THE STOCKHOLM PROJECT: ENERGY-EFFICIENT BUILDING TECHNOLOGY IN NEW APARTMENT BUILDINGS

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ABSTRACT

Since the first energy crisis in 1973 massive efforts have been made in Sweden to make new buildings energy-efficient. The total energy consumtion (heating, ventilation, hot water, domestic electricity) in apartment buildings constructed during the seventies is approximately 200 kWh/m^2 per year. Different techniques can be used to reduce the energy demand, and this the paper discusses strategies for designing energy efficient buildings.

The Stockholm Project is the first big experimental building project in Sweden in which new energy-efficient apartment buildings and solar heating technology are evaluated. The project consists of six buildings containing 280 apartments and 2500 m^2 of office space. Five buildings were finished by August 1985, and the first three are given a detalied presentation in this paper. The last bilding are to be finished in spring 1986. A more general description of the project is given, as well as some experiences from the construction and installation periods.

The City of Stockholm, together with the Swedish Council for Building Research sponsores the demonstration project which is one part in the Council's effort to promote development of new energy conservation technology and systems in both new and existing buildings.

The scope of the project is to try new construction methods and installation systems at full scale, aiming for a considerably lower demand for purchased energy and lower operating costs. According to calculations, total energy consumption is to be reduced about 50% compared to buildings constructed in the early eighties. Well established technology is used primarely, but in each of the buidldings at least one new method for energy conservation is tested, which previously had not been tried at full scale. The new methods vary from improvement of well-established systems to relatively advanced technology. Because new buildings tend to be more and more complex, one of the main concerns in the project is to evaluate how different systems interact in order to form a good background for the design of future buildings.

INTRODUCTION

Since the energy crisis during the early eighties massive efforts have been made in Sweden to develop new technology for energy-efficient buildings. This effort has had a great influence on both new buildings and retrofits. Both the building and installation techniques have developed at great speed during the last ten years and given us a great deal of new experience. One thing we have learned is that a good interaction between the building and installation techniques is essential to accomplish an optimal system. Another thing we have learned is that the new energy-efficient technology can be adapted to traditional building techniques. The energy issues cannot, and must not, be treated separately but integrated as one of several important factors in the construction of a building.

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Sweden is situated between latitudes 56° and 69°N, which means that Sweden is further north than the border between the USA and Canada. Stockholm is situated at latitude 60°, which is the same as the border between Alberta and the Northwest Territories. However the climate in Sweden is milder due to the Gulf current. The climate in the southern part is somewhat milder but the climate in the northern part of Sweden is considerably colder. The sun angles during the winter are low due to the northern latitude, and the number of possible sunny hours is very small.

The fuel for the heating of buildings before the Second World War was mostly wood in rural areas and coal in the cities. Even if the supply of wood was good, it caused heavy work and emissions, and so efforts were made to decrease the amount of wood used. Because of this early effort to lower fuel consumpton, the quality of early Sweadish building was quite high.

After World War II, oil started to be substituted for coal and wood, and at the beginning of the eighties 70% of all space heating was oil heating. Due to the fact that Sweden has to import all its oil, the oil dependence was enormous at the time of the energy crisis in 1973/74. Great efforts have been made since then both to decrease the total energy demand and to minimize the amount of oil used for heating. As of 1984, the oil share has been recuced to almost 40% and the total consumption of energy for the heating of dwellings and other buildings has been reduced with 20% .

PASSIVE TECHNIQUES

Experience shows that passive technuiqes are often the most suitable for simple buildings such as dwellings. By passive techniques, we mean a careful design of buildings to make them as durable as possible, not to conmplex systems for heating and ventilation, very good thermal insulation, avoiding of thermal bridges, windows with very high insulation capabilities, and buildings made as airtight as possible to ventilate them efficiently regardless of the outdoor climate. This kind of building technique will have a low gross energy demand, as well as a low energy demand for heating, making it possible to use a lower capacity heating system.

A result of low energy demand and low installed heating capacity is the importance of constructing all parts of the building according to the design. If that goal is accomplished, is it possible to use simple and hopefully reliable equipment and installations. Also, the costs for operating and maintenance will be low with this kind of system. Buildings designed after this principle are also less susceptible to future increased energy cost. It is also quite easy to maintain thermal comfort at a low cost in this kind of building.

From society's point of view, the low energy demand leads to less investment in and less emmission from energy production plants. The demand for imported fuel will also be lower and this benefits the GNP. It is also possible to use already existing energy production plants for a greater amount of building area without any new investment in the existing system. The capital saved on the energy production could be released and used in improvement of the buildings, thus increasing the value of the building stock. Passive techniques are in most cases preferable for apartment buildings when it is important to reduce the maintenance costs.

ACTIVE TECHNIQUES

In some categories of more complex buildings, such as schools, offices, and hospitals, is it often suitable to use a strategy where more active techniques to adapt the systems to different kinds of specialized use, such as intermittent use or large interior heat loads. This means that an advanced mechanical technology is used to reduce the amount of purchased energy for heat and ventilation. This kind of building often has large gross energy consumption. It is also sometimes possible to use a simpler and less expensive building technique.

In buildings with large internal loads it is suitable to use HVAC systems for heat recovery and/or short- or long-time storage to reduce the requirements of purchased energy.

The advanced technology used, however, requires a very good quality of both equipment and installation, good maintenance by qualified and motivated maintenence personnel, and an advanced energy management and control systems. This is important as an active technique will result in higher maintenance costs than a passive system. The installation and start-up periods must be given great attention. During this time is it important that the designer's and installation technician's knowledge be transferred to the maintenance personnel. This take time and resources.

Our experience is that energy-saving equipment, such as heat pumps and heat exchangers, usually works well separately, but when combined in a system, weak parts often reduce its performence. We see dampers that do not shut; pumps wrongly installed, malfunctioning, or even wrongly dimensioned; temperature sensors at wrong places or out of order; shunts wrongly installed etc. The design of and choice of equipment as well as control of the working system is, as you see, essential for the result. You always need qualified maintenance personnel when using active techniques, since the installations normally have shorter durability than the building itself. It can also in the future be necessary to change the installation system to a newer and more energy efficient.

THE STOCKHOLM PROJECT - SIX EXPERIMENTAL BUILDINGS

In the evaluation of full-scale experimental buildings, we have unique possibilities to closely study strategies for energy savings as well as how different systems interact. The result can be used as well for new buildings as for retrofits.

The Stockholm Project is Sweden's first big experimental project for evaluation of new energy-efficient apartment buildings. The City of Stockholm, together with the Swedish Council for Building Research, made a demonstration project to try new strategies for energy conservation in buildings. The project is one part in the Council's effort to promote development of new energy conservation technology and systems in both new and existing buildings. Six different builders are responsible for the building design, construction, and management of the buildings, while the Energy Conservation Group is responsible for the main energy evaluation. The total number of apartments is 280 among six sites; 2500 m^2 of office space is also included in one project. The buildings are to be finished before spring 1986. Three buildings finished before August 1984 are given a more detailed presentation in this paper.

The scope of the project is to try new construction methods and installation systems at full scale, aiming for considerably lower demand for purchased energy and lower operating costs. According to calculations, total energy consumption is to be reduced by about 50% compared to buildings built in the early eighties. Well established technology is used primarily; but in each of the projects at least one new method for energy conservation, which had not been tried previosly at full scale was tested. The new methods vary from improvement and development of well-established systems to relatively advanced new technology. Because new buildings tend to be more and more complex, one of the main issues in the project is to evaluate how different systems interact in order to form a good background for the design of future buildings.

Some kind of solar heating is used in five of the six sites. One uses solar collectors for heating domestic hot water and to preheat the supply ventilation air. Two of the buildings use glazed courtyards, which, apart from being an attractive building feature, serve as passive solar collectors where exessive heat is stored in the building structure or in rock storage. In another the concrete facade is used as a kind of solar collector, where the ventilation air is here taken in behind the surface of the concrete exterior wall. The last solar-heated building uses glazed balconies and circulates warm air (when it is over +22°C) from the balconies through ducts in the concrete floor slab. This site also uses increased insulation to minimize heat losses through the exterior shell. Table 1 lists the buildings, a rough time schedule for the evaluation program, and different building characteristics, and the number of apartments in each building (the name listed is the block name in Swedish).

GENERAL DESCRIPTION

The "Sjuksköterskan" Housing Model

The Sjuksköterskan building complex is an example of a passive technique with increased insulation and conventional building and installation technology. Higher demands than usual are placed on the building and on energy conservation qualities, such as thermal insulation, airtightness, ventilation, etc. These higher demands are met primarily through the use of quality control in the design and building phases.

The complex consist of two buildings with four flats clustered around each stairwell and lift core, 40 apartments in all.

The main evaluation concerns in this project are the increased insulation and the quality control.

Structural System. The buildings has a concrete ground-floor slab. Other floors and bearing walls are cast in place. Exterior walls are for the most part rendered. Infill walls are constructed of timber-framed stud walls. The traditional saddle roof construction is of strutted rafters, built in place and roofed with building paper. The attic is insulated with loose mineral wool blown in place. The following average U-values have been calculated for the Sjuksköterskan buildings:

exterior walls	0,17 $W/m^2 \cdot K$
basement exterior wall (average)	0,40 $W/m^2 \cdot K$
attic floor	0,12 $W/m^2 \cdot K$
ground foor slab (living areas)	0,20 $W/m^2 \cdot K$
exterior ground floor slab areas	0,50 $W/m^2 \cdot K$

Ground Floor Slab. A layer of insulating material is placed both above and below the concrete ground-floor slab. The lower insulating layer also contributes to the moisture-proofing capacity, while the upper layer helps to reduce the thermal bridges at the joints with the lower walls. Therefore, the floor is expected to maintain a high surface temperature. In order to further reduce the heat loss through the floor slab near the exterior walls, a prefabricated socle piece is placed on the exterior edge of the floor slab, and ground insulation is laid out around the slab perimeter.

Exterior Walls. Outer wall surfaces are mostly rendered. Galleries and balconies have parapets of glass-fiber reinforced concrete panels.

The three types of walls are (from outside to inside):

1. Gable walls:

rendering	
lightweight cinderblock	190 mm
air space	20 mm
mineral wool	195 mm
concrete	150 mm

2. Cinderblock walls:

rendering	
lightweight cinderblock	190 mm
mineral wool	145 mm
mineral wool	70 mm
polyethylene film	0,2 mm
gypsum board	13 mm

3. Timber stud infill walls:

plaster board	6 mm
air space	20 mm
gypsum board	9 mm
mineral wool	220 mm
polyethylene film	0,2 mm
mineral wool	45 mm
gypsum board	13 mm

End walls are load-bearing concrete. Mineral wool insulation is affixed by means of cast in ties; these are also used to anchor the cinderblock cladding. It is very important that the insulation fits snugly against the concrete.

The end walls are clad in 600 x 200 x 190 mm lightweight cinderblock masonry. In order to improve the heat transfer coefficient, a mortar is used that mainly consists of a filler composed of light cinders under 4 mm in diameter. No mortar is used in the butt joints. The block wall is rendered on the outside. A specially constructed box is used to ensure uniform thickness of the joints.

Polyurethane foam is used in joints to ensure good weather sealing and insulation properties. In infill walls, foam is applied at the same time to the joint between the wall element and the window framing. When jointing is complete, the inner layer (45 mm) of insulation and the interior gypsum board are installed.

When the plastic film is set back 45 mm from the wall, it is more protected than it would be if placed immediately adjacent to the gypsum board. The plastic film is sealed to the window frame with a sealing compound. The plastic film is attached directly to the polyurethane foam at the concrete walls and floors. The attic floor is insulated using a rather new method. Insulation of loose glassfiber is blown against the floor structure.

Pressurization Tests. The result of a pressurization test made in the building was close to 1.0 air exchange per hour at 50 pascals. That was a higher value than predicted and the reason was found to be leaks in the sealing between the polystyrene film and the windows.

HVAC Systems. The Sjuksköterskan building use an uncomplicated heating system. The apartments are heated by water-borne heat in radiotars and ventilated with pre-warmed fresh air, and the building has a mechanical ventilation system with a heat exchanger.

The fresh air supply and exhaust air ventilation systems are mechanically operated, and both can be adjusted in mixing boxes that can be reached from access panels in the roof. Separate ducts from each apartment lead to the boxes and are connected to the main ducts, which lead to double-crosswork heat exchangers in the fan rooms. The supply air is preheated to 20 °C during the heating season. The degree of efficiency of this type of heat exchanger is calculated to be 70%.

The Kejsaren Housing Model

The Kejsaren building is in the City of Stockholm and adapted to traditional city housing with regarding to bouth architecture and facade materials. It was built using conventional building technology, but parts of the HVAC system is very advanced and untested. The heating system is an active system that uses solar collectors, heat echangers, hot water storage, and heat storage in the concrete slabs between the apartments. Each flat is heated by warm air that has been preheated in a solar collector.

The building is six stories high and contains ten apartments and a shop and garage on the ground floor. The air solar collector of 100 m^2 is a part of the roof construction. The main evaluation conserns in this project are the solar collector and the warm air heating system.

Stuctural System. The structural framework consists of in-situ cast concrete loadbearing walls and floors. Infill walls between the load-bearing sections are made of lightweight cellular concrete blocks, rendered on the outside. The following average U-values have been calculated for the Kejsren building:

exterior walls	0,26 $W/m^2 \cdot K$
attic floor	0,16 $W/m^2 \cdot K$
basement floor	0,25 $W/m^2 \cdot K$
basement walls	0,27 $W/m^2 \cdot K$

Exterior Walls. The exterior walls are of glued 200 x 400 x 600mm lightweigt cellular concrete block, density 400 kg/m^3. The low density also gives a good thermal insulating capacity (0,11 W/m K). The block wall is rendered on the outside with a reinforced three-layer coating. Wall thickness is reduced from 40 to 20 cm at the joints between wall and floor to provide an adequate bearing surface.

Roof. The roof of the Kejsaren building is unusual in that it was designed solely to fit the needs of the solar collector. That makes the angle of the roof fall rather steep, 55° to horizon. The solar collector is mounted upon a framework of timber studs. The space between the studs is filled with mineral wool to reduce the heat loss through the solar collector. The principle of the solar collector is to circulate air between a flat plate and a profiled plate. The flat plate is coated with a selective surface and covered with glass. The attic is insulated with bats of 10 cm + 14 cm mineral wool bats.

Pressurization tests. The result of a pressurization test made in the building was the lowest so far in the Stockholm project, down to 0.35 air exchange per hour at 50 pascals. This low value is a result of the exterior wall construction, where the glued lightweigt concrete, and joint seals of polyurethane foam around the window frame gives an extremely air-tight construction.

Installations. Each flat is heated exclusively by warm air. Fresh air is heated by first transferring heat obtained from return air via a heat exchanger located in the attic. If the solar radiation is high enough, the air is made to pass through the solar collector, obtaining warmth. Thereafter the air passes through a cooling and heating battery. If the air is too warm at the entrance to the battery, the surplus is used to heat the household's hot water supply. When the hot water accumulator is fully charged, then the surplus heat is discharged. If the air is too cool when it reaches the heating battery, it will be warmed with the help of the hot water of the district heat receiving station in the building. A sensor registers the temperature of the air leaving the heat battery, and computer control ensures that the air has the right temperature before passing through ducts in the concrete floor. Heat is stored in the concrete floor on a short-term basis from day to night. During days with an excess of solar heat, the surplus is stored in the concrete floors and later emitted during the night.

Each flat has its own heat aggregate through which ventilation air passes. When necessary the air can be further heated with hot water from the heat-receiving station. Fans enable the airflow to be increased from a rate corresponding to 0.5 exchanges per hour up to a maximum of 1.3 exchanges per hour.

The gross energy requirements are quite high compared with the Sjuksköterskan buildings, but the building has low net energy requirements. During the early evaluation stages, we made some interesting observations (Hambraeus et al. 1985), which clearly show the importance of carefull controls in this kind of buildings. Before the building is turned over to maintenance personnel, every state of operation and each component must be tested for optimum performance.

The Konsolen Housing Model

In the Konsolen buildings we see an example of improvements in traditional building and installation techniques, but this does not mean that no further development can be done. The structure is built of a prefabricated frame of concrete elements for the walls and floors. The characteristics of this type of housing model are the heavy framework and the solar facade where the fresh air supply is warmed by solar radiation striking the surface of the wall.

This building complex consists of two gallery blocks of apartments, 57 flats in all. The main evaluation conserns in this project are the solar facade and the heavy frame.

Stuctural System. The Konsolen building is made mostly of structural elements. Exterior walls, inner walls, and floors are all made of prefabricated concrete. Only the ground-floor slab is cast in place. Painted windows are installed in the walls at the factory, and the entire wall element is delivered painted to the building site. The following average U-values has been calculated for the Konsolen building:

exterior walls	0,28 $W/m^2 \cdot K$
attic floor	0,15 $W/m^2 \cdot K$
ground floor slab	0,21 $W/m^2 \cdot K$

Foundation. The ground-floor slab is made in the following manner:

sand bed above gravel filling	150 mm
styrofoam insulation	100 mm
concrete	100 mm

The edge beam is insulated with 70 mm of styrofoam. In addition styrofoam ground insulation is laid around the perimeter of the buildings.

Exterior Walls. The Konsolen building model is constructed of concrete elements used for both exterior and inner walls. These one-story-high elements are 160 mm thick for inner walls, which may be up to 8 meters long, and 280 mm thick for exterior walls. The latter are built up of an inner 80 mm thick load bearing layer, 140 mm styrofoam insulation, and an exterior layer of 60 mm concrete. The concrete elements are lifted into place by means of a construction crane. Metal fitting washers of appropriate sizes are used to ensure that exact heights of the building elements are obtained, and surveying instruments are used to ensure that horizontal joints are level. A final mortar course is laid out as bedding for the wall elements.

In order to anchor the exterior wall elements at the sides, dowels are driven into the pre-bored holes in the lower part of the exterior wall elements. This fixes the exact location of these elements in relation to neighboring elements. The holes are 50 mm in diameter and the dowels inserted are 25 mm. Before the elements are set in place, the holes are filled with mortar; once this hardens the elements are permanently fixed in place.

Vertical joints between the elements are sealed with a polyethylene encased mineral wool weatherstripping. This weatherstripping is a few tenths of a meter longer than the height of the wall element; the excess is wrapped around the corners of the elements into horizontal joints. A rubber strip fillet is cast into one edge of the element.

As both the exterior and inner wall elements are load-bearing, two different floor elements are used. Those elements that are supported on three sides use non-tensioned reinforcement, while those that only rest upon inner wall elements use pre-stressed reinforcement to reduce deflection since the spans are up to 7.8 m wide.

Sunwalls. The exterior wall elements on the south and southwest (we call them "sunwalls") exposures are equipped with vertical air ducts. The ducts are of sheet metal and mounted together with insulation in the sandwich element. Exhaust fan ventilation underpressurize the flats and force the supply air trough the sunwall. Fresh air is led through the ducts to a ventilator under the window, being warmed in the process by heat stored in the exterior concrete plate resulting from both direct and diffuse solar radiaton. Heat loss by transmission from the inside of the apartments to a certain extent also contributes to warming the air.

Pressurization Tests. The results of pressurization tests made in the building were usually between 0.70 and 1.0 air exchange per hour at 50 pascals. The values were never over the 1.0 recomended by Swedish Building Code for this kind of apartment house. Some areas where it is still possible to achieve lower leakage are the seals around windows and doors in the exterior facade; sealing between apartments is also important.

Installations. The Konsolen buildings are connected to a district heating system. Each apartment is heated by water-filled radiators, and the fresh air supply is warmed by the solar facades. A heat pump recovers heat from the exhaust air. The return air ducts from each apartment lead to the attic, where they are connected to a main duct that leads to a heat exchanger. The heat pump itself is located in the basement and transfers energy to the radiator system if there is any heating demand; otherwise it goes to the domestic hot water system.

The Bodbetjänten, Höstvetet, and Skogsalmen Housing Models

The Bodbetjänten and Höstvetet building projects are in their final stages. Experiences of the buildings and installation systems during operation stages is still not available.

Bodbetjänten consists of an office building coupled to an apartment building. An advanced active technique is used to collect and transfer excess heat from the office areas to the apartments. The return air from the offices circulates through ducts in the concrete floor slabs. Advanced management and control systems are used, and a great effort was made during the design stages to visualize and explain the system and its functions. This will probably make the management and operation more easy.

In Höstvetet an active system for seasonal storage of heat in bedrock will be tested. The storage in this project is of reduced size as it will only provide space heat to this one building. The great potential for this kind of storage is normally considered to reach its optimum when of a size to deliver heat to a numbers of buildings. The goal of the storage is to get experience of the system and its operation.

In both Bodbetjänten and Höstvetet, there are glazed atriums - an interesting new technique used in apartment buildings. The effects of the atriums on the living environment and the tenants' behavior and their use of the atrium will also be closely studied.

In the Skogsalmen project, glazed balconies are used to produce heat during sunny days. The warm air is then used to heat the concrete floor slabs of the apartment. The floor slabs both contribute to the heating during sunny days and store heat from day to night.

MONITORING

During the first year after the buildings were completed, the monitoring system is used primarily to monitor the installation and to check the monitoring and evaluation program. The second year is the main evaluation year, which we have now entered. A more detailed description of the monitoring program is presented in (Hambraeus et al. 1985).

CONCLUSION

Knowledge - The Key to Good Energy Efficient Houses

In the beginning of an evaluation program of this size, it is always important to try to describe its usefulness. Some of the subjects we want to get a deeper understanding of are:

- building dynamics
- empirically based simulations
- verification of analytical simulations
- evaluation of options
- new techniques in relation to existing code criteria
- energy
- economy
- evaluation of indoor climate and environment
- design techniques
- building construction
- maintainance and operation
- system and subsystem performance, etc.

In this paper we have only briefly discussed some of the subjects listed above and briefly described the buildings in the Stockholm project.

The results we have today is not usable for telling the actual energy balances for the first three buildings. The first evaluation year has mainly been used to adjust the installations and the monitoring system. Experience of great importance has been collected according to the importance of complete function control of all different cases of operation possible. We have also learned that it is necessary with extencive monitoring to make it possible to determine if the different parts in the system is working at it's optimum. The back-up systems is activated much to often when there is a malfunction in the system, and if monitoring is not done continously the back-up system will be used in a undesired way during to long time.

New energy efficient buildings tend to be to complex. This complexity demands extencive monitoring and superintendence to ensure a satisfactorily function of the heating and ventilating systems.

The main conclusions we would like to state after this early stage in the evaluation program are the importance of well-built buildings and well integrated, built, and installed heating and ventilating systems and the importance of knowledge, gained from full-scale experimental projects to help develope new building and energy-efficient heating techniques.

REFERENCES

Hambraeus, M.,and Werner, G.,1985. "The Stockholm Project - Program for measuring and analysing new energy efficient buildings. Presented at the joint ASHRAE/DOE/BTECC conference, "Thermal Performance of the Exterior Envelopes of Buildings III," Clearwater Beach, Fl, December 2-5.

TABLE 1

Buildings and Techniques of Special Interest in the Evaluation Program for the Stockholm Project, Number of Apartments and a Rough Time Schedule for the Evaluation Periods.

No.	Building Name	Number of Apartments	Technique	Evaluation Period
1	Sjuksköterskan	40	Increased insulation Quality control	84-86
2	Kejsaren	10	Solar collector Air heating	84-86
3	Konsolen	57	Solar facade Heavy frame	84-86
4	Bodbetjänten	35	"Combined effect" Glazed courtyards	85-87
5	Höstvetet	45	Air heating Glazed courtyards Borehole storage	86-88
6	Skogsalmen	64	Glazed balconies	85-87