LEP

The Low-Energy House Project
The Danish Ministry of Energy

EXTERNAL INSULATING SHUTTERS IN ENERGY CONSERVATION HOUSES

129

Thermal Insulation Laboratory
Technical University of Denmark
November 1982

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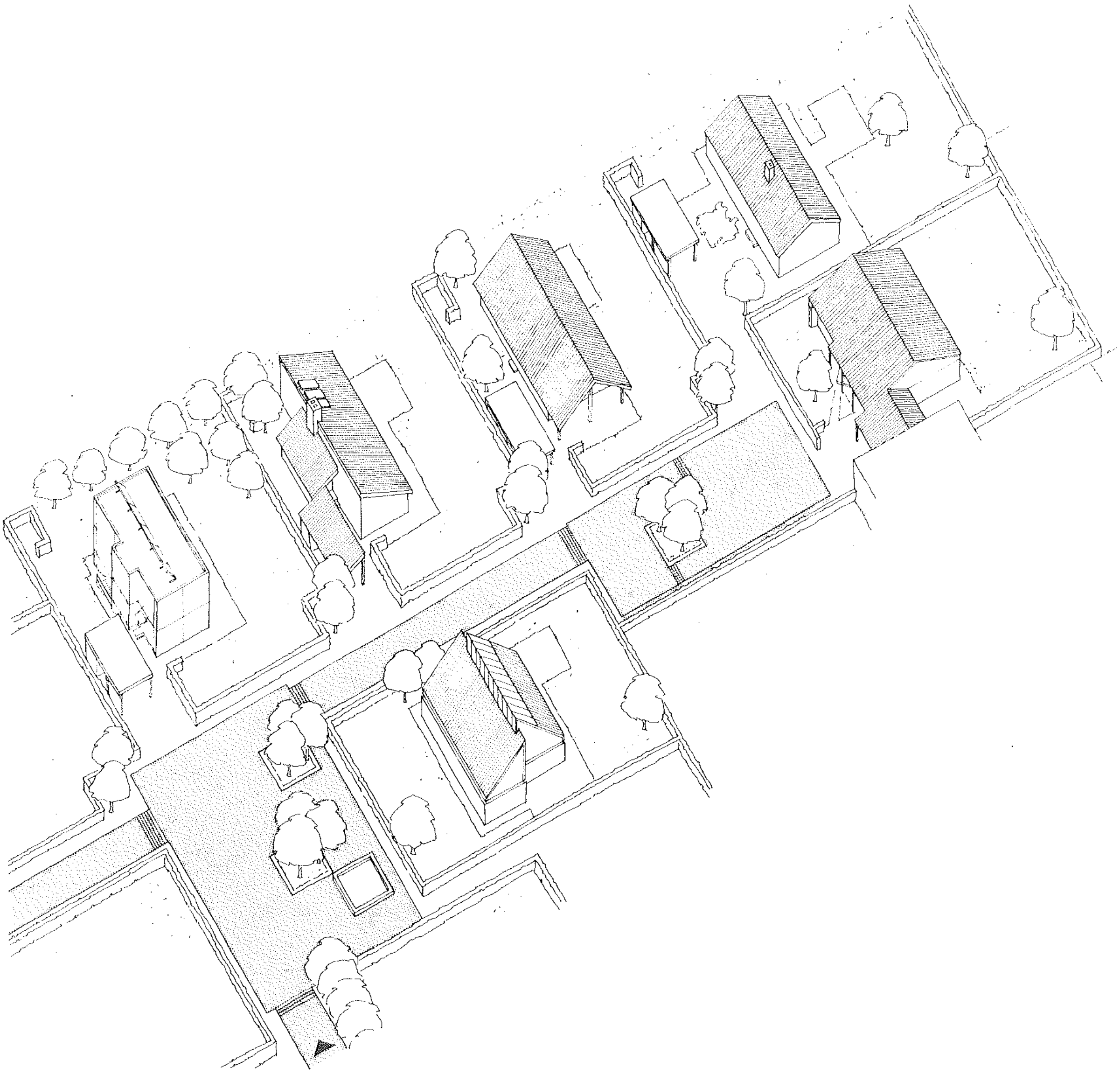

EXTERNAL INSULATING SHUTTERS IN ENERGY CONSERVATION HOUSES - descriptions and experiences from three low-energy houses at Hjortekær, Denmark

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The Low-Energy House Project

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PREFACE

The main part of the results in this report was presented at the ENERGEX'82 SESCI Energy Conference at Regina, Saskatchewan, Canada, August 23-29 1982. The material has been reedited and new illustrations and calculation results have been added.

The Low-Energy House Project is carried out by the Thermal Insulation Laboratory at the Technical University of Denmark. The project is part of the National Energy Research Programme and is funded by the Danish Ministry of Energy.

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ABSTRACT

One way of minimizing the heat loss through windows is to apply movable insulation. This report gives a detailed description of three types of external shutters that were designed for three of six prototype low-energy houses at Hjortekær, Denmark. Some effort has been made to achieve efficient seals, and measurements of infiltration air change rates and results from pressurization and depressurization tests show that the attempts have been successful. The thermal performance of the shutters has been verified by thermal calibration of the houses, and a very good agreement is found between the measured and the calculated heat losses. This forms a basis for an estimate of the annual energy savings obtained by the use of shutters. In the three houses a conservative estimate shows energy savings of approx 800-2000 kWh/year.

When the houses were occupied (1980-81) the operation of the shutters was monitored, and a description is given of the mechanical performance of the shutters as well as of some users' experiences, mainly concerning the problems caused by drifting snow.

INTRODUCTION

As part of the Danish Energy Research and Development Programme six low-energy houses have been built at Hjortekær, north of Copenhagen, as detached single-family houses each having a living area of approx 120 m^2. Five houses were completed in the autumn of 1978 and the last one in March 1979, [1]. Since then, a research team has carried out detailed continuous energy measurements as well as limited investigations of specific problems. During the period from the completion of the houses till May 1980 none of the houses were inhabited, but the occupancy was simulated according to a standard pattern (including electricity consumption for lighting and domestic appliances, heat emission from persons and the use of domestic hot and cold water), [2]. After May 1980 the houses were eventually sold and inhabited, and the monitoring was continued till May 1982.

The houses are all different regarding design, building materials, heating systems etc. A low energy consumption is obtained through an interplay of a low energy demand (mainly through a high degree of insulation and air tightness) and utilization of alternative energy sources (mainly through heat pumps and active solar systems). The greater importance is attached to the low energy demand.

When the solar heat gain is disregarded even good windows with double or triple glazing account for a considerable part of the transmission heat loss from energy conservation houses. Figure 1 illustrates this point using the six houses at Hjortekær as an example. In the Danish climate only south facing windows make a positive contribution to the overall heating of buildings, [3]. For windows oriented otherwise the annual heat loss exceeds the solar heat gain. Thus a reasonable energy conservation design measure is to shift the heat balance for glazed openings by the introduction of mobile insulation for use primarily during the night.

House	(1) [W]	(2) [W]	(2)/(1) [%]
A	2525	1313	52
B	2462	1187	48
C	2753	1296	47
D	3027	1546	51
E	2268	1172	52
F	4257	2280	54

(1) Φ from house

(2) Φ through doors and windows

Figure 1. Design transmission heat loss (design internal to external temperature difference 32 deg C).

DESCRIPTION

Three of the houses at Hjortekær (D, E, and F in Figure 1) have external insulating shutters as movable insulation of the major glass areas. The windows and some of the doors are equipped with double or triple glazed sealed units, and the shutters have an insulation of 35-75 mm mineral wool or polystyrene foam.

The three houses have three different types of shutters. Two of the houses (both in one storey only) have manually operated sidehinged shutters, one-winged and two-winged respectively. The third (a two-storey house) has automatically working sliding shutters.

Figure 2 shows the operation of the two-winged shutters of house D and lists some principal information on the transmission areas. As the roof slopes to the south three small windows in the high north wall cannot be seen on the floor plan - these windows have no shutters. Sealed units with double glazing are used in windows with and triple glazing in windows without shutters. All shutters can be operated from the inside, as the windows open inwards, but it is much easier to work them from the outside.

Figure 3 shows a south facing window and shutter in greater detail. It should be noticed that the shutters are two-winged without a central post. Each wing is made as a wooden frame construction with 14 mm wood panelling on both sides. The frames for the large shutters for the south facing doors have two wooden cross bars while the smaller frames have a single cross bar. Approx 20-25% of the transmission area thus consists of solid wood. The remaining transmission area is insulated with 50 mm of mineral wool. The edging is equipped with weather strips. When closed the shutters are locked with a pasquil lock mounted on the left wing (left referring to Figure 3).

Figure 4 for house E shows the equivalent of Figure 2. In this case only the entrance door is not equipped with movable insulation. All windows have sealed units with double glazing, gas filled and coated. The south facing windows have a different coating giving a slightly higher U-value, but allowing more insolation (Thermoplus 1.4 and 1.6 respectively). As in house D the shutters may be operated from the inside, but only if the windows are opened first.

Figure 5 shows one of the small windows and its shutter. These shutters are made as wooden frames with 9 mm plywood boards on each side and are insulated with 35 mm of expanded polystyrene. The use of plywood and a fairly heavy frame eliminates the need of cross bars. However, due to the heavy frames 28-42% of the transmission area is solid wood (28% for the French windows, 42% for the small windows). As in house D the edgings are weather stripped. When closed the shutters are locked with a pasquil lock.

The shutters in house F slide horizontally on the south aspect as indicated in Figure 6. It should be noticed that the windows of the house are primarily oriented to the south. They are all triple glazed (sealed units in reinforced plastic frames). The shutters are operated automatically, all working simultaneously controlled by a time switch. A manually controlled switch at each window allows separate operation of each shutter. This is a prototype system developed by the Department of Mechanical Technology, AMT, at the Technical University of Denmark.

The construction of the shutter and the mechanical system is illustrated in Figure 7 and 8. Though the shutter is large (approx 3.6 m^2) it is made as a single frame construction with 9 mm plywood boards on either side. Thus only 13% of the transmission area is solid wood. Except for the solid part the shutter is insulated with 75 mm of mineral wool.

As the shutter is quite heavy (approx 65 kg) a strong suspension system is necessary. In this case an iron pipe bolted onto the concrete wall serves as track for two ball bearing wheels. The wheels are affixed to two hangers that bear the weight of the shutter. The lower edge of the shutter is equipped with ball bearings and guided by a track as shown in Figure 8.

The ball bearing wheels are protected from snow and rain by a canopy and ensure that the shutters slide easily even in very cold periods.

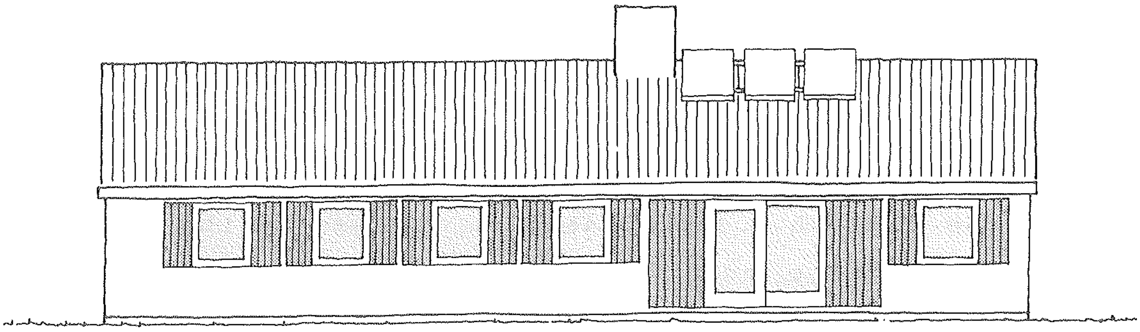
The sealing of external shutters is very important and has constituted a major problem in connection with sliding shutters. Some years ago the Thermal Insulation Laboratory and the Institute of Building Design designed some sliding shutters for the Zero Energy House [4] using brush seals for all four edges. These seals have not performed well [5] and so the experiences from the Zero Energy House compelled a quite different solution to the problem.

As indicated on Figure 7 and 8 a so-called reinforced synthetic rubber tube is fastened at the edge of the shutter on the inner side. The tube has a diameter of approx 35 mm and is mitred and glued at the corners of the shutter. The interconnected load-bearing hangers are connected to the shutter by lever arms attached to vertical steel rods that pass all the way through the shutter proper and are attached to the bottom guide track by other lever arms with ball bearings (as shown in Figure 8). If the interconnected hangers are pulled to the west (to the left in Figure 7) the shutter will roll along until its route is blocked by a steel rod protruding from the wall (at point A in Figure 7). As the shutter proper cannot go any further the continued pull on the hangers will cause the levers to press the shutter against the wall and thus squeeze the rubber tube between the wooden frame and the concrete surface.

The push/pull movement is delivered by a low-power electric motor (just above point A in Figure 7) rotating a threaded spindle within the load-bearing iron tube. The spindle moves a slide connected to the shutter through a slit along the bottom of the iron tube.

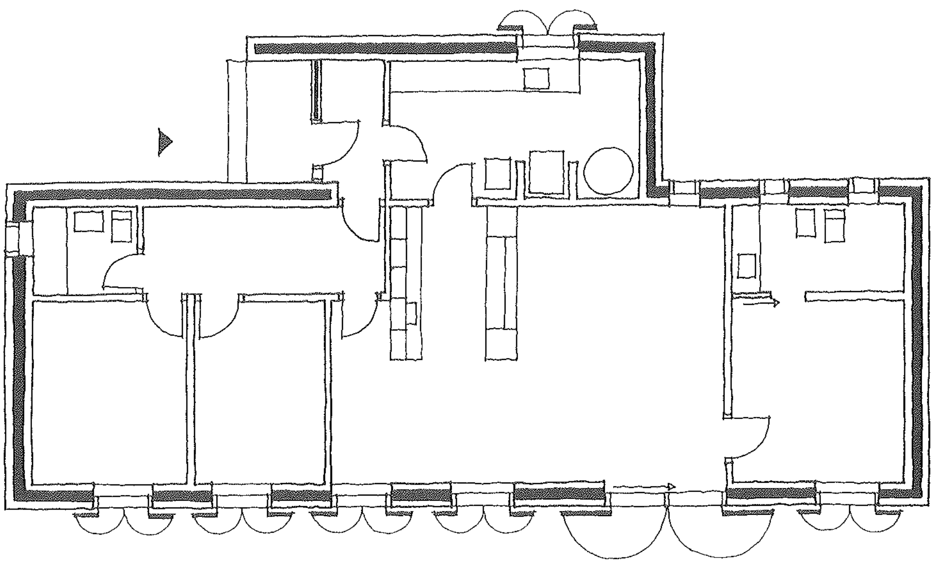
To have the windows accepted as fire escapes by the authorities in Denmark it must be possible to open the shutters manually in case of power failure utilizing a force not exceeding 100 N. Thus the slide cannot permanently be mechanically affixed to the shutter. The designers have chosen to have a permanent magnet pulling the shutter during the closing movement. This solution has one obvious advantage: no one gets jammed as the shutter is closed.

The shutter is pushed to the east to open and pulled to the west to close, both ways in a slow steady movement taking about 8 minutes. The motor is controlled by a time relay set to run for about 10 minutes. The allowed pull of the magnet is insufficient to complete the closing movement by compressing the rubber tube sealing the desired 10 mm (from a diameter of 35 mm to 25 mm). Therefore, the catch shown in Figure 9 is activated just before the shutter reaches point A of Figure 7 and the shutter thus mechanically affixed to the power-driven slide. In case of an emergency a wire pull at point A in Figure 9 releases the catch, a tension spring (shown in Figure 7, at the top) helps disengaging the lever arms, and the shutter can then be pushed open quite easily. The thin steel wire runs in a tube from the top of the shutter to about waist level on the interior side.



South aspect

Gross floor space	137.9 m^2
Volume	345.2 m^3
Area of window and door openings	20.50 m^2
of these south facing:	13.64 m^2
Corresponding transparent areas	10.98 m^2
of these south facing:	8.58 m^2
Area of shuttered openings	15.10 m^2
of these south facing:	13.64 m^2
Corresponding transparent areas	9.39 m^2
of these south facing:	8.58 m^2



Floor plan

Figure 2. House D. Operation of external shutters.

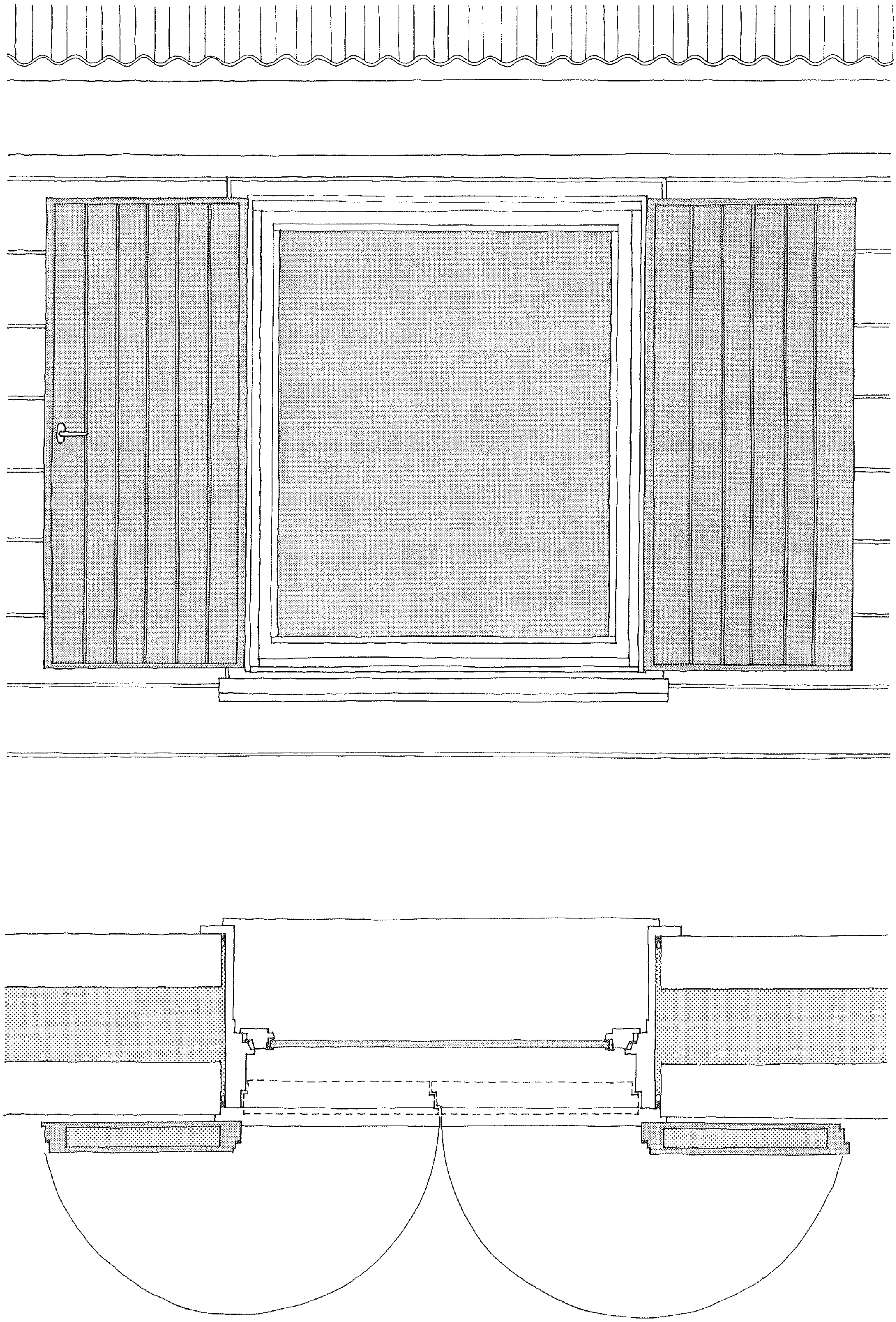
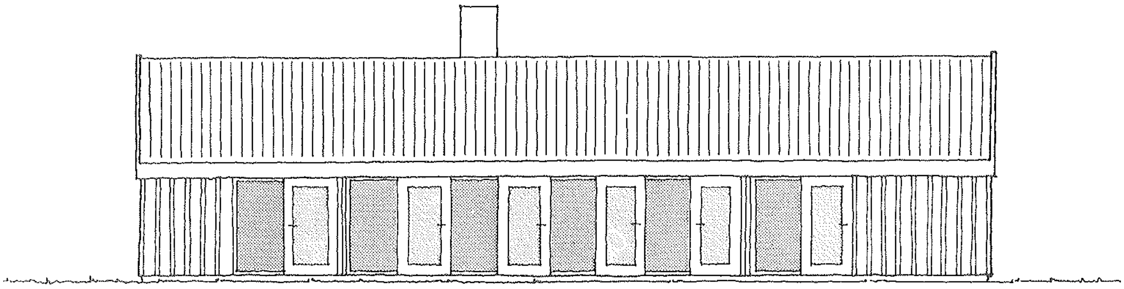
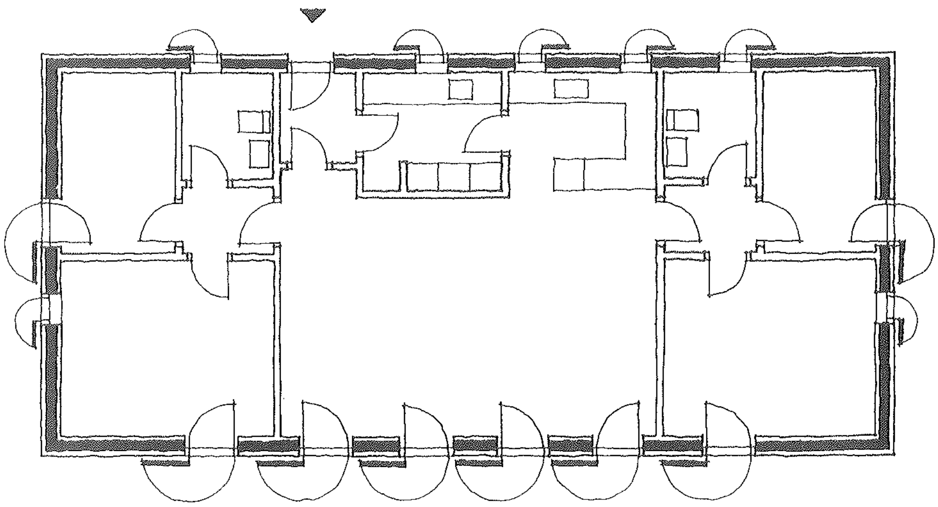


Figure 3. House D. Window with external shutters.



South aspect

Gross floor space	135.8 m^2
Volume	410.8 m^3
Area of window and door openings	21.99 m^2
of these south facing:	13.74 m^2
Corresponding transparent area	10.43 m^2
of these south facing:	7.28 m^2
Area of shuttered openings	20.08 m^2
of these south facing:	13.74 m^2
Corresponding transparent area	10.43 m^2
of these south facing:	7.28 m^2



Floor plan

Figure 4. House E. Operation of external shutters.

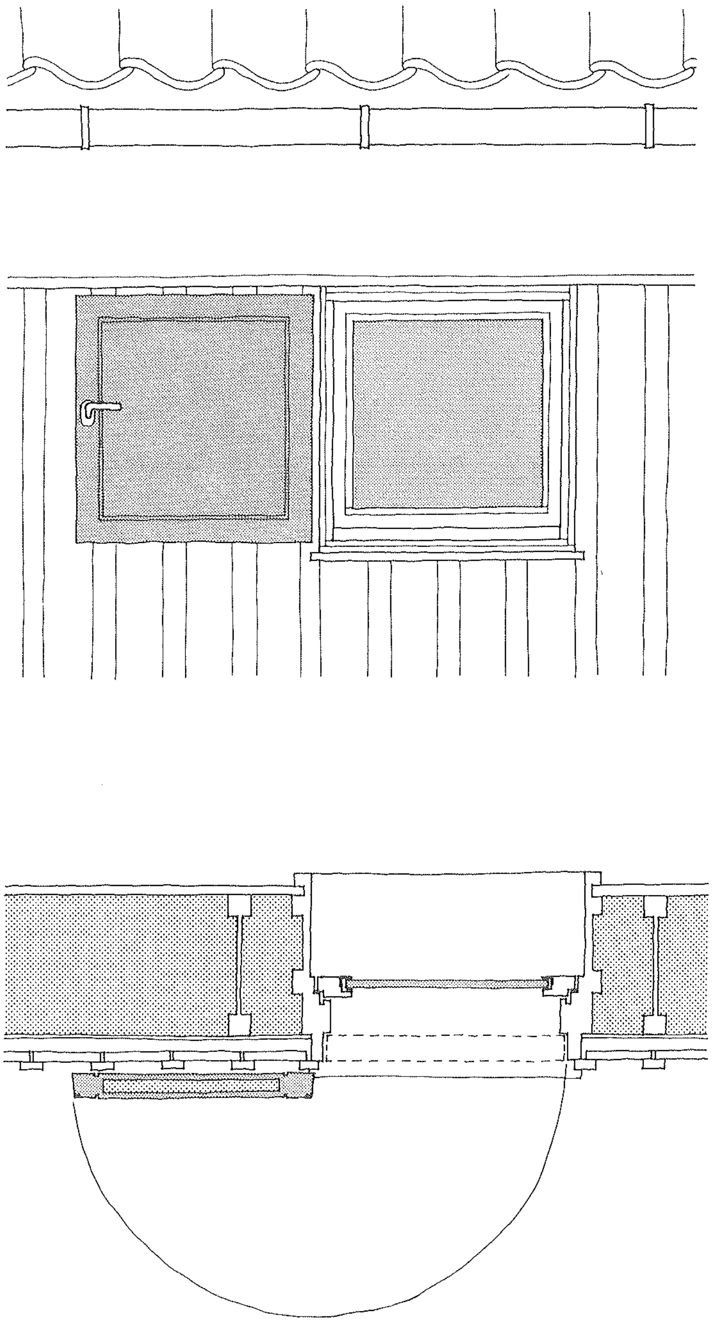
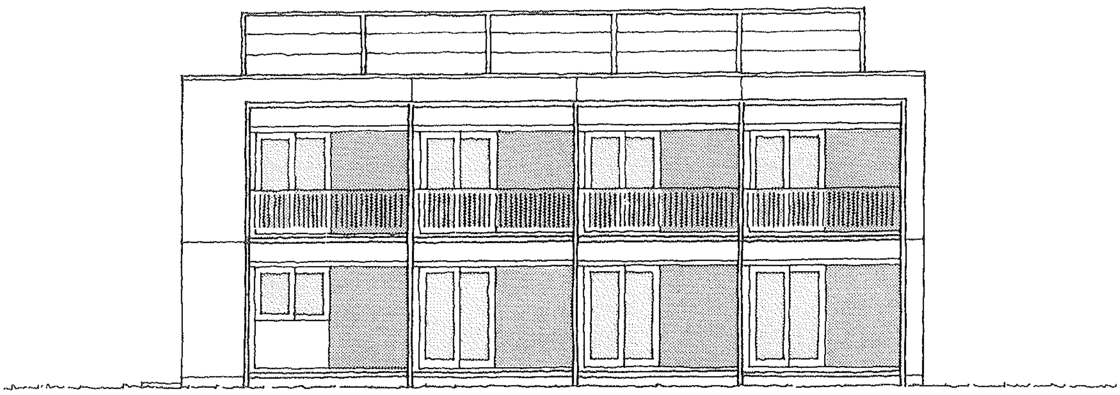


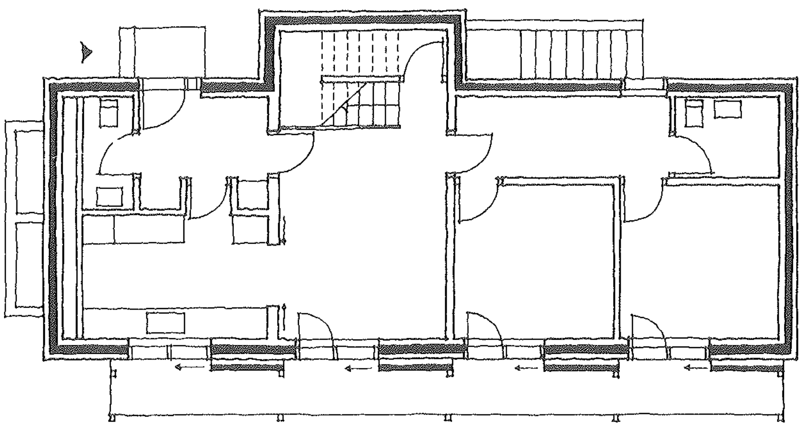
Figure 5. House E. Small window with external shutter.



South aspect

Gross floor space	176.1 m^2
Volume	349.2 m^3
Area of window and door openings *)	31.04 m^2
of these south facing:	26.88 m^2
Corresponding transparent area	19.81 m^2
of these south facing:	18.66 m^2
Area of shuttered openings **)	26.88 m^2
of these south facing:	26.88 m^2
Corresponding transparent area	18.66 m^2
of these south facing:	18.66 m^2

*) Ground floor and first floor
**) Of this 1.44 m^2 is a well insulated parapet (top drawing, to the bottom left)



Ground floor

Figure 6. House F. Operation of external shutters.

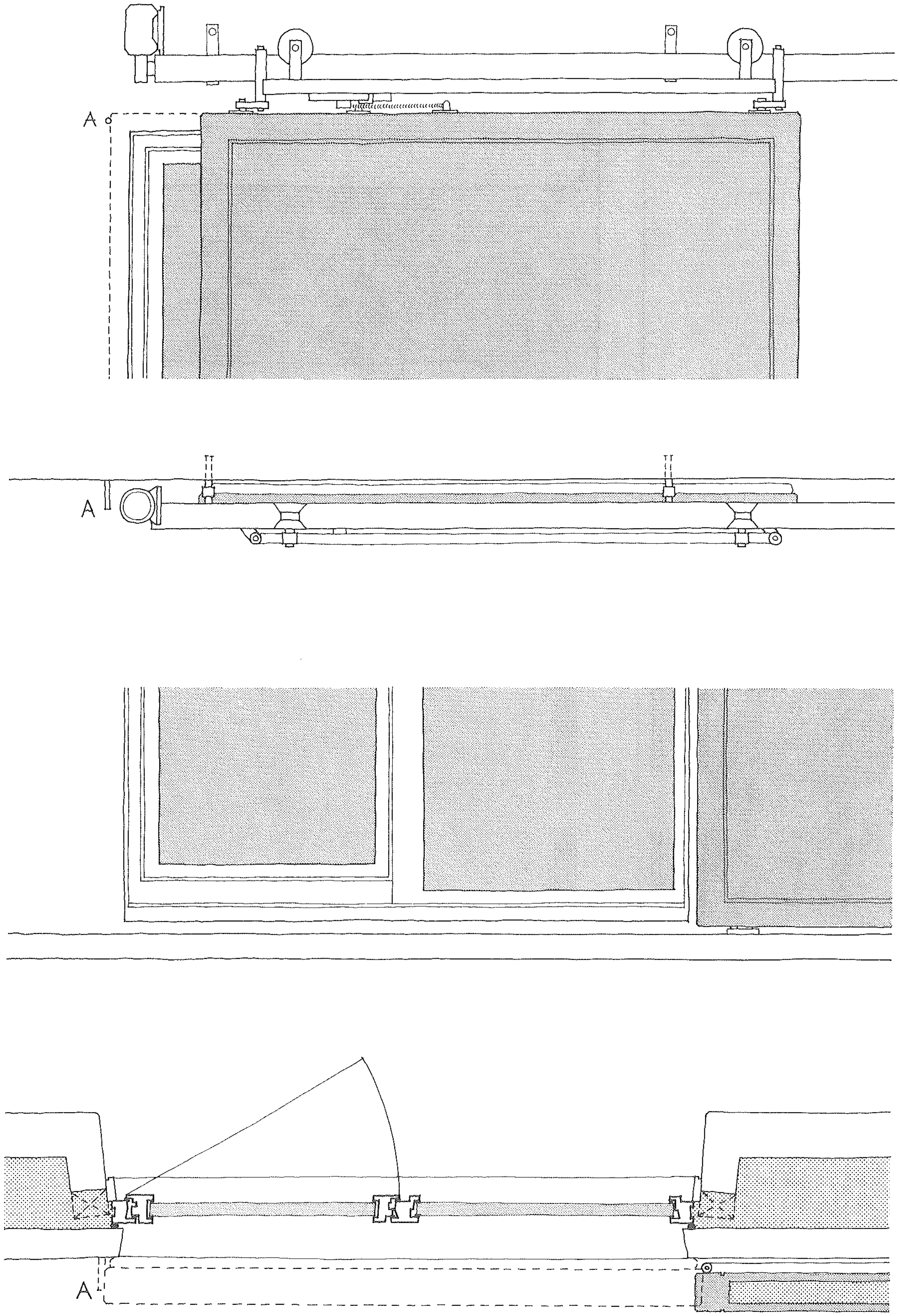


Figure 7. House F. South facing French window with external horizontally sliding shutter.

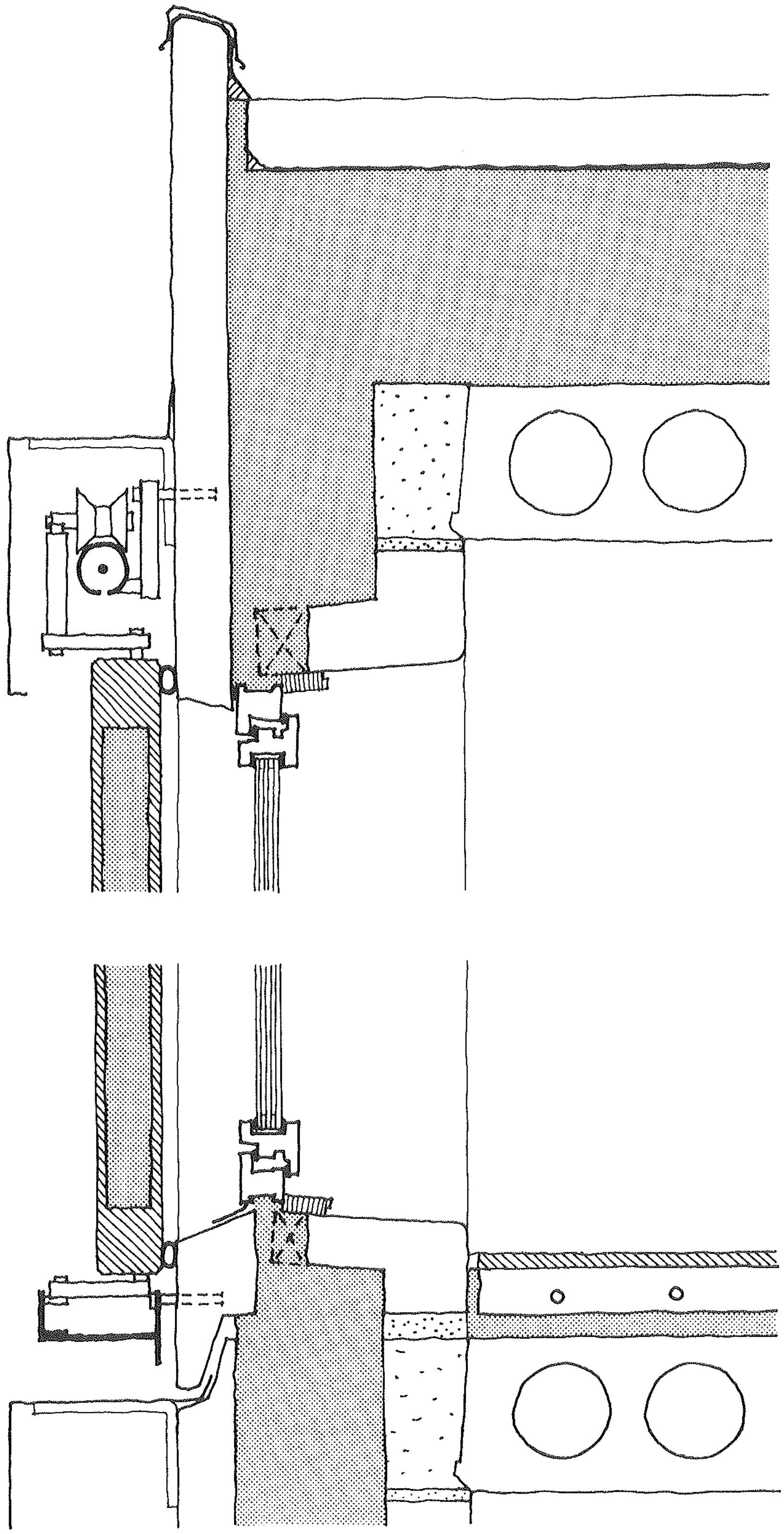


Figure 8. House F. Section of sliding shutter.

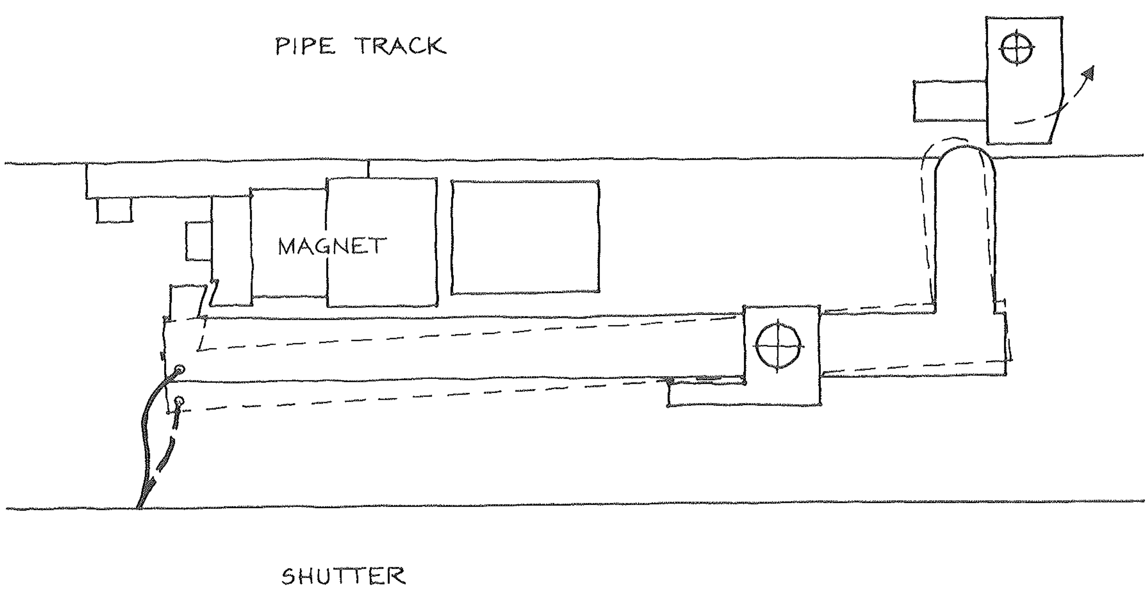


Figure 9. House F. Detail of shutter mechanism.

AIR TIGHTNESS

External shutters are subject to the wind forces, and the insulating efficiency depends on the air tightness of the joints. A comparison of the three shutter constructions at Hjortekær (Figure 3, 5 and 7 respectively) makes it quite clear that the sliding shutters of house F are the most vulnerable as the two other types are flush with the wall surface when closed.

To determine the performance of the shutter seals in the three cases the infiltration air change rate of the houses has been measured by the tracer gas decay method, and depressurization tests have been made. The test procedures are described in [6]. It should be noticed that at the time of the first measurements the houses were about 18 months old and had been heated all the time.

The main results are listed in Figure 10 and were obtained from three operating conditions:

a) all windows closed &
   all shutters open

b) all windows closed &
   all shutters closed

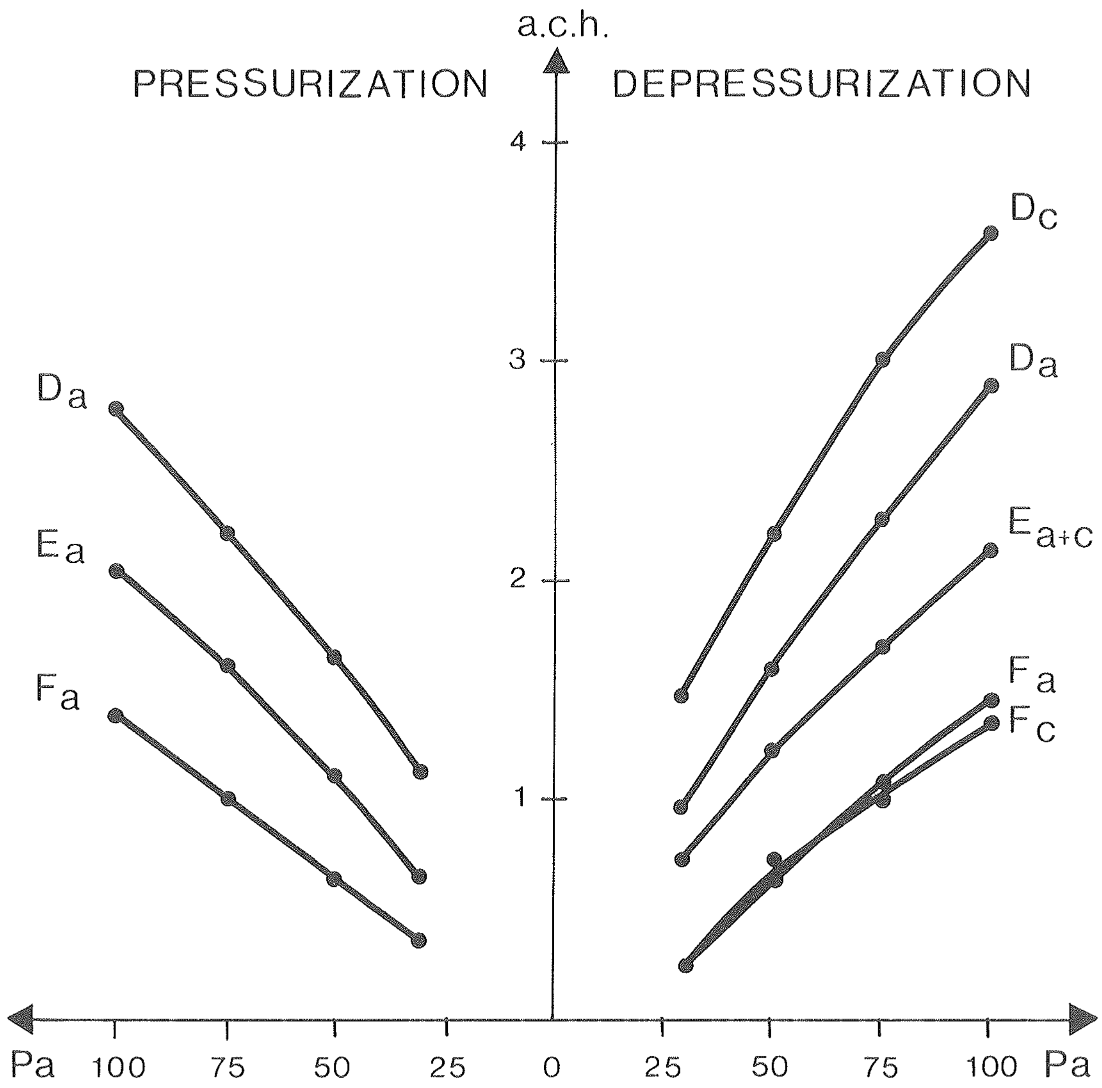
c) all windows behind shutters open &
   all shutters closed.

TRANSMISSION HEAT LOSS, CALCULATED AND MEASURED

The U-values of the windows with and without shutters have been calculated according to the Danish rules, [7]. Typical U-values for south facing windows have been listed in Figure 11. The thermal performance of the shutters has been verified indirectly. The houses were heated electrically for periods of approx 13-19 days and the heat loss worked out from the meter readings, allowing for the solar heat gain. The infiltration heat loss (10% or less of the total) was deducted, thus giving the transmission heat loss - from this an average transmisison heat loss coefficient [W/C] was derived. The thermal calibration of the houses was carried out twice, the shutters being closed the first time and open the second. The results are listed in Figure 12. The test procedure and results not quoted here are described in [6].

DISCUSSION OF THE RESULTS

The infiltration air change rates measured as well as the results of the pressurization and depressurization tests show that all three houses must be considered very tight - at a differential pressure of 50 Pa any value under 3 a.c.h.



House		D	E	F
Infiltration measurement	a)	0.08	0.10	0.08
	b)	0.08	0.08	0.05
[a.c.h.]	c)	0.10	0.08	0.06
Depressurization 50 Pa	a)	1.61	1.24	0.64
	b)	1.57	1.19	0.53
[a.c.h.]	c)	2.22	1.23	0.72

Figure 10. Measured air change rates illustrating extremely good air tightness performance of insulating shutters.

House		D	E	F
U-value of window, shutter opened	[W/m^{2}C]	2.50	1.71	2.43
U-value of window, shutter closed	[W/m^{2}C]	0.62	0.67	0.43

Figure 11. Typical U-values of south facing windows with and without shutters.

Transmission heat loss coefficients [W/C]			
House	Shutters open	Shutters closed	Energy savings
D(calculated)	97	68	29
D(measured)	97	66	31
E(calculated)	82	60	22
E(measured)	88	62	26
F(calculated)	145	92	53
F(measured)	155	100	55

Figure 12. Thermal performance of shutters, calculated and measured.

would be satisfactory. The results also show that the shutters in all three houses perform remarkably well regarding air tightness. Here, again it must be emphasized that house F has horizontally sliding shutters. However, in house E and F the tightness of the shutters equals that of the windows. It is not surprising that this is not the case in house D as these shutters are two-winged (without a central post), Figure 13 (left). The comparison to the solution with a central post, Figure 13 (right), shows that in both cases it is possible to have the sealing strip at practically the same vertical level all around the edges. However, the construction to the left is less rigid and inevitably leaks a little at top and bottom where the two wings meet.

It should be noticed that pressurization and depressurization cause approx the same air change in any one of these houses - the normal operating condition would be a slight depressurization.

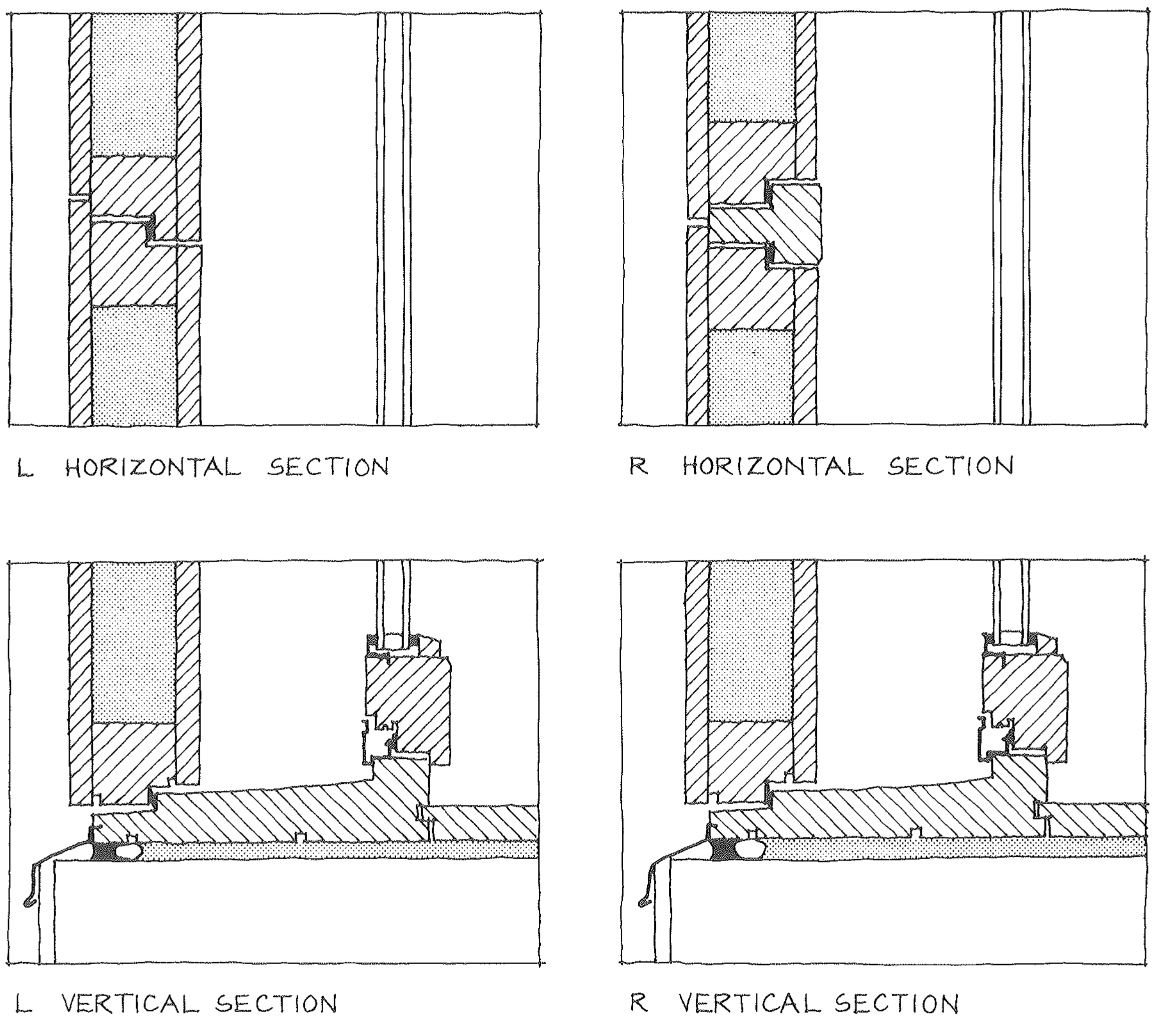


Figure 13. Two-winged shutters, construction detail. Solution without a central post as in house D (L) and a similar construction with a central post (R).

Thus the shutters are shown to have a good basis for a satisfactory thermal performance - and so they have, as is evident from Figure 12. The agreement between the calculated and the measured energy saving effect of using shutters is very good, all measured effects being slightly higher than the calculated values. The effect is seen to be considerable, typically about a 15% reduction of the total transmission heat loss when the shutters are used 12 hours a day. It is important to remember that the practical energy savings may be substantially larger. First of all, it is colder at night, and secondly, the solar heat gain is used more efficiently. Furthermore, the shutters may be used to cut the peak loads as they can be kept closed on those unfortunate days where the combination of frost and wind increase the fuel consumption to expensive peaks in normal houses.

ESTIMATED ANNUAL ENERGY SAVINGS

During the period of simulated occupancy the shutters were operated strictly as night shutters by members of the research team according to the pattern shown in Figure 14 (shutters closed for about 52% of the heating season). Later, the owners have operated the shutters according to their individual wishes.

The product of the energy saving heat coefficient (Figure 12), the relative working time and the number of heating degree hours makes up a conservative estimate of the annual energy savings. Thus the fact that the shutters are used more intensely during the coldest months is disregarded. Denmark has approx 70,000 heating degree hours (17 deg C base) in a year. The stipulation of a 17 deg C base does to some extent compensate for the free heat effect (due to insolation, heat emission from persons, electric appliances etc).

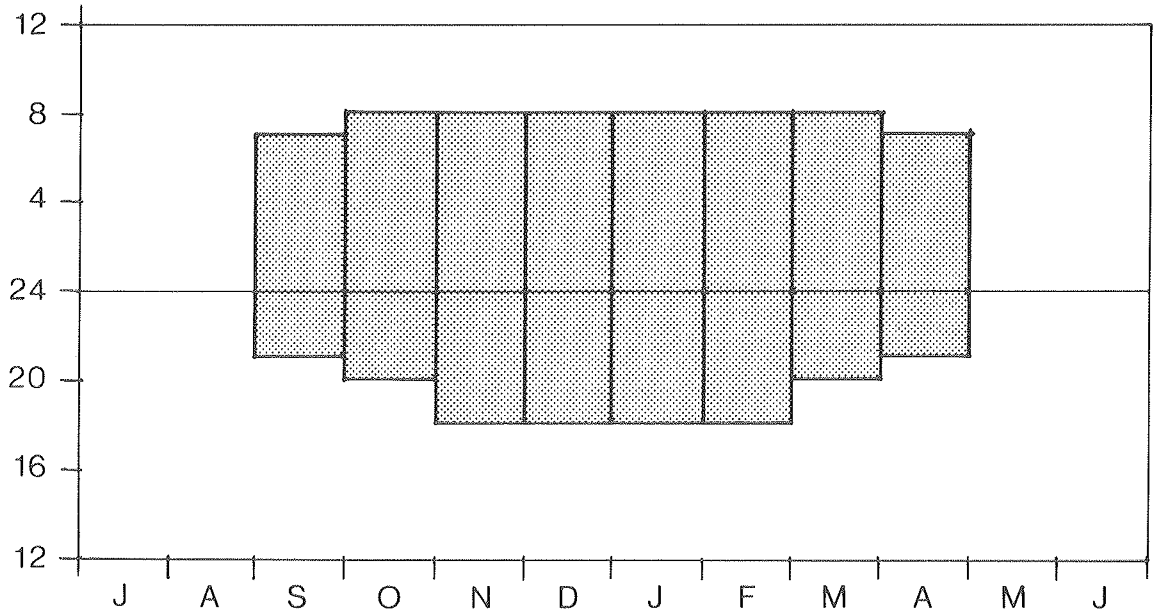


Figure 14. Shutter operation pattern during simulated occupancy.

Another estimate is made using the difference between the desired internal temperature (21 deg C) and the average monthly external temperatures in a normal year, again with the pattern of operation shown in Figure 14.

The results are shown in Figure 15 - the calculated energy saving coefficients from Figure 12 have been used in both cases. During the same period (one heating season) the 8 low-power electrical motors for the sliding shutters in house F have consumed 40 kWh.

Finally, the Danish heat load computer program BA4, [8], has been used to calculate the energy demand of the houses during the heating season in a normal year, [9], with and without the shutters (operated according to Figure 14). The results are included in Figure 15. It should be noticed that the computer simulation for house D indicates energy savings close to Estimate 2, while the results for house E and F are closer to Estimate 1. The reason for this is the difference in thermal mass. The main building material used in house D is aerated concrete - in house F it is concrete. House E is built as a wood frame house with some internal brick walls and tile floors - however, it has a hot air heating system with a rock bed storage. It must be emphasized that BA4 was not developed for low-energy houses and cannot be considered a satisfactory model for simulating passive solar systems.

House		D	E	F
Estimate 1	[kWh]	1060	800	1930
Estimate 2	[kWh]	1500	1140	2740
Computer simulation	[kWh]	1450	900	2140
Estimate 1	[kWh/m^2]	70	40	72
Estimate 2	[kWh/m^2]	99	57	102
Computer simulation	[kWh/m^2]	96	45	80

Figure 15. Estimated annual energy savings during a period of simulated occupancy: Estimate 1 (by degree hours), Estimate 2 (by temperature difference) and Computer simulation (by Program BA4). Total energy savings as well as average values per square unit shuttered window area are listed.

PERFORMANCE - USERS' EXPERIENCES

The estimated annual energy savings were calculated on the condition that all shutters were operated according to the pattern shown in Figure 14. This was accomplished without serious problems in the two houses with simple manually operated shutter systems, D and E. In house F, however, the mechanical operating of the shutters caused initial as well as fundamental problems. At this point it should be emphasized that this prototype system was developed for the house and that the actual system was also the first full scale model. House F was completed in March 1979 and in principle the shutter system was operated according to the simulated occupancy pattern from April 1 1979 to April 30 1980 except for the two house calibration periods. When the calibration periods (34 days) are deducted the shutters had 208 working days from May 1 1979 to April 30 1980. The assumed total number of shutter closings was thus 1664. The operation of the shutters was registered by the research staff members working the shutters in house D and E. During that period 235 cases of closing failures were registered, an error percentage of about 14%. Apart from some initial problems with electromechanical relays and adjustment of bearings etc the cause of almost all these failures is the permanent magnet connecting the slide and the shutter. To be absolutely certain to meet the "100 N" emergency exit demand (cf the description) the fitter used a fairly weak magnet having a slip force of 60-70 N or maybe less. Most failures occurred during September and October 1979.

During the summer of 1980 the system was thoroughly overhauled and has since then performed better, but still occasional magnet slips occur. Two of the motors had to be replaced, probably because the time relay let them run for too long after the shutters were closed, cf the description. Through adjustment that operation has been limited to 20 seconds.

House F has been occupied from May 1980, house E from January 1981 and house D from April 1981. In this context a period of one year starting in April 1981 is examined. Two major differences in operation pattern are noticeable. The owner of house D operates the shutters in the heating season only while the owners of house E and F use the shutters all the year round. The power-driven shutters of house F are operated according to a strict schedule interrupted only by occasional manual control of single shutters and by failure of operation. The time switch is set regularly, the shutters being closed for periods varying from 7 to 14 hours a day, in summer and winter respectively. The manually operated shutters of house D and E are used in a quite different way. Typically, shutters of unoccupied rooms are kept closed all the time, or almost - on the other hand, at least in house D, one or two sets of shutters are never used. In some cases the shutters replace curtains and blinds and are also used in the daytime as shadings. Corresponding to Figure 15, Figure 16 shows two estimates of annual energy savings based on the standard data and the actual closing pattern.

House		D	E	F
Estimate 1	[kWh]	620	1130	1510
Estimate 2	[kWh]	980	1830	2410

Figure 16. Estimated annual energy savings based on actual shutter operation patterns: Estimate 1 (by degree hours) and Estimate 2 (by temperature difference).

During the strict daily operation of the period of simulated occupancy the research staff experienced some problems caused by drifting snow. During the day the wind and the snow have access to the external sills. If drifting snow is not very carefully brushed away from the sill before closing the shutter it usually melts during the night - and freezes along the bottom sealing strip. Thus the shutter gets stuck and has to be forced open from the inside. It occurred several times in house D and E, without damage to the sealing strips however. The sliding shutters of House F are not very susceptible to this problem, mainly because they are opened by a push movement, and the motor power is sufficient to release the shutter under all circumstances. As the closing movement is very slow and steady a little snow on the bottom guide track does not disturb the operation. A few opening failures during the winter were all caused by faulty relays. The owners have not experienced the freezing problem, probably because they have kept the shutters closed for the main part of the cold windy periods.

The exposure to the outdoor climate has caused another problem in house D. As the shutters are two-winged they are highly susceptible to shrinking and - especially - expanding, and it is no coincidence that the heavy shutters in front of the terrace door are one of the two sets rarely operated by the owner. Generally, it would also be easier to operate the shutters of house D if the handle of the pasquil lock was placed lower (preferably near to the bottom edge).

Finally, some users' experience as a point to shutter designers: As illustrated in Figure 17 French windows and external shutters in a ground floor do some times make an akward combination due to thick blankets of snow on the ground. Even though Denmark does not normally get a lot of snow this situation occurred three consecutive winters.

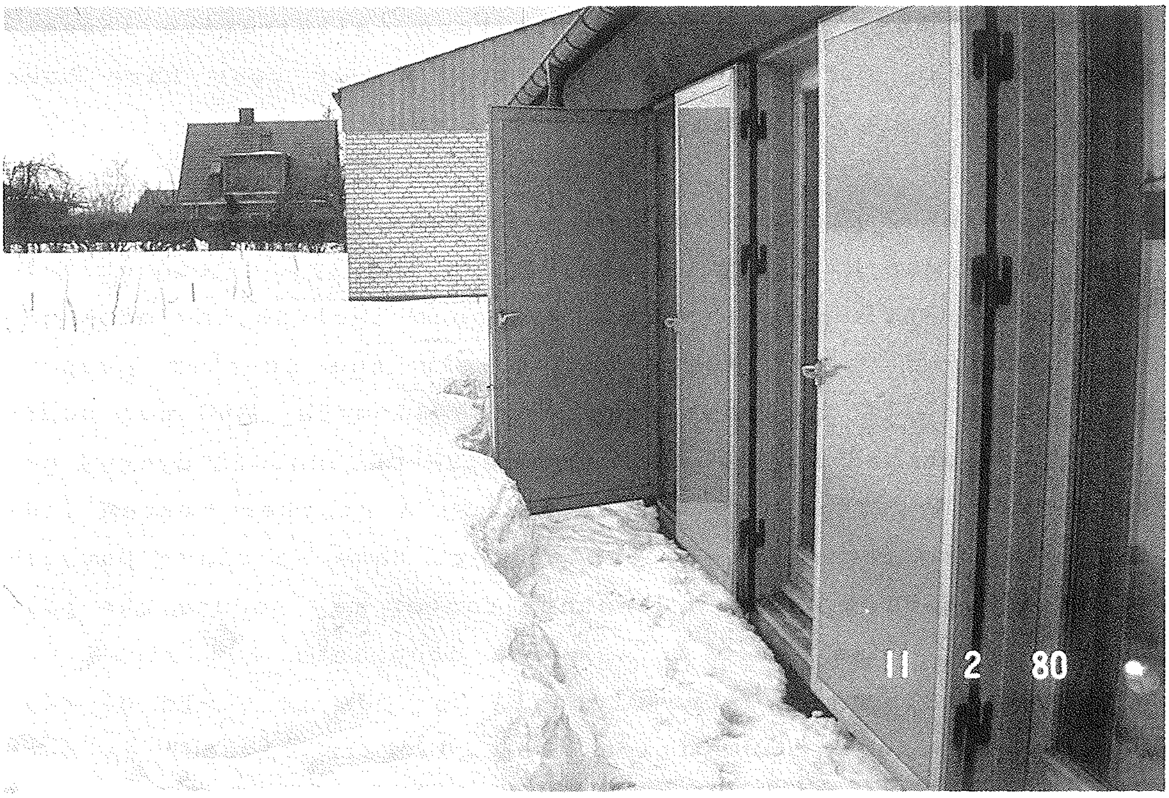


Figure 17. House E. Snow problems at French windows.

ECONOMY

Always an interesting point regarding energy saving measures is whether they can be considered cost-effective. In this case no relevant investment information was available, mainly due to the fact that all systems were handmade prototypes. In general shutter constructions, like windows, can be expected to have a useful life of 10-20 years. In Figure 18 the Exact Payback method, [10], has been used to find the investment giving an exact payback of 10, 15 and 20 years respectively. The annual energy savings of Figure 16 (estimate 2) have been used at an energy price level of 0.44 DKR/kWh, obtained by using oil in a heating system with an overall efficiency of 75% (1 US Dollar is about 9 DKR). Alternatively the use of electricity in a heating system with an overall efficiency of 90%, giving a price of 0.85 DKR/kWh, would thus make investments of about twice the amounts in Figure 18 profitable. Fuel cost is assumed to escalate 0% or 4% above the inflation (e). A discount rate above the inflation (i) of 0% or -4% is used; the Danish income tax laws for private investors, alternative investments and an inflation rate of 10-12% per year have been taken into consideration.

The calculated present cost of materials for the shutters in house D, E and F are DKR 6,500, 7,200 and 7,100 respectively - the calculation for house F does not include the mechanical parts of the system, but solely the shutter proper. Wage costs will at least equal these amounts, and for house F the investment in a rather expensive mechanical system has to be added. Thus, an investment in a shutter system like one of these three can be expected to have an exact payback of 15-20 years. However, another factor may reduce the payback period considerably. As the occupants can close the shutters during the extremely cold periods it would be reasonable to use the condition "all shutters closed" as part of the design criteria for heating systems - and thus reduce the initial expenditure for the heating system.

House			D	E	F
i	e	Exact payback [years]			
0.00	0.04	10	5400	10100	13200
		15	9000	16800	22100
		20	13400	24900	32800
-0.04	0.00	10	5400	10100	13400
		15	9100	17000	22400
		20	13600	25400	33500
-0.04	0.04	10	6900	12800	16900
		15	13000	24300	32000
		20	22200	41400	54600

Figure 18. Investments in shutters [DKR] giving an exact payback of 10, 15 and 20 years at the present fuel cost 0.44 DKR/kWh.

CONCLUSIONS

It may be concluded that the heat loss through the weak point of the thermal envelope, the windows, can be substantially reduced through the application of movable insulation. For one- or two-storey houses external shutters seem to be a practical solution to the problem. Three different types of external shutters including a sliding type all having very tight seals have been shown to have the calculated effect: a house transmission heat loss reduction of 30-35% when closed.

During one year of inhabitancy the shutter operation has been monitored, and an estimate of the annual energy savings based on the individual user's habits shows savings of approx 1000-2400 kWh per year.

No actual costs have been available, but an analysis indicates that the shutter systems should have a useful life of at least 15 years to be cost-effective. As to the shutter proper this is easily accomplished, but the mechanical parts of the automatic shutter system will probably have to be serviced regularly, and the present day value of this cost must be added to the investment. A fully automatic shutter system may or may not be cost-effective in energy conservation houses, but indisputably it offers the utmost convenience to the owner.

If the design peak loads for heating systems are calculated on condition of closed shutters the initial cost of the heating systems can be reduced and thus contribute considerably to the cost-effectiveness of insulating shutters.

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