



AIC 1505



THE SEVENTH LOW-ENERGY HOUSE AT HJORTEKÆR, DENMARK

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Based on the experience gained from the six houses built in 1978-79 as part of the first Low-Energy House Project funded by the Danish Ministry of Energy, a new conservation house has been designed and built at Hjørtækær during 1984 (completed in February 1985). The house has been built by KD Kreditforeningen Danmark (a major Danish credit association) in collaboration with Thermal Insulation Laboratory, KD having financed the erection of the house. As before, the project management is carried out by the Thermal Insulation Laboratory.

Objective of the Project

A common denominator for the first six houses was the desire for an extremely low energy consumption (5000 kWh/year) for heating, ventilation and domestic hot water without any reduction of the demands to indoor climate and thermal comfort. In this "2nd generation" low-energy house more emphasis has been placed on the cost-effectiveness of the applied energy saving techniques (the achievement of a balance between the money value of the energy savings and the necessary marginal investment), and more attention has been given to heating cost than to the kWh-demand. However, the corresponding calculated annual energy consumption in the new house does not exceed 6500 kWh. Furthermore, the house should have a heating and ventilation system designed and operated according to the low heat demand that is characteristic for a low-energy house. It should be emphasized that the heating system is turned off completely when there is no heat demand.

As a consequence of this the main features of the house are:

- 1) a highly insulated and very airtight thermal envelope
- 2) a fairly simple quickly responding heating system.

General Description

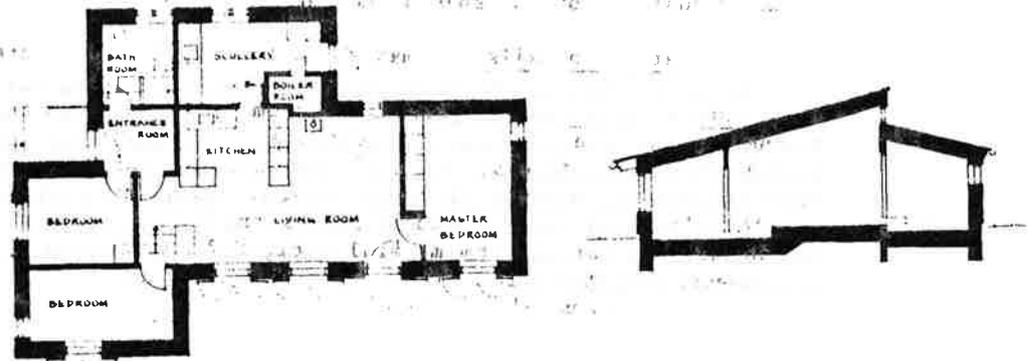
The house is detached and one-storeyed, with a built-up area of 124 m². It has a main section and two smaller sections at slightly lower levels, all floors being slab-on-ground constructions (Fig. 1). The shape of the house (an irregular L-shape with a sloping ceiling) is determined from architectural rather than energy saving considerations - the influence on the annual heat demand has been calculated and is found to be an increase of 7-8% compared to a conventional rectangular house insulated in the same way.

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This house has been built on site as traditional craftsmanship, but the type was designed for - at least partial - construction from prefabricated building units.

Fig. 1. House G. Floor plan and section.



Energy Saving Measures

As in the first six low-energy houses the emphasis has been placed on heavily insulated constructions and a special effort has been made to avoid cold bridges. Special importance has also been attached to the air tightness of the thermal envelope. A balanced ventilation system secures a controlled air exchange, and the tightness of the building renders a high efficiency of the heat recovery on the exhaust air possible.

Most of the glazed area is placed in the south elevation. To achieve the best utilization of the solar heat gain double glazed sealed units have been chosen for the windows in combination with insulating shutters to minimize the heat loss during the night. A roof overhang to the south protects the rooms against overheating in the summer.

Building Structures - Construction Members

The main insulating material is mineral wool, type "Super A" according to the Danish classification (in practise, $\lambda = 0.036 \text{ W/mC}$).

The foundation consists of a concrete base cast on site in an earth trench on top of which are built 390 mm wide, solid blocks of expanded clay concrete up to about 0.3 m below ground level where the top two courses are built as a sandwich construction (two 150 mm wide blocks of expanded clay concrete and 100 mm mineral wool). The external surface is tarred and rendered. Internally, the foundation is insulated with vertical 75x500 mm polystyrene boards.

The floor is made of 150 mm loose expanded clay clinkers, 100+100 mm insulation (rigid polystyrene boards with tongue and groove joints), 100 mm concrete (cast on site) and either 22 mm floorboards on 75x50 mm floor joists on chocks or 100 mm polystyrene insulation with 70 mm concrete (with

embedded electric floor heating in entrance room and bathroom) and 15 mm floor tiles.

The exterior walls are built as double walls, having (listed from the interior) 100 mm load-bearing wall units of aerated concrete, 100+100 mm mineral wool, 50x100 mm studs with 100 mm mineral wool, but without interties, 12 mm asphalt impregnated wood fibre board, 50x100 mm laths and finally boarding or an asbestos cement sheet facing.

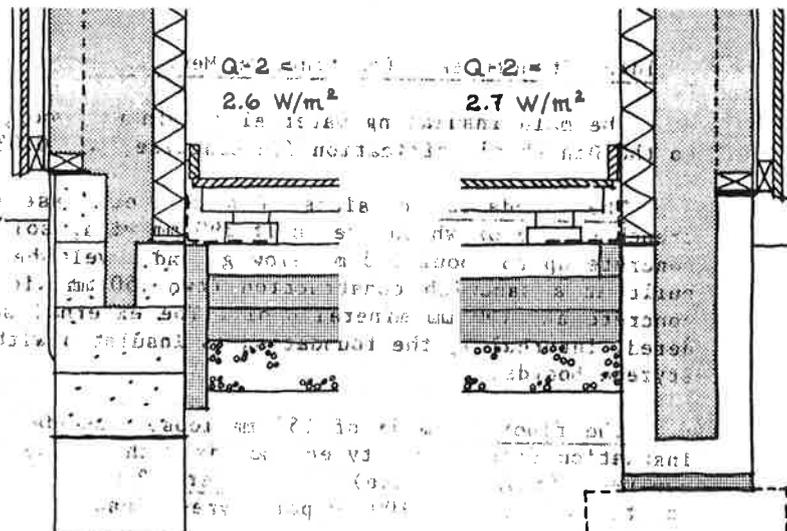
The partition walls are made from 100 mm aerated concrete wall units.

The roof and ceiling are made from 300 mm "RM" masonite beams (two laths joined with a masonite web plate, thus forming an I-section) spaced out 1.2 m apart, insulated with 300 mm mineral wool. On top of these there are 3.2 mm hardened wood fibre boards, 19 mm space slats along the rafters and finally corrugated roofing sheets on laths. Beneath the rafters are 50x50 mm laths with 50 mm mineral wool, 0.2 mm polythene, further 50x50 mm intersecting laths with 50 mm mineral wool, and finally either ceiling boards or gypsum panels.

Avoidance of Thermal Bridges

In the foundation the use of expanded clay concrete, the insulated sandwich construction of the upper courses and the internal vertical perimeter insulation (completely separating the concrete floor slab from the foundation) form an efficient disconnection of the traditional cold bridge. In a recent study (1) a typical traditional construction used as reference was found to have a (two-dimensional) heat loss $Q-2$ to the ground of 4.8 W/m^2 floor area.

Fig. 2. Floor and foundation. House G (left) and a foundation type recommended in (1) (right).



The exterior walls are in principle without thermal bridges as the load-bearing aerated concrete wall is separated from the outer wood frame with 200 mm mineral wool - the wood frame is attached to the rafters and to the outer leaf of the sandwich foundation. A minor (insignificant) thermal bridge occurs at the window and door apertures, but it is limited to the casing and a 5 mm plywood board (cf Fig. 3).

In the roof there are no cold bridges of any significance because of the web plate of the RM beam being very thin (6 mm) and made of wood fibre board.

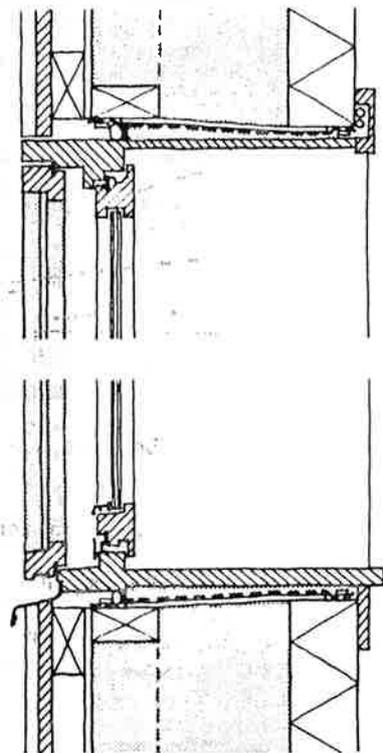
Air Tightness

The air tightness of the building envelope is achieved through the polythene vapour barrier in the ceiling, the pattered and painted interior surface of the aerated concrete walls, the concrete floor, and airtight connections between joining construction members (ie ceiling/wall, wall/floor etc).

The polythene sheeting in the ceiling is well protected between the intersecting laths. The lap joints between the polythene sheets are squeezed with thin slats against the upper laths. At the joining of ceiling and walls (partition walls as well as exterior walls) the sheets are squeezed against the pattered wall surface by slats tacked on to the walls - sealing mastic is applied to compensate for warping.

Fig. 3. Vertical section through wall and window, also showing a new simple type of manually operated light-weight insulating shutters made from standard window frames. The U-value of the window is reduced from $2.8 \text{ W/m}^2\text{C}$ (shutters open) to $0.6 \text{ W/m}^2\text{C}$ (shutters closed).

As previously mentioned the tightness of the wall is achieved through pattering and painting the interior surface. The pattering along the top and base must be carried out early in the building process to provide the proper basis for the joining with the polythene sheets and the bituminous millboard. The window and door grooves are pattered for the same reason. In the door and window grooves (Fig. 3) a 5 mm plywood panel supports a 0.2 mm polythene sheet that is squeezed by slats against the studs (and cross-bars) and the pattered aerated concrete respectively (with mastic in between). The joint between the window frame and the polythene sheets is sealed with mastic.

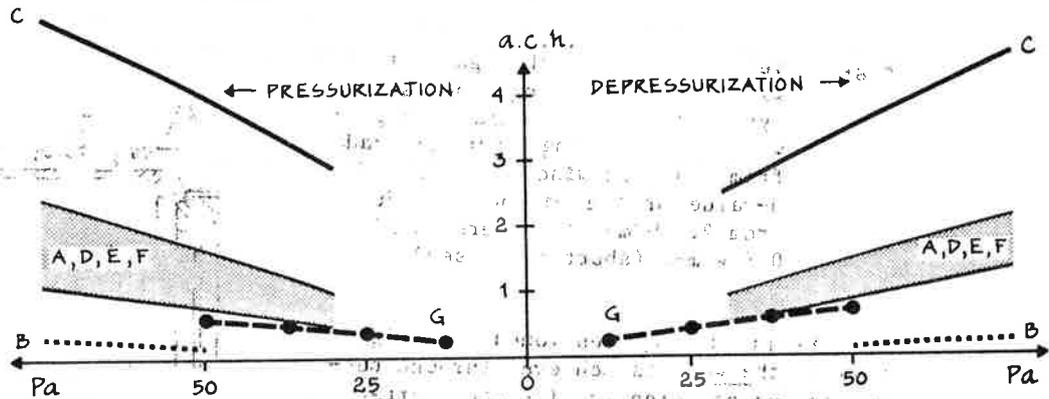


The concrete slab (cast on site and vibrated) makes up the airtight part of the floor construction. The airtight connection between the floor slab and the puttered walls is secured through a 350 mm wide strip of supple bituminous millboard attached to the surfaces with cutback along all exterior walls and along the first 0.5 m of adjoining partition walls. A connecting piece of airtight material is necessary as the floor slab is separated from the wall base by 75 mm polystyrene insulation (cf Fig. 2).

Preliminary Test Results

Some preliminary measurements of air change rates were carried out shortly before the house was completed. The infiltration rate was measured by the tracer gas decay method, and a series of pressurization tests was carried out according to the principles outlined in (2), but blowing through an air duct (thus leaving all exterior doors in normal operation), and at low pressure differences only. The results (Fig. 4) clearly show that the house must be considered extremely airtight, even when compared to the first six low-energy houses, A-F, (2). No specific air leaks could be detected, and a comparison to the Sherman/Grimsrud model (3) shows a good agreement with uniformly distributed leakage area.

Fig. 4. Results from infiltration measurement and pressurization and depressurization tests. House volume 260 m³. Ext air temperature 8 C. Int air temperature 17 C. Wind speed at building 3.6 m/s. Indices o, w, c and f stand for overall, walls, ceiling and floor.



| | | |
|---|-------|-----------------|
| Leakage area $A_0 = A_w + A_c + A_f$ (3) | 28.0 | cm ² |
| Infiltration rate, predicted (3), $A_w = A_c = A_f$ | 0.030 | a.c.h. |
| Do, A_w 60%, A_c 20%, A_f 20% | 0.036 | a.c.h. |
| Do, A_w 80%, A_c 10%, A_f 10% | 0.040 | a.c.h. |
| Infiltration rate, measured | 0.029 | a.c.h. |

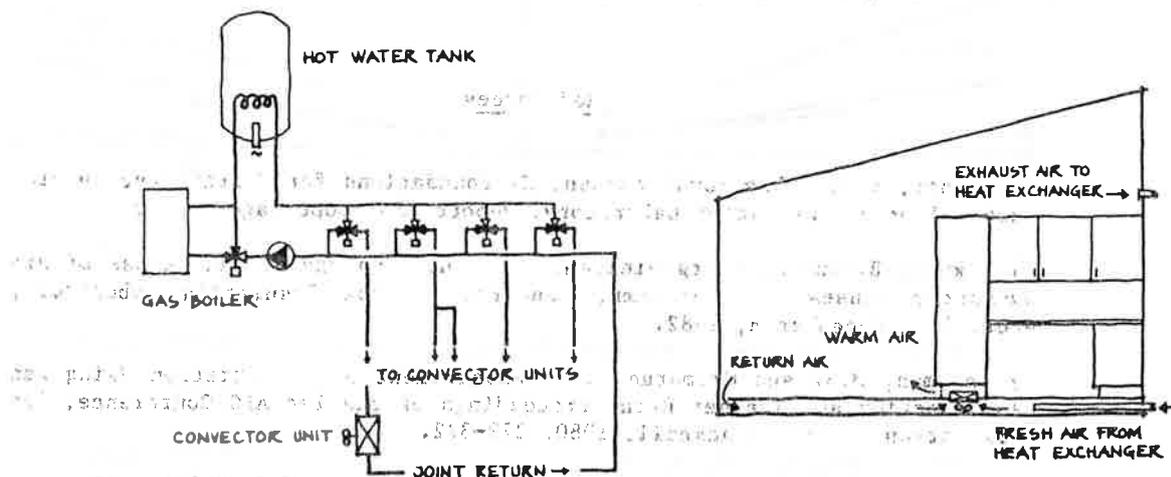
The Heating System

In a low-energy house it is extremely important that the heating system reacts immediately to free heat gains, eg solar input, to avoid overheating and to utilize free heat to the maximum extent. A pilot study (4) on the effect of an improved room thermostat for an air heating system in one of the first houses indicated considerable energy savings (30-40%). When the very low heat demand of house "G" is considered, a simple electric resistance heating system would be the easiest to control and the cheapest to install.

For experimental reasons, however, a different system has been chosen - a hydronic system where water from a boiler distributes the heat to five small individually controlled convector units fitted under stationary cupboard boards with air inlets in the base. The fans are normally running noiselessly at a reduced speed, thus having a power consumption of only 4-5 W. Through a switch control on each room thermostat the fans may be allowed to run at full speed for a desired quick rise in temperature. Return air is sucked through an 8 mm wide slot behind the skirting boards along the external walls.

Two alternative heat sources have been installed for experimental reasons (Fig. 5). The heat is supplied either from a 110 l electric hot water boiler (through an immersed heat exchanger) or from a small gas boiler with electric ignition and a very low water content. The gas boiler heats the hot water through the heat exchanger, ie the hot water tank doubles as buffer capacity for the heating system. The gas boiler has so far been approved for hotted gas only. In order to keep the no-load losses as low as possible the operating temperatures are kept low, and the supply line receives warm water from the manifold only while the room requires heating.

Fig. 5. Simplified diagram of heating system (left), and section showing air movements in heating and ventilation system (right).



In principle the heat source of the house could, thus be an oil- or gas-fired boiler, district heating supply, a heat pump or an electric boiler.

The entrance room and the bathroom have electric floor heating - the scullery is not heated. A woodburning stove is installed in the living room by request of the owner - it has a separate air intake that may be shut off with a swivel damper.

Ventilation System

A balanced mechanical ventilation system with heat recovery on the exhaust air secures an air change of approx 0.5 a.c.h. The fresh air is pre-heated in a counterflow plate type heat exchanger with an estimated annual efficiency of 75-80% and injected under the wooden floors. The exhaust air is sucked from kitchen, scullery and bathroom.

The range hood is separated from the ventilation system to avoid dirtying the heat exchanger. The hood ventilator is turned off by a time switch and when the hood is not used a motorized valve automatically closes the exhaust air duct.

Future Investigations

The house will be reserved for studies of energy consumption, operating conditions, thermal comfort etc for about a year. The Thermal Insulation Laboratory is going to carry out detailed continuous measurements for selected periods each lasting one month. During these periods the house will be unoccupied, but a standard pattern of inhabitancy will be simulated. In between the periods specific tests will be carried out, eg measurements of insulation efficiency and heating system efficiency as well as further air leakage tests. Eventually, the house will be sold and the measurements will be continued during a period of normal occupancy.

References

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- (2) Saxhof, B. and Aasbjerg Nielsen, A. Insulation and Air Tightness of six Low-Energy Houses at Hjørtekær, Denmark. Thermal Insulation Laboratory, Report 121, Copenhagen, 1982.
- (3) Sherman, M.H. and Grimsrud, D.T. Measurement of Infiltration Using Fan Pressurization and Weather Data. Proceedings of the 1st AIC Conference, Air Infiltration Centre, Bracknell, 1980, 279-322.
- (4) Huusom, J. and Lund Madsen, T. The Importance of the Room Thermostat for the Indoor Climate and the Energy Consumption in Buildings. Thermal Insulation Laboratory, Report 98, Copenhagen, 1980.

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SUMMARY

Bjarne Saxhof: The Seventh Low-Energy House at Hjørtekær, Denmark. This paper gives a short description of a "2nd generation" low-energy house built at Hjørtekær in 1984 having a calculated annual heat demand of 3500 kWh (not including domestic hot water). The house is superinsulated and has a very airtight building envelope. The roof and the walls are insulated with 400 respectively 300 mm high quality mineral wool with but infinitesimal thermal bridges, and the floor is a slab-on-grade construction insulated with 200 mm polystyrene. Most of the windows are south facing and externally supplied with a new simple type of lightweight insulating shutters (manually operated). The description includes a few typical construction details chosen as illustrations of airtight constructions without cold bridges. The paper also describes the quickly responding convector heating system and it presents some preliminary results from pressurization tests and infiltration measurements.

RÉSUMÉ

Bjarne Saxhof: Une septième maison à énergie réduite à Hjørtekær, Danemark. Cette communication fait la description d'une maison à énergie réduite de la "seconde génération" construite près de Copenhague en 1984. Les besoins calculés d'énergie nécessaires pour le chauffage sont 3500 kWh par an. La maison est marquée par d'avoir une enveloppe thermique très bien isolée et pratiquement étanche à l'air (taux de renouvellement d'air 0,03 par h). Le toit et les murs sont isolés avec 400 mm respectivement 300 mm de laine minérale de première qualité sans des ponts thermiques perceptibles, et le plancher est une construction dalles sur le sol, isolé avec 200 mm de polystyrène. La plupart des fenêtres est orientée au sud et équipée de volets isolants d'une construction nouvelle très simple. Deux détails de construction sont décrit à fond comme exemples de constructions étanche d'air et sans de ponts thermiques. L'article décrit aussi le système de chauffage à convecteurs (un système à action rapide) et présente des résultats des mesures du renouvellement d'air préliminaires (par les méthodes du traceur à gaz et de pressurisation).

KURZFASSUNG

Bjarne Saxhof: Ein siebentes Niedrigenergiehaus in Hjørtekær, Dänemark. Dieser Artikel beschreibt ein neues Niedrigenergiehaus "zweiter Generation", das 1984 in der Nähe von Kopenhagen gebaut worden ist. Der berechnete jährliche Energiebedarf für Heizung ist etwa 3500 kWh (Warmwasserversorgung nicht einbegriffen). Das Haus ist durch hochisolierte und ganz luftdichte Konstruktionen (natürliche Luftwechselzahl 0,03 h⁻¹) charakterisiert. Das Dach und die Wände sind mit 400 mm, bzw. 300 mm Mineralwolle bester Qualität isoliert, ohne merkbare Wärmebrücken, und der Fußboden ist eine mit 200 mm Hartschaumplatten isolierte Planumdeckkonstruktion. Die größten Fensterareale sind nach Süden orientiert, und die Fenster sind aussen mit einfachen, aus Normalfensterrahmen hergestellten isolierten Klappäden versehen. Zwei Konstruktionsdetails sind als Beispiele wärmebrückenloser, luftdichter Hausbauart gründlich beschrieben. Der Artikel beschreibt auch das schnellreagierende Konvektor-Heizsystem des Hauses, und er stellt vorläufige Resultate einiger Luftwechsellmessungen (nach den Methoden der Prüfgase, bzw. der Differenzdrücke) vor.