TWO DANISH TASK 13 LOW-ENERGY HOUSES
DESIGNS AND PARAMETRIC STUDIES

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PREFACE

This report is a part of work done of Task 13 of the IEA Solar Heating and Cooling Programme. The work has been funded by the Danish Energy Agency as part as the projects EFP-88 16143/13-1 "Skitseprojektering af avanceret lavenergihus [Sketch Planning of Advanced Low Energy House]" and EFP-89 1213/89-8 "Projektering af avanceret lavenergihus [Design of Advanced Low Energy House]", both Task 13 - Advanced Solar Low Energy Buildings, IEA Solar Heating and Cooling.

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SUMMARY

The report describes two rowhouse designs that have been developed in the Danish IEA SHC Task 13 project. The two building types have the facades facing north-south and east-west respectively, thus having one type designed specifically to meet the challenge of an unfavourable building site. The design aim was to achieve a total energy demand lower than 6000 kWh/a including use of electricity, which presupposes a space heating demand lower than 1500-2000 kWh/a. In a normal year, Denmark has 1500 sunshine hours and about 2900 degree days at a 17°C base. A combination of superinsulation, heat recovery, active and passive solar, electricity saving lights and appliances, and water saving devices is used to reach the low demands.

The report shows some of the results from parameter analyses of different energy conservation strategies. Simulations based on conventional one-dimensional heat flows are compared with simulations corrected for two-dimensional heat flows, and a detailed 2D window analysis is included. Even in this type of highly insulated buildings practically without thermal bridges, the 2D effects are not negligible.

1. THE DANISH GOAL AND THE WAYS TO REACH IT

1.1 The Danish goal

It is the main purpose of the Danish Low-Energy Research Programme to design, build and monitor dwellings with about 100-105 m^2 living area (which appears to be the size affordable to people in the 1990'ies) corresponding to about 125 m^2 built-up area, with as low a total energy consumption as possible, set as less than 6,000 kWh/a total, [1]. If this goal is to be reached, the space heating demand should be kept below 1500 kWh/a, which is about one seventh of the demand in a typical detached single family house.

In conformity with the international IEA Task 13 objectives, a number of solutions that are not immediately feasible and cost-effective, but are likely to be so in the future, have been included in the analyses.

1.2 Ways to reach the low total energy demand

The only way to reach a very low total energy demand is through integrated design of the building envelope and the building service systems. The product, a low-energy building, offers the user the possibility of a very small energy bill. The building may be more or less sensitive to the way it is used (and should be designed for the latter, if at all possible), but in the end, extremely low energy consumptions require energy conscious users. The strategies pursued in the Danish project in order to obtain a robust advanced solar low-energy building are summarized in the following seven bullets:

- Superinsulation (quantity and quality)
- Passive solar
- Active solar (primarily for hot water)
- Efficient heating system
- Heat recovery on ventilation
- Water saving devices, low-temperature systems
- Efficient use of electricity

As to the first bullet, large insulation thicknesses, typically about 300 mm, are considered. However, it is even more important that the constructions designed contain practically no thermal bridges and are extremely airtight, thus securing the thermal efficiency of the insulation material in practice. The superinsulation strategy is very important, because Denmark usually has very little sunshine in the winter, especially in the months November-January.

Achieving a high utilization of solar gains, especially direct gains, is not only a question of house design (size, type and orientation of windows, accessable thermal mass), it also includes minimizing internal gains, ie those to be paid for: chiefly stand-by losses from the technical systems. Thus there should be no operation of pumps and fans outside demand periods, no circulation of hot water etc, and efficient appliances and lighting that emit only little heat should be selected.

It is important to have a heating system that does not compete with the utilization of solar gains, preferably a fast responding system with low no-load losses and a high operating efficiency, also at part loads. As the gross ventilation heat losses equal the transmission losses, heat recovery is important, thus requiring some mechanical system.

An active solar system can be designed to meet a large part of the domestic hot water demand. The demand itself should be kept low through efficient use of water (application of water saving devices in taps, special showerheads etc) and short supply lines (a floor plan design problem) so that circulation can be avoided. The system may also be designed so that only the necessary hot water temperature for the actual purpose is demanded.

The secondary reason for consistent use of low consumption lighting, appliances, fans etc, as well as minimum operating time for equipment, has already been mentioned (minimizing internal gains) - the primary reason of course being as low an electricity consumption in the house as possible.

2. HOUSE DESIGNS

The result of these strategies was the design of two different superinsulated rowhouse types, one for east-west running rows and one for north-south running rows. The second type was designed as a deliberate attempt to meet the challenge of unfavourable building sites, not allowing for conventional desired south facing facades.

The two house types have been designed in collaboration between the architect, professor Boje Lundgaard, Royal Academy of Arts, the Danish School of Architecture, and the engineering team from the Thermal Insulation Laboratory (TIL). All thermal analyses have been performed at TIL.

Through the design process, it has been a deliberate desire to express the energy consciousness in the architectural idiom of the buildings as well as to obtain good living qualities, eg daylighting conditions, in the limited space available.

In this case, rowhouses have been designed - however, the design and construction principles are easily transferable to other building types, eg detached or semidetached single family houses or small apartment buildings.

2.1 Common features for the two house types

In principle, the same thermal envelope constructions, ventilation and heating system, combined active solar system (mainly for domestic hot water), water and electricity saving devices, lights and appliances are used in the two house types.

Both house types are built slab-on-ground, totally or partially in two storeys with the main rooms organized around a two-storey high family room. All rooms receive daylight, through skylights or normal windows - or a combination of the two.

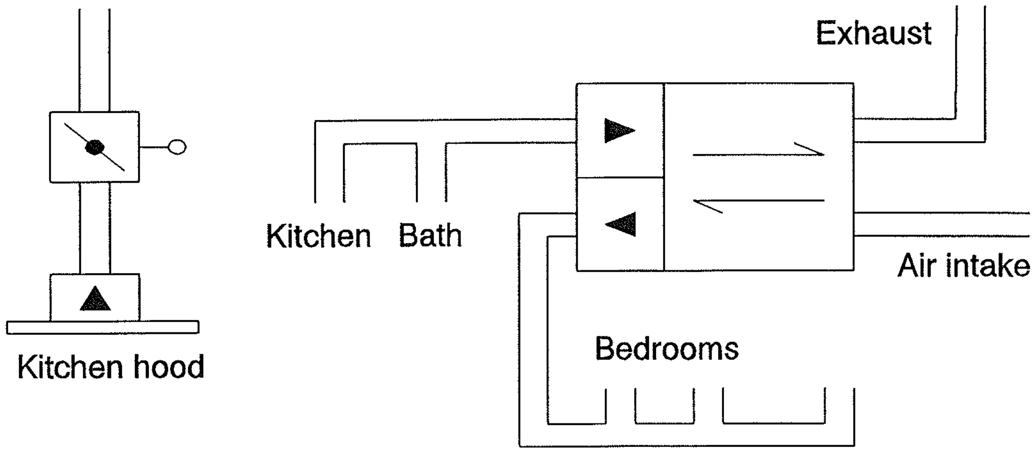
For insulation of walls and roof, a high density mineral wool with a design thermal conductivity of 0.036 W/mK is used, giving the constructions a U-value of 0.11 W/m^2K. Under the floor slab, either the same product or a rigid expanded polystyrene with the same thermal conductivity is used. The traditional thermal bridge at the foundation is partially broken through use of lightweight concrete foundation blocks and parameter insulation separating the foundation and the slab. The constructions are briefly described in Figure 2 and 3.

The principle of the heating and ventilation systems is shown in Figure 1. A small high-efficiency gas burner with low water content is the heat source, operating with a 400 l domestic hot water tank as buffer. The heat is distributed in a hydronic system, the heat being emitted in the rooms by small fan coil units, controlled by room thermostats. The active solar system may be described as an oversized low-flow domestic hot water system with vertical collectors.

The ventilation system is essentially a balanced mechanical system with a counterflow plate type heat exchanger, drawing exhaust air from kitchen and bathrooms and injecting fresh preheated air into the bedrooms. To avoid dirtying the heat exchanger the kitchen hood is given a separate duct - a timer turns off the hood fan and closes a damper in the duct when the system is off. The temperature build-up under the ceiling in the two-storey rooms is counteracted with a propeller fan.

2.2 House Type A - South facing rowhouse

The dwellings in this type are in two storeys, with a total area of 106 m^2 and a heated volume of 252 m^3. In the base case, the window area is 23 m^2 (13.5 m^2 south facing, and 5.5 m^2 in skylights) equal to 22% of the floor area.



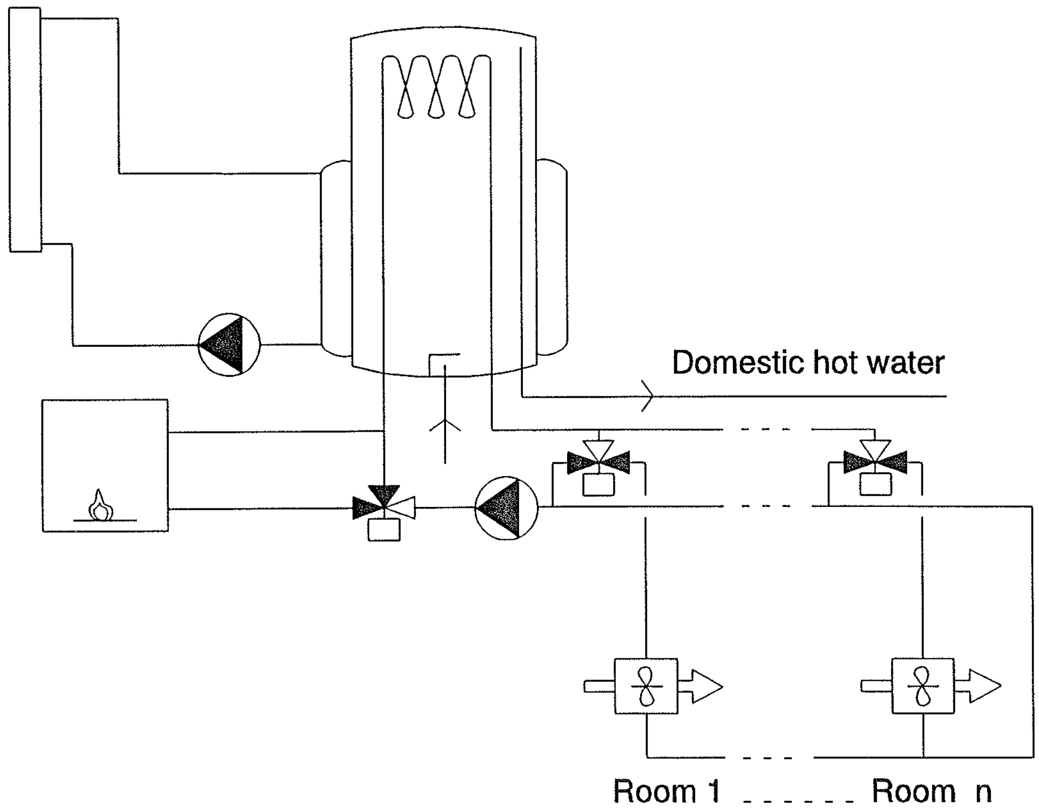


Figure 1. Simplified diagram of ventilation and heating systems.

The slight curvature of the lopsided roof with the one-sided slope creates aspecial cave-like quality in the inner rooms. All primary rooms are south facing. The back rooms on the top floor get sunlight through raised skylights. The vertical south side of the skylight construction gives room for an array of solar collectors.

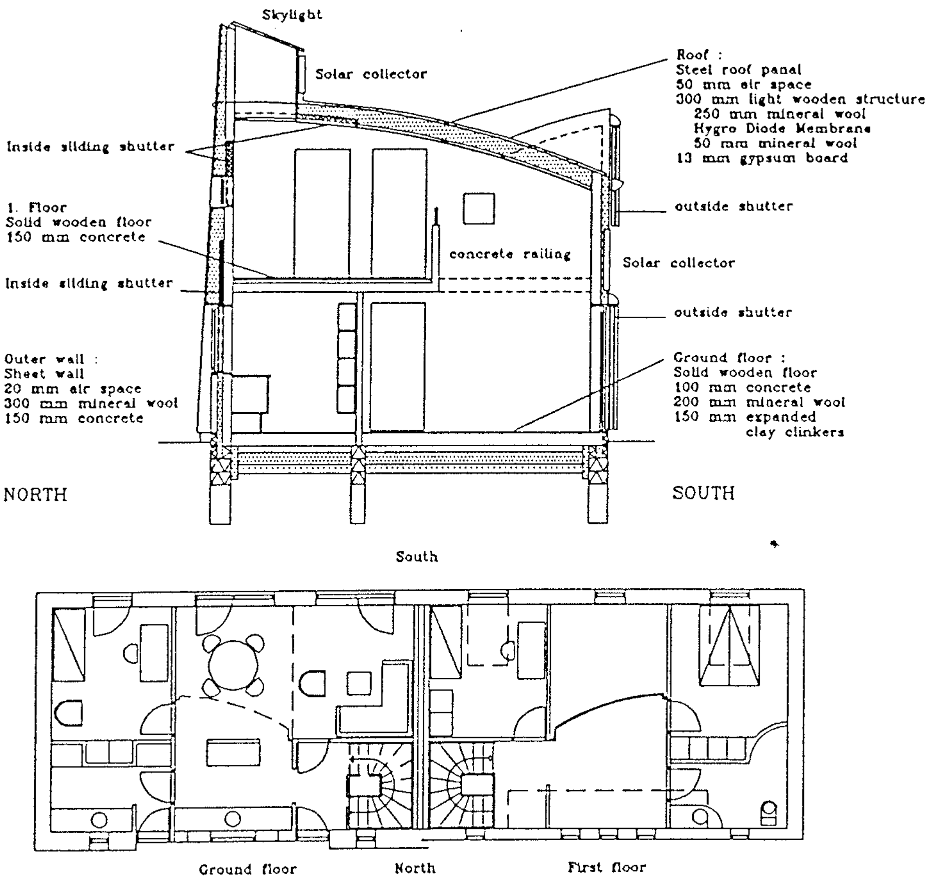


Figure 2. Plan and section of House type A. The plan shows 2 dwellings of a longer row, the ground floor of one unit to the left, and the top floor of the neighbour unit to the right.

2.3 House Type B - East/west facing rowhouse

The challenge to be met in the design of these houses with the rows running north-south was to achieve satisfactory daylighting conditions and a substantial utilization of solar gains.

The dwellings in this type are partly in one, partly in two storeys, with a total area of 111 m^2 and a heated volume of 273 m^3. In the base case, the window area is 28 m^2 (8.4 m^2 south facing, and 6.1 m^2 in skylights) equal to 25% of the floor area. Under the south facing windows there is room for an array of vertical solar collectors.

The large continuous quarter circular roof construction makes it possible to have some south facing windows through which direct sunlight is transmitted to the main living rooms, ie the deck on the top floor and the family room/kitchen on the ground floor. This way substantial solar gains as well as untraditional rooms and light effects are achieved.

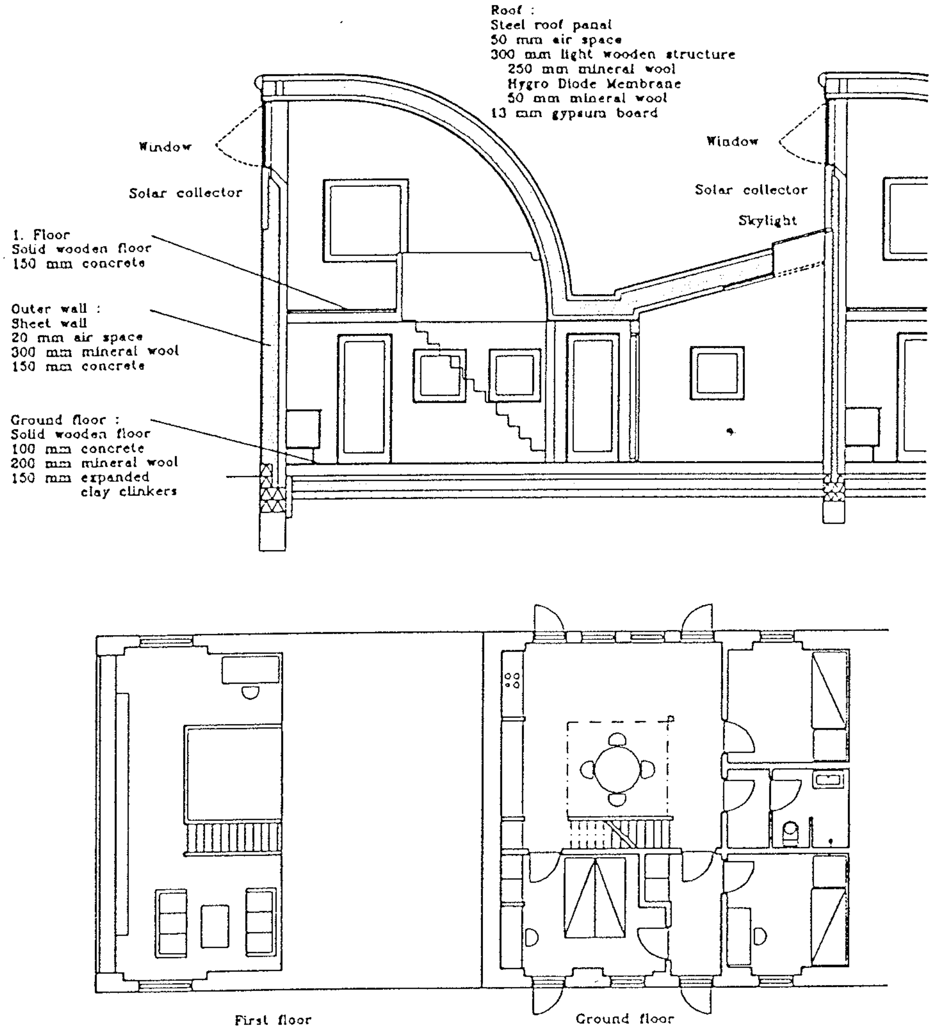


Figure 3. Plan and section of House type B. The plan shows 2 dwellings of a longer row, the ground floor of one unit to the right, and the top floor of the neighbour unit to the left.

3. PARAMETRIC STUDIES ON THE HOUSE DESIGNS

The Danish multizone building energy simulation program TSBI3, [2], has been used for the calculations of the heating load. The active solar system performance has been calculated with the program EMGP3, [3], with the TSBI3 heating load as input for the space heating calculation.

The calculations have generally been performed using standard procedure input, eg transmission heat loss coefficients based on one-dimensional heat flow, design material values and internal measurements according to the Danish Standard, [4]. Later on, corrections for two- and three-dimensional heat flow have been introduced as described in section 3.2.

3.1 Base assumptions made for the calculations

The Danish Test Reference Year (TRY), [5], has been used as weather data. The house is divided into three zones. All thermostats are considered ideal and set at 20°C. The heating system is turned off in the night (from 22 to 05). The controlled air change is constant, at 0.5 ach with a heat recovery efficiency of 60%. Airing (3 ach) is presupposed, if the zone temperature rises above 23°C. The internal gains are set as a pattern for a family of four (2 adults and 2 children) - the gains are 2849 kWh/a from the people and 1270 kWh/a from their use of electricity. The results shown are valid for a unit with a neighbour unit on each side. Only the heating season (Oct-Apr incl) is considered.

3.2 Corrections for two- or three-dimensional heat flow

Three types of corrections have been made to the standard procedure input to TSBI3: corrections for a) the heat flows at corners, and especially at the dormers and raised skylights, b) the heat flow at the foundation (a 2D case), and c) the heat flow at door and window openings.

a) The corrections have been made using conductive shape factors, [6], which for well insulated constructions without thermal bridges give satisfactory results. One case has been checked by comparison with results from 2D computer calculations - the corrections were identical. The corrections are 1.0 and 1.3 W/K in House Type A and B respectively.

b) The corrections have been calculated based on steady state 2D computer calculations. Though the foundation must be described as well insulated, the corrections are 3.5 and 3.3 W/K in House Type A and B respectively.

c) The corrections come directly into TSBI3 as new and more correct U-values for glazing and frame, from calculations with the 2D computer analysis program FRAME, [7]. The detailed window analyses are described in section 3.3. In the base case (section 3.4) the corrections amount to about 3.4 and 4.1 W/K in House Type A and B respectively. As shown in Figure 4, the aluminium spacer and the presence of a number of small windows contribute heavily; the 1D total U-value is 0.8 W/m^{2}K. If the aluminium spacers are replaced by Superspacers, the corrections are reduced to 0.4 and 0.9 W/K in House Type A and B respectively.

3.3 Detailed window analyses

Windows in low-energy buildings have always been the weakest part of the thermal envelope with heat loss coefficients about 10 times higher (ordinary double glazed units) than the rest of the thermal envelope. However, it cannot be disputed that windows are needed: to allow daylight to enter the building and let the occupants look out. South oriented windows furthermore act as solar collectors which on sunny days results in a free energy supply to the building.

Insulating shutters meant for daily operation have been used in some experimental low-energy buildings, but the effect is strongly dependent on the presence and discipline of the occupants. As another solution, the window glazing manufacturers have developed new glazing systems with low-emissivity (lowE) coatings and filling of the sealed unit with a low-conductive gas. However, the lowE coating reflects some of the solar radiation and reduces the passive solar gains. At the moment a centre U-value of the glazing of 0.8 W/m^2K can be achieved in a triple glazed unit with 2 lowE coatings and Argon filling. The total solar transmittance is 0.5, which should be compared with the transmittance of 0.7 of a triple glazed unit without coatings. Due to the aluminium spacer along the perimeter of the sealed units, the overall U-value for the glazing of a 1 m^2 unit with centre value 0.8 becomes 1.0 W/m^2K.

If the above described glazing is put into an ordinary wooden frame the total U-value of a 1.2 x 1.2 m^2 window will be approx 1.2-1.3 W/m^2K which compared to the glazing itself (including the spacer) is an increase of 20-30%. The promising low U-value at the centre of the glazing does not reflect in the total U-value of the window due to thermal bridges in spacer and frame, which furthermore form a relatively large part of the window area.

In 1991 a competition was announced in Sweden to highlight this problem - to make a window with a total U-value lower than 0.9 W/m^2K. The goal of the competition was met, but all contestants had used 4 layers of glass and the frames became rather voluminous. In parallel a project was carried out at the Thermal Insulation Laboratory, [8], to develop new frames for the highly insulating glazings. Figure 4 shows the total U-values of a window pane with centre U-value of 0.8 W/m^2K put into a wooden frame and an insulating frame respectively; also the result of replacing the aluminium spacer with a Superspacer is shown.

As seen in figure 4 the effect of using a frame construction with a U-value comparable to the centre U-value of the glazing leads to a strong reduction in the total U-value, especially in case of small windows.

In the project carried out at the Thermal Insulation Laboratory the aim was to develop frames for highly insulating glazing. A detailed theoretical investigation was performed showing that the optimum way to reduce the U-value of the frame is to divide the frame into two parts with an insulation layer in between. However, the window frame must still have the required structural strength.

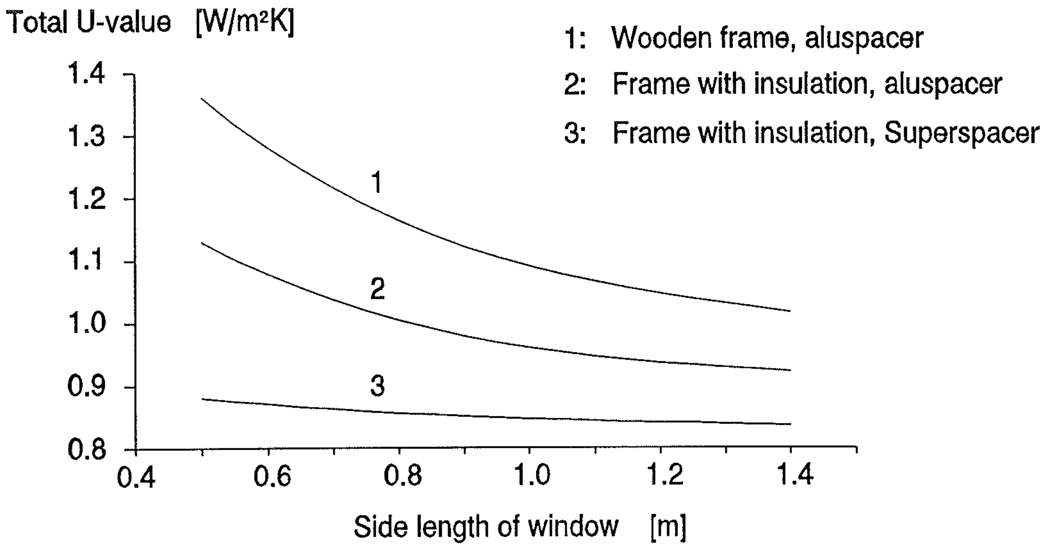


Figure 4. Total U-value as a function of window size and frame. Centre U-value of glazing = 0.8 W/m^{2}K, U-value of wooden frame = 1.6 W/m^{2}K, U-value of the insulating frame = 0.8 W/m^{2}K, frame width = 98 mm.

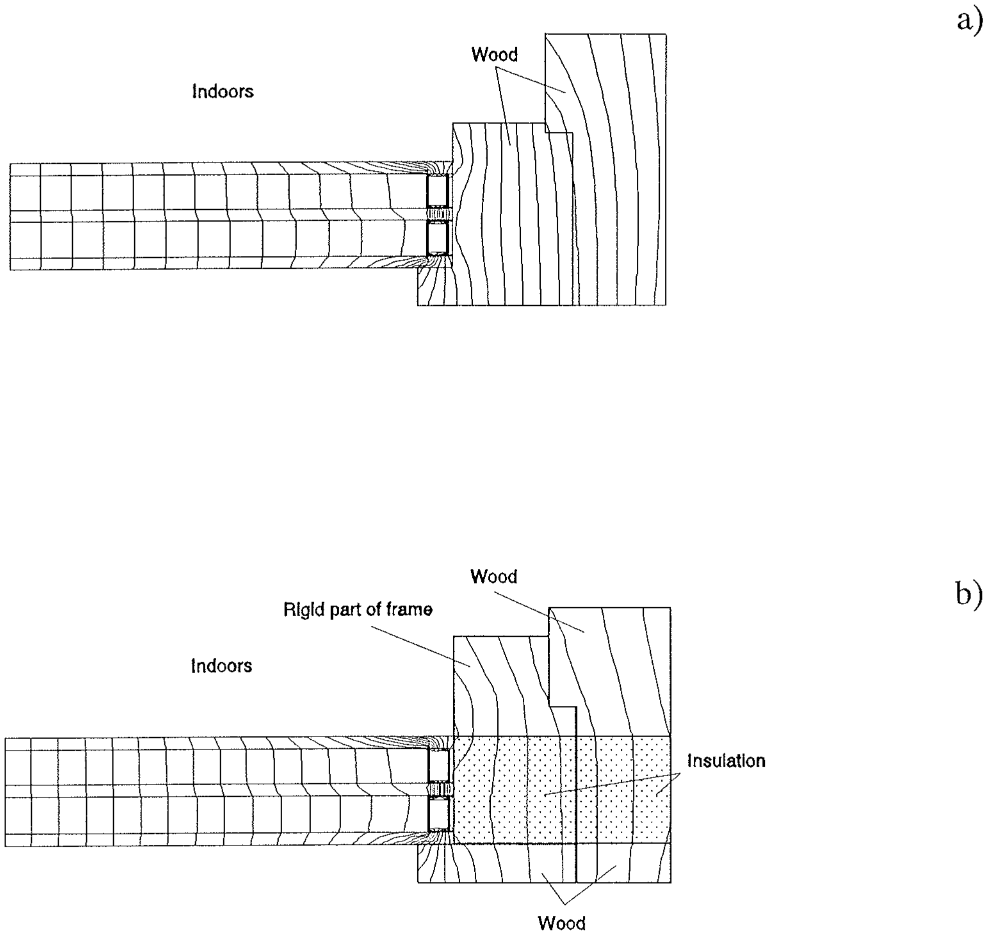


Figure 5. Schematic view of an ordinary wooden frame a) and the frame with thermal barrier as continuation of the window pane b) including heat flow lines.

This problem has been solved by keeping the load-bearing part of the frame on one side (either inside or outside) of the window pane and the frame insulation - then, a thin frame on the other side of the glazing and frame insulation keeps the glazing in place by means of a few relatively small connections (dowels) through the insulating layer.

The system has the advantage that the rigid part of the frame can be made of eg steel or aluminium leading to smaller dimensions, without serious thermal bridges. This is due to the position entirely on the warm side or on the cold side of the window. Prototypes of the described frames have been tested at laboratory level and proved successful. A schematic drawing including heat flow lines of an ordinary wooden frame and the frame with the thermal barrier are shown in figure 5. Notice the difference in heat flow lines between the two frames.

3.4 Case description

The base low-energy case is a superinsulated house that may be built from materials and components that are on the market today, if not necessarily in serial production. It has 300 mm insulation in walls and roof, and triple glazed windows with aluminium spacers, two low-emissivity coatings and Argon filling. Insulating frames as described in section 3.3 are used. The building geometry, transmission areas including glazed areas, etc, are as described in section 2. For comparison, the same buildings insulated at the present Building Code level are included.

In a series of calculations, the usual aluminium spacer in the sealed window units has been replaced with a Superspacer. Insulating shutters (R-value 1.69 m^2K/W) have been applied in a couple of cases, with standard double windows or with the best triple glazed windows.

Also some experimental glazing types from recent Danish research projects have been included in the analyses. The (double glazed) evacuated windows have a centre U-value of 0.67 W/m^2K and a total solar transmittance of 0.65 (1 coated surface, air space evacuated, pane distance only 0.5 mm, and a fairly severe thermal bridge of glass at the edge seal - special frame required). So far, only small prototypes (laboratory samples) have been produced. The partially evacuated (~80-100 mb) aerogel windows (double glazed) have a centre U-value of 0.50 W/m^2K and a total solar transmittance of 0.75 (space between panes filled with 20 mm monolithic silica aerogel [Airglass], special stainless steel spacer and seal). Full size window prototypes have been produced, but at the present stage aerogel is not completely transparent - thus one set of calculations for this project suggests use of these windows for skylights and elevated ribbon windows where the view is not an issue.

Cases A0 & B0	Houses insulated according to the current Building Code, [9]
Cases A1 & B1	***Base low-energy cases, houses insulated with 300 mm mineral wool, triple glazed lowE-coated windows with aluminium spacers and insulated frames, etc***
Cases A2 & B2	As Case 1, with Superspacer replacing the alu-spacer
Cases A3 & B3	As Case 1, with normal double glazed windows in wooden frames, and insulating shutters
Cases A4 & B4	As Case 2, but with insulating shutters
Cases A5 & B5	As Case 1, with double glazed lowE-coated windows, aluminium spacers and insulated frames
Cases A6 & B6	As Case 1, with evacuated windows
Cases A7 & B7	As Case 2, with aerogel windows in skylights and elevated ribbon windows (B7), triple glazed windows as in Case 2 everywhere else
Cases A8 & B8	As Case 1, with aerogel windows instead of triple glazed

For Cases 1, 2 and 8, additional simulation runs were made without solar gains, and without any gains at all, to quantify the free heat contribution.

Also, parametric studies of insulation thickness in walls and roof were made on the base cases (A1, B1 as well as A2, B2) - using 200, 250, 300 and 350 mm of insulation (simulations based on the 1D-calculation as well as the 2D-corrections).

Finally, parametric studies on glazed area were performed on House Type B, because it has windows to the south as well as to east/west, so that both may be varied for the same building. Three window types were selected for these simulations: Double glazed with 1 lowE coating and Argon filling, triple glazed with 2 lowE coatings and Argon filling, and aerogel windows (cases 2, 5 and 8). Typical facades of both house types are shown in Figure 6.

Figure 6. Two dwellings of a longer row. South facade of House type A, with shutters (top). West facade of House type B (bottom).

3.5 Results from the simulations

Table 1 shows examples of calculated useful gains in the houses, and Table 2 shows the annual net heat demands for the 9 cases listed above, with and without corrections for two-dimensional heat flows.

Table 1. Heating loads for the Cases 2 and 8 (Base low-energy case with triple glazed coated windows, and the same buildings with aerogel windows) calculated as before, then without any internal or solar gains, and just without solar gains, showing the useful gains that meet a substantial part of the gross heating load.

Case no.	Gross heating load, no gains (kWh/a)	Heating load, no solar gains (kWh/a)	Net heating load (kWh/a)	Useful internal gains (kWh/a)	Useful solar gains (kWh/a)
A2	5190	2750	1380	2440	1370
B2	5700	3460	1890	2240	1570
A8	4810	2380	770	2430	1610
B8	5230	3010	1190	2220	1820

Table 2. List of results from simulation runs (TSBI3 calculations) - the brackets around some figures only indicate that the 1D-calculation does not take the superspacer into account.

	Annual heat demand, based on 1D-calculation (kWh/a)		Annual heat demand, with 2D-corrections (kWh/a)	
Case no.	House A	House B	House A	House B
0	7240	9000	-	-
1	1060	1520	1550	2100
2	(1060)	(1520)	1380	1890
3	1940	2320	2290	2690
4	(790)	(1240)	1080	1550
5	1480	2190	1750	2440
6	730	1150	1100	1510
7	(880)	(1060)	1180	1400
8	520	870	770	1190

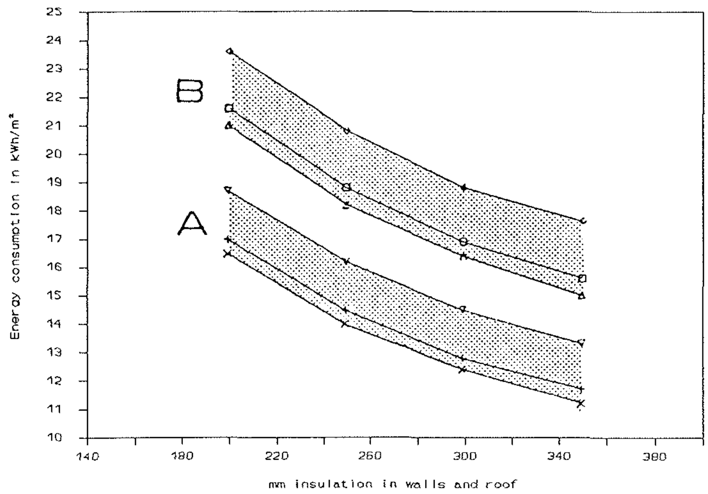


Figure 7. Heating load per m² floor area, House type A (x, +, ▽) and B (△, □, ◇), calculated at 4 different insulation levels. Triple lowE windows are used: x and △ represent 1D calculations with 2D corrections for corners etc and foundation (section 3.2 a and b), + and □ represent additional 2D-corrections for doors and windows with Superspacer, as in Case no. 2, ▽ and ◇ similarly windows with aluminium spacers, as in Case no. 1. Case A1, A2, B1 and B2 appear in the diagram at X=300 mm.

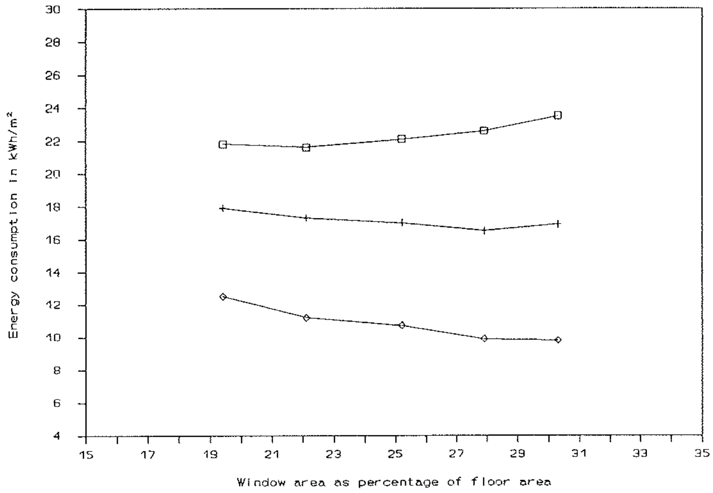


Figure 8. Heating load per m² floor area, House type B, calculated at five different south facing window areas, for three window types (□ Double glazed, 1 lowE coating, + Triple glazed, 2 lowE coatings, ◇ Aerogel windows). The relative total window area 25% has been used in the general calculations (Cases B2, B5 and B8 appearing in this diagram).

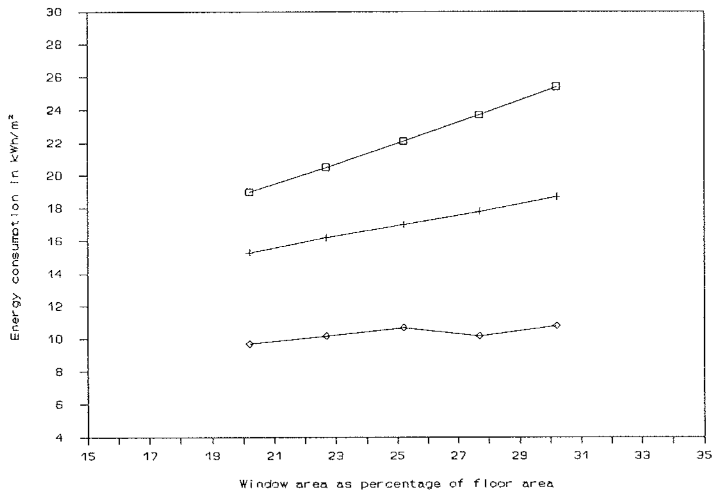


Figure 9. Heating load per m² floor area, House type B, calculated at five different east/west facing window areas, for three window types (□ Double glazed, 1 lowE coating, + Triple glazed, 2 lowE coatings, ◇ Aerogel windows). The relative total window area 25% has been used in the general calculations (Cases B2, B5 and B8 appearing in this diagram).

3.6 Performance of the active solar system

A parametric study has been performed in order to investigate how large a part of the domestic hot water and space heating demand it is reasonable to cover by use of an active solar heating system.

As the name indicates, the heating demand is very low for a low-energy house. This means, that although it is possible to cover a large part of the heating load, the absolute savings are small, which makes it difficult to pay back the capital cost of the solar heating system. Thus the system must be cheap. Therefore, it was chosen to investigate an oversized domestic hot water system, where a separate convector is connected to the mantle of the storage. The system is of the low flow type, ie it has a flow of 0.15 l/m^2 per minute instead of the normal 0.5-1 l/m^2 per minute. The low flow concept will increase the performance of this solar heating system with more than 10% [10].

The performance of the system has been analysed by use of EMGP3 [3], a PC-based simulation program developed within the CEC concerted action OPSYS. As EMGP3 is not an integrated part of the used building simulation program (or any other), the TSBI3 space heating demand for the house has been used as input (on an hourly basis). The storage is a 400 litre cylindric tank with a mantle covering the lower 75% of the storage.

The domestic hot water demand is 130 litres per day, heated from 10 to 50°C = 2200 kWh/year. The space heating demand is approx 2000 kWh/year.

The collector area and the tilt of the collector has been varied. The solar heating system with the collector tilted 45° has a higher performance for small collector areas, where the contribution to space heating is low. For larger collector areas with a larger contribution to space heating the system with the collector tilted 90° has the highest performance, as the collector here is oversized for domestic hot water purposes and better oriented during the winter-time. The advantage of a 90° tilt is that the maximum temperature of the collector is lower than for a 45° tilt - 100 and 163°C respectively for a system with a collector area of 8 m^2.

The contribution to space heating is almost insignificant. Therefore, the reference system has been compared with two systems for domestic hot water only. The only differences from the reference system are that there is no space heating load and that the storage is 300 litres.

It can be seen that the contribution to space heating for the reference system is "stolen" from the contribution to domestic hot water. Thus there seems to be no real point in using an oversized domestic hot water system, as the performance is almost identical to the performance of a pure domestic hot water system, which is cheaper, as it does not need the separate convector.

The analyses show that the active solar system can cover about 75% of the domestic hot water load and typically about 10% of the heating load for the base cases, [11] and [12]. A 45° tilt gives the same result for this collector and storage size.

4. DISCUSSION OF AND CONCLUSIONS FROM THE RESULTS

Table 1 shows that about 70% of the gross heating load in the base low-energy cases is met by free heat, a fraction that goes up to about 80% when aerogel windows are used. The internal gains are almost 100% utilized, leaving a direct gain solar contribution of about the same size as the net heating load or larger. The solar gains are higher for the cases with aerogel windows because of the higher solar transmittance of the glazing.

Table 2 shows clearly that two- and three-dimensional heat flows have a significant impact on the predicted annual heating demands, and that they must be taken into consideration in the simulations. When the net heat load is so low, it is sensitive even to relatively small changes in the heat loss factors. The largest impacts, 40-50%, occur when the major part of available free heat has been utilized, eg in the base low-energy case. Even so, it has been possible to design passive solar low-energy buildings with extremely low heating demands.

A comparison of Case 1 or 2, respectively 5, and Case 3 shows that insulating shutters on normal double glazed units cannot compeat with windows with lowE glazing. The same shutters used on the triple glazed windows can save an additional 300-340 kWh/a, with the drawbacks: cost, maintenance, and daily operation. The main advantage of shutters is the low peak load obtained, and the good thermal comfort conditions under windy peak load conditions.

Table 2 clearly shows the major role of the windows, and implies the possibilities of the new window types under development. Table 2 and Figure 7 both show that the use of aluminium spacers in low-energy windows causes a significant thermal bridge and should be avoided.

A rough calculation indicates that it would be possible to lower the heating load by 500-600 kWh/a through use of ventilated solar walls (ventilated and insulated walls externally covered with transparent insulation), but it may prove difficult to control the heat flow efficiently, and thus to prevent frequent overheating.

Figure 7 indicates that further savings through improvement of the opaque part of the thermal envelope are possible. The decision on increased insulation thickness must be based on economic evaluation, possible problems with construction details, and perhaps a wanted maximum total wall thickness.

Figure 8 and 9 first of all again show the important savings obtainable through use of efficient windows. With aerogel windows, and to a certain degree with the triple glazed units in insulated frames, an increase in south facing window area gives a lower heating demand. However, an increase in east/west facing window area is an energy user even with high performance glazing, except for aerogel windows, for which a change in area hardly affects the heating demand.

It should be emphasized that the number of windows has been changed, not the size of the single window units. As shown in Figure 4, the total U-value is strongly dependent on the window size, unless an insulating spacer as well as an insulating frame is used. Even with a Superspacer, the energy performance of very small window units is poor, mainly because of the small relative glazing area, giving only small solar gains.

It is obvious from Figure 4 and the simulation results that a 2D-analysis of the windows is essential, and that it is important to use insulated frames as well as high performance glazings.

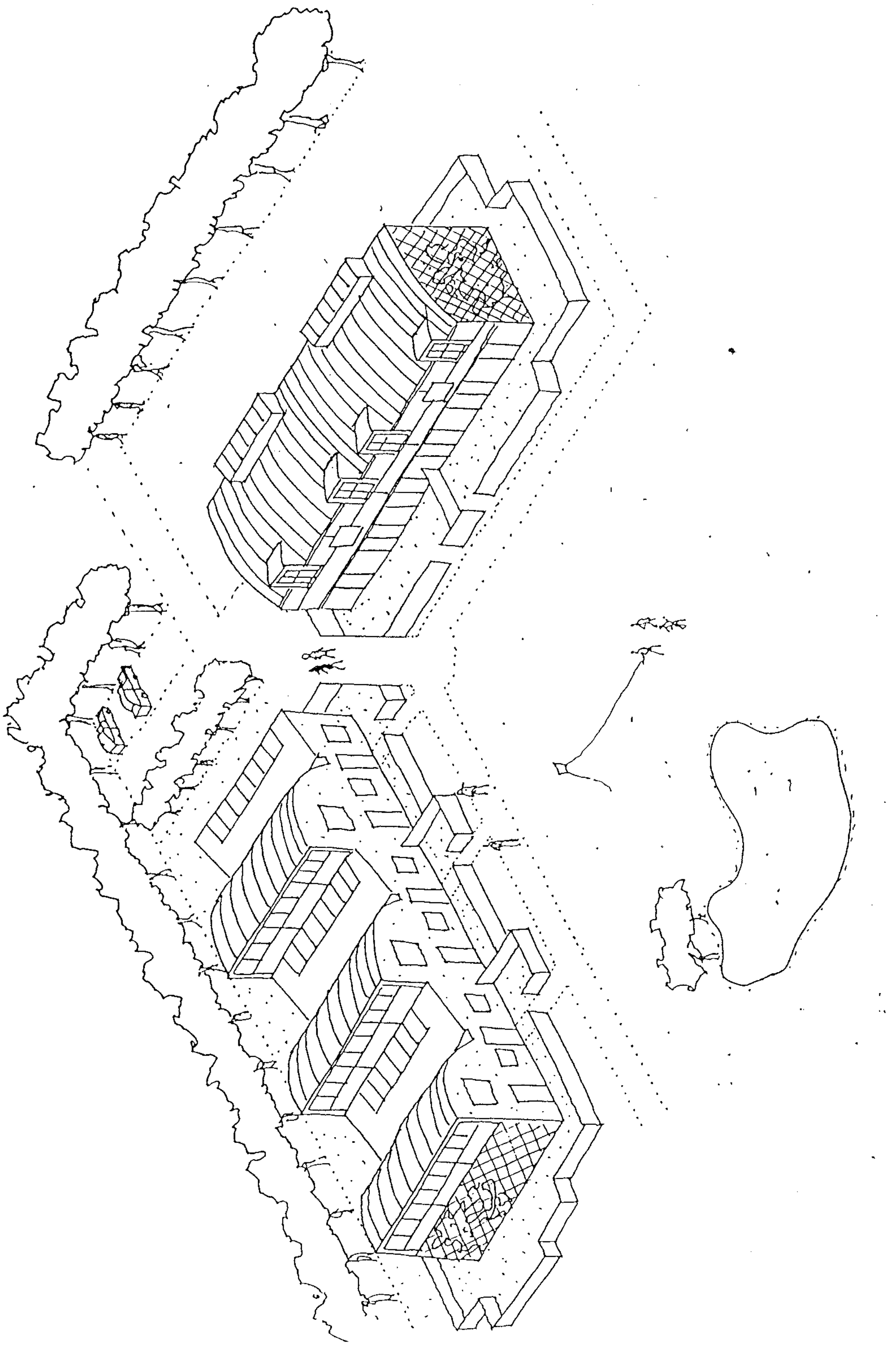
Without long term storage the contribution of the active solar system to the space heating load will be negligible. Using the hot water tank as buffer for the heating system improves the efficiency of the heating system, but it is difficult to estimate how much.

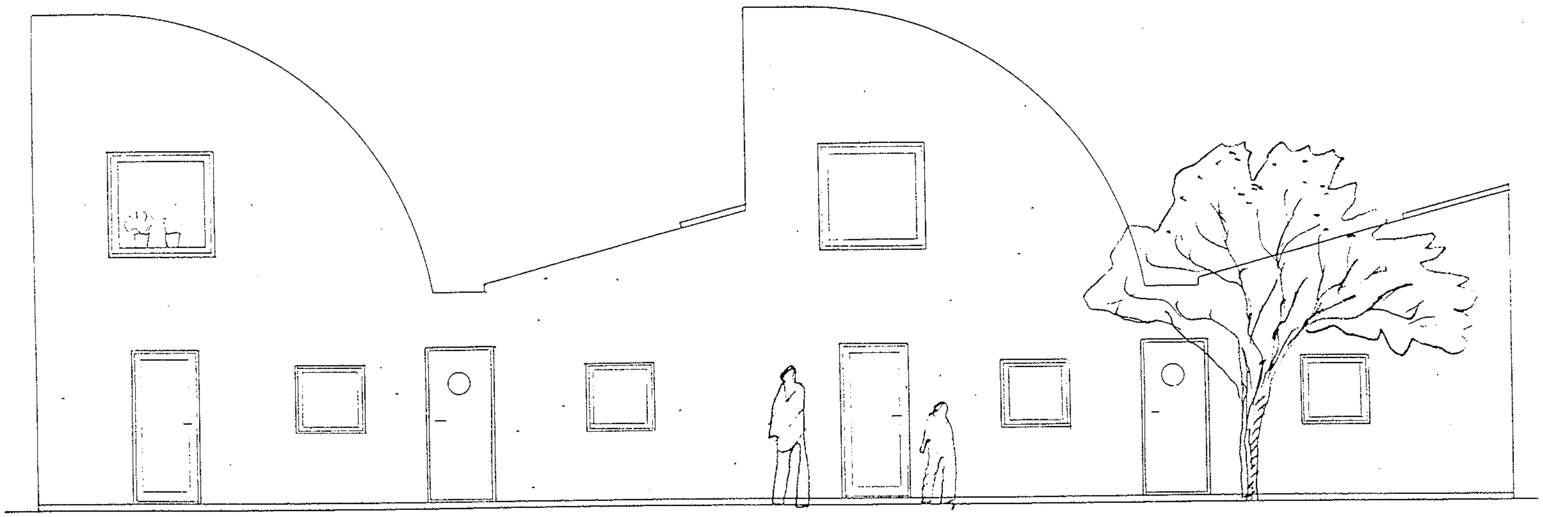
In table 3 the total energy consumption for a rowhouse is shown in kWh/year.

Table 3. Total energy consumption (kWh/m^2 per year).

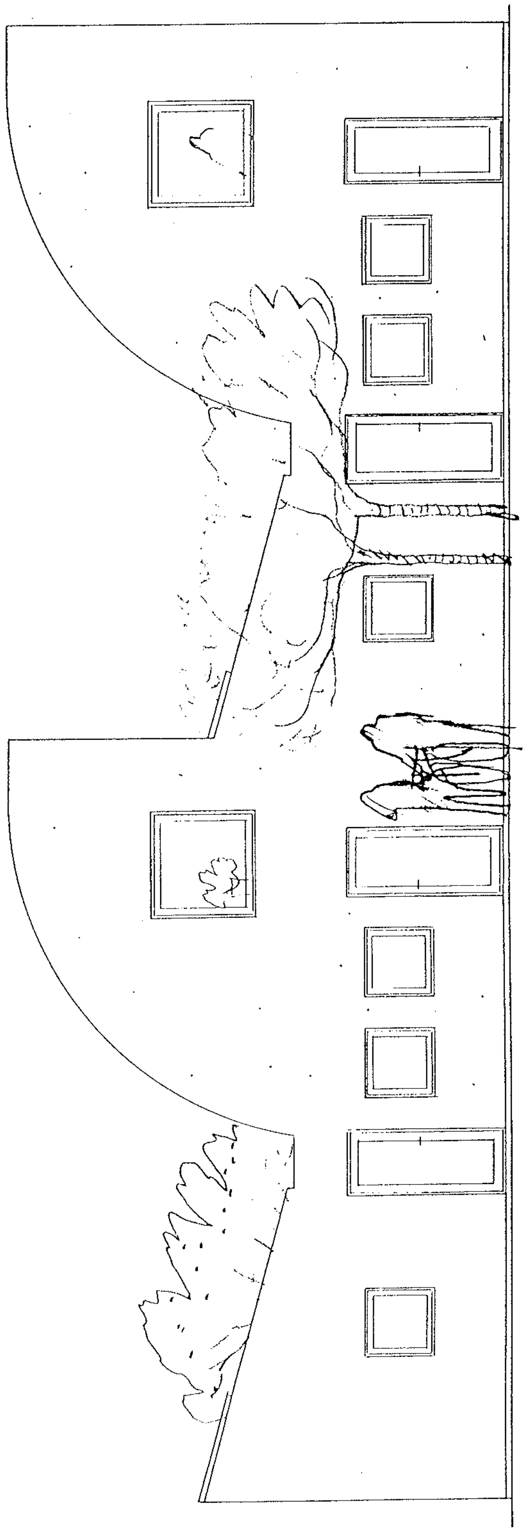
Net heating load	10.0
Auxiliary water heating (DHW)	5.0
Electricity for light & household appliances	13.0
Electricity for fan/pumps	5.0
Total energy consumption	33.0

5. DRAWINGS OF BOTH TYPES OF HOUSES



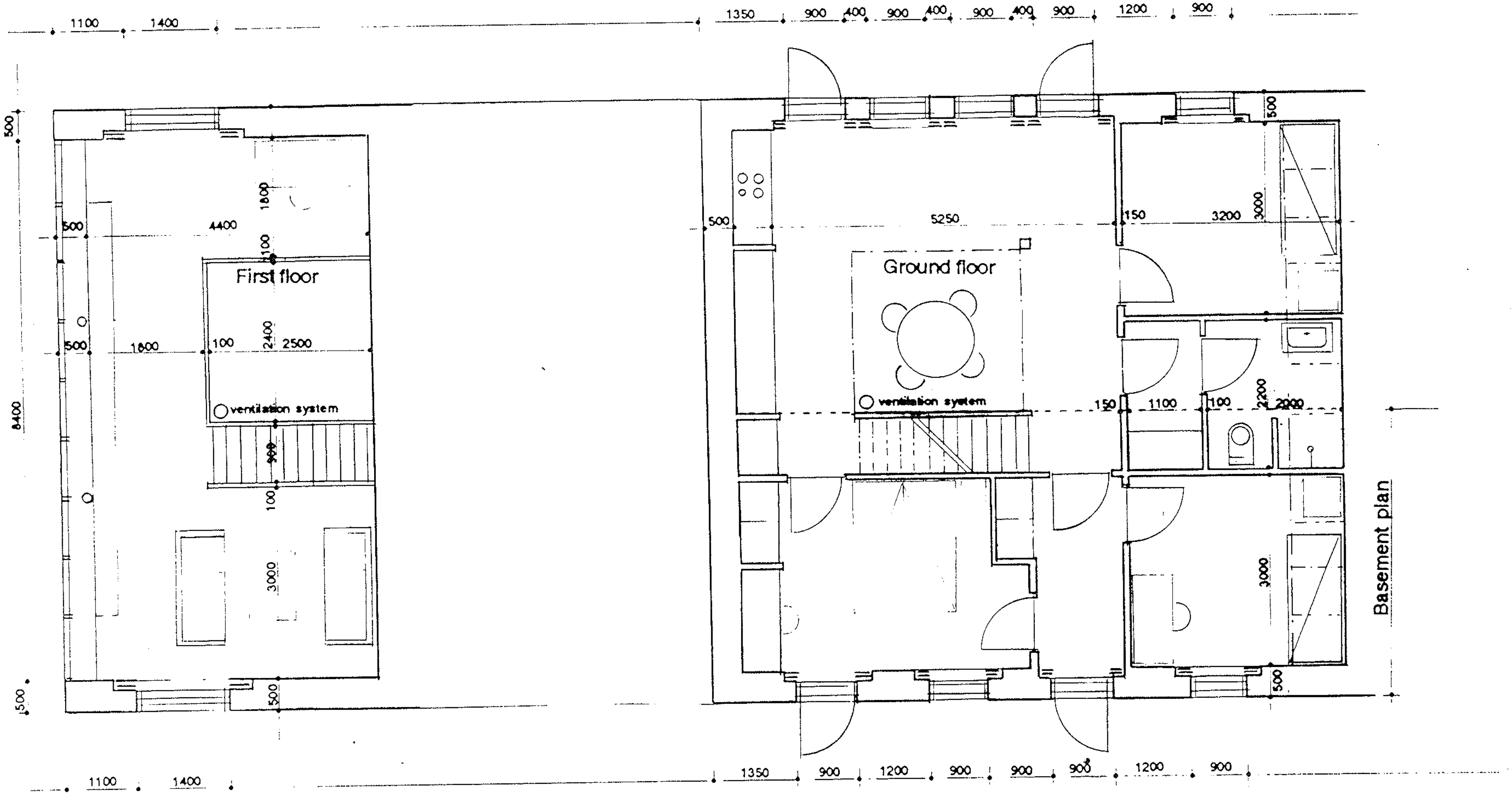


Subject	East facade of a terracehouse facing east-west		
Scale	Date	Revised Date	Drawings no
1:100	06.02.91		1



Subject
West facade of a terracehouse facing east-west

Scale	Date	Revised Date	Drawings no
1:100	06.02.91		2

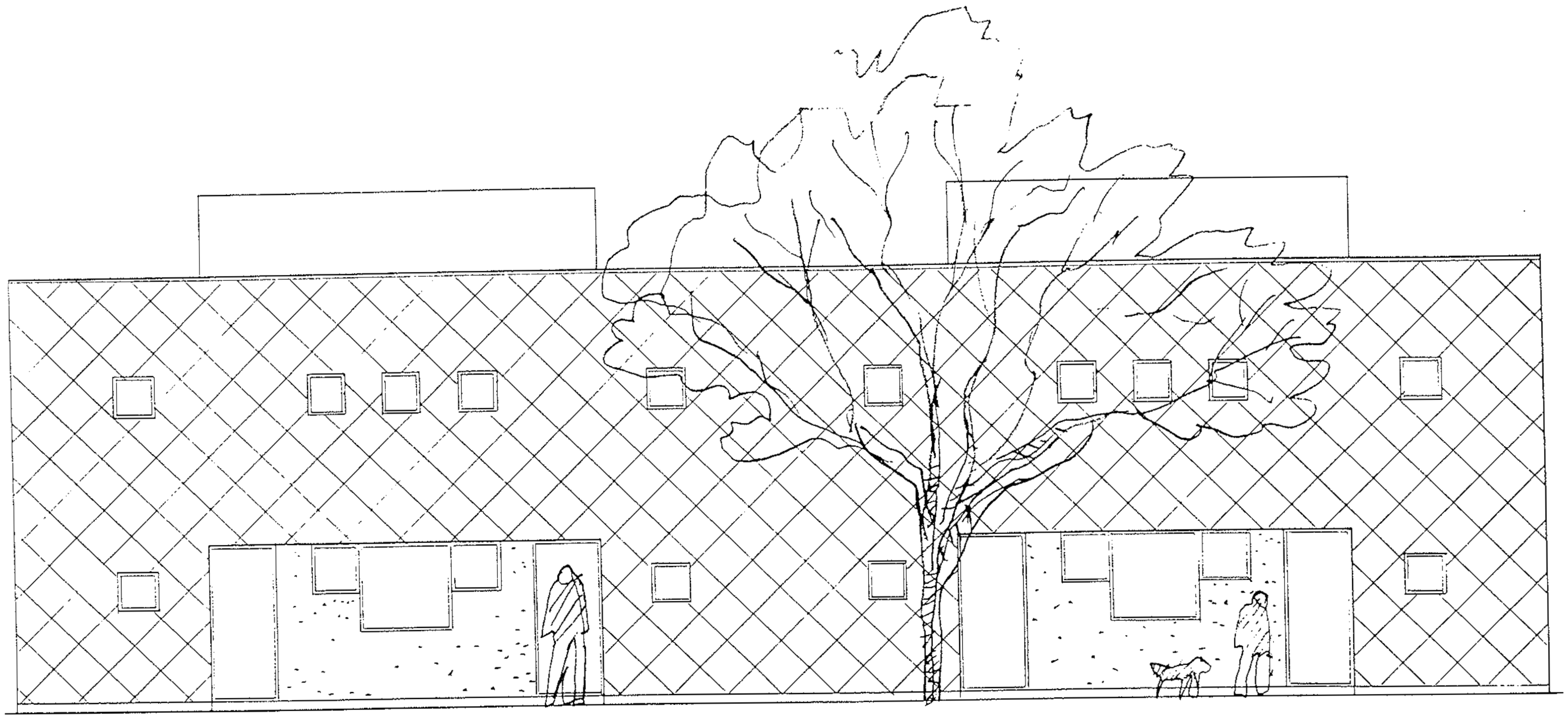


Subject: Plan of terracehouse facing east-west

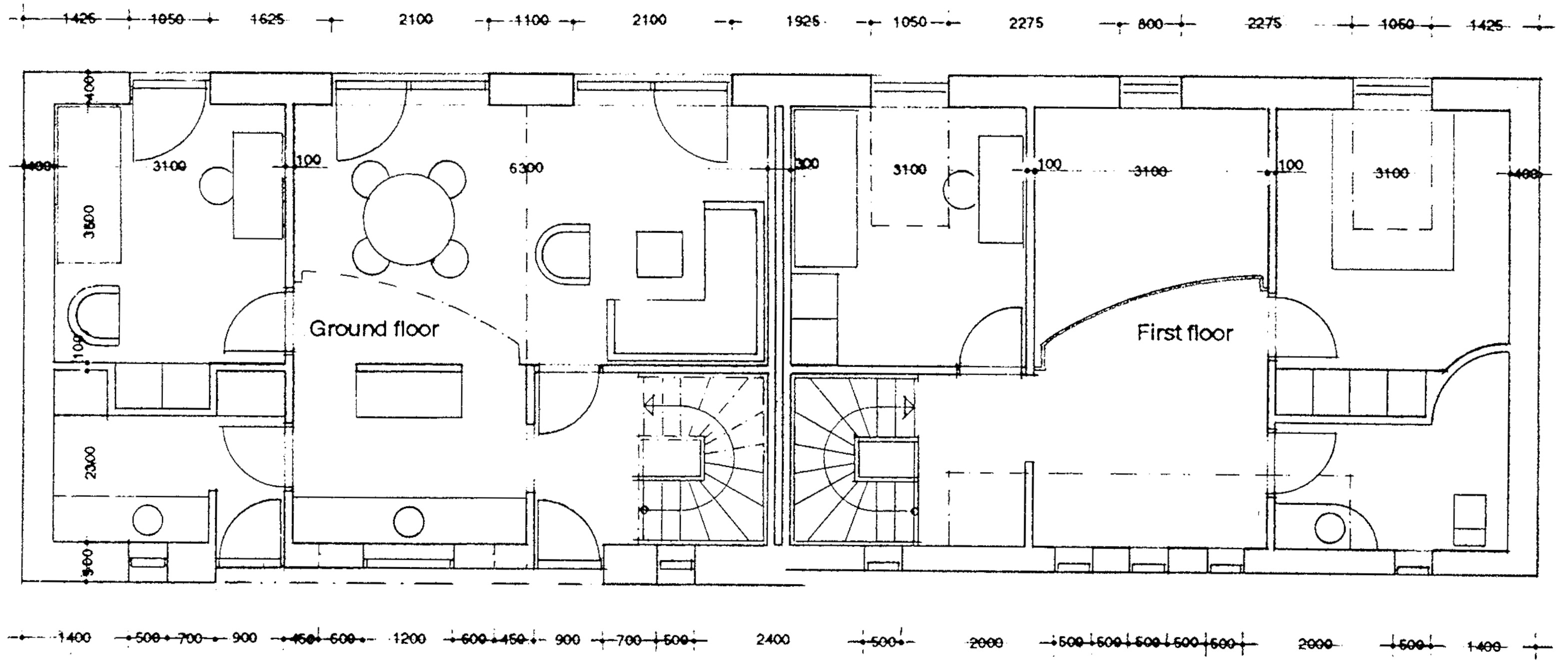
Scale	Date	Revised Date	Drawings no
1:100	06.02.91	18.04.91.	3

Subject
Southern facade of a terracehouse facing south

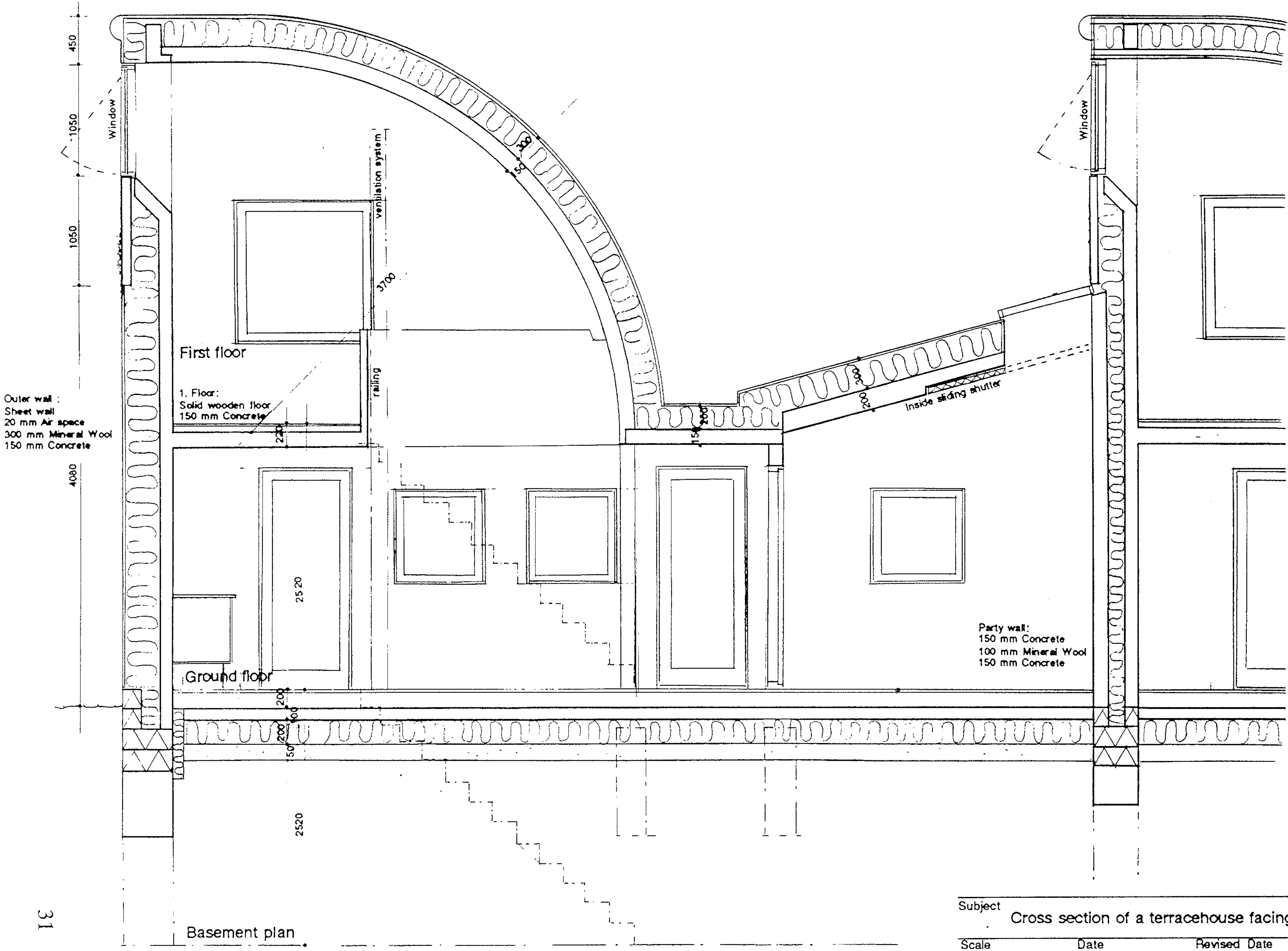
Scale	Date	Revised Date	Drawings no
1:100	06.02.91		4



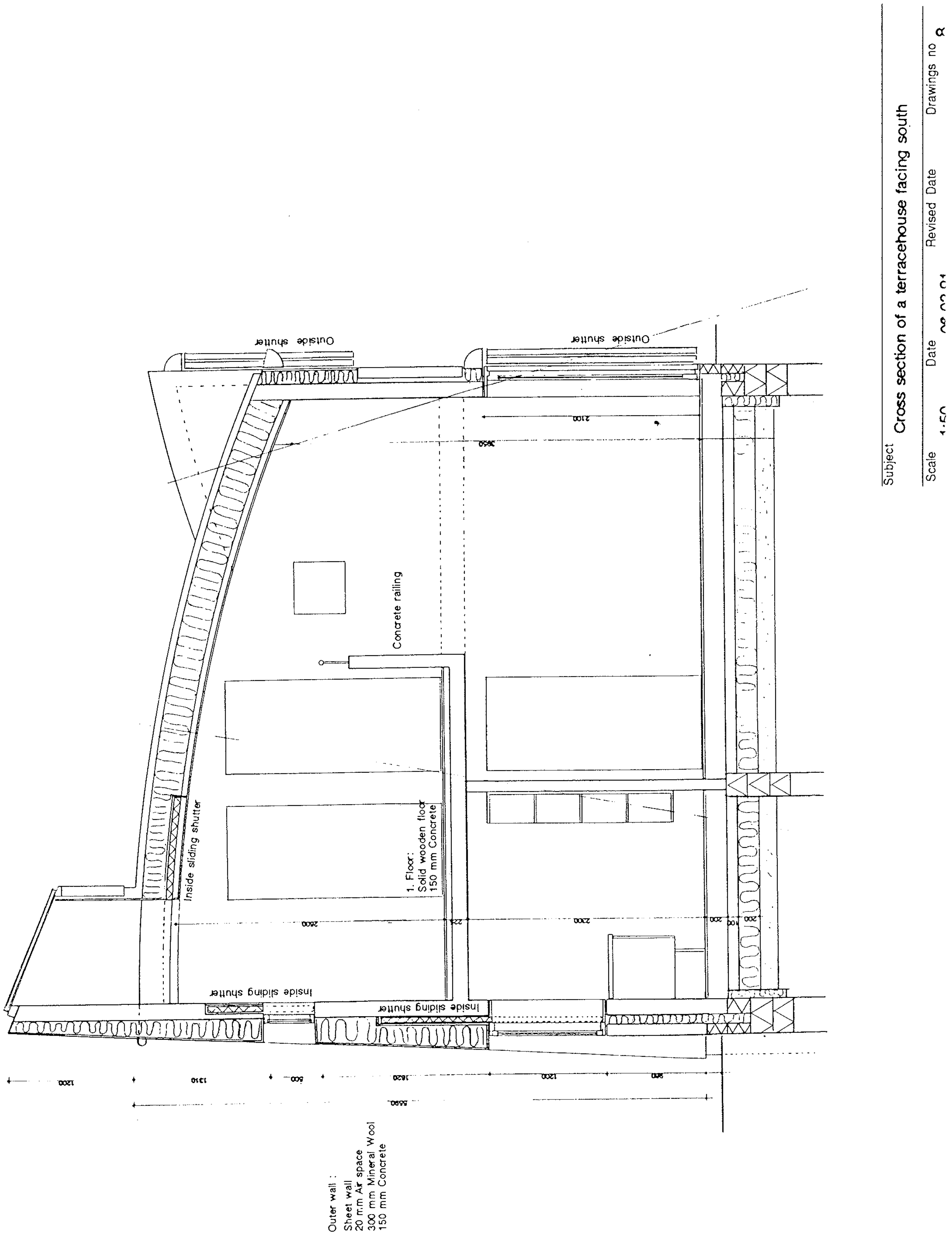
Subject	North facade of a terracehouse facing south		
Scale 1:100	Date 06.02.91	Revised Date	Drawings no 5

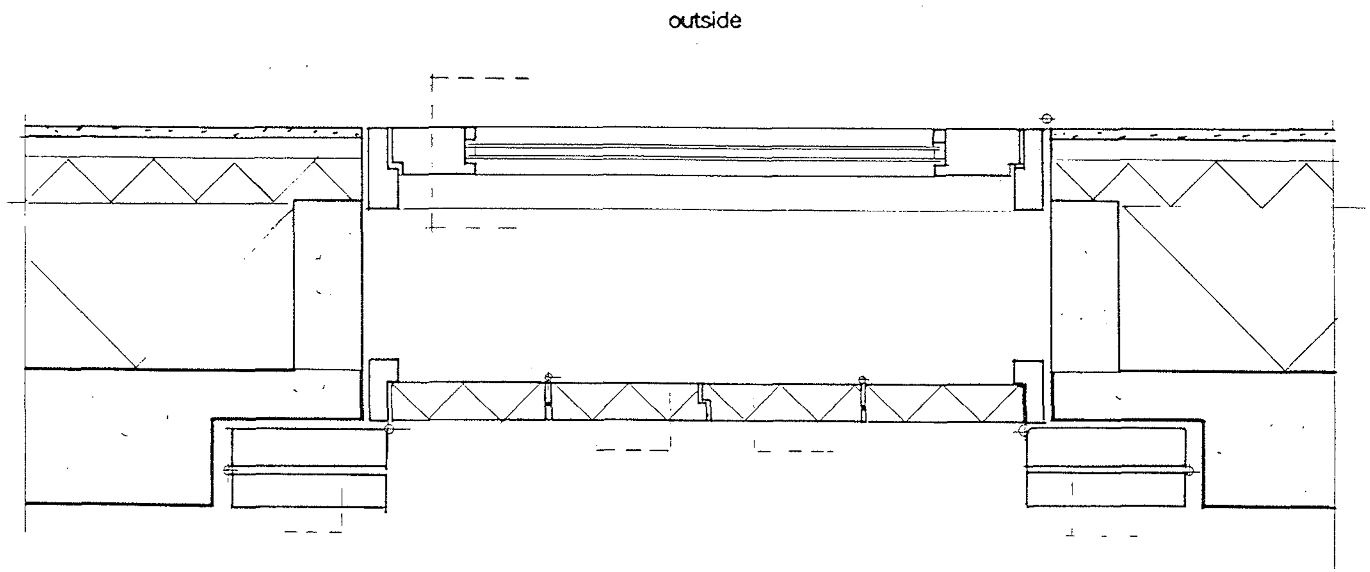


Subject			
Plan of terracehouse facing south			
Scale	Date	Revised Date	Drawings no
1:100	18.04.91.		6



Subject	Cross section of a terracehouse facing east-west		
Scale	Date	Revised Date	Drawings no
1:50	06.02.91	18.04.91.	7


Outside shutter
Outside shutter
Concrete railing
Inside sliding shutter
Inside sliding shutter
Inside sliding shutter
1. Floor:
Solid wooden floor
150 mm Concrete
Outer wall :
Sheet wall
20 m.m Air space
300 mm Mineral Wool
150 mm Concrete
Subject
Cross section of a terracehouse facing south
Scale
Date
Revised Date
Drawings no



Subject	Horizontal principle section of the shutter on the facade facing east-west		
Scale	Date	Revised Date	Drawings no
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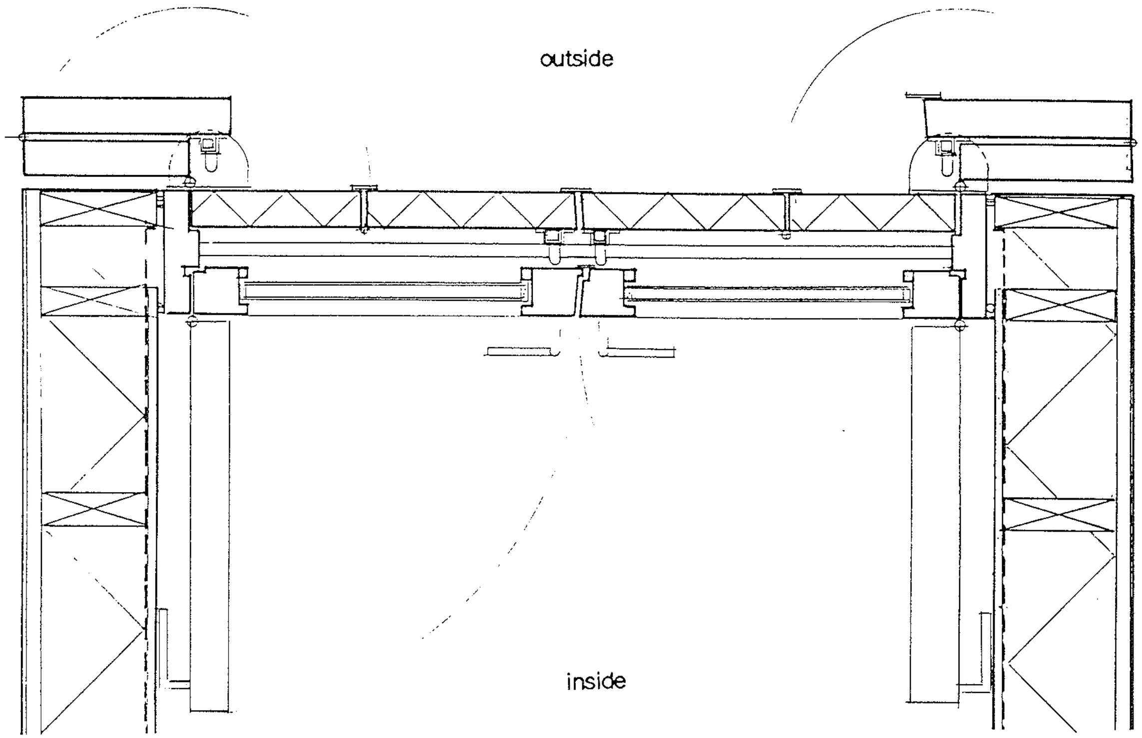

Subject	Horizontal principle section of the shutter on the facade facing south		
Scale	Date	Revised Date	Drawings no
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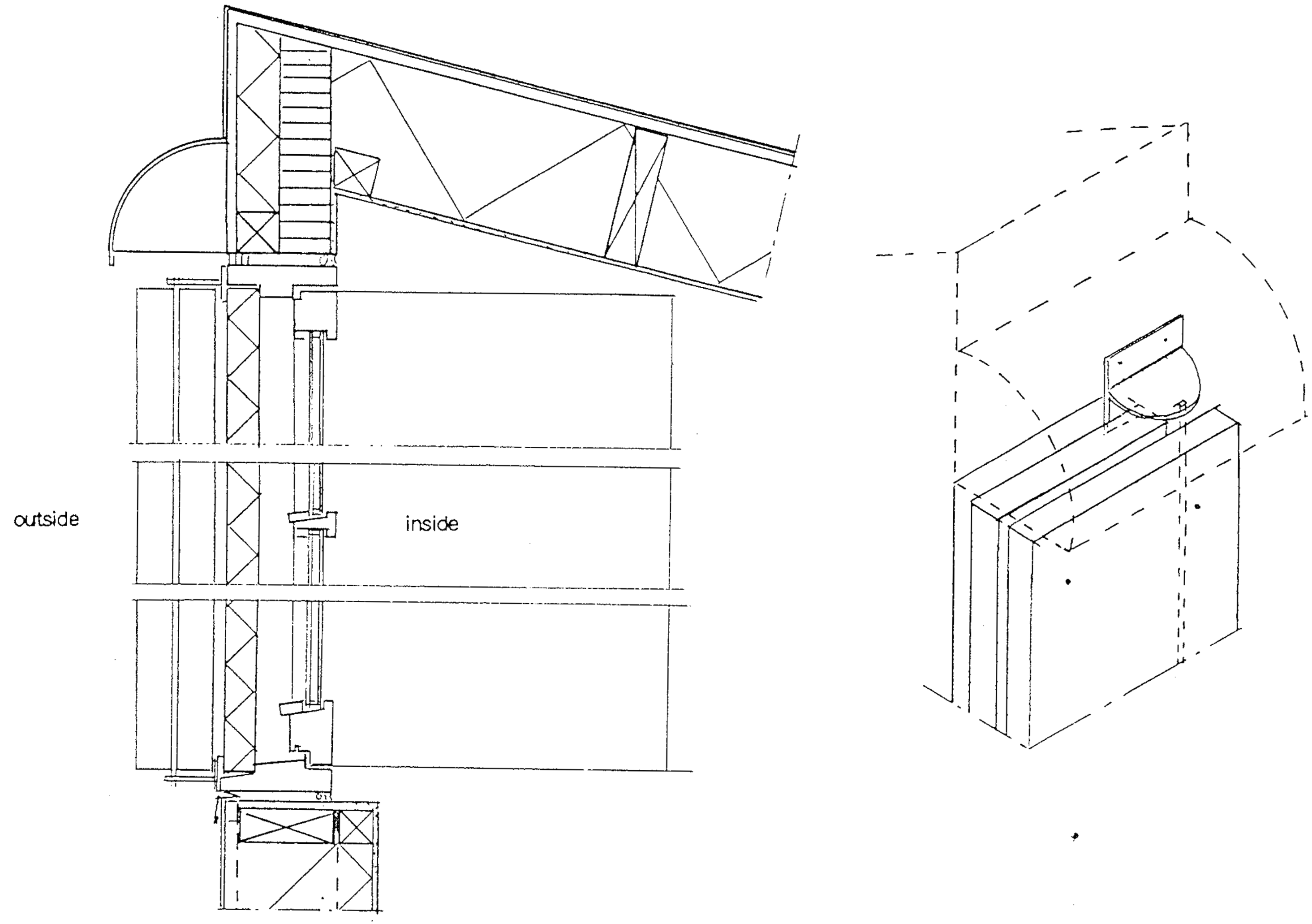
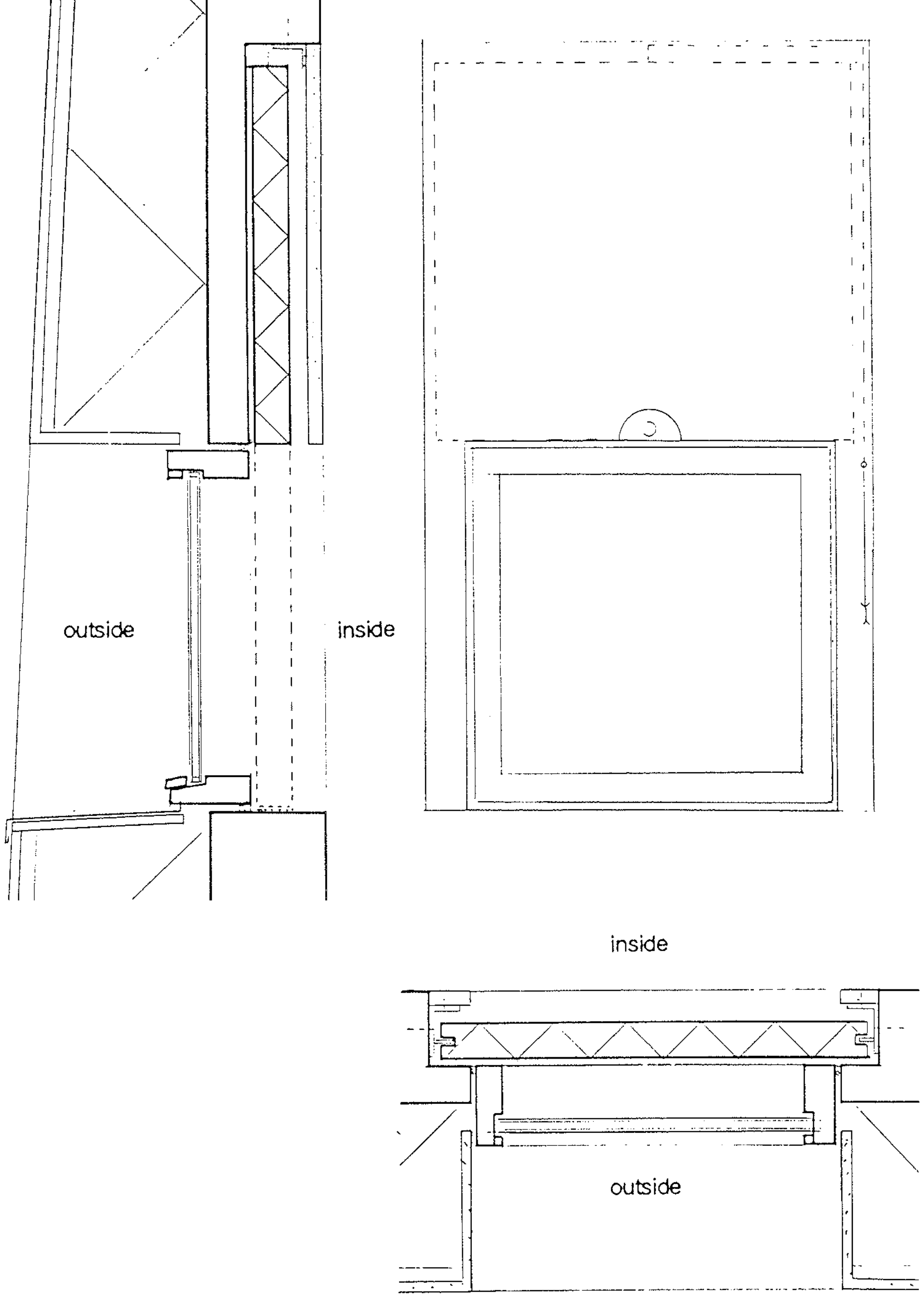


Subject	Vertical principle section of the shutter on the facade facing south		
Scale	Date	Revised Date	Drawings no
1:10	06.02.91		11



Subject			
Principle for shutter on the facade facing north			
Scale	Date	Revised Date	Drawings no
1:10	06.02.91		12

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