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Experiences of the Durability of Wooden Houses in Finland

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ABSTRACT

Finland is one of the leading timber construction countries in the world. Finnish houses have traditionally been wooden houses. The danger of fire has led to restrictions which have allowed a wooden frame only in one or two story high buildings. That's why wooden buildings in Finland have mainly been single-family houses. Since the 1990s Finland has strongly invested in timber construction and tried to increase the use of wood in all types of buildings. Also the Finnish fire code has been renewed and today it allows wooden strucures in multi-storey buildings.

The experiences of wooden houses have not been only positive in Finland. Serious moisture damage has been found in 82 % of single-family houses built after the 1950s. The worst damage has been leaking of low-pitched roofs, base floor damage as a result of building too close to the ground, damage of wet areas and damage resulting from leaks in the plumbing.

The large amount of damage indicates that timber structures are very susceptible to damage. However, the damage has resulted more from changes and experiments in the way of building than from the use of wood as a building material. Before timber construction can become common also in larger scale buildings it will be necessary to eliminate design faults and learn to build sound and lasting timber structures. When properly structurally protected, wood is a lasting and reliable material that creates beauty, warmth and pleasantness in its environment.

KEYWORDS

Timber structures, moisture damage, long-term durability, healthy buildings.

1. INTRODUCTION

Finland is one of the world's leading timber construction countries. This is a consequence of the abundance of Finland's wood resources. Finland is the most forested country in Europe. Finland is situated in the northern coniferous forest belt and its most common wood species are pine and spruce. 45 % of the forests are covered with pine and 37 % with spruce. Until recently, the growth of Finland's forests has been greater than removal, and the annual utilisation of wood can clearly be increased. Increasing the use of wood creates new jobs, boosts Finland's exports and improves the national economy. According to estimates it would be possible to even double the current export income from Finland's forest industry. That's why the Finnish government has invested significantly in the development and research of timber construction since the 1990s. The goal of this effort has been to increase the wood expressly in construction. [Heikkilä 2003].

Wood is an excellent natural building material with a long tradition of use. The long history of timber construction demonstrates that durable and long-term houses can be built from wood. However, wood also has its weak qualities. Thus there have also been doubts about increasing the use of wood. The strongest misgivings concern the combustibility and durability of timber structures. Along with fire, the other significant risk of timber construction is moisture. About 80 % of all damage in wooden houses is a result of moisture. As a consequence of long-term moisture, timber structures become mouldy, rot and spoil. There are plenty of examples of this, too, in the history of timber construction. This presentation concerns the durability of wooden houses expressly from the standpoint of moisture damage.

A precondition for the success and increase of timber construction is the ability to make durable and lasting structures from wood. When building from wood, one must recognise the biological and physical qualities of wood and the behaviour of timber structures under different conditions. Special attention must always be directed at protecting wood from moisture in construction.

The most important wood species in Finnish construction is pine. Spruce is the second one and it is used in the same way as pine. The durability of wood against biological damage is varying between wood species, individual trees and different parts of each tree trunk. Heartwood is normally more durable than surface wood. According to international classifications (EN350 1-2) pine and spruce are quite sensitive to biological damage. Wood begins to be damaged if its moisture stays above 20 % for a long time. In that case the relative humidity of the surrounding air is usually above 80 %. A relative humidity of 70 % can be considered the critical value with respect to mould in wood. When the relative humidity of air exceeds 90 % wood begins to rot. Another precondition for the moulding and rotting of wood is that the temperature is between 0 and +40 °C. Mould spores and rot fungus require oxygen and nutrients to function; normally there is a sufficient amount of these in wood as well as the surrounding air.

From wooden buildings and structures hundreds of years old, we can see that wood does indeed last for a long time if its structural protection is taken care of. The precondition for the durability of wood is that the moisture of the wood stays continuously under 20 %. Wood is a demanding building material that requires meticulous design, building and maintenance.

2 FINLAND'S WOODEN BUILDING STOCK

Wood has always been a natural building material in Finland. In old construction wood has been used in a very versatile manner because there were no other building materials available or they were too expensive. Until the beginning of the 1900s, wood was almost the only building material used in residential as well as public buildings, in load-bearing as well as supplementary building elements.

Up to the mid 1800s Finnish towns were also wooden house towns. As a result of the great town fires of the early 1800s, stone houses began to be favoured in the construction of towns. Gradually stone

houses grew into multi-storey buildings and were larger than wooden houses. The way of building was controlled with fire safety regulations that permitted the use of wood only in low one- or two-storey buildings. As a result, the use of timber structures all across Finland during the 1900s was practically limited to single-family houses. [Heikkilä 2003]. New Finnish wooden houses are mostly one- or two-storey single-family houses. Wood has also been used to build row houses and small commercial or public buildings. When assessing the experiences of the durability of wooden houses, one can lean on the experiences of single-family houses. No comprehensive study of the damage of single-family houses has ever been conducted in Finland. Instead a large amount of empirical data has been collected, and based on that we can deduce the most common damages and their causes.

Before drawing conclusions regarding the durability of timber structures and faults in wooden houses, we must remember that wooden houses have been quite different in different times. Damage cannot be discussed without knowledge of this background. One must know the ways of building commonly practised in various times. Experiments have also been carried out in the history of timber construction; feedback has been received from these experiments and ways of building changed. This chain of trials and errors must also be known. Next is a description of the typical way of building in Finland over different time periods.

2.1 Log house tradition (-1940)

The traditional Finnish wooden house has been a log house, in which horizontal logs have simultaneously comprised the load-bearing structure of the walls, thermal insulation and, often, the interior and exterior cladding. Log houses contained a timber-framed floor that had a ventilated crawl space; for insulation of the floor, natural materials such as moss were used at first, later sawdust. The ceiling has been similar in structure. It must be remembered that originally there were no wet areas at all in these buildings. The sauna and related washing facilities in traditional construction have always been located in separate outbuildings. Log houses have been wood-heated; fireplaces that generated strong ventilation were built into the rooms. Efforts were also made to make log houses air proof. That is why people began to coat the interior with cardboard and wallpaper and cover the exterior with boards. These log houses have proven to be long-lived if their roof is kept in good condition. Damages have been found in the crawl space when ventilation has been insufficient or surface water has gone under the house or the ground has been exceptionally wet. This way of building prevailed in Finland until the beginning decades of the 1900s. [Heikkilä 2003], [Kääriäinen *et al*.1998].

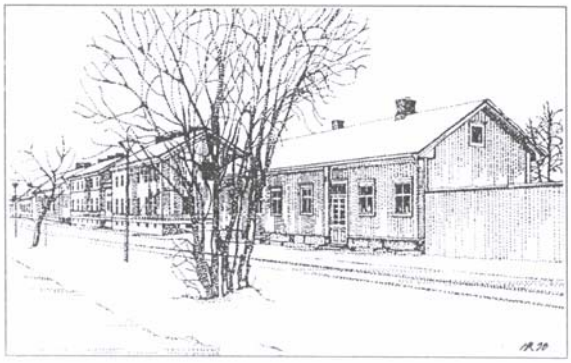

Figure 1. Log houses of wooden towns are one- or two-storey. Their roofs are steep, facades are boarded over, and they have a high base.

2.2 Period of reconstruction (1940s and 50s)

In the early 1900s American-style lightweight timber frame was imported to Finland; it fairly quickly replaced the log structure thanks to its affordability, quickness to build and better thermal insulation. Sawdust and plane chips were used as insulation in the frame structures and cardboard was used as a sealing material, whereupon the structures functioned in the same way as traditional log walls with respect to the physics of moisture. The height of popularity for this structure was during the

reconstruction of the Second World War. The timber-framed "veteran homes" of the 1940s and -50s are one-and-a-half-storey and have a cellar. The houses are high and shaped like a cube, and have a steep roof. Owing to the cellar the wooden floor structure is ventilated and lies clearly above the ground. The sauna and washing facilities are located in the stone-structured cellar. The woodwork of these houses is in good condition if the roof has been kept in good condition. However, a substantial amount of moisture damage has occurred in the cellars of these houses due to the poor water-tightness of the cellar walls. [Heikkilä 2003], [Kääriäinen *et al.*1998].

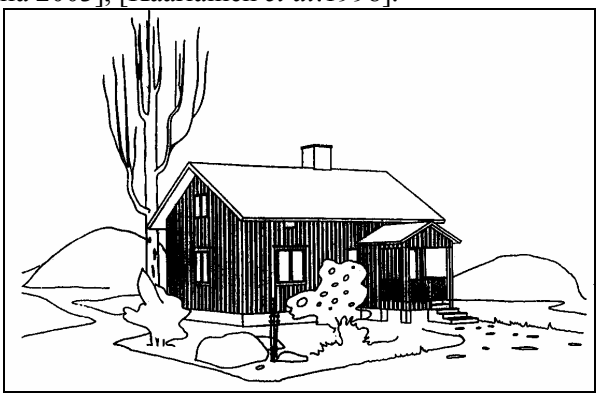

Figure 2. A house of the reconstruction period is one-and-a-half-storey and its roof is steep. The house always has a cellar.

2.3 Period of modernism and structural experiments (1960s and 70s)

At the onset of the 1960s the way of building wooden houses changed dramatically. When it was discovered that a low foundation could be laid without danger of frost damage, the practice of building cellars was abandoned and dwellings, including service spaces, began to be built in single storey. As a result, architectural ideals also changed and designers aspired to make houses low and to make them accentuate the horizontal direction. Floors became ground-supported concrete slabs and were pressed as close to the ground as possible. In wooden houses the result was that the bottom of the exterior walls extended underground, which has proven to be one of the worst mistakes in timber construction. This way of building has not even yet been completely abandoned even though its erroneousness was demonstrated as early as 25 years ago. Patterned on the same architectural goals, designers also wanted roofs to be as gently sloped as possible. In the beginning of the 1970s new wooden houses changed into entirely flat-roofed houses, and eaves, which protected the façade, went away at the same time. In a short period of time, flat roofs proved to be a fateful mistake in Finland's harsh climate.

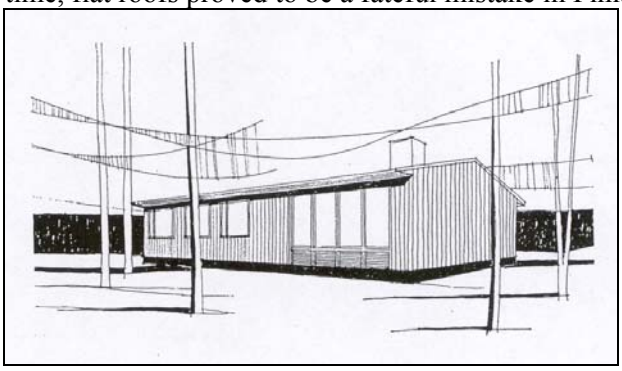

Figure 3. Wooden houses from the 1960s were built into one storey and cellars were no longer built. The houses were made low and the roofs gently sloped.

When cellars stopped being built, the sauna and washing facilities were moved inside the building. This has resulted in a significant increase in the moisture stress of dwellings and also the placement of piping, susceptible to leaks, into structures. This increase in the use of water took place without developing the structural solutions of wet areas or boosting the ventilation of houses. Another fateful

mistake was embedding the pipework into structures. The hidden pipes could leak for a long time before the damage was noticed.

The operating principle of wooden structures with respect to the physics of moisture changed in the 1960s when industrial mineral wool products replaced the earlier wood-based insulating materials. With the use of mineral wool, which insulated heat well and absorbed moisture poorly, plastic sheeting was required in the wooden structures to ensure air- and vapour-tightness. The more impervious wall solutions and poor ventilation led to quality problems in the indoor air of single-family houses.

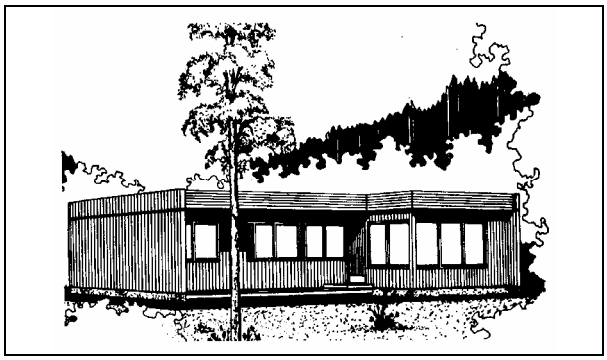

Figure 4. Wooden houses from the 1970s were made entirely flat-roofed.

The wooden houses of the 1960s and 70s have proven to be very problematic. Some of the solutions used at that time were abandoned quickly. Most houses of that period have received a new roof and flat roofs have not been built on single-family houses since then. Plumbing was also no longer embedded, and since then piping has been installed in casing pipe so that their condition could be monitored and they could be replaced without demolishing the surrounding structure. As a result of the evident indoor air problems, later houses have most often been equipped with mechanical ventilation. [Heikkilä 2003], [Kääriäinen *et al*.1998].

2.4 A step backwards (1980-)

In the timber construction of the 1980s, designers returned back in the direction of tradition and worked to avoid the problems caused by the excesses of the previous decades. Since the 1980s Finnish single-family houses have again had inclined ridge roofs. Efficient thermal insulation and improved air-tightness of the envelope are typical of new houses. The houses are, to a large extent, equipped with mechanical ventilation. Water pipes are situated in casing pipe so that leaks can be detected and pipes can be replaced without demolishing structures. Walls of stone materials are often used in wet areas. Some of the damage typical in wooden houses of the previous decades has thus been prevented. A problem even in new houses is building too close to the ground, which has continuously resulted in moisture damage in the base floor and the lower part of exterior walls. [Heikkilä 2003], [Kääriäinen *et al*.1998].

Wooden structures have maintained their dominance even in the newest Finnish single-family construction of the 21st century. In 2002, 87 % of new Finnish single-family houses, 80 % of row houses and 100 % of holiday houses were wooden buildings.

In the 1990s Finland's fire safety restrictions were renewed to be in accordance with pan-European principles. According to fire safety restrictions in force, wood can also be used to make 3-4 storey residential and employment buildings. Construction of wooden apartment buildings has been tested in Finland, but it appears that the wooden share of multi-story housing construction will remain fairly small despite the removal of fire technical barriers.

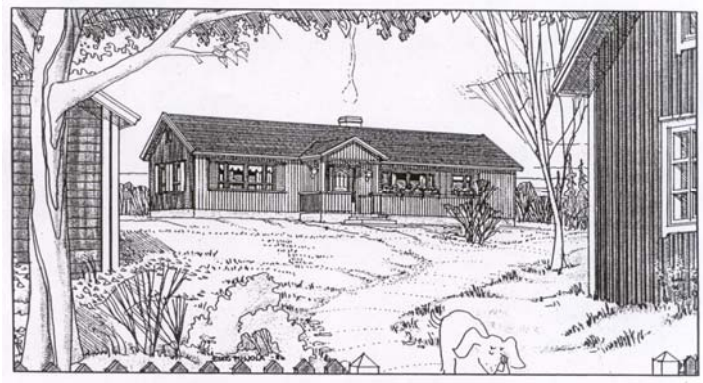

Figure 5. Lessons were learned from tradition in the construction of wooden houses in the 1980s. Once again houses have steep roofs.

3 CONDITION OF FINNISH WOODEN HOUSES AND TYPICAL DAMAGE

The moisture damage of Finnish wooden buildings can be evaluated based on sampling research conducted in 1995 on single-family houses. The amount of moisture damage in Finnish single-family houses is alarmingly great. This study shows that moisture damage exists in 82 % of single-family houses built after 1950. The fact that nearly 500,000 or 55 % of Finnish single-family houses are in need of prompt repair is an indication of the seriousness of moisture damage. [Partanen *et al*.1995].

The study indicates that there is moisture damage in wooden houses of all ages. However, most moisture damage clearly exists in houses from the 1960s and 70s, in which new types of materials and architectural solutions were used. Based on the study it appears that something has been learned from the mistakes, as the amount of moisture damage in houses built after the early 1980s has somewhat decreased. [Partanen *et al*.1995]. One can conclude from the study that the danger of moisture damage in wooden buildings is always great.

When studying the moisture damage in wooden houses of different ages, we can see that the types of damage are closely linked to each way of building. The biggest moisture technical problem of houses from the 1950s is the leaking of stone-structured cellar walls. Other moisture damage is related to the ageing of roofs and plumbing. The actual timber structures in these houses are in good condition. The reason for this is the location of timber structures high above ground level, steep roofs and protective eaves as well as the absence of actual wet areas inside the wooden frame. Damage in houses from the 1960s is plentiful and exists in all parts of the buildings. Most of the damage is in the timber-framed ceiling structures due to the leaking of gently sloping roofs. There is also a lot of damage in base floor structures. The damage develops from leaks from embedded plumbing and outdoor surface water. A large amount of moisture damage is also located in the floors and walls of wet areas, which have not been made waterproof. The worst moisture damage in houses of the 1970s is damage in ceilings resulting from leaks in the flat roofs. Another significant type of damage is wall and floor damage. Base floor damage is also caused by outdoor surface water. As late as the 1970s, it was customary to sink pipework into base floor structures, and plumbing damage is a significant problem group. In wooden houses from the 1980s, moisture damage in ceilings no longer exists because sufficiently steep roofs have been built on the houses. On the other hand, wall and base floor damage of wet areas continue to be common. Base floor damage caused by outdoor surface water also continues to occur. [Partanen *et al*.1995].

Moisture damages in houses built after the 1960s are connected with four areas:

1) leaking of gently sloped roofs
2) base floor damage caused by building too close to the ground
3) wet areas
4) plumbing leaks.

More than 70 % of flat roofs are damaged. There is damage in the wet areas of nearly 42 % of all houses. Of all base floor damage, 50 % is caused by outdoor surface water. Plumbing damage appears to be proportional to the age of the pipework. [Partanen *et al.*1995]. Leaks in pipes are also common in new houses. Water leakage was found in 17,000 single-family houses in Finland in 1995 [Määttä *et al.*1997]. The total sum of the cost of repairing the moisture damages in single-family houses is estimated to be 600 million euro, or approximately 1,200 euro per house. [Partanen *et al.*1995].

The large amount of moisture damage suggests that timber structures would be particularly problematic. In this respect, however, one should be critical. Moisture damage is more related to the ways of building in use than the use of wood as the principal building material. The cellar walls of houses from the 1950s are stone-structured and their problems with water-tightness are not related to wood. The roof leaks of the houses from the 1960s and 70s are caused by too slight an inclination and poor waterproofing materials. The damage as such is not related to the use of wood as a building material. The experiences demonstrate that damage has occurred in the flat roofs of stone buildings in the same way. Neither can the damages in wet areas be considered only the fault of timber structures. The prime cause of the damage is inadequate waterproofing. Moisture damage has also occurred in stone-structured wet areas whose structures lack waterproofing. Plumbing leaks are caused by the ageing of piping materials and are thus are not only a problem of wooden buildings. Pipes also leak in stone houses. Base floor damage is a result of outdoor surface water and building too close to the ground. Damaged base floors have been concrete slabs. Damage has also naturally occurred in the timber structures that are in close contact with the concrete. Based on what has been presented, we can conclude that wood material itself has contributed little to the worst damage of wooden houses. This is confirmed by the fact that serious moisture damage has been found in 60 % of stone-structured apartment buildings built in Finland over a comparable time period.

4 WAYS TO PREVENT MOISTURE DAMAGE

During the past decade in Finland there has been continuous and extensive public discourse about the quality of construction. The background of this discussion is the large amount of moisture and mould damage in buildings and the resulting indoor air problems. In addition to wooden single-family houses, multi-storey residential buildings and public and commercial buildings have suffered serious moisture damage. On the other hand it must be noted that Finland is not alone with its construction quality and moisture problems because in international assessments the quality of Finnish construction is considered fairly decent. In the discussion on quality it has been stated that it appears that know-how in building physics will become an important key domain of study. Moisture damage can be prevented only through significant investments in research and development of building physics. [Heikkilä 2004]. This particularly applies to timber construction, which is nationally important to Finland.

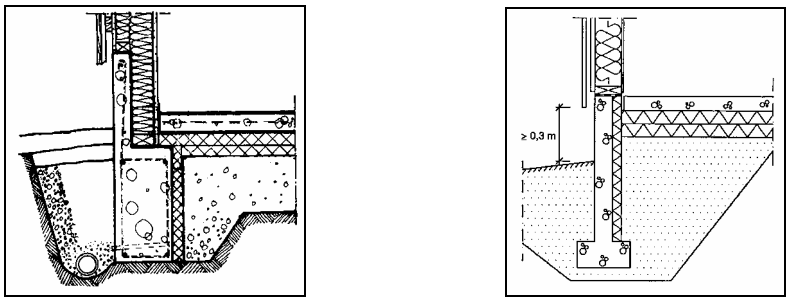

Figure 6. Left. A dangerous solution from the 1970s. The floor and the ground are on the same level. The bottom of the timber frame extends underground. Right. A safe joint of the floor and the exterior wall.

Moisture damage in wooden buildings has not gone away even though information about healthy solutions has been available already for a long time. The same mistakes are continuously repeated in the construction of single-family houses. 60-80 % of the risks of moisture damage in new wooden buildings fall on base floor structures and wet areas. Damages in roofs and plumbing have mostly been

controlled. Base floor structures, the joint of the base floor, foundation and bottom of the exterior wall, and wet areas constitute the most demanding details for the moisture technical design of a wooden house. By working on the careful design, construction and maintenance of these structures it will be possible to ensure long-lasting and safe wood construction. [Heikkilä 2003].

A basic requirement of base floor structures is that the floor area is lifted sufficiently high from the surrounding ground level. An effective layer that cuts off capillary rising of water is needed under a ground-supported base floor. The moisture stress of the base floor and footings can be reduced by sufficiently inclining the ground away from the building and making a subsurface drain around the building. Thermal insulation in ground-supported base floors should be situated under the concrete slab. Wet areas should be built with stone structures where possible even in wooden buildings. In wet areas, not only the floors but also the walls need to be reliably waterproofed. With these quite simple solutions the majority of the moisture problems in timber-framed single-family houses can be prevented. [Heikkilä 2003].

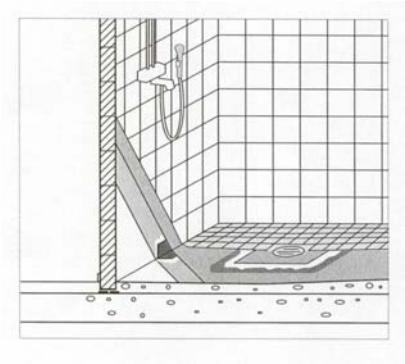

Figure 7. Wet areas should be made with stone structures and there must be reliable waterproofing in their floor and walls.

Moreover, when care is taken that only stone structures are used in possible cellars, piping is installed in casing pipe, a sufficiently inclined roof and façade-protecting eaves are made on buildings, builders are close to achieving a healthy and risk-free way of building with wood. [Heikkilä 2003]. After builders clamp down on structural mistakes, wood, the traditional Finnish building material, will be freed from the groundless suspicions aimed at it. When properly structurally protected, wood is a lasting and reliable material that creates beauty, warmth and pleasantness in its environment.

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