FLEXREN - FLEXIBLE FACADE SYSTEM FOR ENERGY CONSCIOUS RENOVATION OF EUROPEAN HOMES

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Abstract – The FLEXREN project demonstrates an exemplar sustainable building renovation including integration of solar energy. Focussing on buildings from the 1950's owned by the housing organisation Østerbo, the FLEXREN project represents the coming phase of European building renovation. The project involves 94 apartments all facing east and west. The renovation was completed on time and on budget in January 2001. Monitoring before renovation was completed in autumn 2000. Monitoring and evaluation after renovation will be completed in autumn 2001. The key goals of the energy conscious design, which was developed through an integrated design process, are: Implementation of a newly developed flexible facade concept, improved thermal comfort and air quality conditions, substantial energy savings, facade integration of solar energy components and design development through an integrated process (including client and tenants). The main energy elements are: Usage optimised energy efficient glazed balconies, unventilated solar mass wall with transparent insulation, ventilated solar walls, convector integrated fresh air in-lets and demand controlled moisture regulated ventilation. Besides the energy related aspects, the project has focussed on logistical aspects of ecology (optimisation of materials) and modular mass production. Therefore, also Life Cycle Cost analyses have been an important tool in the design phase. The energy demand for heating and ventilation is expected to be reduced by 50% compared to a standard renovation. Thus, the energy demand will be lower than that of a building constructed in accordance with the Danish building code of 1995. The paper includes results from the design studies, a description of the final design and the completed building as well as preliminary monitored data.

1. INTRODUCTION

1.1 Aim

The FLEXREN project represents the coming phase of European building renovation, as it focuses on buildings from the 1950’s, which are the next building types to be renovated. Today, several innovative designs have been developed and demonstrated in numerous international projects dealing with renovation of the old building stock (before 1950). This project makes use of the lessons learned and implements ideas from these projects together with the latest and most promising solar techniques from several ongoing international research projects dealing with energy conscious building renovation.

The key goals of the project were:

- Development of a new flexible facade concept
- Achievement of substantial energy savings
- Implementation of innovative passive and active solar energy components
- Project development through an integrated design process

1.2 Innovation

The project is based on a concept for optimising the integration of solar energy in building renovation. The design team is and have been involved in many international research and demonstration projects initiated by EU and the International Energy Agency. This has helped to ensured that state of the art of innovative solar renovation designs have been implemented in the project. The design development has in particular been based on the experiences from the EU DG XVII Targeted project "SHINE", and on the research project within the IEA SH&C programme, Task 20: “Solar Energy in Building Renovation”.

The most important energy elements involved are: Usage optimised energy efficient glazed balconies, unventilated solar mass walls with transparent insulation, ventilated solar walls, advanced convector integrated fresh air in-lets and demand controlled moisture regulated ventilation.

1.3 Expected results

An exemplar European sustainable renovation of multi storey housing from the 50's shall be demonstrated. It is expected that the design of this building will contribute to the design of the coming phase of urban renewal building projects in Europe, which must focus on similar buildings.

It is expected that the energy demand for heating, ventilation and production of domestic hot water and the energy demand for electricity for household will be reduced by more than 50% and 22% respectively. Thus, the energy demand will be lower than that of a building constructed in accordance with the Danish building code of 1995. Similarly, a significant reduction of the pollutant emissions of 54% is expected.

The innovative renovation scheme is expected to be economically feasible on a short time period.

2. BUILDING LAYOUT BEFORE RENOVATION

2.1 Location of the project and the present situation

The project is situated in the city of Vejle, one of the three main cities in the "triangle-area" of Jutland. In this specific area, a lot of initiatives are carried out regarding business and industry, social activities, "green living" and urban renewal. Thus, on a national as well as on an international level there is a lot of attention towards the activities in this area.

In Vejle, there are a lot of apartment buildings which are administrated by a few housing companies. Of these housing companies, Østerbo in particular is well known for its initiatives to keep their buildings in a good and healthy condition with respect to building physics.

As energy costs amounts to an increasing part of the running costs, the housing company has decided to give more attention to energy saving initiatives. One of the departments of Østerbo (No 9, three east and west facing blocks, 94 apartments ~ 7700 m²) has been selected as especially suited for also carrying out an ambitious energy renovation based on the utilisation of renewables (especially solar energy) in combination with a conventional renovation. Afterwards, the most promising results of this activity will, to the extent practicable, be implemented in the renovation of the remaining departments.

The external walls are either massive brick walls or uninsulated cavity walls. Some of the cavity walls have been insulated. In some of the apartments, the house ends have been insulated with thin plates of polystyrene on the interior side. About 12 years ago, all windows were replaced by conventional double glazing with plastic framing and careful sealing around the windows. The apartments are ventilated through opening of the windows, as there is almost no infiltration. This means that serious mould and condensation problems occur. The heating system is hydronic with older radiators. Heating is district heating.

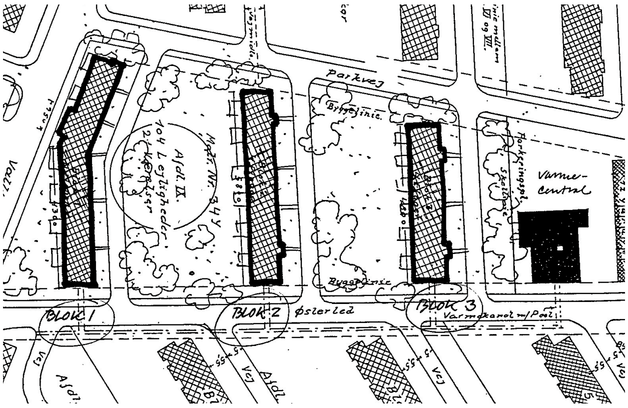

Figure 1 The three east and west facing blocks of department 9 to be renovated

Figure 2 West facade before renovation

Figure 3 East facade before renovation

Figure 4 West facing balcony before renovation

2.2 Conventional renovation

What is especially remarkable among the activities of Østerbo, is that renovation is planned and initiated before the buildings degrade to a level where comprehensive renovations are necessary. As a result of this provident policy, Østerbo during these years is carrying out a standard renovation and modernisation of all their departments. This comprehensive modernisation relates 94 apartments. The modernisation comprehends:

New kitchens, new bathrooms, extension of heating system, new water piping, new drainage piping, new exhaustion system, new ceilings, new floors, new electrical installation, remaining work with the modernisation, new entrance doors, re-housing, complete painting of the modernisation.

3. INTEGRATED DESIGN PROCESS

The above listed aims and energy technology objectives are achieved through a careful integrated design process. The integrated design process consists of three phases: Feasibility study (pre-design), detailed designs and design reviews

3.1 Feasibility study

A pre-design of the project managed by Esbensen was carried out and served as basis for the detailed design work. The results of this work will be published during spring ‘01.

One important result from the feasibility study was the recommendation/decission not to change windows as the windows only a few years ago were replaced by well sealed double glazings. A replacement with low energy glazings will be an attractive future initiative from an energy saving and cost effective point of view, and might be carried out in the coming years without subsidies.

The key design philosophy for the design of the project is “Keep it simple”. This means that even though advanced techniques are implemented, they must be integrated in a way that does not require any kind of special information or comprehensive user manuals to make the building “work” as intended. Therefore, as a part of the pre-design, focus was put on the development of a flexible facade system for a simple integration of solar measures in building renovation. The Flexible Facade System is described in detail in [1]. This work was further developed during the detailed design phase in co-operation with the subcontractors (Plan 1 Architects and Gilling facade contractors).

Furthermore, comprehensive discussions and project presentations were carried out together with and in close co-operation with the client and the tenants and with a strong co-ordination with the local building authorities.

3.2 Detailed design

To significantly reduce the total energy use in buildings, it is beneficial to use different renewable technologies, such as energy conservation, daylighting, passive solar and active solar in combination. The designers therefore need to define the optimum combination of technologies. This requires an integrated design approach, where the different low energy technologies to be used are considered as integrated parts of a complete concept.

Another important aspect of the project is the methodology, which is used during the design phase to identify appropriate energy efficient solutions, weighting them against each other. Energy efficient solutions giving energy savings above those achieved during a normal design process are determined during the design phase by a close co-operation between architects and engineers and by using advanced simulation programmes. This kind of close co-operation between architects and engineers contributes to a cross-disciplinary growth for both parts.

In the detailed design phase, the different technologies were optimised taking a large number of criteria into consideration. These were energy use, comfort, cost, environmental aspects, aesthetics, etc.

An important tool in the design phase was the use of advanced simulation tools (thermal and visual) to ensure that the significant energy savings were not achieved at the expense of the comfort. Parametric studies were carried out integrating different layouts of the innovative features to evaluate the relative influence of the different features. These studies were carried out as a co-operative work of the complete design team making the optimum use of the experiences and expertise of Esbensen and of Fraunhofer.

In the detailed design analyses, the most advanced design and simulation tools were used. Thermal simulations were made using TRNSYS (TRraNsient System Simulation program - development initiated by the Solar Energy Laboratory , University of Wisconsin, US) and tsbi3C (Thermal Simulations of Buildings and Installations ver. 3C - developed at the Danish Building Research Institute). Evaluation of the daylight conditions were based on the ADELINE-package (Advanced Day- and Electric Lighting Integrated New Environment - developed under the International Energy Agency, IEA, SH&C programme Task 12 “Building Energy Analysis and Design Tools for Solar Applications”).

3.3 Design review

In the review of the design a close co-operation between architects and engineers took place to ensure e.g. that the technical solutions proposed by the engineers could be incorporated in the revised design in an aesthetically attractive manner. And also to ensure that the design would be generally applicable to the European building situation.

4. ARCHITECTURAL EFFORT

The main target of the architectural efforts have been to implement the various innovative elements in a way that ensures a high thermal performance, thermal and visual comfort and offers an architecturally attractive solar based building renovation. At the same time, the clear and pure architecturally and historically attractive expression of the classical red brick work building must be impression preserved. This has been achieved, as a close co-operation between all involved partners have been ensured from the very beginning of the project, including production of “easy to understand” drawings with a high level of information.

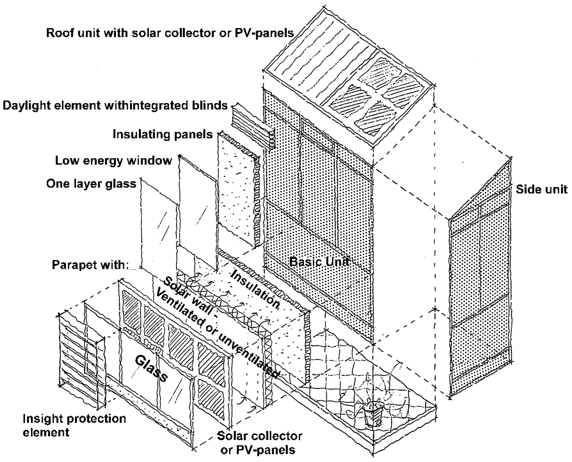

Figure 5 Principle of the flexible facade system

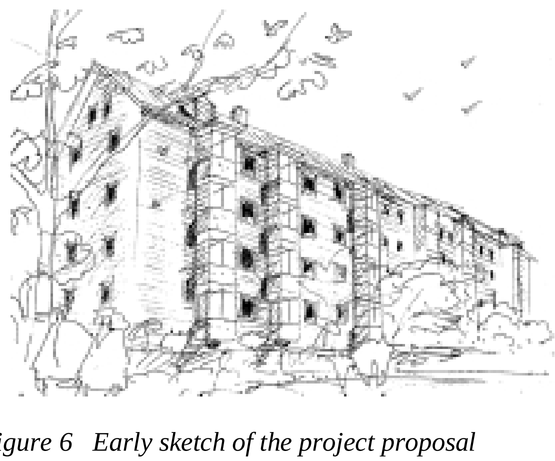

Figure 6 Early sketch of the project proposal

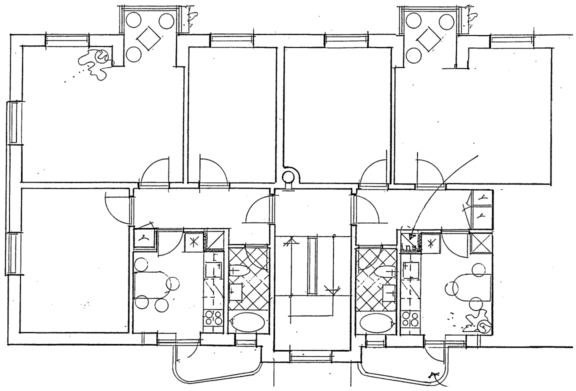

Figure 7 Floor plan of the final project proposal

5. INNOVATIVE ELEMENTS

The innovative energy elements that have been implemented are. Usage optimised advanced glazed balconies, solar mass walls with transparent insulation, ventilated solar walls, convector integrated fresh air in-lets and a demand controlled moisture regulated ventilation system. These elements were integrated with a new heating and ventilation system for the building. Besides, all entrances will be provided with glazed porches in order to avoid draft and heat losses when opening the doors to the apartments. The glazed porches are placed on the East facades of the three blocks.

5.1 Advanced Glazed Balconies

The advanced glazed balconies was designed in a way that make them sturdy against unintended use such as heating the balconies individually with small air heaters. This is achieved by using high performance glazings (U_L = 1.1 W/m^{2}K, LT = 0.8, g = 0.6) and by insulating the parapets (120 mm of mineral wool). This conclusion is based on the work described in [2] and [3]. The main content and results of this work in relation to the FLEXREN project is listed below.

In order to optimise the design of the glazed balconies, the influence of numerous single parameters have been studied. The most important/influential of these parameters proved to be 1) Glazing types and sizes, 2) Orientation and 3) “Use of balcony”:

5.1.1 Glazing types and sizes

Four glazing types were modelled. U-value, light transmittance, and g-value are shown in brackets:

- Single glazing, no frames and sealing (6.0, 0.91, 0.87)
- Single glazing, standard framing (6.0, 0.91, 0.87)
- Double glazing, standard framing (2.9, 0.82, 0.76)
- Low-e glazing (1.1, 0.79, 0.59)

5.1.2 Orientation

Two orientations were modelled: East and West.

5.1.3 "Use of balcony"
11 scenarios of the use of the balconies were modelled:

- Heating of the balconies 24 hours per day during the heating season
- No heating of the balconies
- Heating in weekends (3 variations)
- Heating on week days (3 variations)
- Heating all week (3 variations)

Besides these parameters, also the insulation level of the north facing parts, the air change rate and the daylight levels were analysed. These parameters proved to have less influence with respect to the heating demand and the potential energy savings compared to the above listed parameters and therefore the results from these studies are not included in this paper.

5.1.4 Energy demand
Further studies have especially focussed on the risk of introducing an increase of the energy demand as the tenants might heat the balconies. The main results of the studies are shown in table 1.

Glazing type	Unheated balcony		
	[kWh]	[kWh/m²]	[%]
1	2497	49	27
2	2622	52	23
3	**2078**	**41**	**39**
4	2360	46	31
5	2683	53	22

Glazing type	Heated balcony		
	[kWh]	[kWh/m²]	[%]
1	10922	192	-220
2	6264	110	-83
3	**2446**	**43**	**28**
4	3724	65	-9
5	7735	136	-126

Table 1 Expected annual energy demands and relative savings for space heating for different types of glazed balconies. Results for an apartment with "outside" balcony facing west:

1: Glass from floor to ceiling and insulation of existing wall between balcony and living room
2: 1 layer of glass, uninsulated parapet
3: Highly insulating glass (U = 1.1 W/m²K), insulated parapet
4: Conventional double glazing, insulated parapet
5: Conventional double glazing, uninsulated parapet

From table 1 it is seen that it is of high importance to design glazed balconies in a way that make these sturdy against unintended use such as heating by electrical heaters or similar equipment. The studies have been made for various heating scenarios and the tendency is similar but of course less significant if the balconies are only heated in shorter periods.
The parameter studies show that the largest energy savings for an unheated balcony in all cases are obtained by using low-e and gas-filled double glazings. Hereafter follows conventional double glazing and insulated parapet, then all glass with insulation of existing parapet between balcony and living room, single glazing and insulated parapet and finally conventional double glazing with uninsulated parapet.

5.1.5 Thermal Comfort
The overall thermal comfort conditions have been analysed for the glazed balconies. Selected results are shown in figure 8.

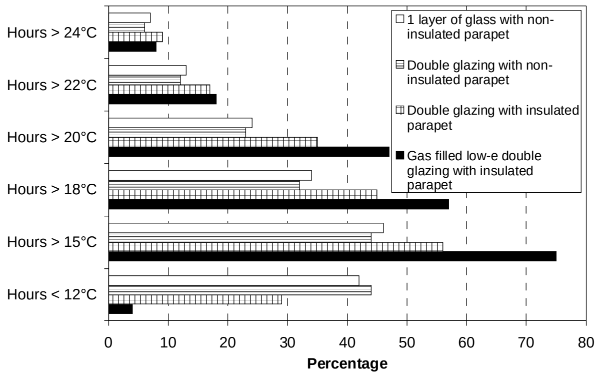

Figure 8 Thermal comfort expressed by the relative period of occupancy exceeding certain operative temperatures and the relative period of occupancy with operative temperatures below 12ºC

5.1.6 Comment
In this as well as in other demonstration projects, the results from the "risk" analyses of energy and comfort conditions made the clients decide for the advanced glazed balconies rather than the traditional ones.

5.2 Solar Walls

5.2.1 Ventilated solar wall
Ventilated solar walls for preheating of fresh air integrated in the parapet of the glazed balconies have been investigated. Different designs and absorber solutions were studies. The main results are shown below in section 5.2.1.1. For the actual geometry, orientation and air velocities, an absorber consisting of porous felt proved to be most efficient. Detailed studies of the ventilated solar wall are included in [4] as well as in the works of the IEA SH&C programme Task 19 "Solar Air Systems", [5].
The air flows into the solar wall due to the under pressure created by the exhaust ventilation system. The exhaust out-lets are placed in kitchen and bathroom which are situated close to the opposite east facing facade. This also

ensures a good airflow through and air change of the complete apartment. Before the heated air enters the apartment it is, if necessary, preheated by the convector integrated air in-lets which are described in section 5.3. The principle construction of the ventilated solar wall and the glazed balconies are shown in figure 9 and 10.

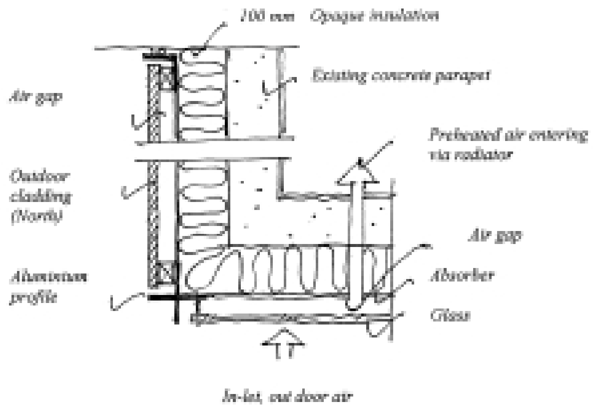

Figure 9 Horizontal cross section of the ventilated solar wall and the glazed balcony

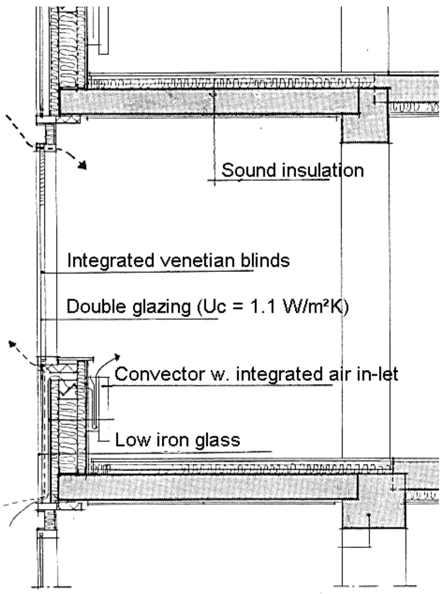

Figure 10 Vertical cross section of the ventilated solar wall and the glazed balcony

5.2.1.1 Simulated results

Four different designs were studied:

- A One layer of glass, air flow behind black painted absorber
- B Two layers of glass, air flow between cover and black painted absorber
- C The Canadian SolarWall
- D One layer of glass, airflow through black porous felt

The studies were made for various air flows as the demand controlled ventilation system will create large variations of the air flow in the individual apartments. The expected efficiencies and yields are shown in table 2 and 3 below.

Solar wall	12 m³/hm² (30 m³/h) [%]	40 m³/hm² (100 m³/h) [%]	74 m³/hm² (185 m³/h) [%]
A	26	38.5	53.5
B	15	27.5	41.5
C	3	31	50
D	**29**	**55**	**63**

Table 2 Efficiency of ventilated solar walls for various flow rates

Solar wall	100 m³/h [kWh/m²year]	"35 and 185" m³/h [kWh/m²year]
A	104	81
B	71	48
C	94	28
D	**139**	**87**

Table 3 Yield of ventilated solar walls for various flow rates

5.2.2 Unventilated solar mass wall

The solar mass walls are placed on the south facing house ends of two of the blocks. Various types of solar mass walls with transparent insulation were investigated. Also different shapes and designs were proposed and discussed.

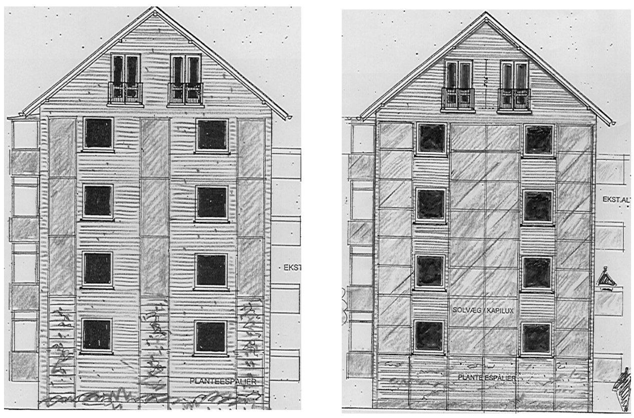

Figure 11 Early proposals for the geometry of the solar mass walls

Due to the serious risk of two- and three-dimensional heat losses, which have been experienced and identified by Fraunhofer ISE in previous similar projects, the different proposals with division of the solar wall panels were rejected.

In order to avoid these multi-dimensional heat losses, it is crucial to reduce the edge area and also to insulate the framing effectively. Thus, the framing of the solar mass wall is insulated with up to 100 mm of mineral wool on the exterior of the house end.
The cover system of the solar mass wall consists of a dark plastering of the red brick work, an air gap and a 49 mm cover of the Okalux system, Kapilux-H (U_L = 1.0 W/m²K, τ_{dir} = 0.80, τ_{dif} = 0,63).

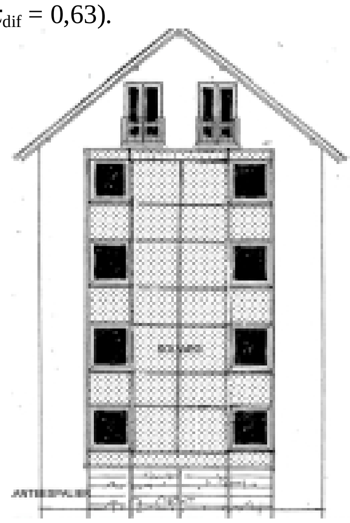

Figure 12 Geometry of final design of the solar mass wall with transparent insulation

5.2.2.2 Thermal comfort

In order to avoid thermal discomfort from overheating during the summer period, also the expected indoor temperatures and surface temperatures have been simulated.
The simulations have showed that the maximum indoor temperatures are expected to be lower than 30°C, and that the indoor air temperature will not exceed 25°C for more than 5% (west zone) and 2% (east zone) of the year.
Thus, no special initiatives for solar gain control (shading systems, venting of solar wall, etc.) are required.

5.3 Efficient convector integrated fresh air in-lets

The fresh air in-lets are integrated in a modular convector, which makes it possible to preheat the fresh air before it enters the apartment. In this way, thermal discomfort from draft is avoided.

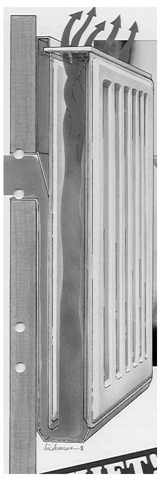

Figure 13 Convector integrated fresh air in-let

5.4 Demand Controlled Ventilation

In order to improve the indoor climate and to obtain energy savings, a mechanical demand controlled moisture regulated ventilation system is introduced and analysed. The principal function of such a system compared to a conventional exhaust air system is illustrated in figure 14.

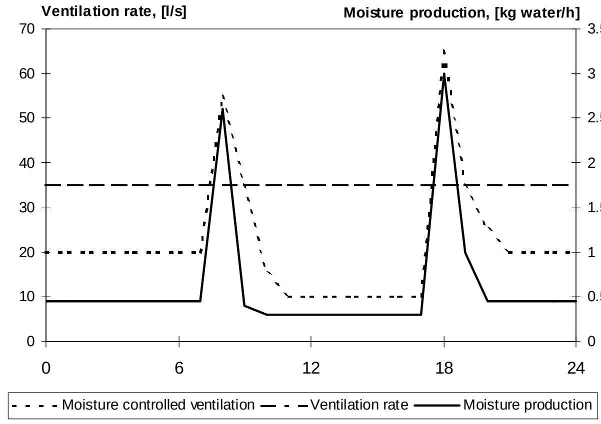

Figure 14 Demand controlled moisture regulated ventilation during 24 hours of the day compared to a conventional exhaust air system with constant ventilation (35 l/s)

The most significant benefits from using a moisture controlled ventilation system compared to a conventional exhaust air system or a ventilation system with heat recovery are:

- Moisture controlled ventilation will improve the indoor air quality much faster than a ventilation system with heat recovery as the polluted air is removed immediately
- The running costs will be reduced significantly as the ventilation rate and thus the use of electricity will be decreased when the moisture content is low
- The installation costs are much lower than for a ventilation system with heat recovery
- Large annual energy savings are possible using moisture controlled ventilation in combination with preheating ventilation air in solar walls or glazed balconies

6. FINAL DESIGN

By optimising the different elements compared to their cost effectiveness and with respect to the amount of finances available, the design team has managed to define a design in which a high quality of living as well as significant energy savings are expected.
The expected annual energy use is shown in figure 15 below. The figure also includes the expected annual energy use for a standard renovation and for a renovation with an improved ventilation system (a standard exhaust ventilation system designed in accordance with the

Danish Building Regulations, 35 l/s ~ 1.25 ach) but no solar initiatives. A standard renovation would only include the initiatives described in section 2.2.

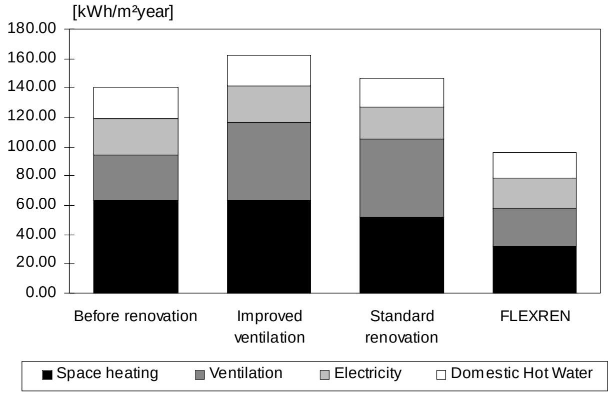

Figure 15 Expected annual energy demand for various renovation scenarios

The completed buildings are shown in figures 16, 17 and 18 below.

Figure 16 House end with solar mass wall. West facing glazed balconies

Figure 17 Glazed balcony from inside

Figure 18 Glazed balconies with ventilated solar walls in parapets

7. MONITORING

7.1 Monitoring programme

The objective of the monitoring programme is to investigate, document and evaluate the thermal and visual performance of the building as a whole and to investigate and document the performance of the innovative elements - glazed balconies, unventilated and ventilated solar walls, convector integrated fresh air in-lets and demand controlled - in particular.

The following areas are investigated:

- The thermal and visual performance of the energy measures integrated in the flexible facade system
- The energy demand for heating and ventilation
- User satisfaction

A monitoring programme during almost two heating seasons and the intervening summer period is carried out in order to be able to evaluate the building performance. Through this period, shorter periods (1-2 months) will be devoted to a detailed monitoring of selected elements.
Evaluation of the monitored results will be done by comparing energy consumption data from these buildings with other buildings of similar size and use. Furthermore, selected data from the detailed monitoring period will be compared with the predictions from the simulations

carried out during the design of the building. The experiences from this comparison will be used as a starting point for deciding the design the other Østerbo buildings to be renovated. Monitoring will be carried out by the Danish Technological Institute.

7.2 Monitored results

Early monitoring results indicated that the energy use and the ventilation rate were much higher than expected. A careful analyse of the data have shown that the reason for this was that the regulation of the ventilation system was not correctly made but also that the set-points had to be adjusted.

The reason for these adjustments are, that the tenants tend to have very different temperatures in the living room and in the kitchen. As the moisture regulation is based on a difference between the relative humidities in the living room and at the exhaust point (the kitchen) the set-point difference had to be increased from 10 - 15% (typical level for moisture regulated ventilation in residential buildings) to 20 – 25%. This was just recently discovered.

As the ventilation level influences the use of energy, the room temperatures, the performance of the solar walls and the comfort conditions, the preliminary monitored data are only interesting from a commissioning point of view.

Therefore and unfortunately, no detailed monitored data are included in this paper. However, within 9 months, the detailed monitoring report is expected to be finalised and the results will be public available. The report may be available from the author of this paper.

7.3 User reactions

Even though some problems have been experienced lately from the commissioning, the tenants as well as the housing company have expressed a large satisfaction with the final building design. This is especially the case with respect to the advanced glazed balconies, which especially the elderly people among the tenants find very attractive and comfortable from a thermal as well as from a social point of view.

8. CONCLUSIONS

From the construction of this ambitious project it can be stated that it certainly is possible to carry out energy conscious solar based building renovation in a technical as well as in an architecturally attractive way.

However, it is important to be aware of large potential behaviour differences between different users, and special attention should be given to this during the commissioning phase.

Finally, it shall be noticed that the public support for the innovative elements (incl. monitoring and reporting) for this project only adds up to less than 7% of the total project costs. Thus, ambitious but also cost effective solar based building renovation is possible and it can be concluded that

Technology is now meeting the market

ACKNOWLEDGEMENTS

The project is mainly financed by the building owner: the Housing Company Østerbo. Besides, the project has been supported financially by the EU DG XVII THERMIE Programme and the Danish Ministry of Energy and Environment. Furthermore, valuable advice and guidance has been received from the participants of the IEA SHC Task 20 project ”Solar Energy in Building Renovation” and from the participants in the EU DG XVII THERMIE Targeted project "SHINE".

REFERENCES

[1] “Flexible Facade System”. Olaf Bruun Jørgensen, Esbensen Consulting Engineers Ltd, Henrik Suhr, Plan 1 Architects. Proceedings of EuroSun 2000, Copenhagen, Denmark.

[2] “Glazed Balconies and Sun Spaces – Energy Savers or Energy Wasters?” Olaf Bruun Jørgensen and Ole Juhl Hendriksen, Esbensen Consulting Engineers Ltd. Proceedings of EuroSun 2000, Copenhagen, Denmark.

[3] “Solar Renovation Concepts and Systems”. Editor Andreas Haller, E. Schweizer AG.1998. See also www.iea-shc.org.

[4] “Integreret energirenovering af etagebolig”. Olaf Bruun Jørgensen, Esbensen Consulting Engineers Ltd., Henrik Suhr, Plan 1 Architects, Søren Østergaard Jensen, Danish Technological Institute, Aase Gilling, Gilling Facade Contractors, to be published in Spring 2001. In Danish with an English summary.

[5] Technical reports of IEA SHC Programme Task 19 “Solar Air Systems”. Operating Agent Robert Hastings, CH, see also www.iea-shc.org.