticed.

These results will be tested in a pilothouse project to be built as a separate project in Kerava. The state of this project in September 1999 is presented in Chapter 6.

Preface

This paper is the final report of the sub project P-2 "Life-cycle cost optimised wooden multi-storey apartment building" in the Nordic Wood project "Trähus i flera våningar", Phase 2.

Nordic Wood is an R&D programme of the Nordic timber industry with an aim to promote the use of timber as building material. Nordic Wood was established by Nordisk Industrifond.

The Nordic Wood programme is financed by Nordic timber industry, Nordisk Industrifond and by the following national foundations: Ehrvervsfremme Styrelsen from Denmark, Tekes from Finland, Islands Forskningsråd from Iceland, Norges Forskningsråd from Norway and NUTEK from Sweden.

In the Nordic Wood project "Trähus i flera våningar", Phase 2, the following organisations have participated:

Södra Timber AB from Sweden
Skanska AB from Sweden
NCC AB from Sweden
Ekologi Byggarna i Östergötland from Sweden
Broman Arkitektkontor from Sweden
COWI from Denmark
Block Watne from Norway
Finnish Wood Research Ltd from Finland.

The members of the leading group of the Nordic Wood project are:

Thomas Thörnquist, Södra Timber AB (chairman)
Björn Aage Lunde, Block Watne
Gunnar Stone, Skanska AB
Keijo Kolu, Schauman Wood Oy
Hans Jørgen Larsen, SBI, Denmark
Lars Söderlind, NCC AB.

The following R&D institutes have participated in the Nordic Wood project:

Lunds Tekniska Högskola
LTH, Avd. för Bärande Konstruktioner, Sweden
Lunds Tekniska Högskola

LTH; Avd. för Teknisk Akustik, Sweden
Träinformation, Stockholm, Sweden
Norges Byggeforskningsinstitut, NBI, Norway
Teknologisk Institut, Denmark
Oulu University, Finland
VTT Building Technology, Finland

This sub project P-2 has concentrated on developing and analysing the concept of the life-cycle-costs optimised wooden multi-storey apartment building. The target has been to offer a competitive wooden alternative to the investors. Structural and mechanical components for a pilothouse have also been developed in co-operation with the architect, the house owner and the contracting company in question.

This sub project P-2 " Life-cycle cost optimised wooden multi-storey apartment house" was done in the Finnish Wood Research Ltd and in the VTT Building Technology. The project P-2 leader was Mr. Pekka Nurro of the Finnish Wood Research Ltd. The project group members from VTT Building Technology were Mr. Erkki Kokko, Pekka Leppänen, Sakari Pulakka, Mikko Saari and Hannu Viitanen.

The project group presents its kind thank to the Nordic Wood Leading Group members for their support, comments and encouragement in various phases of this research. A special word of praise must go to the representants of those companies and organisations which have participated in this project for their valuable contributions.

Espoo, Finland, September 1999

The project group

Contents

1. Introduction

1.1 Background

In everyday construction one has to make evaluations and decisions dealing with the life-cycle costs of for example a solution or a component, on the basis of ones own personal experiences and views. These practical choices are usually not based on research results or objective comparison of various alternatives.

The wooden multi-storey apartment buildings developed in recent years in the Nordic countries are new building types. There still is limited experience in design, construction and the use of these buildings.

In addition, there still are some obstacles for wooden multi-storey buildings. A common prejudice is that they are profitable to build but expensive to maintain. Potential investors often consider the wooden multi-storey building as a risky investment. An important task for timber research and development efforts is to remove the negative feelings among potential investors towards timber as a building material.

1.2 Method

The method of this research work was to collect and analyse the present knowledge on the life-cycle costs, on wooden facades and on structures and mechanical systems of recently built wooden multi-storey apartment buildings. Then, decisive factors and their influence mechanism have been analysed and finally, solutions to life-cycle costs optimised wooden multi-storey apartment buildings will be presented.

To confirm the theorethical results a wooden multi-storey apartment building will be designed, built and monitored as a separate project in Kerava, Finland. The aim is to apply the results of the research and development to a pilot building and to monitore the result. This will verify the set targets and indicate the qualities of wooden multi-storey apartment buildings. What is more, a real high-quality wooden multi-storey apartment building is the best and most efficient way to convince the potential clients and the media about the qualities of this product.

1.3 Targets

The general target of this project is to convince potential building investors, on the basis of the results from this research work, to invest in wooden multi-storey apartment buildings. This would promote the use of Nordic timber in the building construction and establish wooden multi-storey apartment buildings in the Nordic countries, which is the main aim of Nordic Wood, Trähus i flera våningar, Phase 2.

It was decided that a comparison with concrete buildings will not be made as was originally planned in the project plan. It became clear that the investors were only interested in the next 50 years at the most. Both concrete, wooden and steel building will stand this period. All these materials and products made of these materials are intensively developed by the industry in question. Thus for the wood industry, it is most important to concentrate on the development of their own competitive product, the life-cycle-cost optimised wooden multi-storey apartment building.

The cost share of wooden components in the Finnish wooden multi-storey apartment houses is only about 20%. All other costs including taxes etc. are the same as in concrete buildings. Therefore both the product and the construction process need to be developed to be competitive in construction costs.

To optimise the life-cycle costs, effective methods to decrease operating costs need to be found. An efficient way to decrease the life-cycle costs is to simplify and reduce the number of structural, mechanical and electrical components.

Thus, the detailed targets in this research were

- To present an overall view of the state of the art of life-cycle-cost analysis methods.
- To analyse the decisive single factors and their influence mechanism on the life-cycle costs.
- To develop the basis for a life-cycle-cost calculation method for multi-storey apartment buildings.
- To collect and analyse the present knowledge on wooden facades.
- To present solutions for a "high performance" wooden facade for multi-storey apartment building.
- To develop and present system (architectural, structural, mechanical, electrical) level improvements of the wooden multi-storey apartment building on the basis of the research work made and of the life-cycle cost analyses.

The targets of the Kerava pilot building, as a separate project, are

- To test the life-cycle cost analysis method.
- To combine theoretical development with practical construction.

- To develop solutions and components for the pilot building in accordance with the analyses made.
- To demonstrate the research results as a pilot building.
- To monitor the pilot building to verify the targets set.
- To report the results
- To convince potential investors and the media.

1.4 Organisation

- The project group consists of
  - Elanto Oy, commercial trading organisation and a prominent land and real estate owner; the land owner in the Kerava pilot building project
  - Asuntosäätiö, building owner and non-profit developer, the builder of the garden city Tapiola; the owner of the Kerava pilot building project
  - Porvoon Puurakennus Oy, a timber building contractor; the contractor of the Kerava pilot building project
  - Finnish Wood Research Ltd, promoter of research and development of the Finnish wood industry; the P-2 project co-ordinator
  - VTT Building Technology, research organisation.

- The designers of the Kerava pilot building are
  - Launos Oy, architectural design
  - Narmaplan Oy, structural design
  - Åke Jokela Oy, mechanical design
  - Karawatski Oy, electrical design.

1.5 References to the other recent research projects on the area

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- Life-cycle analysis of surface treatments of the wooden facades; VTT Building Technology.
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- Prediction of the service life of building materials and products, wooden facades; VTT Building Technology.

2. Life-cycle cost analyses

2.1 State of art

The buildings are long-sighted investments whose life-cycle costs (acquisition, renovation, maintenance and waste as well as pull down costs) are mainly fixed already on early stages of planning and design. Unfortunately, the planning and control of life-cycle costs has been inadequate, because it has not been claimed and because there has been neither cost nor consumption files or tools for that. However, the lack of calculations has been visible in highly unpredicted maintenance and renovation costs. The facility owners have neither been able to analyse the effects of life-cycle cost on the value nor on the profits of the buildings.

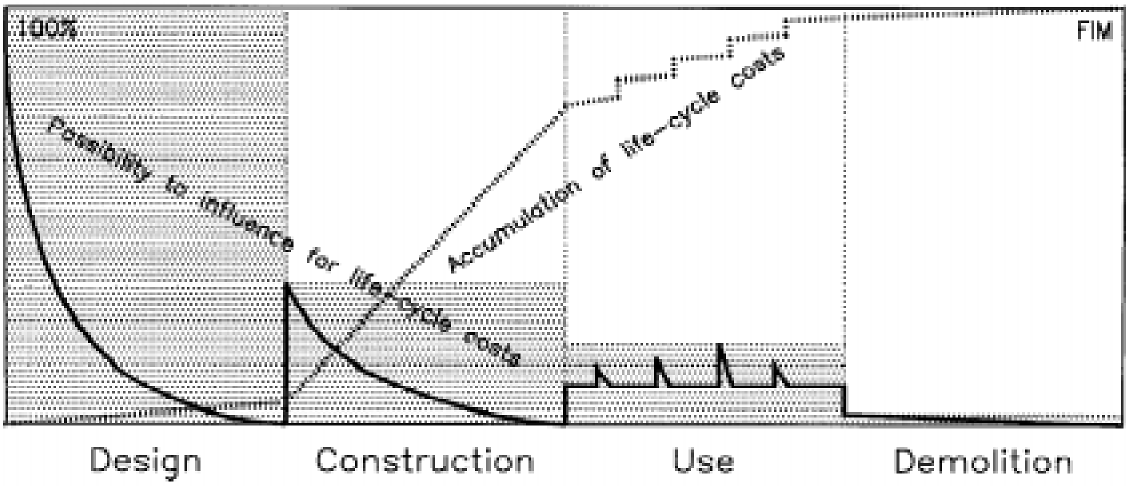

Figure 1. Major part of life-cycle costs are defined in early stages of design.

In this project, international life-cycle models have been charted by of checking relevant literature, which proved that there are no models in permanent use, even though analyses concerning individual building projects have been carried out. As an only general aim has been to separate the costs caused by the user and the owner.

The international needs for life-cycle models are as follows:

- a standard for a life-cycle costs model should be developed and utilized in co-operation with different countries world-wide
- the model should cover spaces and technical systems
- the analysis should also include the analysis of the most important environmental effects caused by the chosen technical systems

- the model must be independent of the information technology used in different countries and companies.

For this reason a new subcommittee (SC14) of ISO TC59 ”Building Construction” has been established. SC14 is working at present on six documents all related to design life as parts of ISO 15686 /1/. One of six elements will be life cycle costing. The phases of the life cycle are suggested to be as follows:

- acquisition
- use and maintenance
- renewal
- adaptation and disposal.

The service life of buildings may also be divided in three life-times /2/:

- functional life-time (for example 20…25 years concerning residential buildings)
- technical life-time (for example 75…100 years)
- economic life-time (for example about 50 years)

At VTT Building Technology there are going on efforts to set reference information, tools, abstracts and files to the world wide web (www) including also some life cycle information within the so called BENCHNET-project /3/.

2.2 Estimate of life cycle costs

Any analysis of an investment should include both initial and ongoing costs and returns over the period of the investment. Such an analysis allows investors to compare different options and decide which offers the best return for their particular circumstances over the life time of the investment. Construction works generally require a considerable initial capital investment and have lifetimes of 20…over 100 years. As a result, building designs are often selected on the basis of the lowest initial acquisition cost, provided that certain functional and aesthetic parameters are met /1/.

The overall concept of life-cycle costs is simple; all the costs associated with the design, construction, use, maintenance and disposal of the building are estimated or calculated over a definited period. This period may be the design life of the building or a shorter period. The costs are then adjusted to take into account interest rates and, in some cases, inflation, to bring the whole life cost over the definited period into today’s currency. This then allows a comparison to be made between different design options. Life cycle costing can be carried out over the whole design life of the building, or over a finite period of the design life (the period of analysis) /1/.

For the analyses, values for the costs can be derived from:
- direct estimation from known costs and components
- historical data from typical applications
- models based on expected performance, averages etc.
- best guesses of the future trends in technology, market and application.

Input parameters are e.g:
- acquisition costs
- operating costs
- maintenance costs
- service life data
- period of analysis
- external costs and savings data
- residual/disposal values/costs
- economic parameters
- discount and inflation rates
- taxes and regulatory expenses
- intangibles
- environmental impacts.

The degree of confidence in the results of life-cycle-costs analysis depends on the quantity and quality of the data used as input into the analysis. For the acquisition phase, cost figures for various options can usually be estimated with some degree of accuracy since they are derived from current costs. Estimates of operating costs are also reliable for the new structure but become less certain as the time span increases due to uncertainties in energy costs, labour and regulatory changes (e.g. environmental legislation).

The use of very long periods of analysis should be avoided since the use of times in excess of about 30 years trends to result in costs beyond this becoming negligible in many cases /1/.

Life-cycle costing can be applied from the very early need analysis design stages to the detailed design of building components. Life-cycle costing may roughly be divided in the following three design stages:
- analysis of functions, setting quality targets and level of energy consumption on the building level
- defining the building, its architecture, quality and functional targets on the system level
- defining building components.

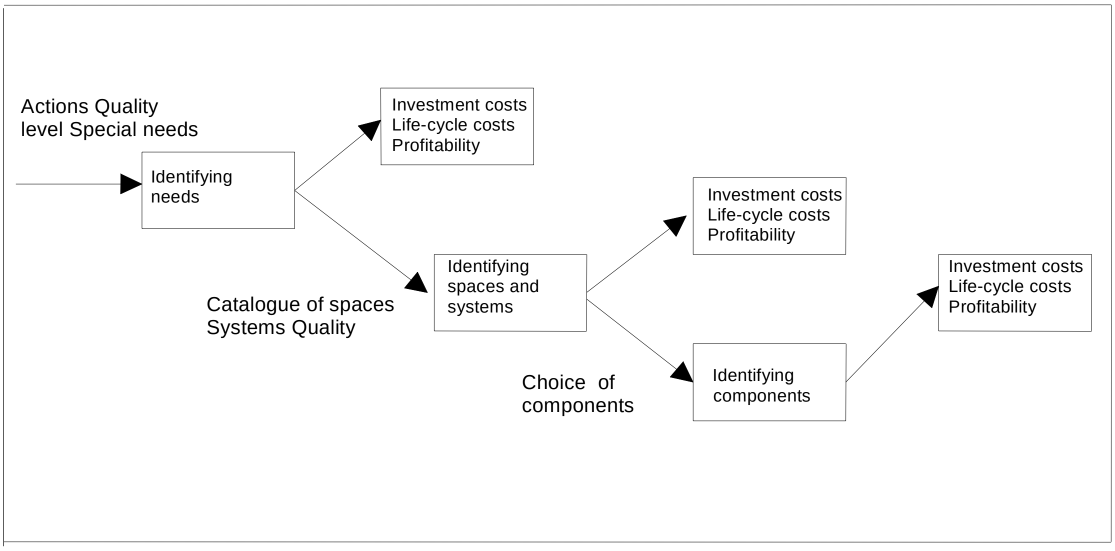

Figure 2. Iterative life-cycle costing on different stages of building design. Identifying needs includes aimed total areas of actions (for example office, dwellings, refreshing…), quality level (for example extremely high, high, ordinary, low) and certain special needs (for example level of energy consumption, needs for modification…). Identifying spaces and systems includes cataloque of spaces, systems (for example ventilations system…) and inner quality. Identifying components is the most complex and the most exact level of costing. Investment costs and life-cycle-costs are divided on systems on the second level and on components on the third level. Profitability is important when calculating the economy of the whole project and for example pay back time of certain special needs.

2.3 Life-cycle costs of multi-storey apartment building

The life cycle costs of an ordinary multi-storey apartment building in Finland are as follows:

- acquisition costs (planning, construction, funding) 60…70%
- maintenance costs 25…30%
- renovation costs 5…10%.

The share of acquisiton costs dominates in the life-cycle-costs. In a wooden multi-storey apartment building, the share of wooden products in the life-cycle costs is only about 10…15% in the life-cycle costs per year. The share of energy costs is about 10%. The need for renovation is dependent of the durability of the building components.

The most effective ways to influence life-cycle costs are as follows:

- using typed components and advanced networking of companies which manufacture or sell those components
- choosing as wide units of spaces as possible
- choosing as simple shape of building as possible
- ensuring the easy buildability of the building.

It is not reasonable to choose low quality concerning functionality, healthiness, accessibility or safety in order to lower life cycle costs.

There are two calculation methods on the following levels:

- the system level estimate (investment FIM/brm^2 and life-cycle cost per year FIM/br m^2/y)
- the component level estimate (FIM/br m^2 and FIM/br m^2/y).

The system level estimate is utilized in pre-planning. Input information is e.g.

- the building area
- the shape of the building
- the level of inner quality
- the level of energy consumption
- the amounts of all or certain systems
- index level (date of estimate).

The component level estimate is applied on the planning level. As input information there are the amounts of all building components. Both calculation methods give as a result estimates of capital and life-cycle-costs per year. The cases studied in this research have been carried out on system level.

2.4 Major components of operating costs

The financial statements statistics of housing corporations collected by Statistics Finland are compiled on the basis of financial statements of housing companies and government-subsidised rental housing. The primary purpose of the statistics is to measure the expenditure of housing corporations and to examine what the costs consist of.

The government-subsidised rental houses included in this statistics are so-called ordinary rental houses. The housing for students, the elderly and other special groups are excluded.

In 1987-97 there has been an annual rise of about 5% in the maintenance costs concerning both housing companies and government-subsidised rental housing /5/. There is some difference in the maintenance costs between housing companies and rental dwellings. This is explained by the different ways of maintaining and repairing the houses.

In housing companies, costs related to personnel are lower because the residents often do part of the work themselves. Repair costs in the rental houses are higher because the repairs made in the flats are included in the rents, whereas in housing companies, the shareholders themselves pay for the repairs made in the flats. In addition, water consumption is higher in rental dwellings.

Figure 3 reveals the most important components of the maintenance costs of multi-storey apartment buildings. About 2/3 of all operating costs fall into the following four categories:

– Space heating and domestic hot water	29%
– House management, taxes, insurance, etc.	17%
– Water and sewage	15%
– Repairs	14%.

Consequently, in the planning and construction of a life-cycle-costs optimised house, one needs to focus on decreasing these costs. There are various possibilities:

- to decrease space heating in an economical way. Here a low-energy house seems to be the solution
- "the user pays" is an effective method to decrease the need of domestic hot water
- taxes and insurance are mostly based on laws. The increase of technical measuring systems in the house might lower house management costs
- the user pays" is an effective method also to reduce water consumption and sewage
- there are various possibilities to decrease the need of repairs. Firstly, don't build anything you do not need. Secondary, when you build, analyse the alternatives and choose life-cycle-costs optimised solutions.

The major components of the repair costs are presented in Figure 4.

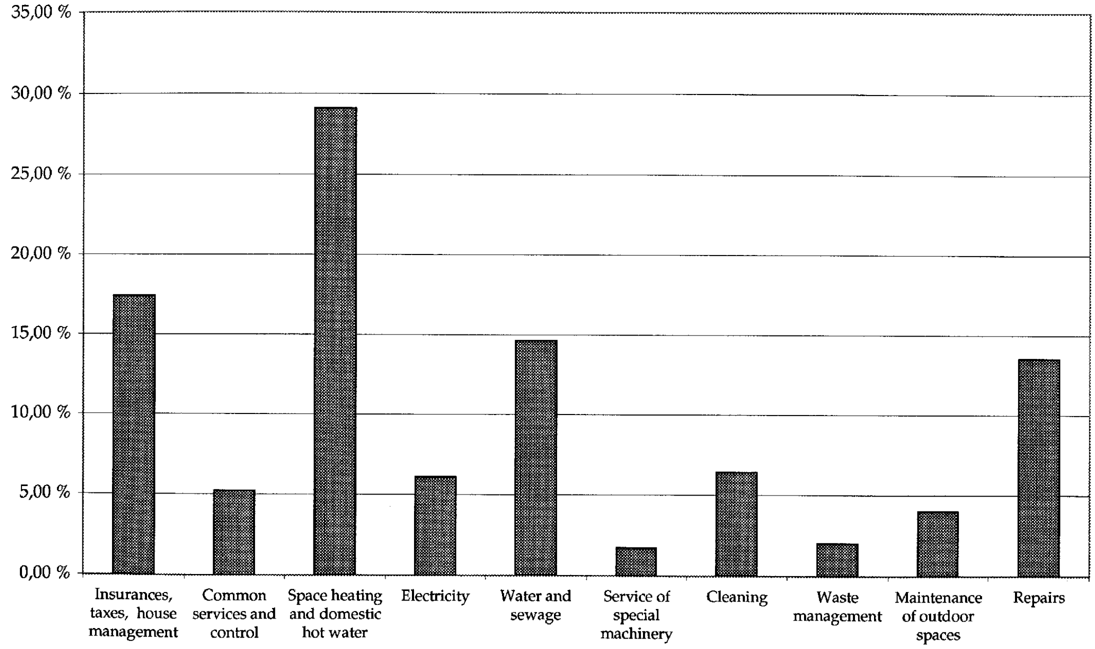

Figure 3. The components of maintenance costs in Finnish multi-storey apartment houses /4/, /5/.

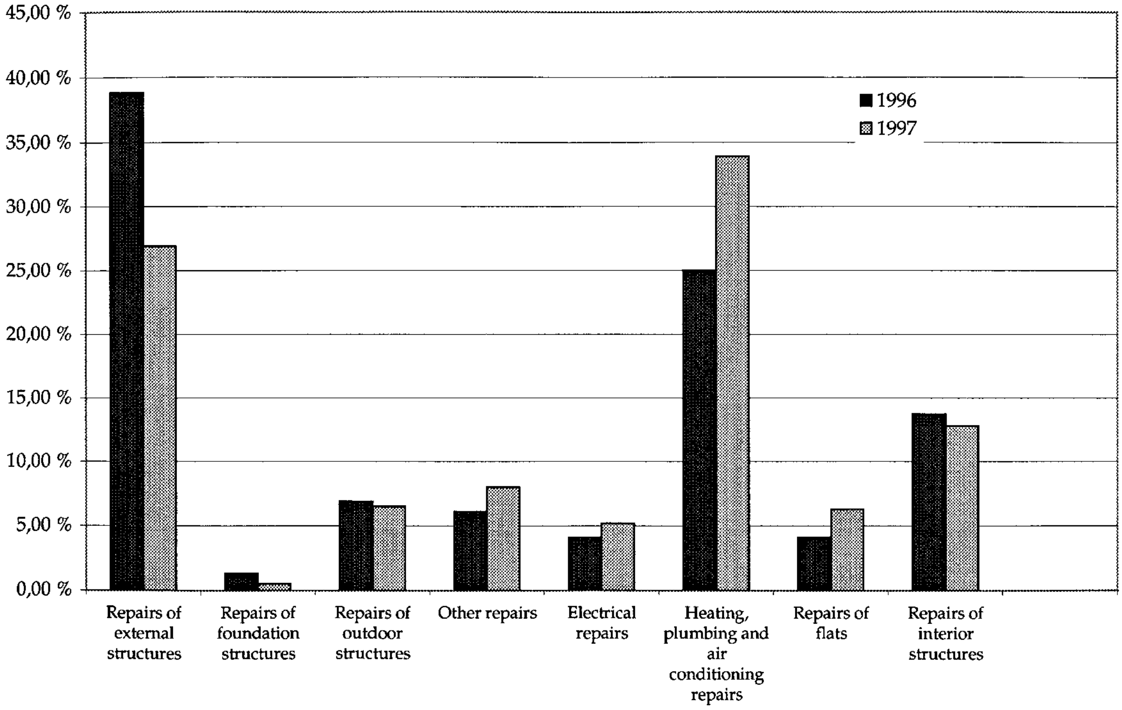

Figure 4. The components of the annual repairs in the Finnish housing companies in 1996 and 1997 /4/, /5/.

There are some changes between 1996 and 1997 but about 3/4 of all repair costs fall into the following categories:

– Repairs on facades and other exterior surfaces	27–39%
– Repairs on mechanical systems	25–34%
– Repairs on interior surfaces and structures	13–14%

Thus, emphasis will be put on the components mentioned above when attempting to decrease the operating costs.

2.5 Life-cycle costs of a multi-storey apartment building having either present type or low-energy envelope

The reference building (having present type envelope) in this comparison is Porvoon Aleksanterinkatu 29, a wooden multi-storey apartment building, built in 1999 by Porvoon Puurakennus Oy.

In the low-energy alternative, the thermal insulation capacity has been improved. The increase of thermal insulation thickness is at walls 97 mm, on the roof 250 mm and at the floor 100 mm. The U value of the windows is improved from U=1,8 W/m^{2}K to U=0,8 W/m^{2}K. The low energy version has dwelling based ventilation heating system with effective heat recovery.

In this analysis, only those systems which are made in alternative ways have been chosen for comparison. The comparison has effects only on systems presented in flat letters in Figure 5a. Those components cover about 20% of the capital costs. Thus, the major part of the costs is fixed. The cost information used is mostly information defined by Porvoon Puurakennus Oy.

The maintenance costs have mainly been declared by using general sources. The energy costs have been calculated with ”WIN-ETANA”, a tool developed by VTT Building Technology.

The output information contains estimates of capital costs (FIM/brm^2) and life-cycle-costs per year (FIM/brm^2/y). The time period is 50 years which well enough describes the cash flows during the service life of buildings.

	FIM/brm^2	**FIM/brm^2/y**
B1. BUILDUP COST	**40**	**2**
B2. STRUCTURAL WORKS	**2 185**	**142**
Site	200	19
Structures		
Ground floor	25	1
Slabs	250	10
External walls	**380**	**18**
- extra cost of the low-energy building	*80*	*4*
Upper floor	**45**	**2**
- extra cost of the low-energy building	*13*	*1*
Windows	**120**	**6**
- extra cost of the low-energy building	*12*	*1*
External doors	40	3
Internal walls and doors	315	19
Other structures	280	24
- extra cost of the low-energy building	*6*	*0,5*
Inner finishes	300	20
Furniture, vehicles	230	20
B3. HVAC	**350**	**20**
Space heating	**65**	**4**
Ventilation	**55**	**3**
- extra cost of the low-energy building	*10*	*0,5*
Water supply	**230**	**13**
B4. ELECTRICAL WORKS	**170**	**13**
SUMMARY B1-B4 (acquisition and renovation)	**2 745**	**177**
- extra cost of the low-energy building	*121*	*7*
C. MAINTENANCE		**115**
Administration		20
General care		6
Cleaning		7
Waste service		2
Outer areas		4
Heating		**34**
- cost savings of the low-energy building		*-18*
Electricity		**23**
- extra cost of the low-energy building		*4*
Water supply		**17**
Vehicle services		**2**
SUMMARY B1 - C	**2745**	**292**
- extra cost of the low-energy building	*121*	*7*
- cost savings of the low-energy building		*-14*
D. General works and VAT	**1100**	**80**
- extra cost of the low-energy building	*40*	*3*
SUMMARY B1-D	**3845**	**372**
- extra cost of the low-energy building	*161*	*10*
- cost savings of the low-energy building		*-14*

Figure 5a. The acquisition and life-cycle-costs per year of the reference building and the low-energy building (cost level 8/1999).

In this cost analysis, the life-cycle-costs and profitability calculations cover the whole building. The result of the cost analysis is presented in Figure 5a and 5b.

According to one pilot-project (Lempäälä Teräslempo) the dwelling based ventilation heating with effective heat recovery means about 80…100 FIM/brm^2 additional acquisition costs compared to a traditional HVAC system with radiators but leads to 70…80 FIM/brm^2 savings in acquisition costs because the radiators are not needed. So, alltogether the dwelling based ventilation heating with effective heat recovery system means about 15 FIM/brm^2 extra acquisition costs. The life-cycle costs per year increase 2 FIM/brm^2/y.

The extra acquisition costs at the low-energy building are a total of 161 FIM/brm^2, which means about 4% extra building costs. The life-cycle-costs per year will increase 10 FIM/brm^2/y.

The total savings per year due to lower energy consumption are approximately 14 FIM/brm^2/y. The pay back time of extra building costs of low-energy building is therefore about 15 years.

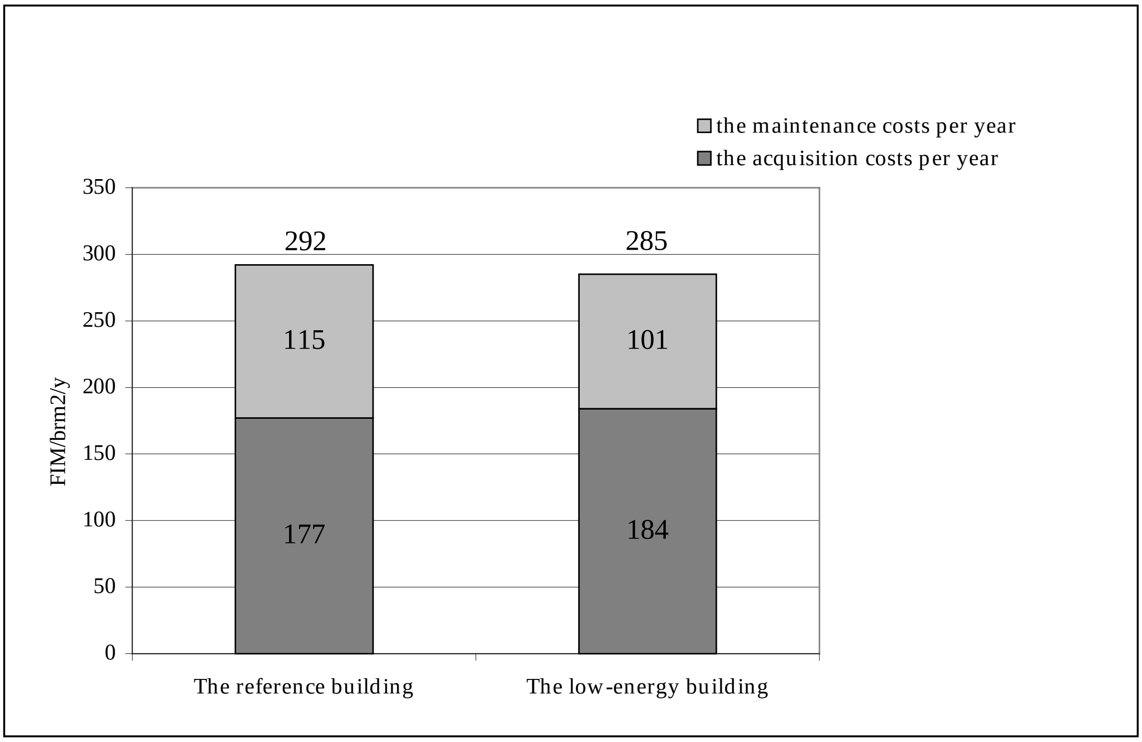

Figure 5b. The acquisition and maintenance costs per year of the reference building and the low-energy building. The low-energy building is more profitable investment than the reference building.

2.6 Life-cycle costs of "Normal" and "High Performance" wooden facade

A comparison between the "normal" facade used normally in the Finnish factory made wooden houses and the "high performance" facade defined in Chapter 3 (item 3.9) was made together with the contractor Porvoon Puurakennus Oy. Both the building costs and the costs of re-treatment per m^2 were calculated by Porvoon Puurakennus Oy.

The "normal" facade is made as follows:

- wood species: spruce
- wood treatment: none
- panelling type: matched, thickness 18 mm
- treatments: 2 layers (primer and topcoat)
- nails: antirust treated.

The "high performance" facade is as specified in Chapter 3 (item 3.9):

- wood species: spruce or pine
- wood treatment: heat-treated wood or pressure impregnated
- panelling type: matched, thickness 26 - 28 mm
- treatments: 3 layers (preimpregnation, primer and topcoat)
  - – preimpregnation prior to manufacture of the cladding
  - – alkyd oil or stains with high UV-protection
  - – acrylate (new types)
- nails: antirust treated.

The life-cycle costs of "normal" facades are estimated as follows:

- the acquisition costs are about 300 FIM/m^2 of the facade area and 180 FIM/brm^2 of the floor area
- the lifetime used is 50 years (any part of facade is not necessary to be totally renewed within this period)
- the re-treatments of facade are needed every 10 years. The re-treatment costs are 200 FIM/m^2 of the facade area and 120 FIM/brm^2 of the floor area.

The life-cycle costs of "high performance" facades are estimated as follows:

- the acquisition costs are 350 - 400 FIM/m^2 of the facade area and 210 - 240 FIM/brm^2 of the floor area
- the lifetime used is 50 years
- the re-treatments of the facade are needed every 20 years. The re-treatment costs are 200 FIM/m^2 of the facade area and 120 FIM/brm^2 of the floor area.

According to the principles presented before, the life-cycle-costs per year of ”normal” facades are approximately 32 FIM/brm^2/y and of ”high performance” facades 24 - 26 FIM/brm^2/y.

Consequently, for the building owner the "high performance" alternative is 20 - 25% more economical than the "normal" one.

3. Optimising the service life and costs of wooden facades

3.1 Background

Facades have at least two main roles the technical and the visual one. The technical function is to protect the building against environmental stress whereas the visual function is to give aesthetic and social impression. In both cases, the performance of the facade is important. Financial inputs are needed for planning, manufacturing, surface treatment, installation as well as service.

The re-treatments and reparations of facades mean a significant cost for the maintenance the building. However, at the building site, these cost factors are not included in the cost estimation. Service life planning is a design process in which the task is to ensure that the service life of a building will exceed its design life.

Service life planning also aims at reducing the costs connected to building ownership. The task of this work was to find out the main cost and benefit factors for the production of “normal” and “high performance” facade quality.

The service life of untreated timber in a structure depends primarily upon the humidity conditions of use, exposure factors, presence of wood attacking organisms, and the natural durability and dimensions of the timber in use. In the building code requirements, the moisture control of material and structure is the main way to diminish the failure risk and to add the durability and lifetime of building products. The purpose of the instruction is to minimise the water and humidity stress of materials and structures.

Moisture damages and failures in buildings are caused by moisture exceeding the tolerance of structures, which after a critical exposure time may lead to the growth of microbes or mould and decay fungi and insect damages in materials.

Typical causes leading to moisture damage are water leakage, convection of damp air and moisture condensation, rising damp from ground, moisture accumulation in the structures as a result of insufficient ventilation, defaults in structures or absorption of water into structures.

Failure to perform as intended can be of various degree: excess moisture can cause reversible or irreversible deterioration or performance degradation resulting from biological processes, chemical processes or physical changes. There are different standards and recommendations defining the service life or durability of materials, e.g. ISO-standards, RILEM recommendations, CSA and ASTM standards. In some ISO-standards, also calculations for life cycles, durability and lifetime are presented.

3.2 Factors affecting the service life of wooden facades

Many factors affect the performance of wooden facades. However, the factors and also the significance of the factors may vary according to case. The main factors in most cases are:

- wood material, wood treatments and modification
- manufacture of cladding, panelling types and structural details
- planning and performance of building shape and structures
- effect of environment (humidity, temperature, exposure time)
- surface treatment (primer, top coat)
- building and installation (critical details)
- maintenance, re-treatment and renovation.

Optimising the quality and service life of facades means that the most important factors are included in the planning and building processes.

3.3 Wood material

The main wood species used for facades in Finland are pine and spruce. Impregnated pinewood is rarely used. Novel wood materials, like heat-treated wood has been used in pilot buildings so experience of it on short-term performance has been gained.

Significant differences on the performance of pine and spruce facades are not found, but spruce facades are found to be slightly more durable. The main differences between pine and spruce materials are:

- permeability of spruce is lower than that of pine sapwood
- drying deformation is higher in spruce than in pine

- resin content of pine is higher than that of spruce
- quality of heartwood is different: Heartwood of pine is less permeable and more decay resistant than that of spruce.

The natural durability of wood varies according to wood species and wood samples. Table 1 shows classification of rot resistance of some wood species under severe exposure conditions. In a normal well functioning structure, wood species having the high durability ranking are not needed. In Table 2 service classes of Eurocode 5 and hazard classes of EN 335 are combined. In Eurocode 5 service classes do not corresponded well to the hazard classes and the different products. E.g. facades and fences should be in different service classes and not in the same class with wood in permanent ground and water contact.

For decay development, the moisture content of wood has to be above 25 - 30%. A moisture content of 20% can be used as a limit for mould development (Table 2 and Figure 6). Mould risk, however, can be diminished with surface treatments. In practice, decay or rot damages may develop in structures, where water is accumulated due to injuries of function of structure.

Table 1. The durability or resistance classification of heartwood against rot in hard exposure conditions (permanent ground contact).

Durability class (EU)	**Durability class (USA)**	**Examples**
Very durable	Resistant or very resistant	teak, iroko, aphzelia, bilinga, mesquite, junipers, redwood (*Sequoia*), meranti
Durable	Resistant or very resistant	western redcedar, oak, American mahogany, meranti, redwood (*Sequoia*) as plantations
Moderately durable	Moderately resistant	larch, Douglas-fir, hickory, African mahogany, khaya, tamarack, Scots pine, southern pine
Non durable	Slightly resistant or non-resistant	pine, spruce, elm, hemlock, hickories, oaks (red and black species in America)
Perishable	Slightly resistant or non-resistant	alder, aspen, beech, birch, maple, poplars, balsa, ramin

Table 2. Hazard and service classes (EN 335 and EC5). In Eurocode 5 service classes do not correspond well to the hazard classes and the different products. E.g. facades and fences should be in different service classes and not in the same class with wood in permanent ground and water contact. For decay development, the moisture content has to be above 25 - 30%. A moisture content of 20% can be used as a limit for mould development.

Hazard classes	**Moisture level**	**Service class**
1 Above ground, covered	< 20 %	1 Moisture conditions: 20 °C and RH 65% Covered and heated areas (inside surfaces)
2 Above ground, covered occasional wetting	Occasional > 20%	2 Moisture conditions: 20 °C and RH 85% Covered areas (facades)
3 Above ground, not covered moderate decay risk	Frequent > 20%	3 Higher moisture content, Outdoor, Unprotected against precipitation (fences)
4 In contact with ground/ fresh water, high decay risk	Permanent > 20%	3 Higher moisture content, Outdoor, Unprotected against precipitation (poles?)
5 In salt water	Permanent > 20%	3 Higher moisture content, Outdoor, Unprotected against precipitation (dock poles?)

3.4 Wood treatments and modification

Pressure impregnation of wood is used to improve rot resistance of wood in high decay risk situations. In Finland, pine is mainly used for impregnation due to its suitable qualities. For spruce, the penetration of preservatives is not sufficient and the demands on penetration are not achieved. The traditional preservatives include chrome compounds for fixing the impregnation compounds to the wood in which case also a better weather resistance is achieved.

In these cases, the impregnated wood has been shown to be better substrate for coatings than untreated wood. However, higher moisture content of impregnated wood (caused by insufficient drying after impregnation) has caused problems in practice. New preservatives without chrome and arsenic compounds have been developed.

New wood modification technologies have been developed, for example heat treatment of wood. In heat treatment, several wood properties may change depending on the treatment process:

- equilibrium moisture content and moisture level is lower and results in better dimensional stability
- colour of wood is darker (brownish)

- strength is a little lower (properties of wood are different depending on wood species)
- better mould and decay resistance will be achieved.

However, the colour of heat-treated wood changes when it is exposed to sunlight. Opaque coatings, however, protect the surface of heat treated wood well.

Manufacturing processes are important for wood quality. The harvesting, log storage and transport affect the quality. The sawing and adjusting procedures are also important factors. Kiln drying affects the wood and wood surface quality. In fast drying, soluble compounds can be transported to the surface and thus affecting the colour and the resistance to blue stain and mould fungi.

Surface roughness is often important for the surface treatments: fine sawn wood surface is regarded to be better substrate for a coating than planed or roughly sawn wood. The adhesion and film thickness of coating is suggested to be the reasons for that.

3.5 Performance of different panelling types

Different panelling types are used in Finland. The main types are:

- vertical boards and panels
- horizontal boards and panels.

Significant differences in the lifetime of different panelling types have not been found. The joint types, edge sealing, profiles and fastening, however, may be different, which affects the performance. The main factors affecting the performance of cladding are

- joints
- sealing
- matching
- fastenings
- dimensions of the board
- fibre orientation of wood in the boards
- knots.

The joints and end grains are critical parts of the facade if water is introduced to the structure. The design of joints, performance of surface treatments and end grain sealing are often key factors for a well functioning facade. The joint types are different in matched and unmatched boards. The joints of matched panels are tighter and a facade performs more like a plate so deformation of a single board is reduced. This also affects the performance of coatings. Fastening type, fibre orientation and thickness of the board affect the structural stability of the facade. Knots affect mainly the performance of coatings.

The performance of boards is dependent also on the building shape and structure itself: e.g. the height of the wall, the height of the foundation, the wide eaves, the orientation of the building in the environment, the construction of the wall and facade.

3.6 Environment

Environmental factors are direction of the facade, precipitation, winds, open or covered landscape, outside air humidity, temperature and its fluctuation, vegetation and its effect on sun light, air humidity and winds. For mould development, critical factors are humidity, moisture content, temperature and the exposure time periods. Ambient RH of 80 - 90% of microclimate is critical for mould development depending on temperature and time. For decay development, the critical value is RH 95% the critical exposure time is longer than that for mould (Figure 6).

In wooden structures, the moisture content of wood must be above 25 - 30% for several weeks or months for decay to develop. In decay damage cases, the function of the structure has failed and water will accumulate in the wood. The development of decay will start in the critical parts of the facade while in the normal well functioning structures decay is not a problem.

Weathering of the wood surface can not be directly connected to the decay development. Blue stain and mould growth is often a part of the normal greying process of untreated wood. The performance of the surface of wood and the paint film is, however, directly connected to the weathering exposure and ageing processes.

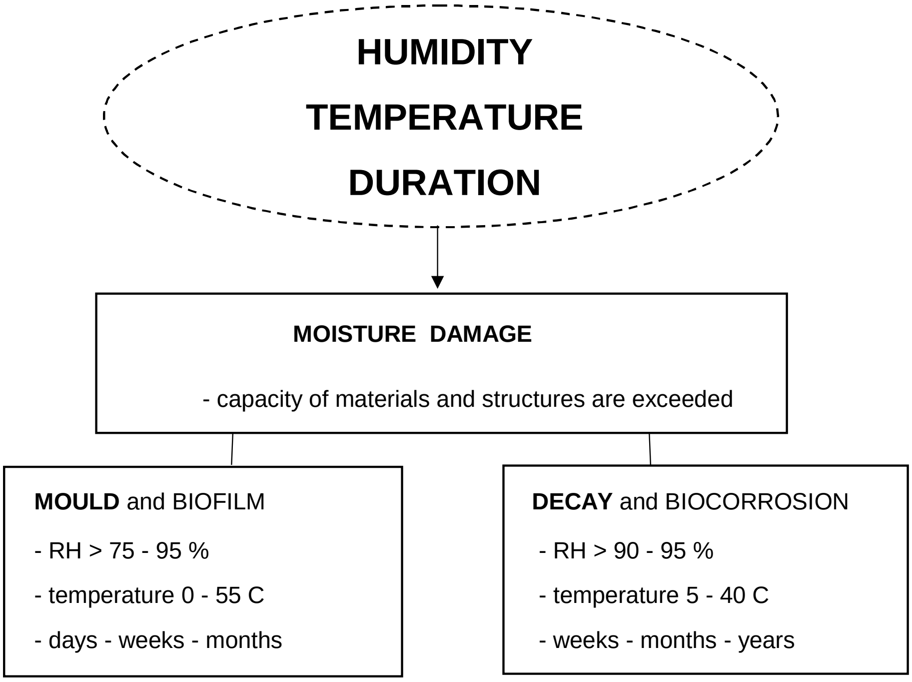

Figure 6. Humidity, temperature and exposure time affect moisture damage and subsequent potential mould and decay problems. For mould development, the critical moisture content of wood is around 18 - 20% and for decay development, around 20 - 30%, depending on temperature and exposure time period. At +20 °C, the permanent critical moisture content for decay development in pine and spruce sapwood is around 25 - 30%. Around 0 °C, no decay or very slow decay process can develop at high moisture content (RH around 97 - 100%).

3.7 Surface treatment and facade structure

The "wood - paint - structure - environment - manufacturing" composition is the main factor for the durability and lifetime of wooden facades. If all these factors are optimised, then also a successful lifetime can be achieved.

The main surface treatment systems used in the Nordic countries are:

- opaque paints, waterborne and solvent borne paints (oil and alkyd paints)
- stains
- barn red.

The performance of these coating systems varies. The barn red is very water permeable. It gives, however, a protection against sunlight. Permeability of stains depends on the binder type and solid content (film forming or non-film forming stains). The permeability of water borne coatings varies, but the permeability is usually higher than that of solvent borne systems. The water borne systems need a primering prior to top coating to protect the wood against water penetration and diffusion in the wood. The higher permeability allows the moisture transport in wood, causing deformation and cracking of wood (Table 3).

The performance of a coating is important and a lot of studies have been carried out in order to understand the relationship between permeability properties of coating and wood, moisture content of wood and the performance of wood coating systems. However, no models have yet been developed.

In several exposure tests at VTT Building Technology, CCA impregnated wood with different coatings have performed well. The key factor is the initial moisture content of wood: if wood is dry prior to coating, performance of the coating on CCA-treated wood has been OK like on unimpregnated wood.

An exposure test simulating a facade has been conducted for 17 years at VTT (Table 3). In this test, the alkyd-oil system has performed well. The boards treated with stains have been cracked and the surface flaked. However, the condition of sawn spruce material has performed better than that of pine.

After 15 years of exposure, the condition of the test material shoved differencies. The uncoated wood was cracked and grey in colour (not anymore suitable for opaque coatings). The coating system affected considerably the conditions of boards: the technical condition of boards coated with alkyd-oil paint system was quite good. Especially sawn spruce performed well but twisting was, however, found. The colour of the alkyd oil paint faded due to chalking thus affecting the general appearance. The best fixed colour was on acrylate painting system.

Sawn board material seemed to have a slightly better condition than planed board material. No decay was found in boards. Mould and blue stain were found, but less on alkyd-oil and acrylate surfaces. The test boards were situated on the outside brickwall below the windows facing south.

Table 3. Results on a study of long term performance of painted wood on outside wall at VTT Building Technology in Espoo after 15 years exposure. Scale of performance estimation:

- *No defects = 0*
- *Very slight defects = 1*
- *Slight defects = 2*
- *Moderate defects = 3*
- *Plenty of defects = 4*
- *Severe, very large defects = 5*

Wood / Paint / Surface	**Cracking**	**Flaking**	**Colour**	**Mould / Blue**
Pine / Uncoated / Planed	5		5	5 (grey)
Pine / Stain / Planed	5	5	4	3
Pine / Alkyd-Oil / Planed	3	1	4	2
Pine / Uncoated / Sawn	5		5	5 (grey)
Pine / Stain / Sawn	5	4	3	4
Pine / Acrylate / Sawn	4	1	1	3
Pine / Alkyd-Oil / Sawn	2	1	4	2

Wood / Paint / Surface	**Cracking**	**Flaking**	**Colour**	**Mould / Blue**
Spruce / Uncoated / Planed	5		5	5 (grey)
Spruce / Stain / Planed	4	4	3	4
Spruce / Alkyd-Oil / Planed	2	1 (knots)	4	1
Spruce / Uncoated / Sawn	5		5	5 (grey)
Spruce / Stain / Sawn	4	2	2	3
Spruce / Acrylate / Sawn	3	1	1	2
Spruce / Alkyd-Oil / Sawn	1	1 (knots)	4	1

The exposure site and its direction, environmental conditions, wind, driving rain, humidity, temperature, sunlight, possible protective components of the environment (other buildings, vegetation) have a significant role for the performance of coated wooden facades. High permeability coatings allow water transport in and out from wood. Semipermeable types are sensitive for high moisture stress, since drying is a slower process than wetting. Low permeability coatings also need a well functioning structure: water penetration should not be allowed into the structure through joints, nails, junctions or other such details. Normally they also need a ventilated facade structure, but the amount of ventilation required is still an open question. The southern wall is most exposed to weathering and the lifetime of this facade is shorter than of those in other directions.

The critical details of facades are the lack of protective structures (like wide eaves, shoulder, high foundation) or presence of unprotected joints, nailing and additive structures on the wall (like wires, fasteners).

The service life and need of re-building depends on the level of maintenance and repainting. Repainting and renovation of a multi-storey house is more difficult and expensive than that of a low-rise house.

3.8 Life time estimations and cost calculation

In the standard ISO / CD 15686, the suggested design life for buildings (DL) and for building components (DLC) are presented (Table 4). According to these figures, the suggested minimum DLC for wooden outdoor walls and facades should be 40 years and for coatings 10 years. For "high performance" facade, the lifetime of coatings should be longer.

Table 4. Suggested minimum design lives for building components (DLC) according to the standard ISO / CD 15686 - 1.

Design life of building (DL)	**Inaccessible or structural components**	**Components, where replacement is expensive or difficult**	**Major replaceable components**	**Service installations and external works**
Unlimited	Limited	100	40	25
150	150	100	40	25
100	100	100	40	25
60	60	60	40	25
25	25	25	25	25
15	15	15	15	15
10	10	10	10	10
♦ Less important components may have design lives of 3 or 6 years. ♦ An unlimited design life should very rarely be used, as it significantly reduces design options.				

For the service life planning, different estimations can be used. In the ISO standard, different factors include in the estimation. These are e.g.

- the environment, including reactions at interfaces between materials and/or components

- the design of the building, the component and installation details
- the materials
- the skill and quality of manufacture
- maintenance
- usage.

The problem is, however, that exact evaluation of the effect of each factor is difficult and knowledge of the factors is hard to find. Also, the critical factors and their effect on the lifetime of wooden facades may vary according to combinations. In this study, a short analysis was performed.

The most significant factors were estimated as follows:

- environmental factors like driving rain, precipitation, sunlight, quality of the building environment (other buildings, vegetation, trees, open or covered landscape, direction of the wall)
- factors depending on building shape and structure like the height of the wall and foundations, width of the eaves
- structural factor of the facade itself (thickness of the board, joint, nails)
- wood quality like wood durability and permeability (wood species, sap-heartwood, impregnation, durable wood species)
- coating system (priming, topcoat, treatment conditions)
- performance of the planning and building processes
- quality of the work
- indoor and outdoor conditions during the use
- maintenance and service.

The lifetime of wooden facades is based on several factors and many of these are difficult to find and analyse in a finished building afterwards. In these polyfunctional cases, the significance of a single factor can be diminished or totally neglected by other factors. For example, good quality material can be destructed by careless planning or wrong structure.

For the optimum results, the critical factors should be identified. The exaggeration of a single factor will not lead to the best or even a good result or solution. Many of these factors, however, do not cause significant costs during the planning and building process. In many cases the price for know how is complicated to fix, because so many factors contribute to the final results and the performance of facades.

The critical factors should be considered and taken care of during the planning and building process, because often minor factors may have the main role in the performance of facades. However, concepts and principles for the quality and lifetime of components and well performing facades presented by different experts and consults can be controversial. This leads to problems but can be partly understood, when dealing with the many different factors like different structures, environments and materials affecting the lifetime of facades.

The main factors, which should be included in the analysis, are:

- material (wood quality, paint type)
- structure of the building and facade (wall high, eaves, joints, water transport systems)
- coating and treatment systems (impregnation, primers, topcoats)
- environment (direction, sunlight exposure, open or covered landscape, rains, wind, RH, temperature)
- usage of a building
- maintenance and service periods and methods.

Table 5 shows some of the most critical factors for normal and "high performance" facades and the evaluated cost and benefit factors (coefficients). The evaluation is based on average cost coefficients of different claddings, wood material, planning, site work, and installation and surface treatments for producing a "high performance" wooden facade.

Benefits of "high performance" products are evaluated based on lower needs of maintenance, repaint and rebuild during the use of the building (benefit coefficients). With wooden materials, minor reparation can be made during the lifetime of the facade. However, the high performance product needs lower level of reparation (longer lifetime, less reparation).

The normal costs of the facade (planning, material, manufacture, coating) are not included, only extra costs caused by "high quality". The costs of maintenance and service have been evaluated on the basis of cost evaluations concerning remedial treatments and rebuilding. Exact values are not presented. These coefficients can be used for evaluation and for comparing the real costs, and thus benefit on the actual costs. However, even this draft calculation gives a positive result on "high performance" products concerning the total cost of use and maintenance of wooden multi-storey house.

This relatively low maintenance cost should be used as a positive factor in the marketing of product. Input in the planning and building process will lead to lower maintenance costs during the use and service of the building.

At VTT Building Technology, wood decay durability has been studied for a longer time in field tests both in ground contact and in weathering tests out of ground contact. On the basis of these results, the lifetime of different wooden species and impregnated wood has been evaluated. Figure 7 shows results and evaluated results from field tests in ground contact (EN 252) in Southern Finland concerning the durability of some wood species and impregnated wood. The lifetime of impregnated wood is clearly longer than that of untreated pine and spruce wood.

The lifetime of pine heartwood and larch heartwood is around the same level. Figure 8 shows evaluated lifetime of the same wood species as tested out of ground contact. The results are based on the field test results performed at VTT and other research institutes. Figure 9 shows some evaluations of the lifetime of painted wood as fence material. The paint type is not defined. These evaluations concern the theoretic fence structure with unprotected joints and can not be directly linked to the conditions of wooden facades.

3.9 Proposal for a life-cycle-cost optimised wooden facade for multi-storey apartment building

On the basis the knowledge and analyses presented before, the combination of "high performance" facade for multi-storey apartment buildings seems to be as follows:

- wood species: spruce or pine
- treatment: heat-treated wood or pressure impregnated
- panelling type: matched, thickness > 25 mm
- treatments: 3 layers (preimpregnation, primer and topcoat)
  - – preimpregnation prior to manufacture of the cladding
  - – alkyd oil or stains with high UV-protection
  - – acrylate (new types)
- nails: antirust treated.

The process of heat treatment should be defined. The impregnated wood has to be dried prior to treatment. The UV-protection needed for heat-treated wood is not achieved by using normal stains.

Table 5. An example of a lifetime and cost estimation for "normal" and "high performance" wooden facade. Only the most significant construction and quality factors are included. Many factors have varied levels and the coefficients are approximated.

Production of wooden facades, analysing of costs and benefits

Normal	**"High Performance"**	**Estimated cost (C) and benefit (B) factors**			
Manufacture procedures			**Heat tr wood**	**CCA pine impregn.**	**Special species**
Cladding	**Cladding**				
- rawmaterial (logs)	- rawmaterial (logs)				
- transport	- transport				
- production of boards	- production of preform				
sawing, kiln-drying, planing	- modification process	**C**	1.5...2		
- storage and transport	- quality control				
	- manufacturing of product	**C**	1.5...2	1.5...2	1.5...2
- normal cladding quality	sawing, planing (thickness)				
	- impregnation	**C**		1.2...1.5	
	- special wood species				2...6
	- primering	**C**	1.5...2	1.5...2	1.5...2
Surface treatments	**Surface treatments**				
- diverse practices	- "3 layer treatments"	**C**	**1.5...2**	**1.5...2**	**1.5...2**
- "cost saving" treatments	- using proper quantities				
Building and installation	**Building and installation**				
- variations of performance:	- planning and performance,				
details of structures /	know how used: optimisation of				
environment / structure /	environment (weather, direction)				
material	structure (details, ventilation)				
interaction not included	material (quality, paintings)	**C**	**1…2**	**1...2**	**1…2**
Benefits during the usage of building					
Normal maintenance	**Lower needs to maintenance**				
	Savings on maintenance	**B**	**- 1.5...- 2**	**- 2….- 3**	**- 1.5…- 2**
Re-treatments of surface	**Re-treatments of surface**				
- southern facade	- southern façade (S)				
at 5 - 10 years intervals	at 15 - 20 years intervals	**B**	- 2...- 4	- 2...- 4	- 2...- 4
- northern facade	- northern façade (N)				
at 8 - 15 years intervals	at 25 - 50 years intervals	**B**	- 3...- 6	- 3...- 6	- 3...- 6
	Savings on re-treatments	**B**	**- 2.5...- 5**	**- 2.5...- 5**	**- 2.5…- 5**
Life time estimation	**Life time estimation**				
- rebuild after 25 y	- rebuild after 50 - 75 y				
	Benefits of rebuild costs	**B**	**- 2….- 3**	**- 2….- 3**	**- 2...- 3**
Price of imago	**Benefits of imago**	**B**	**-1...-2**		**-1...-2**

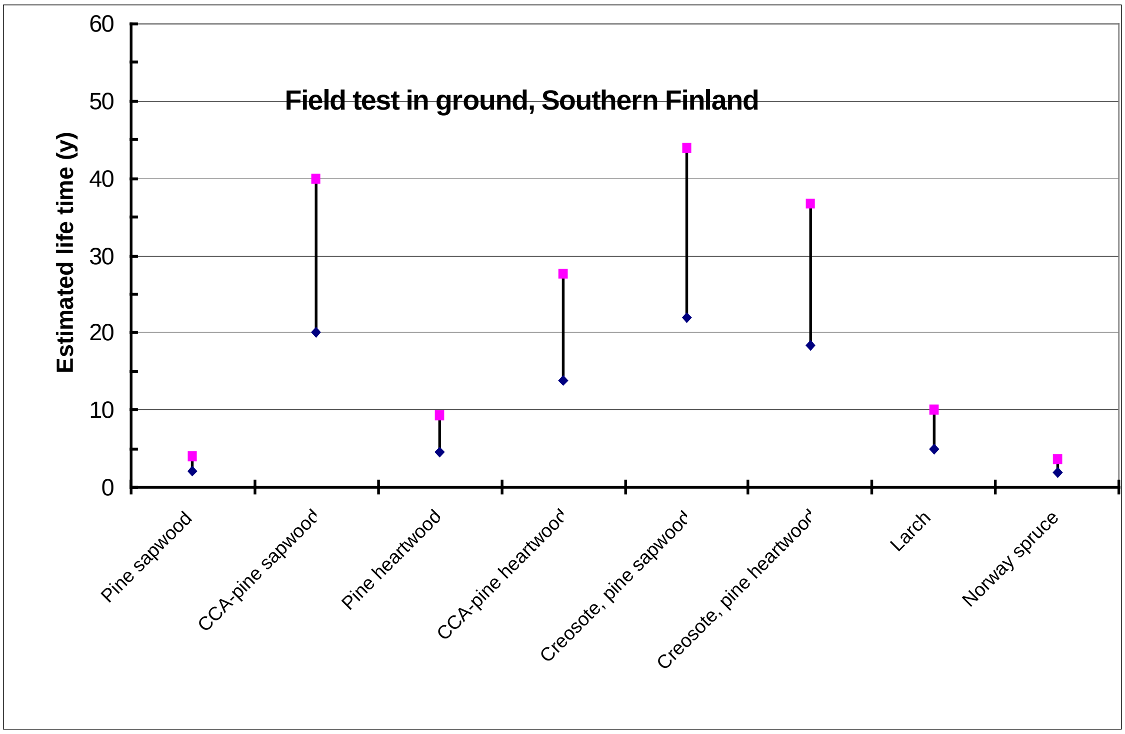

Figure 7. Results on the average lifetime of different wood material in ground contact in Southern Finland, small samples (25 x 50 x 500 mm) buried partly in the ground.

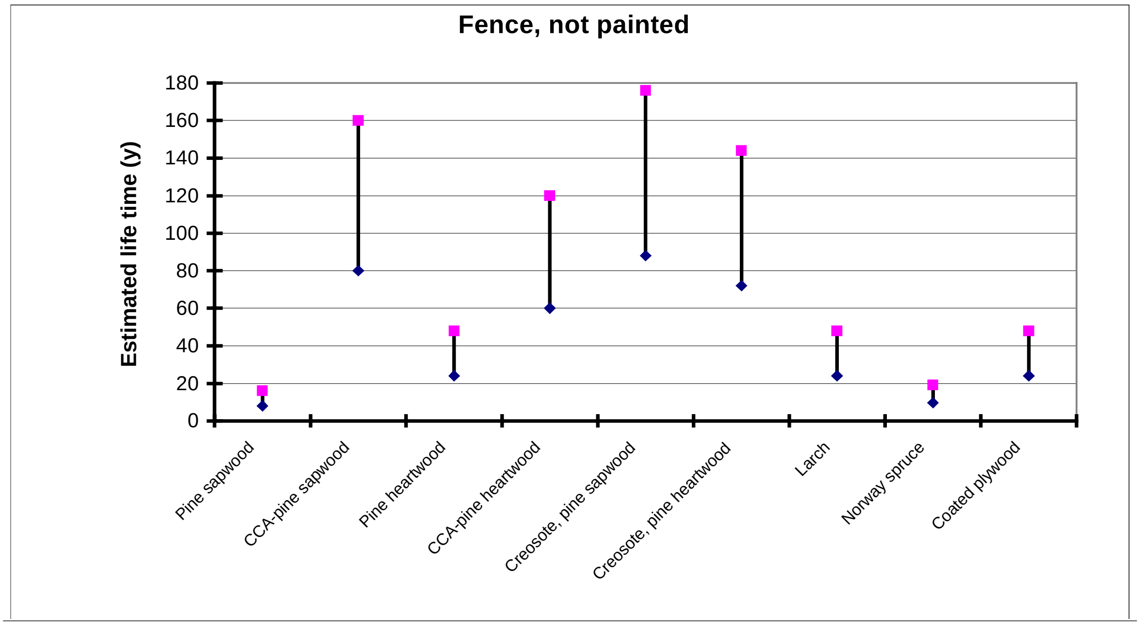

Figure 8. Estimated service life of unpainted wooden samples exposed to outside weathering conditions and moisture in Southern Finland (simulated unpainted fence structure exposed to hard climatic conditions). Coated plywood is spruce plywood with phenolic film and edge sealing.

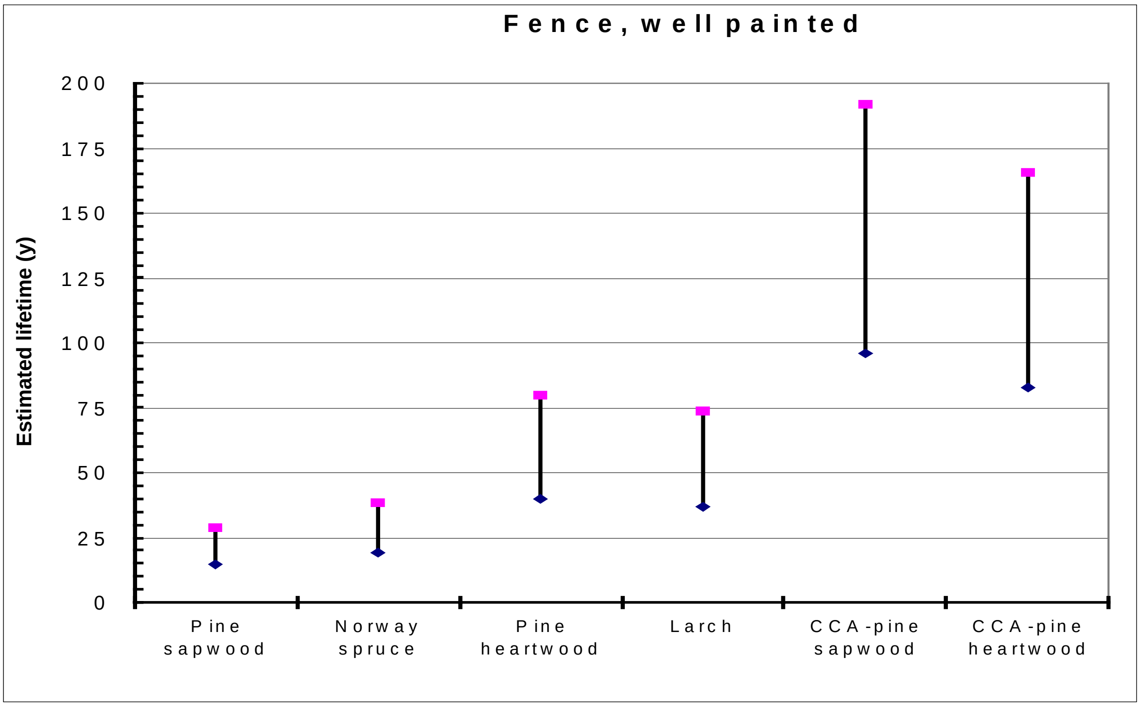

Figure 9. Estimated service life of carefully painted wooden samples exposed to outside weathering conditions and moisture in Southern Finland (simulated fence structure having protective paint treatment and exposed to hard climatic conditions). The effect of building structure (e.g. wall high or wide eaves) is not included in the estimation. In the real facade structure, the lifetime can be significantly longer. Exact definition of the life time of heat treated wood is still difficult. According to some tests performed, the resistance of painted heat treated wood may be around the same level as that of pine heart wood or impregnated wood. The results of different impregnated wood samples can vary depending on the active agents and products used.

4. Moisture and water in a wooden building

4.1 Timber and water

Excessive humidity and water leakage are harmful in all buildings, but especially in a wooden one. Thus, efforts to keep the indoor air humidity on an acceptable level (during the heating period RH < 50%) and to decrease potential sources of water leakage are important in a wooden building.

This is important also because it is a known fact that timber needs dry conditions to remain in good shape and to prevent possible mould and fungi problems. Those problems are very easily connected by people to timber houses.

In the modern apartment house equipped with shower, washing machine, dishwasher etc., the daily production of vapour in room air per inhabitant is about 3 l water. In a family of four this totals about 4,5 m^3 annually. During the heating period, part of this water is used in ventilation to dampen the dry fresh air. Still, an effective ventilation system is needed to extract the excessive humidity from indoor air. In wintertime there is a possibility of moisture condensation at the coldest points of the inner surfaces. The improved thermal insulation and air-tightness of the envelope prevents this danger effectively.

The only effective way to remove the excessive humidity is a mechanical ventilation system. This works always and in all climatic conditions as required and removes in the extract air the vapour produced by the inhabitants and household machinery. For energy-economy reasons an effective heat recovery unit is added to the mechanical ventilation.

The water leakage into wooden structures with many layers is harmful. The damage might be difficult to notice early enough and be very difficult to repair. First of all, the roof of the building with all penetration openings must be watertight. The eaves are effective protection for the upper part of facades against driving rain. Effective groundwater drainage, sloping ground surfaces away from building, high enough foundations, and bituminous felt between foundation and wooden parts protects against ground moisture /6/.

Special attention needs to be paid to water leakage prevention inside the building. In a wooden multi-storey building, there are cold and hot water, sewage and sprinkler systems. The latter is obligatory and according to the local authorities' regulations.

4.2 Air tightness and vapour barrier

Both external and internal air tightness of a wooden multi-storey building is important.

If the air tightness of the outer walls is poor, thermal comfort will decrease due to cold air leakage. At the same time air pressure difference between indoor and outdoor will reduce and a high pressure situation may arise in some wind conditions especially in upper floors. The first sign of overpressure in the heating season is misting and ice between the window glazing. The desired underpressure in the building can be achieved by unbalancing the ventilation airflows, but this will reduce the heat recovery efficiency.

If internal air tightness of the building is poor, it is not possible to avoid overpressure in upper floor due to the stack effect. Odours will spread from one apartment to another through leakage. Noise insulation between apartments will reduce as well.

Measured air tightness figures (n_{50}) in concrete buildings are 0.5 - 0.7 ach (ach = air change per hour) in 50 Pa pressure difference /7/. Target value of n_{50} is 0.5 ach in multi-storey buildings. Air tightness measured in wooden multi-storey building have been about 3 ach. Thus, some improvements should be made in wooden buildings.

Maximum leakage airflow of intermediate floors is 0.1 $dm^3/s/m^2$ in 50 Pa pressure difference. Maximum leakage airflow of doors or windows is about 2 dm^3/s at 50 Pa pressure difference.

To avoid moisture problems and to ensure a long potential lifespan for wooden buildings, special attention needs to be paid to air-tightness and to the vapour barrier of the building envelope. The house construction must be effectively protected against humidity from indoor air, not only against water from outside.

Because of this, the wooden envelope always needs an unbroken air barrier, and depending on the insulation material used, possibly also a vapour barrier at the inside of the envelope. The present understanding is that in the envelope structure made of inner and outer sheathing layers and thermal insulation material between them, the vapour permeability of the outer sheathing layer needs to be at least five times greater than that of the inner sheathing layer /8/.

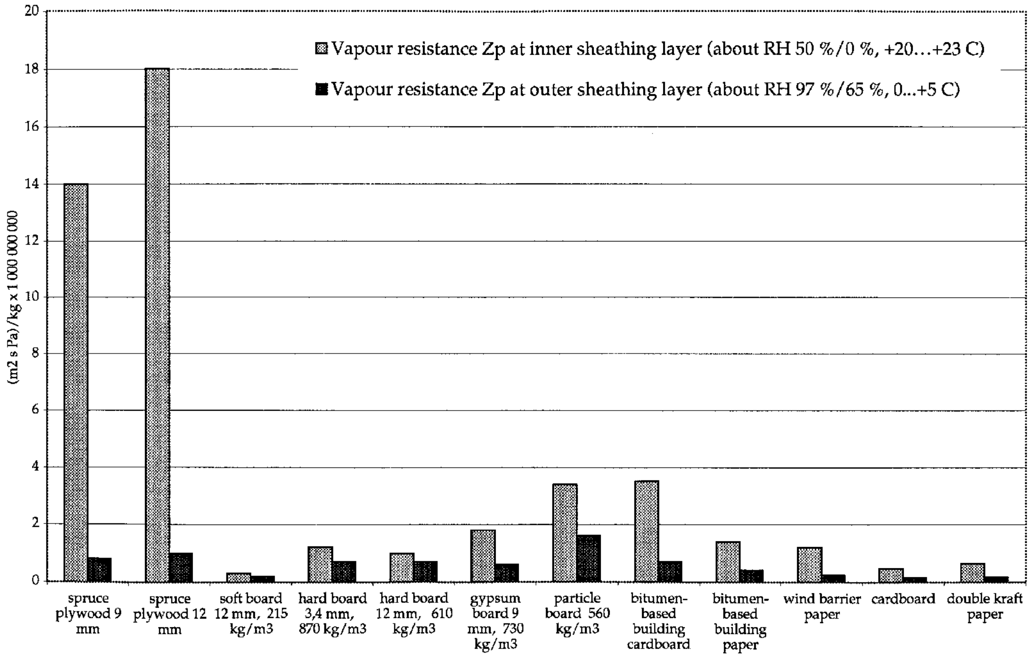

Figure 10. During the heating period, there are different moisture and temperature conditions at inner and outer sides of the envelope structure (wall, floor, and roof). The inner side is warm and dry, the outer side is in conditions where relative humidity RH is high and temperature low, e.g. close to outdoor temperature. The moisture resistance Z_p of various materials used as sheathing can be very different in those two conditions. For example, vapour resistance of dry plywood can be 15 - 20 times higher than that of the wet material. Spruce plywood 9 mm meets the Swedish and Norwegian requirements set for the vapour permeance of the outer sheathing layer /8/.

The air/vapour barrier has to be unbroken. Continuous air exfiltration (indoor airflow out through the envelope structure) causes a moisture risk to all structures in cold climates. Therefore, structural details including air/vapour barrier need to be simple and easy to build. To avoid leakage in the air barrier, the best solution is not to have any electrical installations in the envelope structures.

The lapping joints of the air/vapour barrier need taping and should be located at two structural components e.g. between gypsum board and wooden post. Connections of air/vapour barrier to window or door frames need to be tight. Thus, very careful work on site is needed for an air/vapour barrier. The quality of the result can be tested using pressure test and IR scanning.

In order to be energy efficient, the apartments need an effective supply and exhaust ventilation system with effective heat recovery. This requires an airtight envelope, too.

4.3 Possibilities to improve water leakage prevention

The possibilities to prevent potential water leakage in an apartment building are e.g.:

- providing space heating without hot water circulation radiators. This is possible by improving the thermal insulation of the building envelope and using an air heating system
- during the mechanical system design, the need of each water pipe in the building is analysed and checked whether it is really necessary
- the wet areas of the apartments are produced as watertight factory-made units
- as far as possible, the domestic cold and hot water and sewage systems are located inside the wet area unit
- the plumbing technical cupboard is located inside the watertight unit
- the water pipes outside the watertight unit e.g. in the kitchen area have watertight protective pipe sleeves.

The active reduction of water system components is a new thing in the construction industry. In addition to this it may seem difficult to believe that improvements in a structural system affect component reduction in mechanical systems. In a life-cycle-optimised building a decrease in components is one of the key factors.

4.4 Proposal for life-cycle-costs optimised water system in a wooden multi-storey apartment building

The target is to simplify and concentrate the water systems in one safe leakproof place in the apartment. This proposal is based on supposition that the waste air of ventilation can be blown out through the outer wall in a multi-storey apartment building. Research shows that this does not bring any problems /9/.

The proposal is as follows:

- the factory made watertight wet area unit is located close to the outer wall of the apartment
- the kitchen is located as close to the wet area unit as possible
- in a one storey high apartment, a possible separate WC should be a part of the watertight wet area unit

- the plumbing technical cupboard with e.g. cold and hot water manifolds is located inside the watertight wet area unit
- in the plumbing technical cupboard, there is place for apartment-based cold and hot water metering. Then it is easy to connect to the meter an instrument which reveals leakage at the very outset
- water pipes are continuous between terminal and manifold, minimising joints. All waterpipe joints must be visible
- the water pipes are larger than usual. Due to this, water pressure can be lowered. As a result, the wear in pipes decreases, pipe noise is lower and water pressure remains more constant at various terminals used at the same time.

In an apartment as described earlier, the only water pipes outside the watertight wet area unit are those to the kitchen. They are in watertight protective pipe sleeves which are made so that possible leakage becomes rapidly visible. All sewage pipes in the apartment except from the kitchen area are in the wet area unit.

In addition to this, the electrical systems in the apartment will be simpler when the electrical centre is located in the dry part of the wet area unit. A large part of the electrical installations can be factory made.

5. Effective use of energy

5.1 Background

Buildings which save heating and refrigeration energy are a key objective for the Finnish national energy economy and environmental protection, as well as crucial to the international competitiveness of the Finnish construction and HVAC industry. The indoor climate of a building must be safe and comfortable, the building economical and fast to build, and reasonable in terms of energy consumption.

Various Finnish research projects particularly those related to R&D projects by companies have developed new structural and HVAC prototypes. By applying these, there is a possibility to build various types of energy efficient buildings by which the functioning of developed methods can be studied during practical construction and in use.

The targeted energy consumption (heating energy excluding household hot water) for an energy efficient wooden multi-storey building is 40 - 60 kWh/m^2 of floor area per year for purchased heating energy consumption, which is over 60 % lower than the consumption of present-day reference buildings.

After the demonstration phase, it is possible to move onto the wider implementation of new solutions in the construction of energy efficient buildings. New technology can achieve considerable savings in energy and attain a competitive advantage on the international market /10 - 18/.

In a multi-storey apartment building, heat losses are mainly caused by ventilation. Heat recovery easily decreases this loss by half. After this, other components to be improved are in order of importance: windows, external walls, roof and floor.

The thermal improvement of the building envelope should be made evenly in various parts of the envelope. To avoid cold bridges through the building envelope, care is needed at the structural design stage.

In a wooden multi-storey apartment building, there is good thermal insulation of floors and of party walls between the apartments. Due to this, apartment based heating energy measurement is possible. On the other hand, there may be no sense in measuring these energies because consumption is so low.

The apartment based heating energy measurement is still highly recommendable. "The user pays" motivates the inhabitants in saving energy and their own money. The fact is that the apartments in a multi-storey building have not an equal location as for heating energy consumption. This must and can be taken into account in the energy price of each individual apartment.

5.2 The low-energy envelope for wooden multi-storey buildings

Research and development efforts on efficient energy use in buildings in Finland were initiated at the end of the 1980's. During the current decade, projects have focused on experimental low-energy buildings. When completed, these buildings have been usually monitored over the first two years. The data collected is used as a basis for the next projects. Companies and communities interested in low-energy buildings have participated in research, development and construction work.

In Finland, most of the experimental low-energy buildings until now have been single family houses located around Finland. There are also two multi-storey apartment buildings in Helsinki, both with concrete element frames.

The main characteristics of low-energy buildings are simple. The most important requirements in terms of structures and equipment are efficient thermal insulation of the envelope, windows with a low U-value, and ventilation with heat recovery. An airtight envelope is a precondition for the controlled operation of the ventilation system and for successful heat recovery. An airtight envelope requires careful detail design and construction work.

The low-energy envelope for multi-storey wooden buildings is a new design concept. Although there are some tens of multi-storey wooden buildings in Finland, they all have a thermal insulation on the level of the present Finnish Code of building practise. Also the wooden houses built using the platform system use current thermal insulation practise.

The life cycle cost comparison made in Chapter 2 shows that a low-energy envelope is a vital part of a life-cycle-costs optimised building. The low-energy wooden envelope also includes the building frame.

The building frame and envelope proposed in this project is made of standard components of the Finnish open timber frame system. The design principles are as follows

- the vertical loadbearing components are 48x97 or 48x147 with 2630 mm length
- the floor beams are wooden trussed joists designed according to the spans and loads in question
- the structural floor surface is 18 mm spruce plywood
- against lateral forces, the house frame is braced either by gypsum boards or by 9 mm spruce plywood external walls and at the walls between the apartments
- the air or/and vapour barrier need to be tight in every detail of the envelope
- each apartment is an independent airtight unit having its own ventilation-heating system with effective heat recovery
- in order to maintain the flexibility in each apartment, load-bearing partition walls are minimised.

5.3 Mechanical systems

The principal idea in the design of a low-energy apartment building is to reduce the heat demand to such a low level that a radiator based heat distribution system can be eliminated even in the cold Nordic conditions.

The dimensioned heat demand should be only 25 - 30 W/m^2 of floor area when the outdoor temperature is - 26 C° (southern parts of Finland). The energy consumption of space heating will decrease by about 60%. Then it is possible to heat spaces only with ventilation supply air. Heating energy costs will decrease by at least 40%.

The extra cost of improved thermal insulation can be recovered through simplification of the heating system and lower heating connection charges even during the design and construction phases.

In Finland the majority of new multi-storey buildings are built with a mechanical exhaust air ventilation system only. However this system is not suitable in a cold climate. Draught and poor ventilation in bedrooms are typical complaints. On the other hand the energy economy is poor /19, 20/.

If the building is equipped with a controlled supply and exhaust air ventilation system with effective heat recovery, the thermal climate and indoor air quality will improve considerably. By combining this with an efficient supply air heating device, we obtain a simple, low-cost and efficiently controllable ventilation-heating system (Figure 11).

This system suits energy-efficient buildings well because their heating energy consumption is small, which makes the need for a separate heat distribution system questionable. For example, in an energy-efficient building, the heat generated by two people suffices to heat a bedroom even when the temperature falls a couple of degrees below zero /10/.

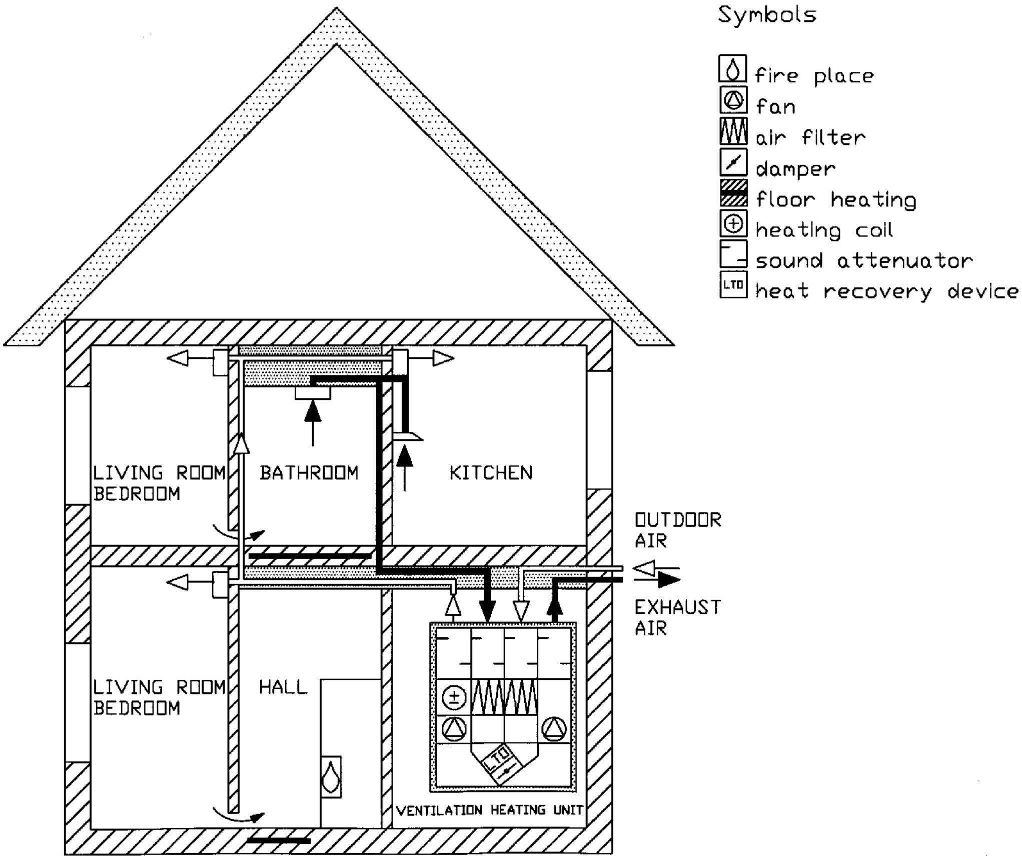

Figure 11. Principle of the ventilation heating system in the energy efficient house.

The apartment-based ventilation-heating unit with heat recovery system is located in a technical closet in the wet area unit. The technical closet is a sound insulated space for all mechanical systems, the engine room of the apartment or house.

Both outdoor air and exhaust air pipes are lead the shortest way through the outer wall. Neither flues nor holes in the roof are needed. The apartment-based ventilation-heating unit with effective heat recovery provides both controlled ventilation in all weather conditions the year round, and effective heating of all spaces.

District heating centre of a low-energy multi-storey building is similar to normal one, but the dimensioned heat effect is only half of normal. It has an influence on the dimensioning of the system and the need of heating centre space.

The extra investment costs of a lice-cycle-costs optimised building are mainly due to improved thermal insulation capacity. The apartment based cold and hot water metering needs considerable fewer investments. The water and sewage water costs in a low-energy multi-storey apartment building in Finland will be more than heating costs.

When "the user pays" the consumption of water and also the energy needed for hot water production decreases. Thus, the investments in order to decrease water use are highly recommendable although the cost savings mostly hit tenants' pocket.

5.4 Proposal for a life-cycle-cost optimised wooden multi-storey apartment building envelope

The proposal for a low-energy wooden envelope presented here has been developed by VTT Building Technology during this research project, in co-operation with Porvoon Puurakennus Oy and Finnish Wood Research Ltd. The proposal is based on components and technology which Porvoon Puurakennus Oy is used to apply. The target has been simplification so as to need fewer components for the building frame, and repetition of the same components and details.

The thermal insulation material is cellulose wool. It is made of waste paper and protected against fire and mould with boric acid and borax (about 20 % of dry weight of paper material). The target has been to use an insulation material which is easy to install with a minimum amount of waste like packing materials and left-overs.

The cellulose wool is mostly sprayed wet on the exterior and party walls between apartments (vertical walls). The floors and related wall section are filled with dry cellulose wool (Fig. 13 and 14). Under the roof, the cellulose wool is blown dry.

The main components used for this low-energy envelope structure are as follows:
- wooden wallplates and posts 48x97
- wooden nailplate floor trusses height 450 mm, c/c 600
- plywood 9 and 18 mm
- gypsum boards 9 and 13 mm
- air/vapour barrier material
- cellulose wool sprayed on site wet or dry.

The foundations/cellar walls need their upper surface to be levelled very carefully (± 2 mm). The bolts to fix the wooden structures to the foundations are dimensioned by the structural designer.

The proposed low-energy envelope structure will be put together as follows:

- installation of the bituminous felt which covers the upper surface of the foundation wall
- installation of a 48x97 wooden wallplate on the foundation, and fixing to the bolts set in the foundation wall
- installation of the open box unit and fixing it to the bolts cast in the foundation
- installation of the ground floor trussed joists and fixing to the wooden wallplate 48x97 on the foundation wall
- installation and nailing/screwing/glueing the 18 mm plywood floor on the floor trussed joists
- installation of ground floor outer wall as open-panels with ready installed windows. The wooden facade structure has factory made preimpregnation and primer on it
- nailing the wall panels to the truss joists and to the open box unit
- installation of a 1,2 m wide strip of air/vapour barrier along the upper end of the wall panels of the ground floor
- nailing the wood 48x97 through the air/vapour barrier on the wall panels of the ground floor to tie the panels together
- installation of the open box unit and nailing to the wall panels of the ground floor
- installation of the floor trussed joists and nailing them on 48x97
- installation and nailing/screwing/glueing the 18 mm plywood floor on the floor trussed joists
- bending the air/vapour barrier strip around the ends of trusses and nailing the 48x97 wooden strip to it
- and so on repeating the procedures as described above.

During the house frame installation, the lateral stability of the house is provided by the outer 9 mm gypsum board which is a part of the open-panel wall structure. Later the inner 13 mm gypsum board when fixed takes the main part of lateral forces.

When needed to improve the building's lateral stability or vertical load bearing capacity:

- verticals in the open box unit are increased as required
- 9 mm spruce plywood is used instead of 9 or 13 mm gypsum boards for more rigid horizontal stability.

An important component of open-panel wall structure is the wall stud. It is made of two 48x97 tied together with e.g. metal or wooden connecters. Connecters that don't increase the total thickness of the wall studs are preferred.

Figures 12 - 14 present the principles of main structural details with solutions for air and vapour barriers.

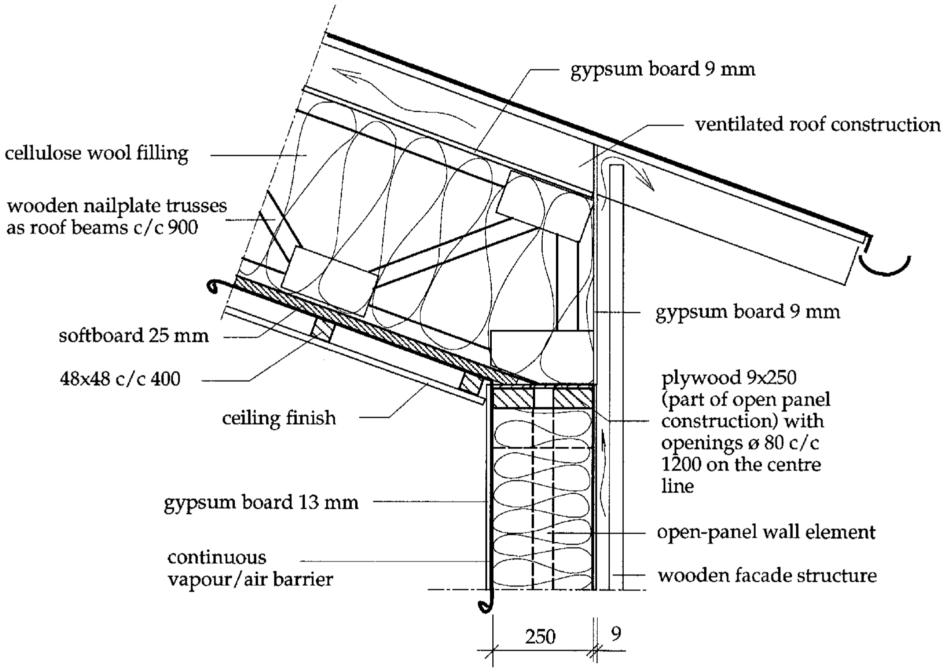

Figure 12 . The connection between inclined roof and external wall.

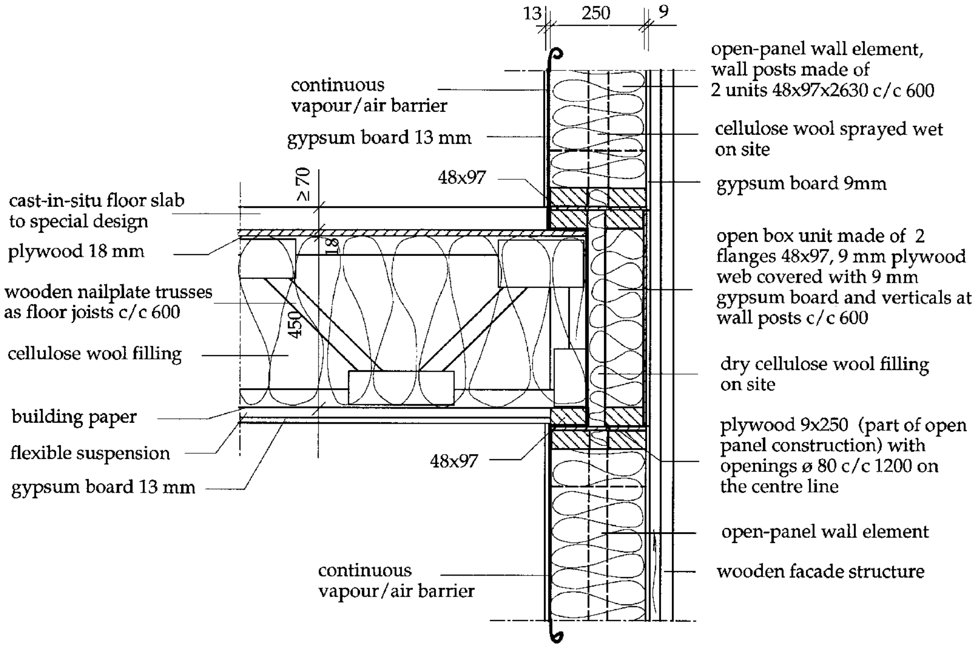

Figure 13. The connection between floor and external wall.

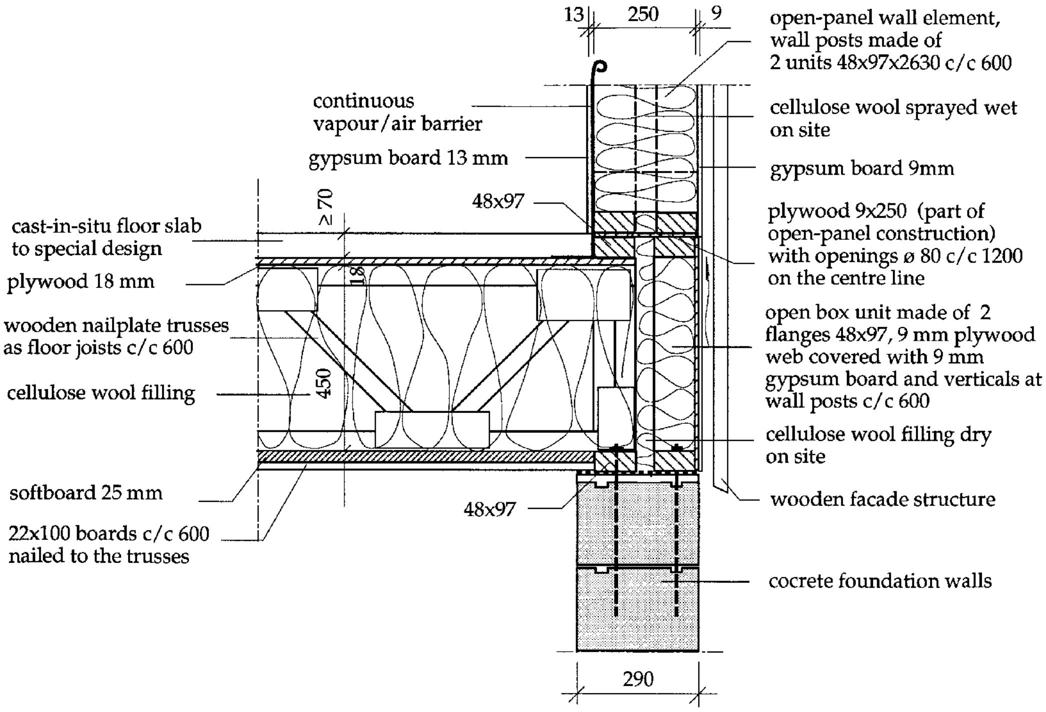

Figure 14. The connection between ground floor and external wall.

6. The Kerava pilot building

6.1 Location and planning principles

The Kerava pilot building will be built in the city of Kerava, some 30 km north of Helsinki. The location (Figure 15) is in the centre of Kerava near the main railway line and a flyover for a main street. At the southern side of the plot there is an old road and some old single-family houses.

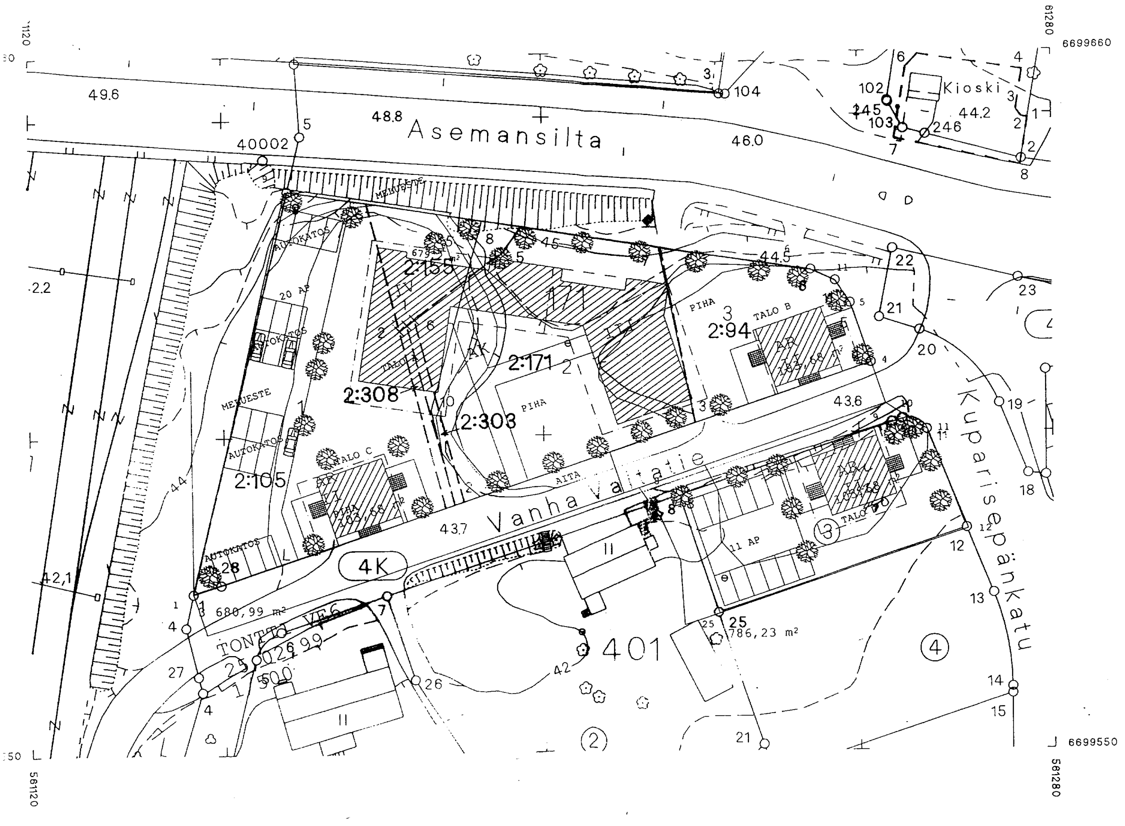

Figure 15. The plot at the corner of the main railway line and a main street (Asemansilta).

The new wooden buildings, the Kerava pilot building and three two-family houses, form part of the present road landscape (Figure 15). Thus the height of the multi-storey building at the old road is three storeys and at the farthest end four storeys. The two-family houses (three similar buildings) are two-storeys high.

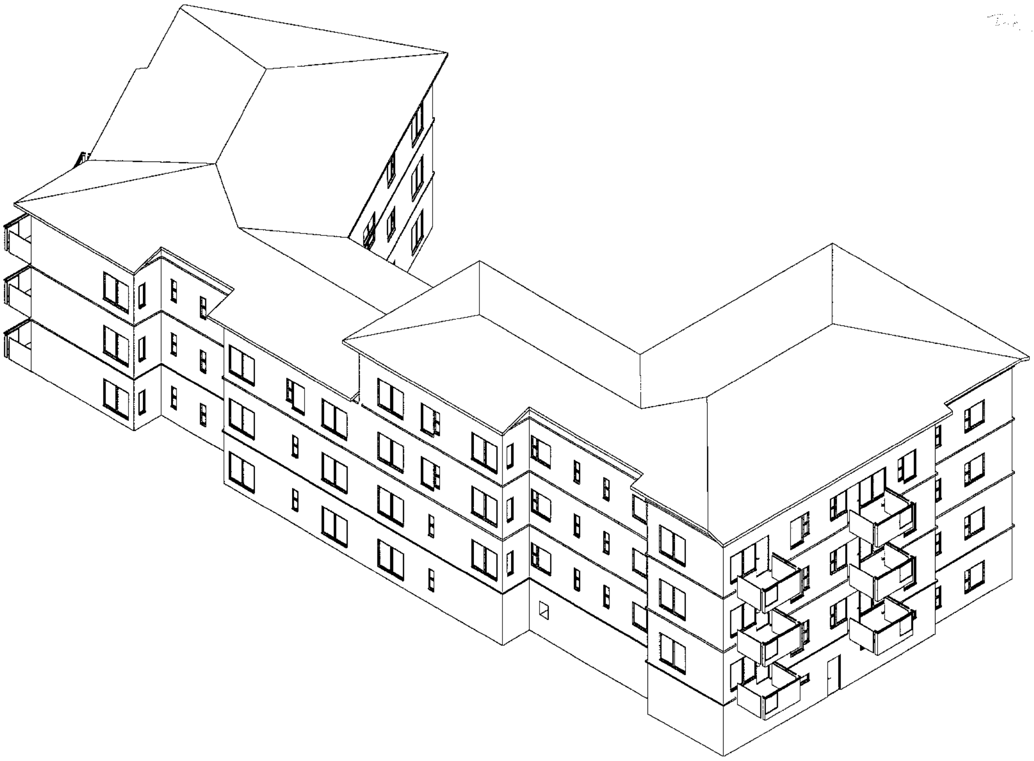

Figure 16. The pilot building seen from the north-west.

The potential client group is senior citizens because the building is in the city centre and close to the railway station and other services. Most apartments are quite small (42 - 53 m^2). There are only a few larger ones (77 - 97 m^2).

The plot is quite noisy. Thus special attention is paid to noise reduction on the outdoor areas of the plot, and in the design of the building envelope.

6.2 Architectural design

The aim of architectural design is good apartments for the occupants to live in, good architecture, economical construction and long-lasting technical solutions. The multi-storey pilot building is otherwise symmetrical to the centre line of the house except for the connection to the inclined end.

All the apartment floor plans are similar (Figure 17). This means repetition of structural and mechanical components, learning by experience, decreasing possibilities for errors. As a result both the construction and running costs will decrease.

Unfortunately, because of the form of the plot and the wishes of the authorities, it is not possible to reach all targets.

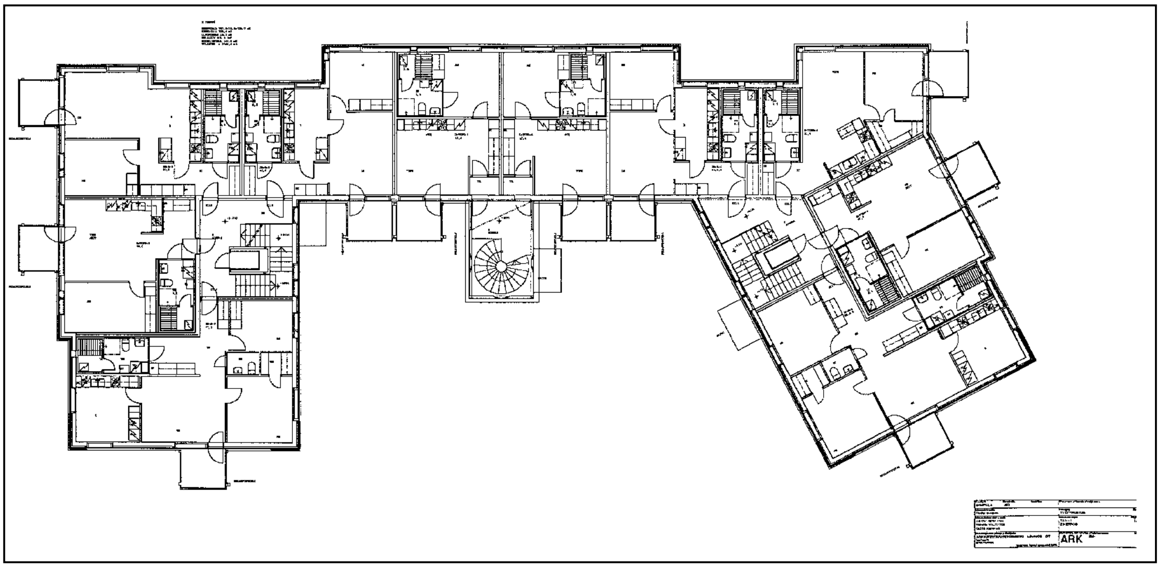

Figure 17. Floorplan.

6.3 Structural, mechanical and electrical design

The basic principles in the structural, mechanical and electrical design are planning for easy building, maintenance and repair. This means use of simple building technologies and details, and reduction of various building materials and components.

The envelope will be a low-energy one with improved thermal insulation capacity and good air tightness. The structural system will be a multi-storey timber frame using the Finnish open timber frame system. The floor beams are wooden trussed joists. Special attention will be paid to protect the structures against moisture from inside. The structural details will be designed in a way which allows a continuous air and vapour barrier. The balconies are designed as balcony towers fully separated from the house envelope and supported on their own foundations.

The energy-efficient solutions will not restrict the layout solutions or other designs. On the contrary, the absence of radiators and the possibility to use large window surfaces, for example, increased the scope for design.

The building will have apartment-based ventilation heating with effective heat recovery. There is no water based radiator system in the building. This decreases the number of water systems. The wet areas in each apartment will be designed as watertight units. Any water leakage inside the unit is lead to the sewage pipe outlet.

The location of the house at the corner of the main railway line and a main street is noisy. The measured noise level on the plot is 58 dB. To improve the noise reduction capability of the building envelope, the following is planned

- improved external walls
- improved windows
- tight envelope of the house by careful construction work
- no replacement air vents through the external walls
- air intake from the silent side of the house when possible.

6.4 Schedule

The planning and design of the project will continue when the authorities have accepted the city plan. Construction work on the site begins at the earliest in the spring 2000.

Figure 18. Illustation to north-east of the Kerava pilot project.

7. Discussion

7.1 Finnish open timber frame system

The Finnish open timber frame system was developed from the platform system. The main ideas remaining are the standard length of wall posts, floor by floor construction and each floor covered by plywood. Various building methods e.g. use of prefabricated wall panels or walls made on the site are possible. The idea of "open" means that the components for Finnish open timber frame system may be designed and built by one or many producers. The components will fit together.

"Open" also means that the system is free for everyone to use. The system of measurements and connecting details needs to be module based.

The wooden low-energy envelope developed in this Nordic Wood project fulfils the requirements of the Finnish open timber frame system.

7.2 The point of view of various important parties concerning this project and technology developed

At the end of this research project, some important persons who have participated in this project were interviewed. They represent architectural design, the construction company, landowner and client (house owner). The aim was to collect their views concerning the project and its subject: design and building of a life-cycle-cost optimised wooden multi-storey apartment building.

The interviews concerned e.g. aims, experiences, advantages and disadvantages of the new technology, obstacles on the way and what should be done next.

The architect’s view

The aim of the architect is to design apartments, which are good to live in for the occupants. A good apartment solution can be repeated many times in a house. All apartments do not need to be individually designed. A building needs to form a whole on its lot. The richness of external architecture is in small details. Thus, the details and treatment of the wooden facade is important. No tricks are necessary but time is needed for development of ideas for good solutions. Wood is a very durable material for facades when designed and built in the right way. The architect has in his own house a 180 years old wooden facade.

The architect does not see the simplification and repetition of technical systems as a problem. Technical solutions need not hamper the design of good living spaces for occupants. In a wooden multi-storey apartment building, a cost-effective frame width is narrower than in a concrete one. A narrower frame gives better opportunities in apartment design, e.g. more natural light.

The Kerava pilothouse project is very important. The experience and results need to be carefully collected and used in the next project to improve the product. Individual needs of the occupants should be taken more into account than now, e.g. the partition walls in an apartment should be located according to the individual needs and wishes of the occupant in question.

The construction company's view

Energy saving is a logical partner of wood construction and strengthens the image of wood as an ecological material. Thus low-energy buildings are the right direction. Energy prices will increase and "green ideas" strengthen among clients in the future. For a construction company it is profitable to be in the forefront when environmentally friendly building technology is developed.

Pilot buildings are important. The new structural and mechanical technology must work as a whole, and keep the building warm and prevent fungi and mould. Quality tested technical systems should be taken more into use than today as basis of building design within architecture. Architecture should not hinder use of safe and tried technical solutions. Ideas need to be tested in a pilot building.

The low-energy buildings need to be a profitable business for a construction company. Clients seem to be ready to pay a little more for a better product. Potential clients are likely to be old people and young families. They are interested in environmental issues.

The landowner's/investor's view

The investor likes to keep his earnings at a desired level all the time of his ownership, that is why he is interested in the life-cycle costs of a building. The investor is especially interested in the first 10-15 years. The earnings in later years are relatively small compared to those at the outset.

The investor knows how running costs are composed. He might be interested in low-energy buildings because they need less heating energy than the present ones. Good living conditions in the building e.g. improved indoor air quality means satisfied tenants.

The investor saves time and money if his tenants are satisfied. An apartment building where the tenants are satisfied needs e.g. less maintenance, and satisfied clients easily accept a higher rent. Thus an investor is interested in buildings where life-cycle costs are low and the tenant is satisfied with the quality of the building.

New technical solutions for buildings must be reliable. They need to be researched and tested by a well-known institute like VTT. In addition to this, to convince the investors, pilot buildings and results from follow-up studies are important, to show that the research results also work in practice.

The house owner's view

The idea of the efficient use of energy is a very good one: why waste limited natural resources if the same or improved living conditions are reached with reduced energy consumption? Unfortunately in Finnish construction practise the minimising of construction costs has traditionally been the only target. The operating costs which the user or owner has to pay, have not interested anybody when the building was designed.

An average individual client on the apartment market is usually interested only in outward appearance in the apartment. He is not interested in technical properties. He is not ready to pay more for improved technical quality, but takes it if the price is not higher. Even if the living conditions are better and the energy bill smaller but pay back time longer than 5 years, he might not be interested because he thinks to move to another apartment sooner than 5 years. A person who plans to buy an apartment is ready to pay more only if he is sure he gets his money back soon. Thus the technical advantages of an apartment have always to be converted into money savings.

The location of the Kerava pilot building is very demanding, but offers at the same time an opportunity to present the qualities of a high quality timber house. The technical systems must work. The noise level inside and outside the building needs to be low enough. The building must be sturdy. Heating and ventilation must provide good living conditions.

It is important that the experience gained in the Kerava pilot building will develop further. Therefore it is important that the same group of companies (designers, contractor, subcontractors etc.) will continue also in future projects and develop the product onwards.

7.3 Indoor climate and air quality

An energy-efficient building consumes less than half the heating energy of a conventional building. In spite of this, indoor air quality and living comfort improve.

The Finnish Society of Indoor Air Quality and Climate (FiSIAQ) has made classification guidelines for indoor climate, construction and finishing materials /21/. Indoor climate has three categories S1 (the best), S2 and S3. The quality of the construction process has two categories P1 (the best) and P2. The purity of the finishing materials has three categories M1 (the best, lowest contaminant emissions), M2 and M3.

The categories S1 and S2 of the Finnish classification represent above-standard quality of indoor climate. Category S3 represents the quality set by the requirements in the National Building Code.

The categories P1 and P2 of the classification represent higher quality requirements than normal fulfilled in the construction process.

The categories M1 and M2 of the classification represent tested and accepted materials. Category M3 represents untested or unacceptable materials. Test method is for example Nordtest method NT BU 1 LD 358. There are over 300 different types of commercial finishing materials tested and accepted in category M1.

7.4 Long-lasting wooden facades in an multi-storey apartment building

Lifetime and cost analyses of wooden facades are based on many different factors. Exact definition of these factors is difficult. However, even draft analyses are needed for the planning and manufacturing process of a wooden facade.

For the production of high performance wooden facades special processes are needed: quality control in different phases of manufacture, wood modification or wood treatment processes, surface treatments, structural planning and performance.

The extra costs caused by "high quality", however, will be balanced by a positive effect of lower costs during the use and maintenance of a wooden multi-storey building. This lower maintenance cost should be used as a positive factor in the marketing of the product. Input for the planning and building process will give lower maintenance costs during the use and maintenance of the building.

7.5 The benefits of the simplifying in the construction

"The best part of a product is a component you can leave out as a result of product development" (Figure 19).

Simplifying and decreasing parts of a product is an important product development target in industries where the competition is hard, like in the electronics and car industry. There is a recent example: the new model of a lorry has about 10 000 components when the previous model had about 16 000. This has helped to decrease the number of suppliers from about 1200 to 260. Competitiveness improved a lot.

In the construction industry these ideas seem to be very new. Even in the recent conference "Durability of building materials and components" having as a main theme "Life-cycle costing and economics" in Vancouver, this matter was not discussed at all.

What could simplifying mean in the construction industry? It doesn't need to mean monotonous architecture. Architectural design requires proficiency in building dimensioning and skilful use of few materials, especially in the facade.

The component left out from your building has the following properties

- you don't need to design it
- you don't need to document it
- you don't need to take care of it in the whole process
- you don't need to produce or buy it
- it needs neither confirmation of order nor control of arrival
- you don't need to store it, it needs no storage space
- it doesn't need investment
- it decreases the work of the acquisition personnel
- it doesn't need space or machinery in production
- it is never lacking in the store
- you don't need to handle it in various phases of the process
- you don't need to install it or check its proper installation
- you don't need to distribute it
- it doesn't need any spare parts
- you don't find it in your spare parts store
- it never needs maintenance
- you never need to renew it
- it is never a cause of a change
- it never breaks down
- it doesn't have any environmental effects

Figure 19. Simplifying has a lot of positive effects on both construction and operating costs.

In structural and mechanical design simplifying means firstly decrease in the number of components and materials. Secondly it means simplifying those components which are necessary. As a result, there are in all phases of construction less things to order, transport, handle and fix. There is fewer waste to transport away from the site and less waste management fees.

7.6 Energy economy and environmental protection in the construction industry

Heating energy in Finland is 22% of all energy used, in Germany even more, nearly 30%. All countries that participated in this Nordic Wood Project have signed international agreements like the Kyoto Climate Agreement in order to decrease CO_2 emissions.

The houses built today should last more than 100 years in order to support the aims of sustainable development. Decisions made now in building design and construction affect for many years the life-cycle-costs the house owner has to pay, and the emissions from the use of the building.

Finland's Ecologically Sustainable Construction Programme was set up 1998 to help the construction sector achieve the goals set by the Government in its Sustainable Development Programme, and by Finland's new Land Use and Building Act.

The Finland's Ecologically Sustainable Construction Programme has four key aims

- to significantly reduce the environmental load caused by the construction and use of buildings
- to improve environmental technology and know-how to make Finland's construction sector more internationally competitive
- to make the property and construction sectors better prepared to meet the demands of both the clients and the environment
- to help local authorities work towards more ecologically sustainable forms of development.

The Programme sets targets and defines measures which should be taken into account both in the construction of new buildings and in the repair and maintenance of existing buildings. The programme will be monitored. By the summer of 2001 a detailed progress report will be prepared and presented, on the effects of the programme on the environment, and on the markets in the construction and property sector /22/.

7.7. Heating energy saving potential in Finland

If the energy saving technology now used in energy-efficient buildings in Finland is applied in all new apartment buildings, it would be possible to reduce heating energy consumption in the total Finnish housing stock by 15 % by the year 2020 (Figure 20).

Emissions from energy production would also diminish by 15 %, even though total housing capacity will in the same time period grow by more than 20 %. The annual saving of heating energy for buildings would be 7 TWh, equivalent to the total electrical energy produced by one nuclear power station /10/.

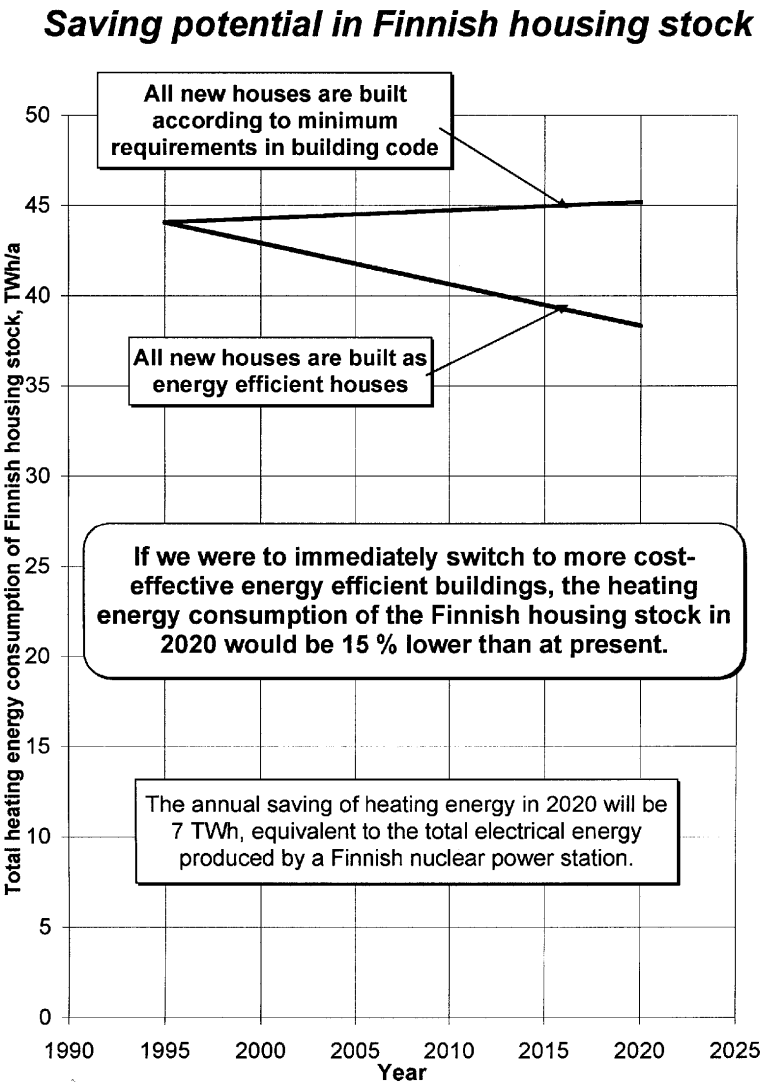

Figure 20. Heating energy saving potential of energy efficient technology in Finnish housing stock /10/.

7.8 Timber, an excellent material, has competitors

Timber is an excellent ecological building material. It is renewable and local in most Nordic countries. One cubic metre of timber binds about 1,9 tons of CO_2. Timber needs as local and lightweight material little transportation.

Producers of other building materials have realised the importance of an ecological image. They are developing their own products to compete with naturally ecological timber. Timber needs to keep this in mind and not to forget the importance of continuous product development.

8. Summary and conclusions

After this research work made over some three years, and a series of other studies on the area, more understanding and new findings related to the life-cycle-cost optimised wooden multi-storey building have been achieved, which may be summarized as follows.

8.1 Results

Life-cycle economy

The life-cycle-cost analyses made on the present types and low-energy wooden multi-storey apartment buildings show that a building with a low-energy envelope needs only 4 % more investment compared with present building practise. Due to the energy savings, the payback time of extra investment costs is only 15 years when calculated using present energy prices.

It is probable that energy prices will continue to increase. In Finland during the last 10 years, the energy price has risen by 4% per year. That is, in 15 years the price will double. If the rise is 7%, the price would be 2,8 times more.

Wooden facades

When two types of wooden facades, a "normal" and a "high performace" were compared, the "high performance" facade showed to be more profitable than the "normal" one. The main factor for the durability of the wooden facade is its composition: "wood-paint-structure-environment-manufacture". When all these factors are optimised, then a long lifetime can also be achieved.

New envelope structure

An energy efficient building needs an improved envelope and the changes are not difficult to fulfil. The only things concerning the structures are thicker thermal insulation, windows having low U value and an airtight envelope. A simple low-energy envelope structure for wooden multi-storey apartment building developed in this research needs further testing in real construction.

Mechanical systems improvements

The improved thermal insulation capacity of the envelope allows simplified mechanical (HVAC) and electrical systems. This results more effective use of space, and lower investment and operating costs. The mechanical system improvements presented here are partly tied to the low-energy envelope, partly feasible in all building types.

The danger of water leakages decreases when the number of water system components decreases. The remaining components are gathered up in watertight units as far as possible and installed so that a possible leakage is rapidly and easily noticed.

8.2 Conclusions

Towards the end of this long project, the participants from the most important organisations (architect, building owner and contracting company) have shown ethusiasm for the new technical improvements which are necessary in designing and contracting a life-cycle cost optimised building. The position of the Kerava pilot building is very demanding but at the same time offers exellent opportunity to present the strength of high quality timber construction.

All participants in the Kerava pilot project will gain a lot of experience. This experience should be developed in the next projects. Therefore it would be fine if this group of companies, a network, would continue. Good examples will promote timber construction in an ecologically sustainable way, and help to establish environmentally friendly timber construction in the Nordic countries.

8.3 Next tasks

In future studies the following would be necessary:

- The design, building and monitoring of the Kerava pilot building is very important. It will be a test of ideas developed. The Kerava pilot building is a real fact to be presented to potential clients.

- It might be a good idea to reserve an apartment just for a visiting potential house owner to stay some nights in the house. Then they would have an opportunity to feel the high quality living condition of that building.
- Giving information to potential clients e.g. to present and future owners of rental houses, about the results of this project
- The effective use of various media to promote the Kerava pilot house as an example of the use of timber as an ecological building material, and an example of good investment and a good place to live.
- Simplifying technical systems needs more attention in the construction industry.

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