Concerns When Improving the Energy Efficiency of 1960s and 1970s Swedish Multi-Family Dwellings

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ABSTRACT

Between the years of 1965 and 1975, some one million apartments were built on an industrial scale in Sweden. The intent was to provide the quickly growing population with modern housing featuring reasonably sized apartments and good functionality, such as central heating and modern kitchens and bathrooms.

Some forty years later, many of these large multi-family dwellings are in dire need of substantial renovation and improvements to extend their life expectancy and improve their desirability.

Improved energy performance is, under the current circumstances, a demand from the property owners, the national government, and the European Union. Previous experiences of trying to reduce energy use in buildings have made concerned parties aware that care must be taken to, among other things, avoid reductions in indoor air quality and minimize the risk of moisture damage in structures.

This paper is an overview of some common features of these Swedish multi-family dwellings and some of the approaches and problems related to improving their energy efficiency while trying to avoid negative impact on the indoor climate and maintaining components in a functionally sound state.

Included is also a brief overview of some currently ongoing research projects related to the improvement of the 1965–1975 Swedish multi-family dwellings.

The eventual challenge is to find a way to adapt these buildings in a controlled manner so that they will be energy efficient, economical, and functional and provide residents with appropriate indoor environments while being aesthetically pleasing.

INTRODUCTION

A few years into the post-war era, the growth of population, labor immigration, concentration of the population to the cities, and smaller family groups had lead to a lack of housing in Sweden. Building regulations and subsidized financing were put in place to achieve affordable and good-quality housing. Large-scale urban planning aimed to offer the inhabitants work, accommodations, and new city centers with social interaction. Municipalities were required to make land available for the new neighborhoods. Standardization and serial production became necessary and became important tools for the building industry to be able to produce apartments at the rate envisioned by the government (Vidén et al. 1992).

Eventually, during the 1960s and 1970s, approximately one million apartments were built on an industrial scale in Sweden. Today, apartments from this era still represent a large part of the total 2.46 million multi-family apartments. Not only technical innovations came about; the use of design-build contracts became common, and Ramberg (2000) argue in a history of Swedish semi-public property owners that poor knowledge of this process resulted in poor tender documents, some allegedly less than a page long, which increased the risk of a poor product. During the 1970s, mortgages for single-family houses became tax deductible and, combined with high tax levels, building your own house became very advantageous compared to renting. As a result, larger apartments were

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not desirable, and the previous truth that a built apartment always had a tenant no longer applied (Ramberg 2000).

Now, some forty years later, many of these multi-family dwellings are in need of substantial renovations and improvements to extend their life expectancy and improve their desirability. Even though many of these buildings for many years have been criticized for their appearances, those appearances are now often considered worth protecting.

METHOD

This paper is mainly a literature study that extensively uses reports and other publications from the Swedish Council for Building Research, a governmental organization that financed research and as of 2001 was superseded by the newly created Formas, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning. Since changes are always made to buildings, earlier reports should better reflect the state of and opinions about the buildings at the time the reports were made.

TYPICAL BUILDING PROPERTIES

Until the 1960s, render (stucco) was the facade material of choice for decades. In the subsequent period, the general belief was that the majority of the multi-family buildings constructed were large-scale concrete structures based on systems such as the concrete-polystyrene sandwich constructions, such as Skarne (see Figure 1). In reality, about 26,000 of the 40,000 buildings constructed between 1961 and 1975 had brick facades, approximately 8000 with render (stucco) and somewhat more than 10,000 with other materials, including concrete surfaces where exposed aggregate is not uncommon. Obviously the average house is more likely to have a brick veneer facade than concrete. However, concrete was extensively used in load-bearing constructions, concrete floors were used in well over 35,000 of the buildings, and just above half of the buildings have concrete walls separating the apartments. The typical construction consisted of concrete floor slabs and load-bearing walls running in the short direction of the building and curtain walls running in the long direction, and the stairwells were used to stabilize the building (Vidén et al. 1985).

About 26,000 of the total 40,000 buildings had between one and three floors above ground, and these buildings housed half of the apartments (Vidén et al. 1985). The large amount of three-floor buildings was due to the requirement of elevators for buildings with four or more floors (Melchert 2006). Most of the buildings were constructed with basements, but during the 1970s slab-on-ground became more common, and a few crawlspaces are also documented (Karpe 1990; Vidén et al. 1985).

An absolute majority of the windows had two panes, and a few thousand of the buildings were fitted with three-pane windows. About a third of the roofs were flat, and somewhat more than a third were gabled. Almost two-thirds of the roofs were covered with bitumen-drenched paper with aggregate (Vidén et al. 1985).

A majority, 70%, of the buildings had forced exhaust ventilation, 15% had balanced forced ventilation, and 15% relied on natural ventilation (Vidén et al. 1992).

The average heat transfer coefficient, the U-factor, for walls of multi-family buildings built from 1961 to 1975 was 0.48±0.16 W/(m^2·K) (R-12, h·ft^2·°F/Btu) according to a recent governmental study (Boverket 2009). For buildings built between 1996 and 2005, the U-factor is 0.2 W/(m^2·K) (R-28, h·ft^2·°F/Btu). The study estimates that to achieve this value in all older single- and multi-family homes, the equivalent of 170 mm (6.7 in.) of mineral wool would have to be added.

Well over half of these buildings were heated with district heating (Vidén et al. 1985), which was being expanded as a part of the developments. The reason for this choice of energy delivery system was not efficiency but reducing the pollution from small wood and oil heaters. Other parts of the infrastructure were also being engineered at a large scale, such as traffic planning (CTH 1968) and water and wastewater treatment. The increased use of cars is reflected in not only city planning but also underground car parks, multilevel car parks, and larger peripheral car parks, which were built beneath or beside larger neighborhoods to allow easy access without mixing cars and people (Melchert 2006).

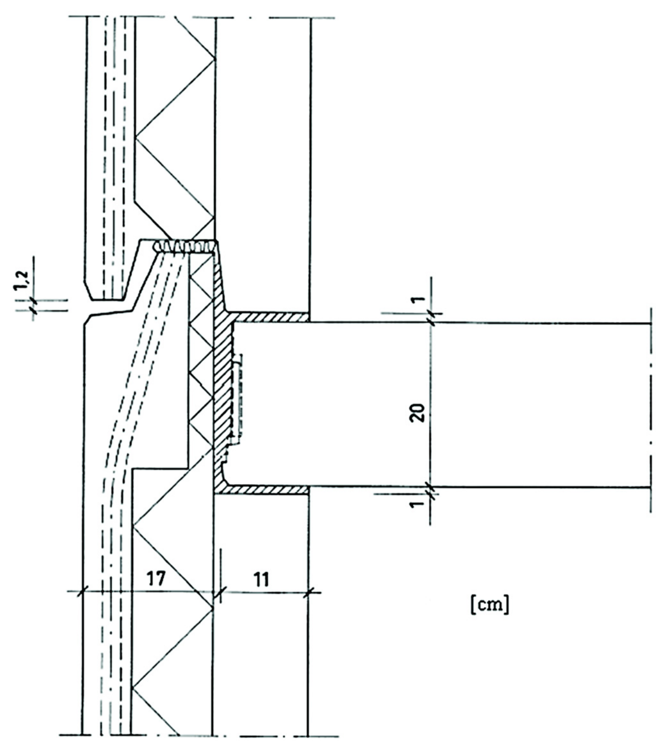

Figure 1 *Wall modules of the Skarne system connecting with the floor slab (Sjöberg and Wichlaj 2007).*

COMMON ADAPTATIONS AND KNOWN PROBLEMS

More or less immediately after being finished, some neighborhoods had their external environments and landscaping improved with the help of governmental subsidization. Typically, flat uninterrupted lawns separated the buildings with no additional landscaping. This was a direct effect of methods such as completely flattening the ground and removing all vegetation to allow for crane tracks (See Figure 2) (Ramberg 2000; Vidén et al. 1992).

In 1983, a rent-loss subsidization introduced a few years earlier, when tenants were no longer lining up for every new apartment, was revoked. This forced property owners to find other ways to cover the costs of unused apartments. The solution was to adapt apartment buildings to other uses such as hotels and offices. In some cases, buildings, apartments, and even single rooms were locked and left with minimum heating. In other cases, entire buildings or a few floors of buildings were relocated.

According to Karpe (1990), buildings produced between 1960 and 1973 have considerably more moisture-related problems than those from other periods. These buildings represent 48% of the stock examined but are responsible for 84% of reported moisture damage to windows; 76% of problems are related to bathrooms and 79% of problems are related to flat roofs. Karpe also notes that when companies maintained and followed a maintenance plan, moisture problems were reduced significantly.

A problem when retrofitting these buildings is that since cost-efficiency was an important part of these projects at inception, the constructions were often optimized to reduce the cost of materials. For example, the amount of reinforcement steel was kept to a minimum. In effect, this means that it might not be possible to add new layers to exterior walls or make other changes that increase the load (Vidén et al. 1992).

In practice, the most obvious problem can often be the poor condition of wastewater pipes (Sverige. Boverket 2003). Replacing the pipes eventually forces the property owner to commence a complete retrofit to comply with regulations.

Attics

Petersson (1983) argued that in 1983, retrofitting insulation in attics was a fairly new method, where knowledge was lacking, especially concerning moisture and heat transfer. Problems noted include poor workmanship, moisture damage, mold, and pipes that ruptured from freezing. Problems can also arise when insulation is added to the attic and lowers the temperature without adequately reducing the moisture transport from the living areas due to diffusion through materials and air leakage due to holes and cracks (Petersson 1983). The reduction in temperature increases the relative humidity in the airspace if the moisture levels stay the same and can lead to mold growth, rot, and even condensate leaking into the structure and living areas (SRB1988).

The mechanism of condensation on interior surfaces of the roof due to night sky radiation—where surfaces open to the sky can become several degrees below ambient temperature, causing condensation—is not mentioned but is described in later Swedish publications, for example in the work by Samuelson (1995). The matter of constructing moisture-proof attics is not considered to be trivial even today, but a more recent study (Harderup and Arfvidsson 2008) indicates that significantly reducing outdoor air ventilation might be beneficial as long no moisture is allowed to reach the attic from the apartments through either diffusion or convection.

Roofs

The aforementioned combination of flat roofs and older bitumen-paper-based materials is a risk construction in colder climates, where water not draining from the roof can freeze and tear the paper substrate or seams. Water not draining will also affect the roofing material over time and allow for biological activity. The problems arising from leakages, and also the desire of property owners to reduce energy costs due to the 1970s energy crisis, caused many roofs to be redone only a few years after they were finished (SRB 1988). Petersson (1983) studied several different possible solutions that added insulation: it was found that a good solution for a flat roof is adding new insulation and a membrane on top of the existing roof while sealing the ventilation in the airspace (see Figure 3). This solution was studied in several buildings in Sweden as well as in Denmark for a few years and was found to be satisfactory. Petersson specifically noted that rain or snow must not be allowed to enter during construction and that a drain from the old membrane should indicate if the new roofing material leaks. Once again, moisture diffusion through materials and convection due to holes and cracks must be eliminated. The

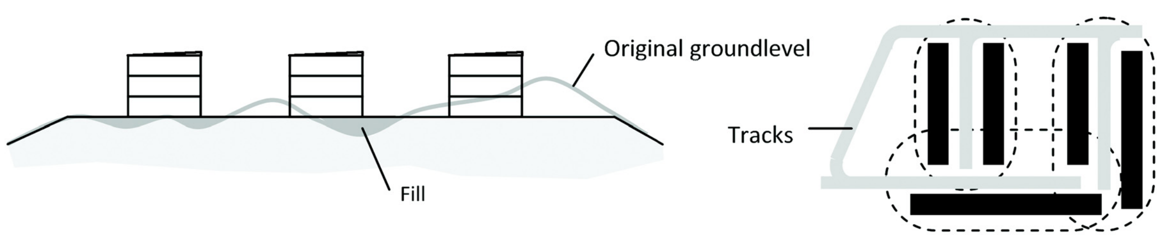

Figure 2 *The ground was flattened and the reach of track-bound cranes defined the placement of buildings.*

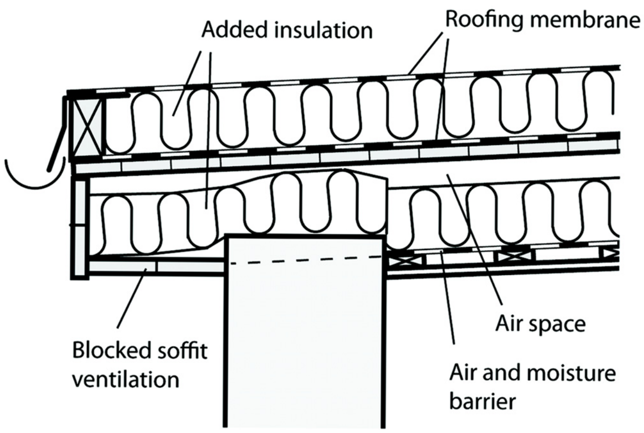

Figure 3 *Example of insulation added on top of original roofing membrane and blocked ventilation.*

two roofing membranes and the lack of a ventilated air space in this construction will drastically reduce the ability of moisture to leave the roof, making it even more important to reduce moisture entering from the living area.

Windows

Even though two-pane wooden windows were almost entirely used, providing fair energy performance, it became apparent that many windows showed signs of rot within only a few years. An early report from the moisture research group at Lunds tekniska högskola (LTH) indicates that the cause of rot is mainly due to the low-quality, fast-grown wood used coupled with poor workmanship; both were a direct effect of price cutting and new, unproven industrialized methods of production (LTH 1983). In some of the buildings, damaged window sashes were exchanged for exterior aluminium sashes and additional metal flashing to improve drainage. Special care was taken to allow for free air movement between metal and wood (Gaffner 1984). These measures have generally been successful. In other buildings, the entire windows, including the frames, had to be replaced due to rot, and the window area was occasionally reduced as an energy-reducing measure, affecting appearance and natural lighting.

Bathrooms

In a study of semi-public multi-family buildings presented by Karpe (1990), it was reported that houses built between 1960 and 1973 were responsible for 76% of the moisture problems found in bathrooms but represented only 48% of the examined apartments. This would mean that almost 18% of the studied apartments built between 1960 and 1973 had some sort of moisture problem in the bathrooms.

Untried plastic surface materials became common at this time, and speed was often preferred over accuracy and good preparations. New materials and paints with poor mold resistance and poorly performed joints made the surfaces sensitive. Originally, taking baths in tubs a few times a week was typical, but daily or more frequent showers became common, introducing much larger amounts of moisture that could not be handled by either the materials or the ventilation. Bathrooms with exterior walls, corners, and ceilings have shown increased problems due to cold surfaces causing condensation and longer periods of dampness. Typical viable solutions in addition to removing inferior materials have included adding year-round heated radiators to increase the moisture capacity of the air by raising the temperature and also by increasing ventilation rates (Vidén et al. 1992). During the 1970s energy crisis the opposite was true, when airtightening the building envelope without allowing for proper ventilation caused moisture problems in some buildings.

Exterior Walls

Due to the typical concrete slab construction, there are normally two types of exterior walls in a building. One type incorporates the load-bearing concrete slab and one is a curtain wall where wooden studs are typically used. Aerated autoclaved concrete (AAC) and other materials are used occasionally (Vidén et al. 1985).

Moisture damage in exterior walls is most frequent in joints of wall modules and on thin render on AAC, according to Karpe (1990). The most common facade type, brick veneer, is not considered to be problematic. There are, however, some cases of whole facades showing excessive spalling and a few vintages of bricks from certain manufacturers that have been known to deteriorate quickly.

There are also known incidents with brick veneer walls where the brick ties have corroded and large parts of multistory walls have come crashing down. Some buildings have had problems with mortar extending over the airspace and wicking moisture into the structure (Werner 2006).

There are other reasons than damage for the changes that were made to exterior walls, though. During 1980, somewhere between 15% and 20% of the buildings were eligible for a special governmental subsidization to add additional insulation to the walls. The results are uncertain, as are how many owners actually took advantage of this opportunity (Sverige. Boverket 2003).

Another important factor for energy efficiency is airtightness, especially if heat recovery is to be used in the ventilation system. Airtightness seams vary dramatically between these buildings, and original performance must today be considered unknown. Today, polyethylene plastic sheet is used as both an air and a moisture barrier on the interior side of the wall, due to the cold climate. The sheet is typically covered by gypsum board directly on top or, when possible, with a small insulated space for installations in between, to avoid puncturing the plastic. As a note, a balanced ventilation system in Sweden is typically set to lower the indoor air pressure somewhat to avoid moisture convection from the interior to the walls.

Interior Insulation

As early as a 1988 publication (SRB 1988), interior insulation was noted to accentuate thermal bridges, making floors near exterior walls colder as well as increasing the risk of condensation on these surfaces. The added interior insulation reduces the average temperature of more exterior parts of the wall, thereby reducing the temperature-dependent saturated vapor pressure. The outdoor vapor concentration remaining the same causes an increase in the relative humidity compared to before the interior insulation is added. With inorganic materials this is rarely a problem but, for example, wood studs in a curtain wall might reach unacceptable moisture levels.

A more recent report (Sjöberg and Wichlaj 2007) explores the effects of interior insulation when applied to a concrete-polystyrene sandwich system (see Figure 1). The authors found that a plastic moisture barrier must be used even when adding thin layers of insulation to avoid high moisture levels due to diffusion from the interior. This also improves the airtightness, benefitting both moisture states and energy consumption. They also concluded that a three-dimensional, nonstationary moisture simulation program would be beneficiary if these kinds of calculations are to be performed on a larger scale.

More practical problems caused by interior insulation include reduced floor area and covered radiator pipes, electric outlets, and switches, requiring new piping and conduits.

Even though there are these well-known problems when applying interior insulation, it continues to be used. Regulated preservation of facades is a common reason where the owner has no choice. Another scenario is when the facade is deemed to be in such a good state that it should be left. This is fairly common with brick veneer facades but should not be considered without verifying the condition of the brick ties.

DEMANDS AND REQUIREMENTS

Current government regulations express a maximal specific energy use (all energy used, excluding electricity not used for heating, hot water, and HVAC) in energy per floor area and year (kWh/m^2 per year; 1 kWh/m^2 equals 317 Btu/ ft^2), with different numbers depending on how far north a building is situated. The intention of allowing a higher use of energy in northern Sweden is that a house shouldn't have to be considerably different in construction in the far north compared to southern Sweden. The current regulations state that the maximum value is 110 kWh/m^2 per year in southern Sweden and 150 kWh/m^2 per year far north, with 130 kWh/m^2 per year in the central parts and even lower values for buildings heated with electricity (Sverige. Boverket 2009). Additionally, the Swedish government has set a goal that energy consumption per heated square metre in buildings shall be reduced by 20% by 2020 and 50% by 2050 compared to 1995 consumption.

The Swedish building standard defines the minimum accessibility allowed. Achieving this in typical apartments includes widening doors to the bathroom, kitchen, and at least one bedroom. The bathrooms are typically too small to accommodate a wheelchair properly and may need to be enlarged, affecting the efficiency and layout of an entire apartment.

As previously mentioned, two- and three-story buildings rarely have elevators, but there are possible solutions that allow for adding one, such as using part of the apartment area, reducing the width of stairs, or adding exterior stairwells (Vidén et al. 1992).

The indoor climate must also be satisfactory, so the choice of ventilation systems and materials with low emissions becomes a priority. Good thermal comfort is already more or less guaranteed since fulfilling the energy demands requires measures such as high-performance windows and airtight walls that counter typical causes for discomfort. Unwanted and regulated materials that are common in these buildings and must be taken care of include asbestos, used in grout and mortar, and polychlorinated biphenyl (PCB), used in the caulking of joints between wall slabs as well as windows. Typical measures include removing materials and grinding away affected areas or carefully marking materials and leaving them built into the construction if that is considered safe.

ASPECTS OF PRESERVATION

The Swedish Planning and Building Act (Sverige 2009) demands that changes made on any building should be made gently and with consideration of the character of the building as well as aspects of construction techniques, history, cultural history, environment, and artistic values. The actual interpretation is typically made by the local planning authority in conjunction with local or regional museums.

To aid in the application of the demand above on some typical kinds of 1960s and 1970s multi-family buildings, a publication by the Swedish National Heritage Board (Melchert 2006) was published. It exemplifies and discusses the features and impressions the board considers worth protecting, such as industrialized construction, new modern materials, grand-scale buildings, central planning, controversial buildings, debated buildings, buildings in parks, geometrically organized structures, and the aesthetics of repetition.

Though, as noted by Johansson (2008), making changes to a building before it is considered worth protecting might benefit the owner. Future adaptations are then possible since the building will not be in an original state and will therefore not be considered worth protecting.

TYPICAL ENERGY IMPROVEMENTS

Typical improvements made today include adding insulation to both attic and walls as well as adding new windows or at least new efficient low-emission panes. Using air-to-air heat recovery to heat incoming air with the outgoing is very common. A recurring problem with no satisfactory general solution is how to run the air ducts without reducing usable space. There are also attempts to affect the behavior of tenants by measuring their use of heating and hot water and adding the costs to their rent or rewarding low consumption.

The long-term effect of these measures on the structure and indoor environment is not yet known. Some concerns have been raised as to how both internal insulation and heat recovery systems are being applied, but no general results are available at this time.

RELATED ONGOING RESEARCH PROJECTS IN SWEDEN

There are currently many ongoing research and development projects concerning the 1960s and 1970s Swedish multi-family homes. Three projects with somewhat different goals are briefly described in the following sections.

Milparena

Milparena is a regional Swedish project that includes participants from Chalmers University of Technology and SP Technical Research Institute of Sweden as well as the cooperation of several property owners. The project documents and offers advice and experimental resources to some retrofit projects being undertaken by the cooperating property owners. Results and experiences are intended to be shared between the participants and other concerned parties.

Square

The main goal of the European research project Square, coordinated by SP Technical Research Institute of Sweden, is to develop a quality assurance system and apply it to pilot projects consisting of 1960s and 1970s buildings in several European countries. The intention is to achieve good indoor environment and energy performance by the means of a structured workflow from early preplanning to follow-ups during the management phase. Good examples and experiences are to be collected within the pilot projects and are to be communicated together with the quality assurance system to interested parties within the construction industry, property owners, consultants, and so on (Square 2010).

Energy-Efficient Measures

An ongoing project at Lund University studies the effects of added interior insulation. The project includes moisture measurements on full-scale wall elements in a climate chamber, simulations, and field measurements. The field measurements are made with the collaboration of a project of Bebo, a cooperation between some major owners of multi-family residential buildings and the Swedish Energy Agency. The project documents and evaluates the whole process of retrofitting 1960s and 1970s housing projects, from initial planning to energy and moisture measurements during normal operation, with the intent of spreading acquired knowledge and experiences.

DISCUSSION

Karpe (1990) cited a housing company that, in 1990, described the situation of a large part of the housing stock about to be in dire need of radical renovation as “an avalanche coming straight at us” (p. 23). Twenty years later, that avalanche is here and a large portion of these buildings are in need of thorough renovations.

The modifications and corrections that have been made to the buildings over time as a result of problems occurring are rarely properly documented, and the sheer amount of corrections ensures that unknowns will arise during retrofits. This positively poses a problem when trying to keep costs down, time scheduled, and quality high in a controlled manner. When planning is made based on incorrect assumptions concerning the potential of improvement, the calculated gains in energy efficiency as well as financial gains will bring the project to the wrong conclusions. This can lead to expensive and unnecessary measures being taken or to not reaching set targets. Even when all involved are aware of the possible problems that could occur, undertaking a project with a wide margin of error will be expensive. When an owner has many similar buildings, a pilot study on one or a few buildings is one way to reduce uncertainties and try possible solutions.

The typical nonstationary moisture simulations in real projects today are made in one dimension, in large due to the capabilities of available commercial software. The problems, however, are not one-dimensional; the worst-case scenario could, for example, be at the lower exterior corner where a load-bearing concrete wall meets a curtain wall with wood studs on top of the ground slab—a three-dimensional problem not easily simplified. In a new building this can be handled by adapting the construction, but an existing building can only be changed to a degree before demolition might be preferred. Add to this uncertainties related to the construction and aged materials in older buildings, and it might make more sense to remove sensitive material than to trust simulations.

The often good condition of the brick veneer facades is in a sense a problem when it comes to retrofits. Spalling or cracking brick overrides the question of preservation and expected remaining lifetime of the facade. Exterior insulation beneath a new facade material will then typically be the choice. A brick veneer facade in seemingly good condition will, however, have to be examined so that all parts of the wall are in good condition, including brick ties, air spaces, and so on, if the wall is to fulfil its intended function, at least until the next scheduled major renovation.

An obvious conflict of interest is the will to preserve versus the will to reduce energy use. This is a very complicated question where one law is put up against another and interpretations have to be made. It is, however, without doubt a question that brings even more complexity into the process.

These 1960s and 1970s buildings are now approximately 40 years old, and these retrofits are supposed to last another 40 or 50 years. If they do, they should be able to handle the demands of the next 40 years, including energy demands. The previously mentioned national goal that energy consumption per heated square metre in buildings be reduced by 20% by 2020 and 50% by 2050 compared to 1995 consumption will be difficult to achieve. Since the majority of the buildings that will exist by 2050 are already built, existing buildings must be retrofitted with good energy performance for the entire building stock to fulfil this goal, unless future buildings are to be zero energy or net producers. The only economical opportunity for doing these adaptations for the 1960s and 1970s multi-family buildings is now, when large-scale retrofits are necessary due to the general aging of the buildings and their systems.

From the standpoint of the property owner, the cost of retrofitting must be paid for and the desired payback period becomes crucial for how large an investment can be made. In Sweden today, it is not really possible to raise rents by large amounts after a retrofit since the original quality level of these apartments is fairly high, though of course worn. If the property owner has previously argued that wear should not affect the rent level as long as function is not affected, it becomes harder to argue that a retrofitted apartment with retained functionality and quality level should significantly affect the rent. An example of what can be considered a reduction in quality level is when the solid wood cabinetry originally installed in the apartments is replaced by cabinets made of engineered wood during the retrofit (Sverige. Boverket 2003).

Yet another question is how to handle the information and findings produced by the large number of research projects currently examining these buildings. Even though many projects have dissemination packets, the sheer amount of projects is daunting. The research community will no doubt digest the material, but the findings need to be palatable and useful for the industry to reach practical use.

There are inherent conflicts between the demands of reducing energy consumption while providing a good indoor climate and durable structures. For example, outdoor air ventilation rates can't be reduced below certain levels to conserve energy without negatively affecting indoor climate. Durability of the retrofit and original construction will be affected if moisture levels rise to dangerous levels due to poor construction or workmanship. Durability can't be extended by applying treatments that affect the indoor climate. During a retrofit, the possible gains and risks must be assessed based on knowledge of the building's properties and the mechanisms affecting them.

CONCLUSION

Despite the large amount of multi-family buildings produced in Sweden during the 1960s and 1970s, there are typical features and problems among them, mainly because of the industrialized construction methods and required standardization at the time. Today, however, the possible uniformity of yesterday is gone due to many reparations and adaptations. This makes it difficult to plan retrofits in detail, especially since documentation detailing the building and its components, materials, and changes is often hard to find or not correct. Due to this, it becomes difficult to predict the effects of energy-reducing measures, both the savings to be expected and the possible problems. Also, these retrofits should provide a good indoor climate with good comfort and air quality.

Yet another problem is how to balance preservation and energy reduction. This question is in many parts a matter of opinion, and finding common ground will not be easy.

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