05

TOWARDS ZERO-ENERGY BUILDINGS

05.01 Minimum-Energy Dwellings

05.01.01 Energy saving in social housing through limited investment

In 1980 at a symposium held in Spijkenisse, the Netherlands, there was discussion about the feasibility of utilising waste heat or geothermal energy for city scaled heating systems and, more specifically, building energy-saving dwellings at Pernis, Rotterdam (a new expansion adjacent to a Shell refinery). The investment for each housing design being no more than 10,000 Dutch guilders (now € 4,500).
Several offices were invited to propose a scheme. Our office of course presented an energy-saving concept. Although the focus was on the 120 dwellings that had to be built in Spijkenisse, the numerous solutions were also intended to bepartly applicable to other new dwellings elsewhere.

The architectural strategies and calculations applied to a new dwelling aimed to improve on the thermal insulation norms of 1978. This dwelling has a volume of 330 m^3 and consumes 74,000 MJ per year for heating (hot tap water not included); this corresponds with 2350 m^3 gas equivalent with a high-performance (90%) boiler for the central heating system.
The second proposal was closest to the specified budget of € 4,500, being € 3,900. The thermal insulation, reducing transmission losses by 42% in comparison to the index dwelling, had the highest return on investment.

A clear measure in the cost-conscious housing industry can be calculated by construction investments in euros per m^3 of natural gas saved per year. For a small consumer in 1980 we could calculate approximately € 0.14/m^3 nge/year. The smallest investment, for an isolated floor with 40 mm of insulation, is € 0.67/m^3 nge/year. When the roof insulation thickness increases from 30 mm to 150 mm, the investment amounts to € 0.95/m^3 nge/year. On top of these, other facilities became cheaper: heat recovery on the ventilated air for € 1.32/m^3 nge/year and an extra sealing of seams for € 1.70/m^3 nge/year.
The use of a 'seasonal adaptive façade' with thermally insulated shutters or shutters with external sunblinds is favourable in regards to double glazing, but when compared to three-layered glazing it is quite expensive in this stage of development: € 4.55/m^3 nge/year.

With the available money of € 3,900 (excluding VAT) a dwelling can be designed which has its energy consumption reduced to about 12,000 MJ/year (and 33.4 MJ = 1 m^3 nge). Together with a high-performance boiler using natural gas this means savings of 2350 – 410 = 1940 m^3 nge/year! In Spijkenisse, where $345*10^6$ MJ of geothermal energy is available, the costs can be reduced from € 4,070 to € 1,135 per dwelling, because at the moment we start building truly energy-efficient dwellings 10,000 extra dwellings can be connected to the geothermal energy supply!

The heating demand of 12,000 MJ is almost equal to the hot tap water of 10,000 MJ per year. The building materials, the orientation, the window openings, the external sunblinds and the use of passive and active solar energy can become critical factors.

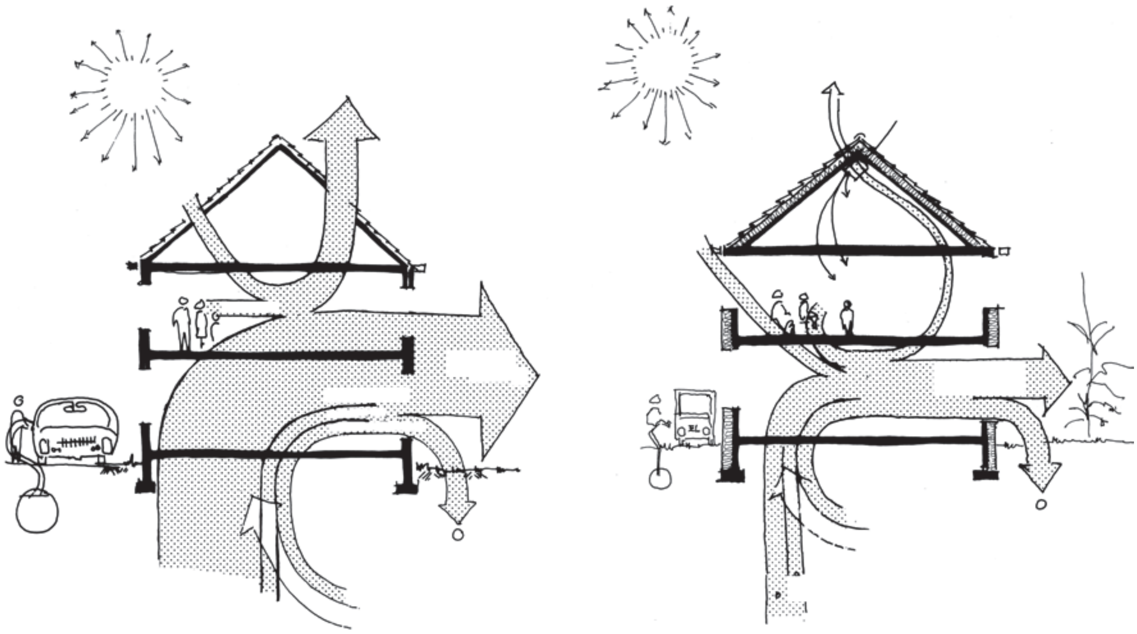


Fig. 05.01: Heat balance of a conventional house (left) and one adjusted according to the ideas proposed at the Spijkenisse symposium (right).

The conclusion of the Spijkenisse symposium was that with an extra investment of € 3,900 energy-efficient dwellings can be constructed that reduce the heating demand from 74,000 MJ to 12,000 MJ per dwelling per year. Only 410 m^3 nge/year would still be needed!
Thus, a central heating system would become unnecessary. Thirty years later, the building industry still has not shown any significant improvement in this respect: most dwellings still need central heating and still consume more than 500 m^3 of gas for heating.

05.01.02 The Dwelling without Central Heating, a giant leap forward (1981)

The Spijkenisse symposium proved that dwellings without a central heating were possible, reducing the demand for fossil fuel. Together with Peter Ghijsen as project architect, we elaborated the 'Dwelling without Central Heating' by means of external funding. Afterwards a press conference was organised in our office to make the news known to the world.

New philosophy
New building materials
New building techniques
New building services
Passive solar energy
Physical calculations

The design philosophy was to invest extra money in a package deal of energy-saving measures that lowered the heating demand so much so that savings could be made on the purchase of a central heating system. A part of the extra investment could be recovered, and the remaining part could be found in savings on heating expenses.

Fig. 05.02: The team of the Dwelling without Central Heating and the Minimum-Energy Dwellings (left): Koos Slootweg, Peter Ghijsen, Willem Schuringa and Jón Kristinsson. Press conference at the Kristinsson office (right).

The overall design principles were:
- Large windows on south elevations, small windows on the north.
- Windows with thermally insulated shutters, operable from the inside.
- Zoning of living spaces on the south side, to create a heat buffer.
- Kitchen, storage and hobby spaces on the north side.
- Bathroom in the ‘warm’ core of the house.
- Dwellings are made extra seam sealed (no draught), by means of a closed entrance hall at the front and balanced ventilation with heat recovery.
- Extraction of air takes place in the kitchen, bathroom and toilet.
- Cheap building services that are easy to maintain.

The preferred heat source was a double-sided incinerator for wood and paper with a small combustion room, this design ensuring high incineration temperatures that transmit heat quickly. It’s double-sided canal providing heat recovery from exhausted gasses.
The underlying idea was to collect papers, wooden crates and similar materials throughout the year, and to use them for extra heating when required. With this approach no central heating was necessary and therefore a major saving was possible.

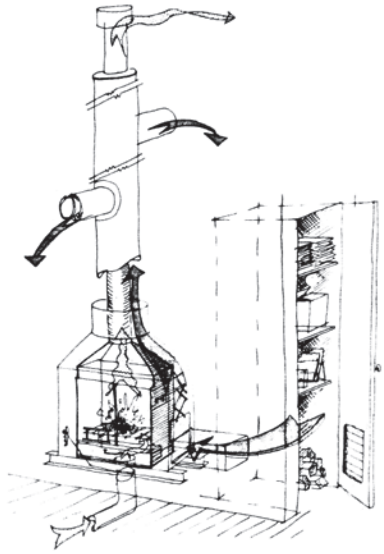


Fig. 05.03: Double-sided incinerator for wood and paper with storage cupboard.

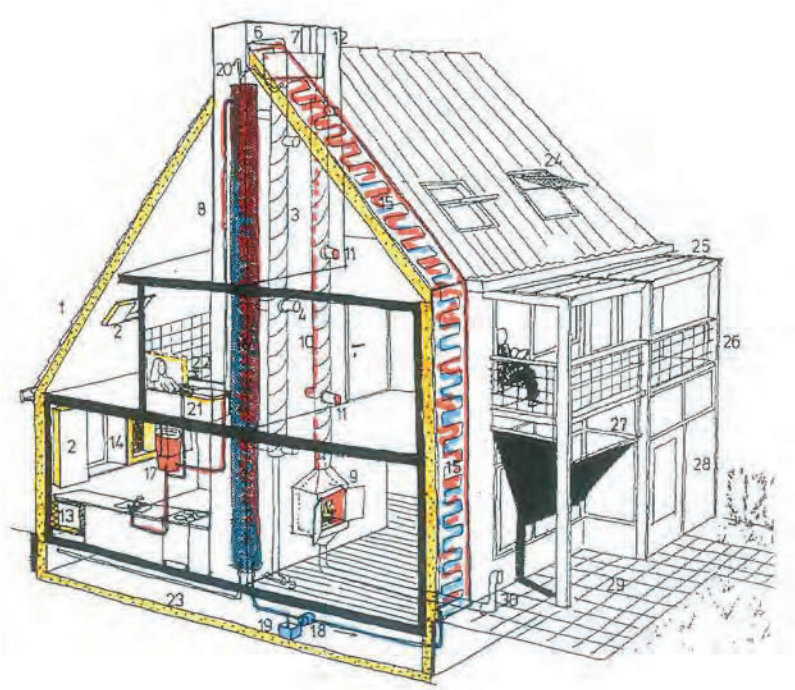


Fig. 05.04: Sketch for the 'Dwelling without Central Heating' (1981):

1. 150 mm insulation | *2. Insulated shutters*
3. Heat exchanger & balanced ventilation | *4. Blow-in air valve*
5. Extraction of air from the crawl space | *6. Supply of fresh air*
7. Outlet of exhaust air | *8. Central pipe shaft*
9. Wood/paper incinerator | *10. Double-sided canal*
11. Warm air valve | *12. Outlet of exhaust gases*
13. Insulated small fridge | *14. Meat-safe*
15. Solar collector | *16. Hot water cask*
17. Re-heater | *18. Pump*
19. Expansion keg | *20. Overflow*
21. Bath with insulation cover | *22. Tap directly from the storage cask*
23. Cold water supply | *24. Roof window sunblinds*
25. Bedroom window sunblinds | *26. Balcony*
27. Living room sunblinds | *28. Enclosed porch*
29. Terrace | *30. Air supply for wood/paper incinerator*

Thanks partly to TV commercials from the Ministry of Economic Affairs, on energy savings in traditional dwellings, it had widely been rightly assumed in the Netherlands that dwellings cool down at night in summer. However, a well-insulated house will not cool down at night if the windows remain shut. Through the use of balanced ventilation in combination with an inlet of fresh air, there is no need to open a window at night. Furthermore, it was possible to avoid overheating in summer by incorporating sunblinds on the outside.

A relatively simple and cheap solar collector could be made with a high storage cask using stratification (temperature gradation). Optimal efficiency of a balanced ventilation system was established through double airshafts in a vertical heat exchanger. This air was extracted from the crawl space. Extra costs of this additional installation can be paid from the savings on fuel.

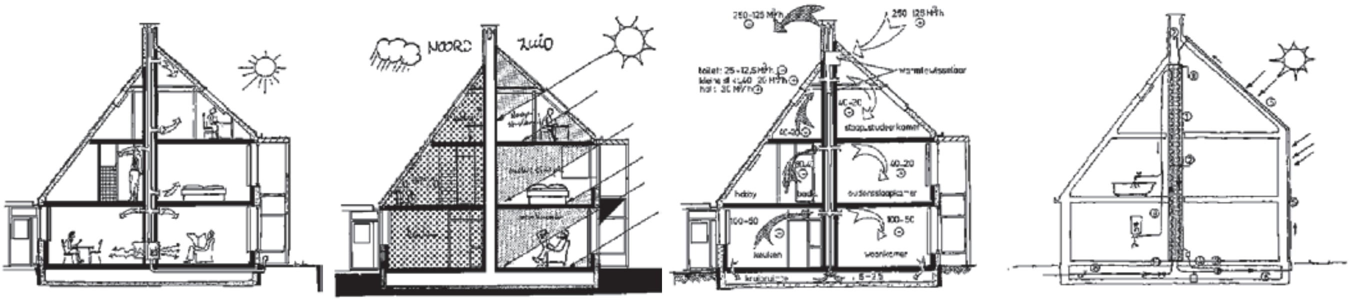


Fig. 05.05: *Principles for the dwelling without central heating: Insulation all around; retention of heat, auxiliary heating with hot air (top left). Zoning and passive solar energy: living areas on the south side (top right). For airtight dwellings balanced ventilation is a necessity (bottom left) Cheap solar boiler with temperature gradation in the tall storage cask (bottom right).*

There is only a small kitchen heater for hot tap water. The large loss of energy in the cooking process is used for the dwelling heating. Usually this heat is extracted directly by the hood above the stove. All pipes and utilities are easily accessible in a specially designed shaft.

For the calculations of the heat balance we used the calculation model of Fläkt from Stockholm, because this was the most accurate programme at that moment. Incoming solar radiation, heat-accumulation in walls and floors, preferable opening of shutters (open from 7:00 till 17:00 o'clock), and separation of the internal heat gains (residents, illumination and the electrical devices) were optimised.

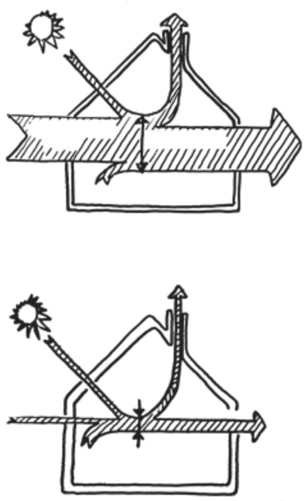
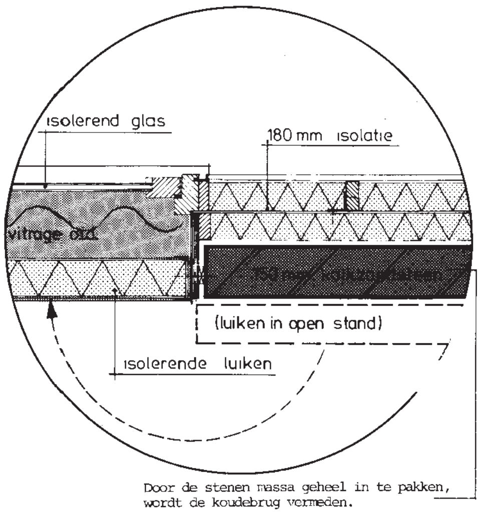


Fig. 05.06: *Heat balance of a common dwelling (above) and of the Dwelling without Central Heating, with a heat recovery of 50% on ventilated air (preliminary study, below).*



We chose to use shutters on the inside, which are easy and quick to handle, as well as low to maintain. They reduce heat-loss by transmission by around 50% in contrast to a dwelling without insulated shutters.

Fig. 05.07: *Connection detail of the insulation shutter.*

After cooling down at night there is a peak in the heat demand in the morning of 1500 W (sunny day) respectively 2500 W (cloudy day). If the sun is shining this declines to zero at a fast rate.

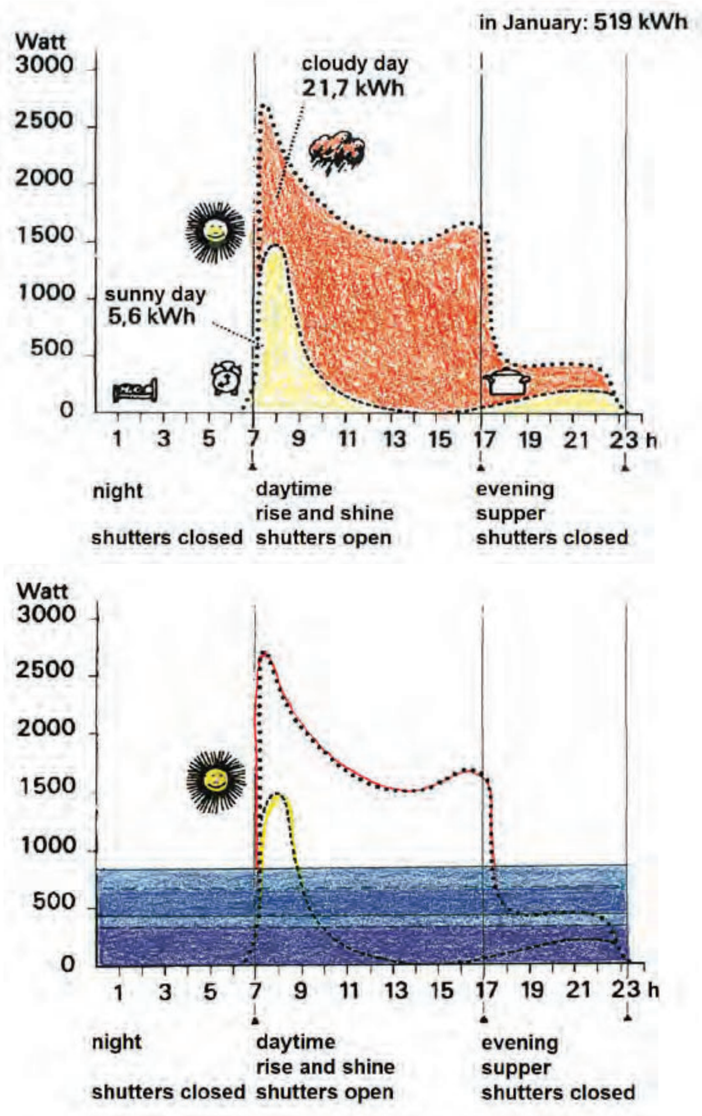


Fig. 05.08: *Heat demanded by a working family during a 24-hour sunny and a cloudy day in January per 24-hours* [23]*. Power x time = Energy. 1 kW (1000 Watt) x 1 h = 1 kWh (kilowatt-hour), i.e. the area in the graphs.*

There is always loss of heat as a result of ventilation in the 'Dwelling without Central Heating'. Natural ventilation through seams in a common house can be equal to, or even twice the total

[23] Source: Adviesbureau Jongen, Vlaardingen.

volume, i.e. 250 to 400 m^3/24 hours. Mechanical ventilation will operate for 24 hours a day if programmed, there will be additional ventilation of 50 m^3/h (during the day) due to leakages.

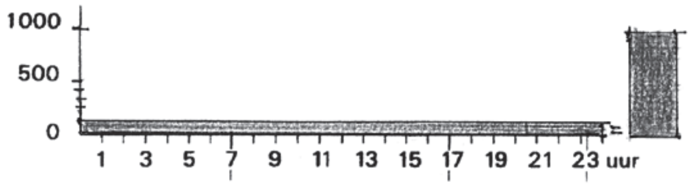
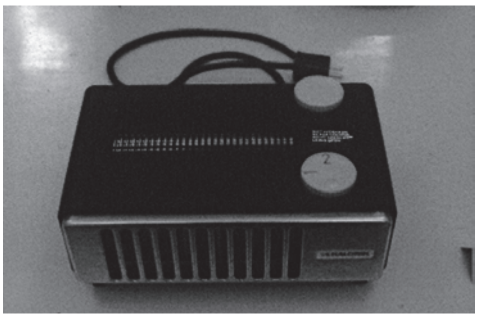


Fig. 05.09: The metabolism of a human being: 100 Watt x 24 hours = 2,400 Wh or 2.4 kWh of heat per twenty-four hours. One person generates 2.4 kWh of heat per 24 hours (100 W x 24 h). This is complemented with 30 W of latent heat (e.g. in perspiration).

With balanced ventilation with a heat recovery of 66% to 75%, the transmission loss becomes approximately equal to the ventilation loss. We need 20 m^3/h of air per person (50 m^3/h for smokers). For a family, a decrease from 250 m^3/h to 125 m^3/h does not appear to be unhealthy.

Table 05.01: Energy savings and remaining heat demand through insulated shutters

	Energy saving by shutters		**Remaining heat demand**	
	MJ	kWh	MJ	kWh
January	1100	305	1900	528
February	1050	291	1200	333
March	950	266	500	139
April	750	208	200	55
October	650	180	250	69
November	850	236	1150	319
December	950	264	1800	550
TOTAL	**6300**	**1750**	**7000**	**1943**



Calculations determined that during the morning hours in winter about 2 kW of extra heat would be needed if all the shutters were open. If we assume that the desired indoor temperature is 20°C, this heat could be delivered by a small electric heater. While a common dwelling on average consumed 25,260 kWh annually (mainly natural gas), the Dwelling without Central Heating only needs 1,943 kWh, which comes down to 15 kWh/m^2 per annum.

Fig. 05.10: Electrical heater with a capacity of 2 kW is sufficient to keep the Minimum-Energy House warm.

The PBE, later called Novem, then SenterNovem and currently Agency NL(an agency of the Dutch Ministry of Economic Affairs) attended the ‘Dwelling without Central Heating’ press conference and immediately announced their financial support for the realisation of the dwellings. It became the first pilot project of the national PREGO research programme (rational energy use in the built environment).

05.01.03   Minimum-Energy Dwellings, Schiedam (1984)

Fig. 05.11:   The Woudhoek-Noord Minimum-Energy Dwellings, Schiedam.

Following the press conference on the ‘Dwelling without Central Heating’ (which was also broadcast on the national children news channel ‘Jeugdjournaal’), Chris Zijdeveld, a Schiedam councillor and mechanical engineer, called to ask whether he could be the first to build these dwellings in his town. Zijdeveld was an advocate of solar energy applications, explaining his nickname 'the sun king'.
The opportunity to develop 76 single family dwellings and 108 apartments presented itself in the social housing sector at Woudhoek-Noord in Schiedam. All housing would follow the principle of the ‘Dwelling without Central Heating’. The urban plan had a fan form, which made it possible to apply passive solar energy in repeated shifts of orientation.

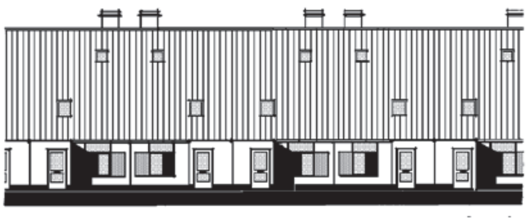
 

Fig. 05.12: North elevation of the terraced houses in Schiedam (left) and south elevation of the stacked terraced-houses (right).

With an investment of € 5,000/dwelling the calculated energy consumption for space heating at Schiedam came to 160 m^3 nge/year. Although the short-term cost is an substantial one, it must be put into perspective with the long-term energy and financial demands of conventional subsidised housing. For example, in the REGO programme (1982) the energy consumption was set at 2,150 m^3 nge/year!

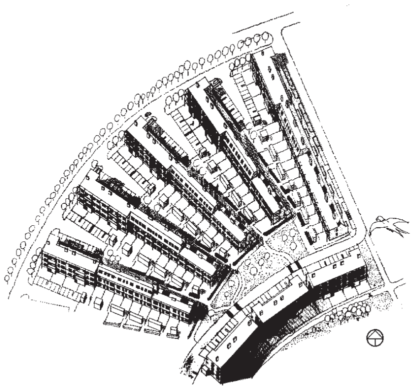
 

Fig. 05.13: The Schiedam neighbourhood of Woudhoek-Noord in aerial perspective, with 184 Minimum-Energy Dwellings (left) and an impression of the plan from street view (right).

This extremely low energy consumption was achieved by implementing an extended package of energy-saving measures:

- Southerly orientated building blocks (minimal facades facing east and west).
- Optimal insulation of façade and roof (180 mm mineral wool).
- Extra insulation of the ground floor (R = 5 m^2K/W)
- Insulated shutters in front of windows, three-layered glazing.
- Insulated foundation piles to avoid thermal bridges.
- Avoiding thermal bridges in the construction R = 1.3 m^2K/W
- Insulated panel at the entrance of the crawling space.
- High quality draught sealing in the Swedish and Danish windows with architectural connections.
- Enclosed porches (at the front and back) to reduce heat loss.
- Heat storage and delay in cooling by retaining concrete mass inside the insulated building envelope.
- Benefitting from passive solar energy, large windows on the south, small windows for all other directions, living areas on the south side, compartmentalised.

- Balanced ventilation with heat recovery from ventilated air.
- Accessibility of cables and ducts in a duct shaft.
- Additional heating system that heats ventilated air with hot water from the kitchen heater.
- Electrical ignition of the geyser flame.
- Small refrigerator in combination with a meat safe (to be discussed in chapter 10).

Fig. 05.14: Window (with shutter) in the upper roof on the south provides sunlight in the northern room.

Thermal insulation is the pre-eminent energy-saving measure. It is relatively cheap and utmost effective. External insulation was chosen, which was fastened to an inner gable of stone and finished with mineral plasterwork. The insulation value of the façade was as high as possible: 180 mm of mineral wool. The advantage of the mass on the inside was that heat could be accumulated. Hereby the inside temperature will remain warmer in winter and cooler in summer. All windows are supplied with insulation glass.

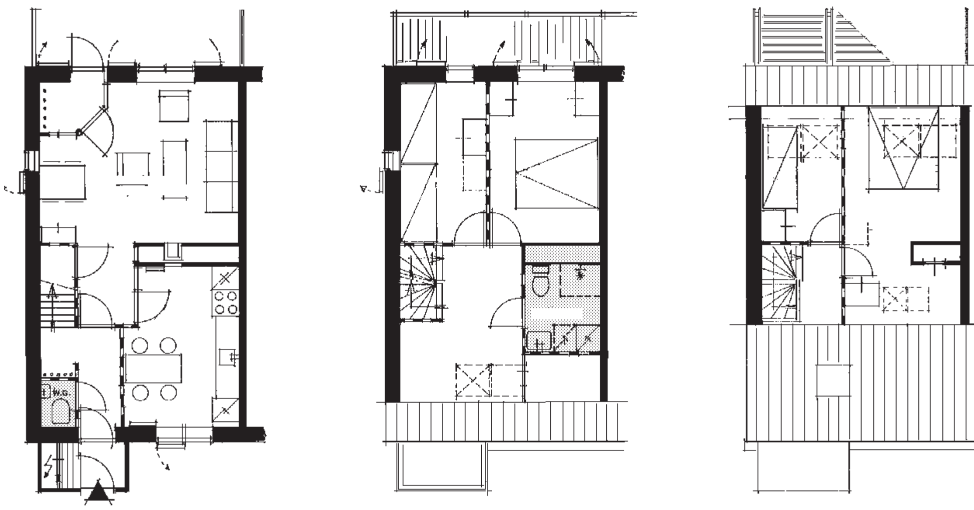


Fig. 05.15: Ground floor, 1st floor and 2nd floor of the Minimum-Energy Dwellings in Schiedam.

The heat balance indicates that, in order to guarantee a comfortable indoor climate, there has to be an equilibrium between energy loss and energy gain. Minimising the additional heating enforces avoidance of transmission losses, as well as the use of solar energy and internal heat production. This entails decreasing the ratio of surface/volume, decreasing the thermal transmission coefficient and decreasing the difference between in- and outside temperature.

Houses with a deep plan have a more favourable (outside) surface/volume ratio than shallow ones. In relation to passive solar design this measure is disadvantageous. A solution is to compartmentalise spaces and activities that have similarities in heat demand. The activities that demand a relatively high temperature should occupy minimal space and volume.

In the bathroom the heat demand is larger than in the rest of the house: approximately 22°C instead of 19 to 20°C. If the bathroom is situated in-between the bedrooms and the landing – as with low-rise dwellings – and the temperature of these spaces is around 18°C, the difference will be 4°C.

The heating demand of the bathroom is 250 W. However, if the shower is switched on there will be a surplus of heat. The water, which cools down from 45°C to 30°C, generates 500 W of heat! So, in the bathroom, before we enter the shower, there is a lack of heat, but as soon as the shower is switched on the bathroom becomes comfortable almost immediately. Conclusion: it is a waste to constantly heat a bathroom; heating by a simple lamp is sufficient.

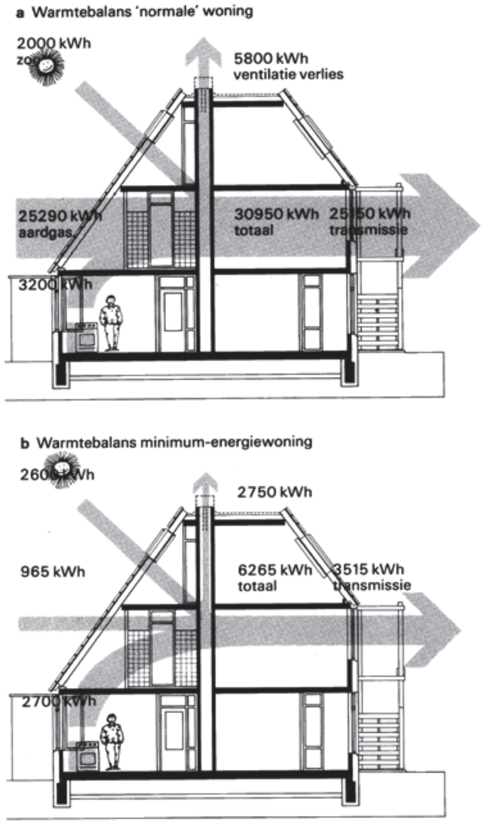


Fig. 05.16: *In traditional dwellings the solar heat and internal heat are negligible, in the Minimum-Energy Dwellings these sources of free energy are used for heating.*

From the calculated energy balance (Fig. 05.20) three observation can be made: (1) in the winter months there is not enough solar energy; (2) the internal heat production is equal to the amount of additional heating; (3) ventilation losses and transmission losses are similar – therefore, high efficiency in heat recovery is desirable (1 m^3 nge = 33.4 MJ).

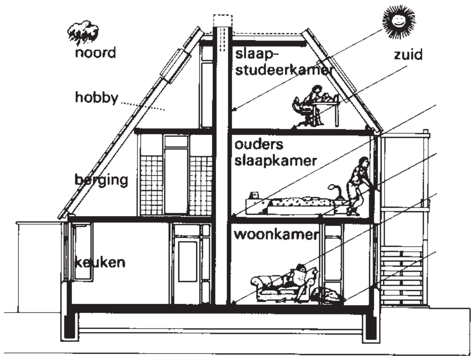


Fig. 05.17: *Space zoning: the living areas requiring heat are situated on the warm south side; the (closed) kitchen, entrance, storage and hobby spaces are located on the north side.*

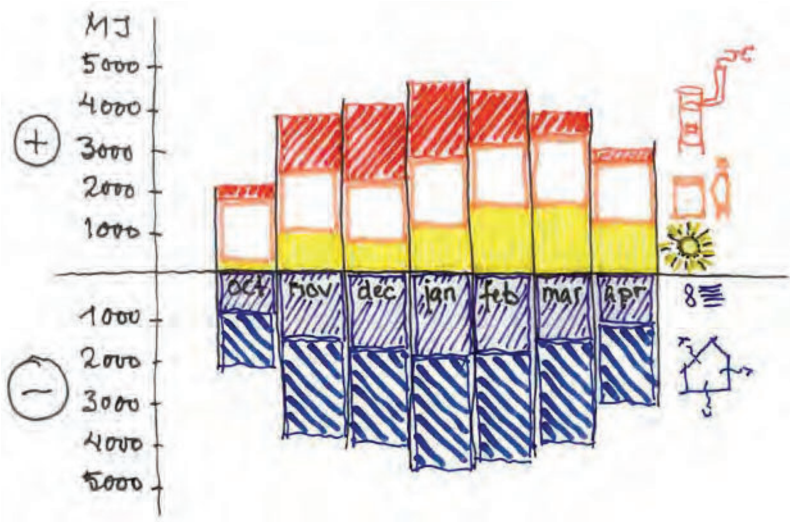


Fig. 05.18: Calculated energy balance of a 'Dwelling without Central Heating' [source: Jongen consultancy office, Vlaardingen, with the calculation model by Flåkt in Stockholm].

The Minimum-Energy Dwelling was made air-tight by the following measures:

- Extra rabbet for windows.
- Draught-proof connection of the window-frame, wall and roof.
- Enclosed porches at the front and back side entrance.
- No ventilation or air supply grills.
- Two-points latch for windows and three for doors, against warping.

Fig. 05.19: Insulated panel to the crawling space behind the front door.

By these measures the dwelling is almost air-tight (q < 5 Pa). The necessary ventilation was obtained by the balanced ventilation system.

A concrete inner gable was chosen for the façade. The surface of the thermal mass had to be maximized so the temperature fluxes inside would be minimal. In this experiment one house was constructed with a timber framework. Studies showed that air temperature fluctuations were hardly influenced by the concrete inner gable.

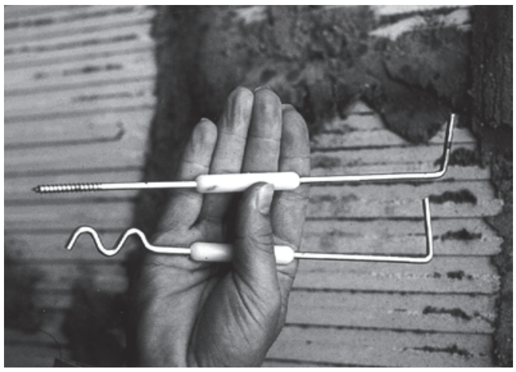


Fig. 05.20 Insulating wall-ties

In current housing developments the detailing of outer insulation is constructed in a more cost effective manner. The use of plasterboard with a vapour-proof foil is a common method together with a timber frame with insulation, vapour-permeable foil, cavity and outer gable of stone, wood or cladding.

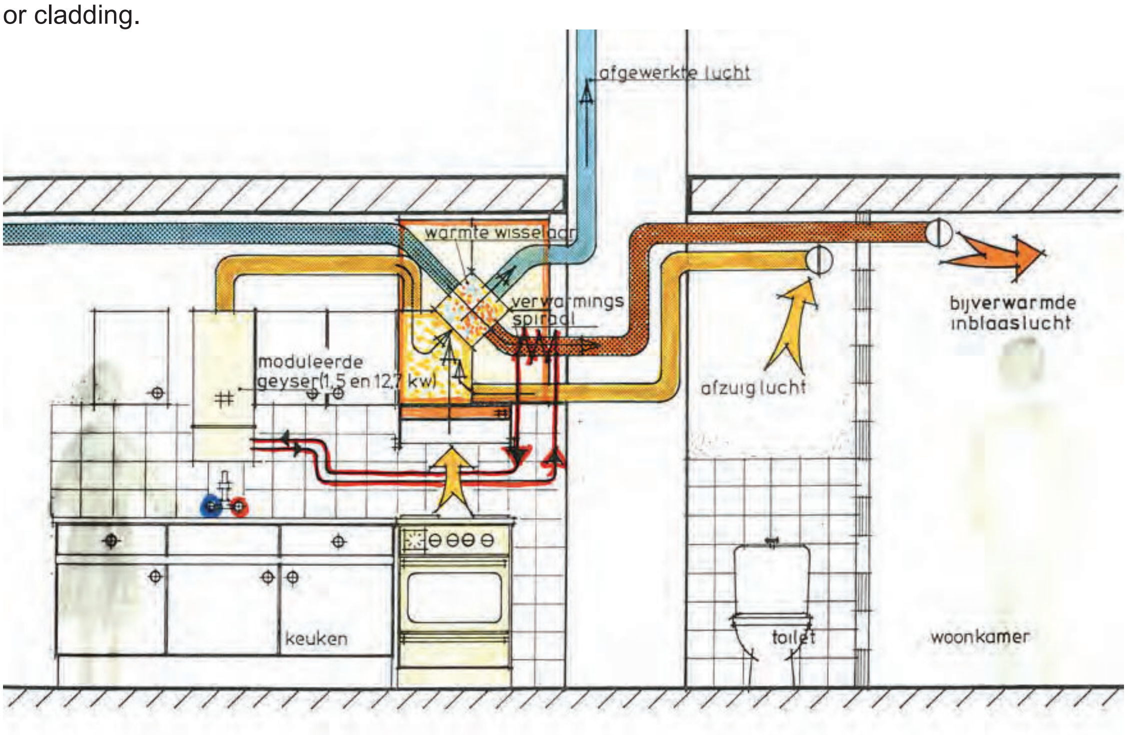


Fig. 05.21: Heating system of stacked dwellings with a horizontal supply of fresh air. The kitchen heater without pilot flame generates 12.5 kW of hot tap water and 1.5 - 5 kW of heating water. A compact air treatment device with a heat exchanger and heating spiral, integrated in the cooker hood above the stove, generates additional heating for the air supply.

The contribution of the internal heat and the use of the insulated shutters is significant. On sunny days the additional heating of about 2 kW is necessary only in the morning hours. On cloudy days this is the case from seven in the morning till five in the afternoon. More use could be made of heat stratification in the dwellings by blowing warm air from the ridge to the ground floor.

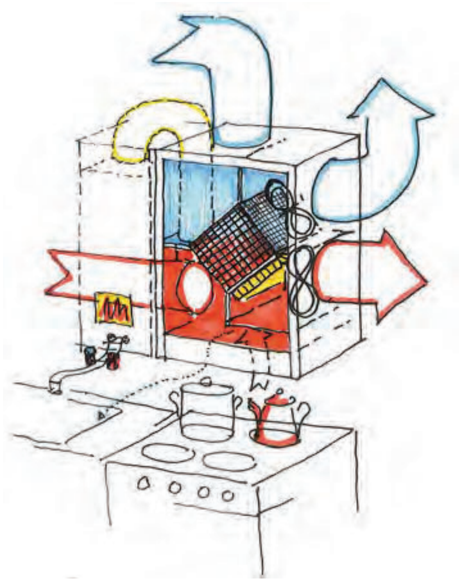
The design received a PREGO award (PREGO is a Dutch governmental organisation that tests projects of sustainable energy use).

Heating and ventilation

Only 17 dwellings were allowed to install a wood/paper incinerator due to the risk of air pollution. Therefore the design team looked for other options for air heating that met the following criteria:

- Ventilation of 150 m^3/h.
- Heating up to 4 kW.
- 100 m^3 recirculation of air

The Fläkt ventilator factory in Sweden had an air unit with too large a capacity for domestic use. After some investigation it appeared the Dutch ventilation market was not interested in developing an alternative. In response, design team member Koos Slootweg, in collaboration with geyser manufacturer ‘Fasto’, decided to design and build a domestically scaled prototype.



The wood/paper incinerator was to be replaced by a compact air treatment device in combination with an advanced gas geyser without pilot flame. The geyser supplied hot tap water (1.5 l/min at 60 °C and 12.5 kW) as well as heating water (1.5 to 5 kW). What was remarkable is the fact that both the kitchen heater and the compact air treatment device were integrated in the cooker hood above the kitchen stove. The solar boiler was later omitted as the system become over-complicated.
Initially the gas supply via the heat exchanger was rejected, but after the development of a special electronic control system and with results from measurements by TNO, Gastec gave its approval. This combination was used for the stacked flats. Therefore the fresh air was supplied via the façade through long insulated ducts. For the low-rise houses the municipality wanted the heat exchanger to be placed on the roof to allow easier maintenance.

Fig. 05.22: Combined installation of the geyser with heat exchanger.

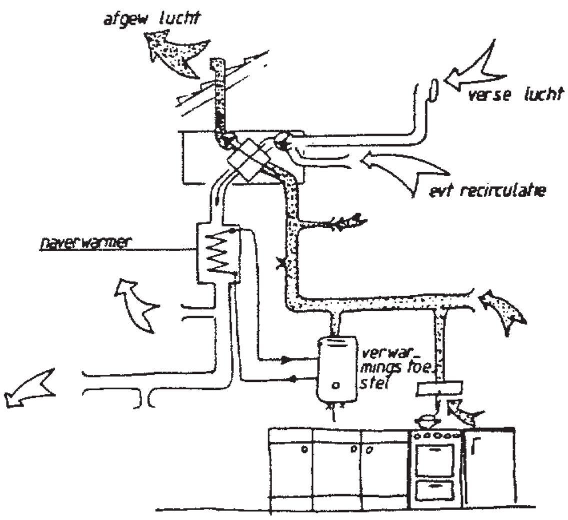
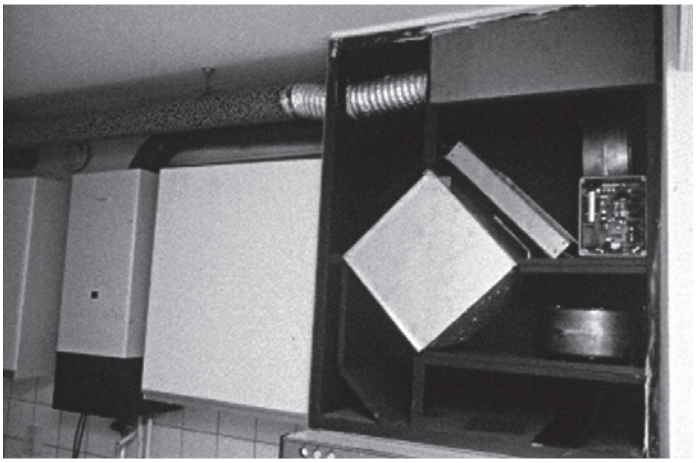


Fig. 05.23 Diagram of low-rise houses with heat exchanger on the roof (left) and roof installation of the heat exchanger, winter 1983-1984 (right) [24].

[24] The municipals decision to place the heat exchanger on the roof for inspection purposes was incorrect. Due to the external conditions the performance of the unit decreased by a factor of two.

With a capacity of 1.5 and 10 kW, the 'Slootweg unit' was unique at that time - an output that even modern devices would find difficult to compete. However, what was particularly fascinating about the Minimum-Energy Dwellings was that heat-losses through ventilation and through transmission were almost equal. A situation that warrants further investigation.



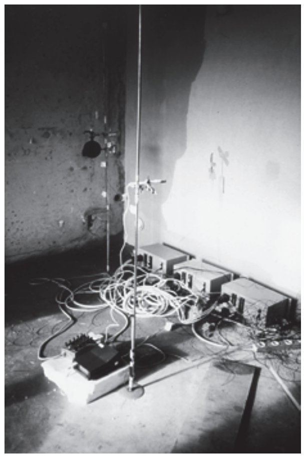


Fig. 05.24: Slootweg unit with Fasto geyser (left) and TNO measuring equipment in the dwelling in favour of the surface and air temperature (right)

The following products for sustainable building did not exist at the time of the ‘Minimum-Energy Dwelling’:

- Thermal insulation as permanent formwork for foundation beams.
- A ground floor with a heat resistance value R = 5 m^2K/W.
- Impact-resistant outer insulation of mineral wool.
- Internally operated insulated shutters in front of the windows.
- Modulating kitchen geyser with electrical ignition.
- A compact air treatment device for balanced ventilation with 66% heat recovery.
- Avoidance of thermal bridges and noise insulation at the front doors.
- Air-tight dwellings with high specification draught-proofing detailing.
- Insulating wall-ties.

The average of the total measured fuel consumption was approximately 550 to 600 m^3 of natural gas per year per dwelling for cooking, hot tap water and space heating. The space heating alone came down to approximately 360 m^3 natural gas per year. At that time a reference dwelling demanded a total of 3000 m^3 nge/year!

The ‘Minimal-energy dwellings’ design became a great inspiration for the energy-efficient building community in the Netherlands. A primary benefit resulting from this large experiment was that companies were now willing to develop new innovative products. Within a period of two years the Dutch market for building materials changed forever.

05.01.04 25 years ahead of the Energy Performance Code

Since December 1995, in accordance with the Energy Performance Code (EPC), any new building in the Netherlands must prove its energy credentials in order to obtain a building permit. In 1995 the Energy Performance Score (EPS) required for dwellings was 1.60; after that year it was lowered several times and currently is 0.75. For the 1981 design of the ‘Dwelling without Central Heating’ we were 30 years ahead of our time. In the document 'Demonstration-projects and energy-saving housing” Dr. Sacha Silvester mentioned that the energy performance requirements from 1995 had not yet reached the level of these dwellings [Silvester, 1996]. We calculated the Energy Performance Score (EPS) according to today's standards and came to 0.58-0.75, which still amply complies with the EPC regulations of 2010.

How did we achieve this?
The document 'Rules of thumb for EPC in housing' [Novem, 2002], originating from an initiative of Novem and the Dutch Architects Association, summarises EPC’s main criteria:

(Urban) Architectural

- Orientation: for the EPS a north-south orientation is favourable and east-west least favourable; this is demonstrated by a difference in EPS of approximately 0.03.
- The addition of a glasshouse will only affect the EPS if the extensive calculation method is applied or if an input for the linear heat losses is quantified, in which case the EPS improves by 0.02 and 0.08 respectively.
- Ultra-high-performance glazing (U_{glass} = 1.2 W/m^{2}K) gives an improvement of EPS of 0.02 in comparison with high-performance glazing (U_{glass} = 1.6 W/m^{2}K).
- An insulated door (U_{door} = 2.0 W/m^{2}K) gives an improvement of the EPS of 0.02 in comparison to a traditional door (U_{door} = 3.4 W/m^{2}K).
- Increasing the thermal insulation of the total building envelope ($R_{c,facade/floor}$ = 4.0 m^{2}K/W, $R_{c,dak}$ = 5.0 m^{2}K/W, U_{glass} = 1.2 W/m^{2}K and U_{door} = 2.0 W/m^{2}K) improves the EPS by 0.08.
- If there are small linear heat losses it is simpler to meet the EPS requirements; in the case of high linear heat losses, as with corner houses, detached houses or houses with porches the EPC will remain the same or increase slightly.
- Submitting own values for linear heat losses (for example via reference details) the EPS will improve substantially: this can be an improvement of 0.01 to 0.06; for dwellings with a relatively high amount of linear heat loss the effect of submitting own values on the EPC is approximately 0.05.
- Applying shutters in front of the windows results in an improvement in the EPS of approximately 0.05, when only applied to the north 0.02.
- Improving the seam sealing ($q_{v;10}$) will decrease the EPS with approximately 0.02.

Building services

Ventilation

- Balanced ventilation (with 'normal' heat recovery of around 70%) instead of natural supply and mechanical discharge of air results in a lower EPS of 0.10.
- In comparison with an alternating current ventilator for mechanical discharge a direct current ventilator gives an improvement in the EPS of approximately 0.02; for balanced ventilation this improvement is approximately 0.05.

- Increasing the heat recovery efficiency from 70% (standard) to 95% (high efficiency), can reduce the EPS by approximately 0.05.
- Pre-heating the ventilated air in the glasshouse can improve the EPS by 0.01.
- The addition of demand-driven grills with mechanical ventilation gives an improvement of the EPS of 0.13.

<u>Heating</u>

- A low-temperature system with floor and/or wall heating gives an improvement of the EPS of approximately 0.02 in comparison with a high temperature system with radiators.
- Solar collectors (5.6 m^2) for the heating of rooms and hot tap water (solar boiler combination) will improve the EPS by approximately 0.20 compared to a high-performance combi-boiler (HR107) – a solar boiler combination is often applied with a low temperature system.
- A heat pump in combination with floor and/or wall heating results in an EPS improvement, depending on the source (soil, ground water or outside air), of approximately 0.03-0.12 in comparison with an HR 107 combi-boiler with floor and/or wall heating.
- An electrical heat pump with a ground water source is, regardless of the temperature of the water supplied, is favoured by the EPS method; with the soil or outside air as a source the EPC is about 0.02 and 0.04 higher respectively.
- Heat supply by others (STEG, industrial production process, incineration of waste, or gas engine heat pump) improves the EPS by about 0.15 compared with an HR 107 combi-boiler.
- A cogeneration plant gives, depending on its capacity, an EPS improvement of approximately 0.03-0.06 in comparison with an HR 107 combi-boiler.

<u>Hot tap water</u>

- The addition of solar collectors (2.8 m^2) for hot tap water (solar boiler combination), together with a high-temperature HR107 combi-boiler improves the EPS by around 0.10.
- Solar boilers and residential buildings: the application of a solar boiler, as an addition to a HR107 combi-boiler, lowers the EPS in a residential building (gallery flats) by approximately 0.03. Here the effect of a solar boiler (combination) is much smaller than in an individual house because of distribution losses.
- The application of a heat pump boiler instead of an HR107 combi-boiler results in a reduction of the EPS by 0.07; starting-point is mechanical ventilation and no balanced ventilation.
- When the piping has relatively short lengths, calculating with the actual length gives an improvement of about 0.03 on the EPS compared with the fixed lengths; therefore the location of the boiler is important.
- A lower comfort level for hot tap water improves the EPS by approximately 0.02.

<u>PV cells</u>

- Orientation of PV cells to the south is favourable for the EPS; enlarging the area from 7 m^2 to 10 m^2 gives an improvement of around 0.05 and from 10 m^2 to 13 m^2 an EPS improvement of 0.05.

Epilogue

Within the building industry people are questioning whether the search for a lower EPS needs to be continued. Put simply without the excessive criteria, a flexible design, offering the possibility to be built and used without construction and demolition waste, contributes greatly to the sustainable use of resources.

05.02 Solar Cavity Wall Dwellings

05.02.01 Background of the solar cavity

Solar collectors
As a response to the design for the Lelystad city hall (discussed further on in this book), our engineer Koos Slootweg proposed the installation of a solar collector system in our studio offices. In 1979, collectors were commonly filled with anti-freeze. Our experiment used an emptying principle that didn't rely on toxic additives. When the collector temperature was less than $\Delta T = 7°C$ higher than the water in the reservoir, the collector water would be drained into a small tank adjacent to the circulation pump. Draining would be repeated to prevent overheating i.e. when the water was close to boiling point. This method quickly became an obvious solution for sustainable houses.

Years later we also made two types of air collectors in our garden. The first absorbing material was a permeable black cloth. The second collector had black roof tiles as an absorber. Measurements indicated that the synthetic cloth collector reacted much faster to solar radiation, however for the total capacity the difference was negligible. The conclusion was therefore: every tiled roof can be transformed into an air collector.

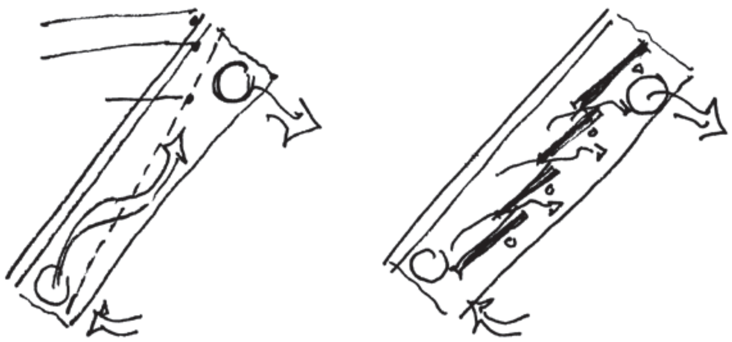


Fig. 05.25: Two principles of a solar collector with Tedlar and Teflon: above with black cloth as an absorber, below with black concrete tiles (or normal roof tiles).

Solar cavity wall dwellings with hybrid solar heating
As a result of the 'Memo' fair in the Berg church, Deventer (1979) we were asked by the Leiderdorp solar dwellings foundation to design nine terraced houses in accordance with their philosophy: "contribute to knowledge and application possibilities concerning solar energy in dwellings, with the awareness of working towards the development of a clean, safe and infinite energy source that cannot be monopolised". These became our first solar cavity wall dwellings.

The heating system by solar air collectors is based on heat storage of air in toothed cavity walls without wall-ties separating terraced houses. This principle has four advantages: saving fossil energy (no central boiler needed), harvesting solar energy, heat storage and the frost-insensitivity of air. With a difference in phasing between summer and winter, that is to say between a surplus and a lack of sun hours, each form of heat storage is appropriate for the northern hemisphere:

- Solar heat is used adequately.
- Heat is stored in the building mass.
- Phasing difference: the heat is released from the other side of the wall only after five hours.
- The temperature of the radiating surface may be low because of the large surface of the separating wall.
- There is no threat of freezing.
- The cavity wall between the dwellings is also sound-insulating.
- In southern countries the installation can be used for cooling during summer nights.
- Control of the ventilators is easily managed through a thermostat in winter and with an on-off switch in summer.
- The principle is very suited for the spring and autumn period and to a smaller extent for dark winter days.

The disadvantages are:
- In winter a secondary heating system is necessary (hence the term ‘hybrid’).
- Air has little thermal capacity.
- A silencer is necessary on the air supply pipe.
- In order to avoid the mixture of air between two dwellings, only one heating source can be connected per solar cavity.

05.02.02 Background of the solar garden

Our studio office resides in an old mansion originally constructed in around 1890. The building has had an interesting past. Built for Deventer’s elite, damaged in the Second World War, then serving as housing for immigrant workers in 1965. Finally, with the aid of governmental subsidies this heavily neglected structure could be made suitable for living or for offices. Because of its large spaces with high ceilings no air conditioning was needed, and it was comfortably cool in summer.

Conservatories and greenhouses
In the mansion a conservatory (constructed 100 years ago without central heating) was separated from the living room by glazed sliding doors. In spring and autumn these doors could be opened to gain solar heat in the living room. In summer they were closed to keep the living room cool while the back door was opened towards the garden to enjoy summer and the garden. In winter they were closed to keep out the cold.

When we started to design conservatories and greenhouses by the end of the 1980’s, difficulties arose. There are now technical ways now to direct heated air from the conservatory into the living space i.e. through ventilators, instead of opening sliding doors. This does not mean that the conservatory now should be part of the living area. It is still a separate space that generates heat in winter and is cold in summer. Unfortunately many residents expect their greenhouse to have the same temperature as the living room. They remove the sliding doors and then complain that it is too warm in summer and impossible to heat in winter.

Fig. 05.26: The high slanted roof-light in the glasshouse providing daylight to the meeting room.

Principle of the solar garden heating

This next section will discuss examples of houses we developed with a so-called solar garden: an ‘outdoor’ space inside a greenhouse, attached to a dwelling. This solar garden plays an important role in the heating system of the dwelling.

Operation:

In the solar garden the air is heated by the sun (in the Netherlands solar energy yield is typically 500 – 1000 W/m^2 of horizontal surface). The air is directed into the hollow space of a tie-free cavity wall that separates two dwellings. This cavity wall forms the 'heat battery' of the house, which radiates the heat to the spaces on the other side of the wall. The bricks accumulate the heat and, after approximately four or five hours, deliver this heat as infrared radiation into the living areas (two dwellings benefitting from one system).

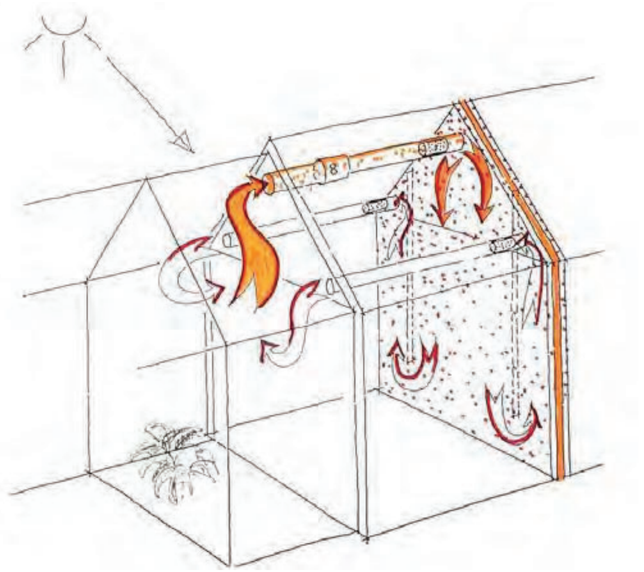


Fig. 05.27: Airflows in the solar garden heating system

An electric thermostatically controlled ventilator is placed in the duct in the ridge of the pitched roof. The fan only runs when the air is sufficiently heated. This ventilator draws in preheated air from the ridge of the glasshouse and directs it through a spiral duct into the cavity of the separating wall. The air flows down in the middle and up again at the sides. The air returns to the solar garden through ducts in the attic floor.

Elementary components of the system are:

- Ridge of the solar garden.
- System of ducts with the ventilator in the attic.
- Cavity in the wall that separates the dwellings.

How much energy can we roughly generate by this system?
Let's assume that in the winter months (the heating season) the sun shines 10% of the time. In Western Europe the heating season measures five months, so we have 360 effective sun hours. The glass surface on the south side of the glasshouse is 5 m x 7 m = 35 m^2, and the solar intensity has a mean value of 500 W/m^2 (in winter). For a low capacity installation, for example 50%, this results in 35 m^2 x 500 W/m^2 x 0.5 = 8.75 kW.
Duration x power = energy; 360 hours x 8.75 kW = 3150 kWh.
This is comparable with a reduction of approximately 300 m^3 of natural gas per year.

The Delft University of Technology conducted research on the cavity wall, concluding that in practice, the additional heating in these privately owned dwellings is around 500 m^3 nge/year.

By 2002 the technical construction requirements of cavity walls was made more stringent: the dwelling-separating tie-free cavity with gables of 2 x 100 mm, was now increased to 2 x 150 mm. This additional mass slowing down the heating system, the effects being felt after several days, rather than within a desired twenty-four hour period.

05.02.03 1st generation Solar Cavity Wall Dwellings: Leiderdorp (1983)

Fig. 05.28: The nine Solar Cavity Wall Dwellings with fixed wooden sunshading on the first floor and external sunshading on the conservatory roofs to avoid overheating.

All nine dwellings in the Leiderdorp plan had their own solar cavity wall heating. The lightweight solar air collector covered the whole southern half of the pitched roofs. A prefabricated collectors compiled from various components fitted between the roof beams with a double layer of storm-proof Tedlar foil on the outside and a heat-resistant Teflon foil on the inside sealing it off. The black glass fibre absorber (acrylic paint) was installed between two wedge-shaped spaces. From a narrow shaft above the solar collector the air was extracted into the crawling space, after which the air spread slowly through the air cavity towards the collector in the attic. The ventilator was placed in the crawling space under the ground floor.

As secondary heater, a balanced ventilation device with heat recovery, was placed in the attic. Each system was developed in such a way that it can function stand-alone. The slow supply of heated air into the living areas took place in the upper part of the inner walls and in the bedrooms above the doors. A separate solar collector for hot tap water was integrated into the solar air collector system on the roof. The cavity wall without wall-ties was made of toothed, glued limestone blocks and of aerated concrete on the neighbouring walls. As heated air was guided under the ground floor this floor was not thermally insulated.

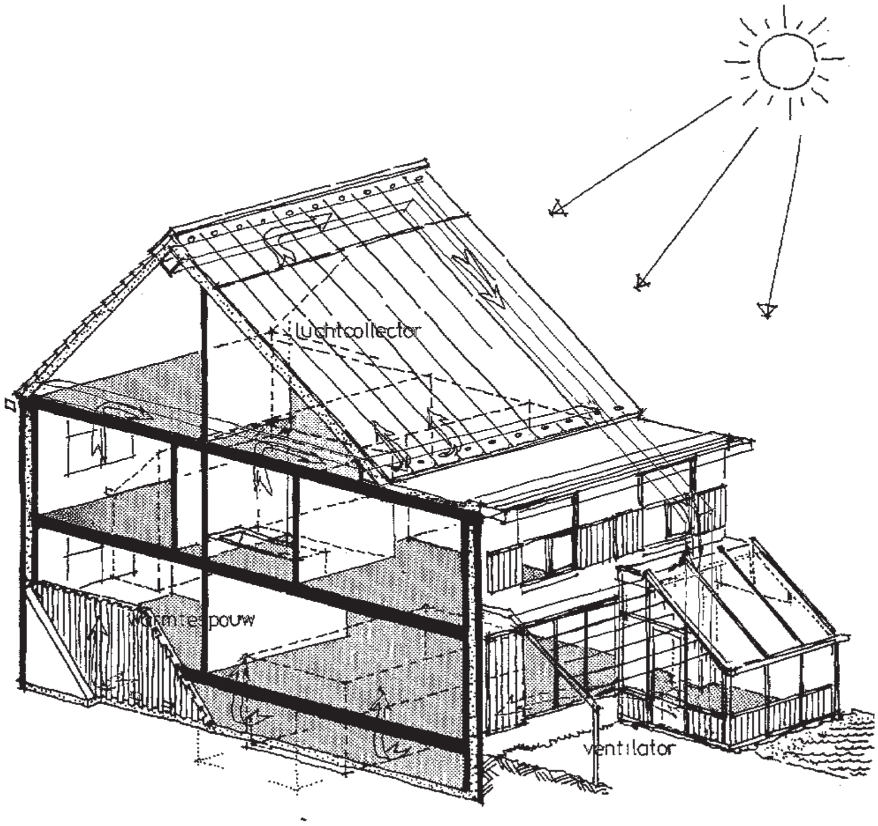


Fig. 05.29: Perspective of the Solar Cavity Wall Dwelling in Leiderdorp

01) Air duct in the ridge collects the heated air that is then led to the crawling space through a tube.
02) Air collector generates heated air.
03) Pipe in the attic transports the air from the cavity to the air collector.
04) Air duct at the bottom of the roof distributes the air over the collector.
05) Crawling space spreads air in the cavity.
06) Heated cavity toothed to increase its contact surface.
07) Ventilator in crawling space generates circulation of air.
08) Water collector for hot tap water.
09) Fixed sunshading device.
10) Conservatory constructed separately from the system, with external sun shading.
11) 'Cool' cellar.

A new technique specifically developed at Leiderdorp by Pittsburgh Corning was the floor system. Given the name ‘Perinsul’, the floor was completely constructed of foam glass insulation panels, this heavy load-bearing (HLB) structure was then coated with bitumen. The function of Perinsul is twofold: thermal insulation between the soil and foundation and a vapour-proof layer against the capillary rise of moisture in the brick foundation. The average pressure strength for Perinsul was 0.83 N/m^2, for which a safety coefficient of 1.8 was applied. The study of properties of this material would be partly funded by governmental energy agency PBE.

Fig. 05.30: Placement of heavy load-bearing foam glass in the foundation.

The air-tight houses had an unheated enclosed porch on the north side, and a conservatory on the garden side. To further reduce heat losses a layer of 180 mm wall insulation was applied to the ventilated cavity wall. The lower windows had external shutters, while the upper window shutters were placed on the inside and were hinged near the ceiling. External fixed timber slats provided sunshading.

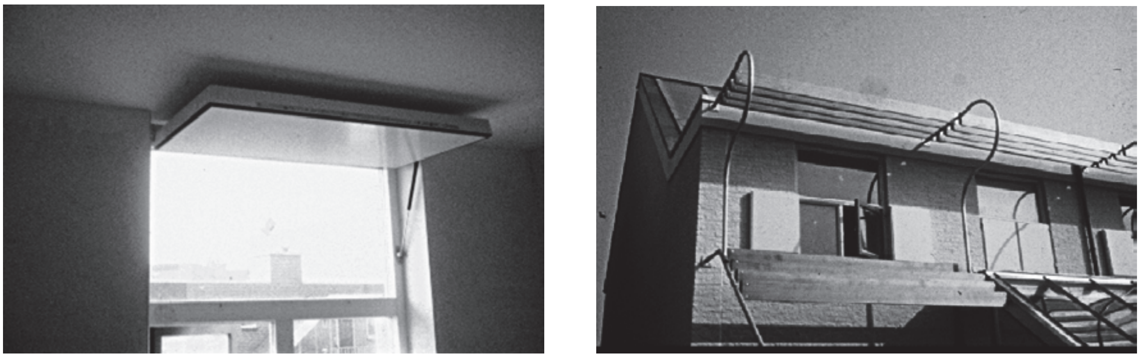


Fig. 05.31: Insulating shutter on the inside with a telescopic operation system (left) and fixed external sunshading (right).

The Delft University of Technology investigated the dwellings by PBE commission. The conclusions were:
- The collector surface can be reduced by 50%.
- The rough (toothed) surface of the cavity wall is not necessary.
- The individual computer-controlled volume for the solar air collector can be used collectively.

These large houses had an average consumption of natural gas (1985) of approximately 230 m^3 nge/year per dwelling.

Producer Ruud van Hemert filmed the construction of the dwellings for the ‘Puur natuur’ (pure nature) series by the VPRO, a Dutch broadcasting company. The construction workers were particularly motivated by this media exposure, which made them aware of their involvement in a building of ‘national importance’.

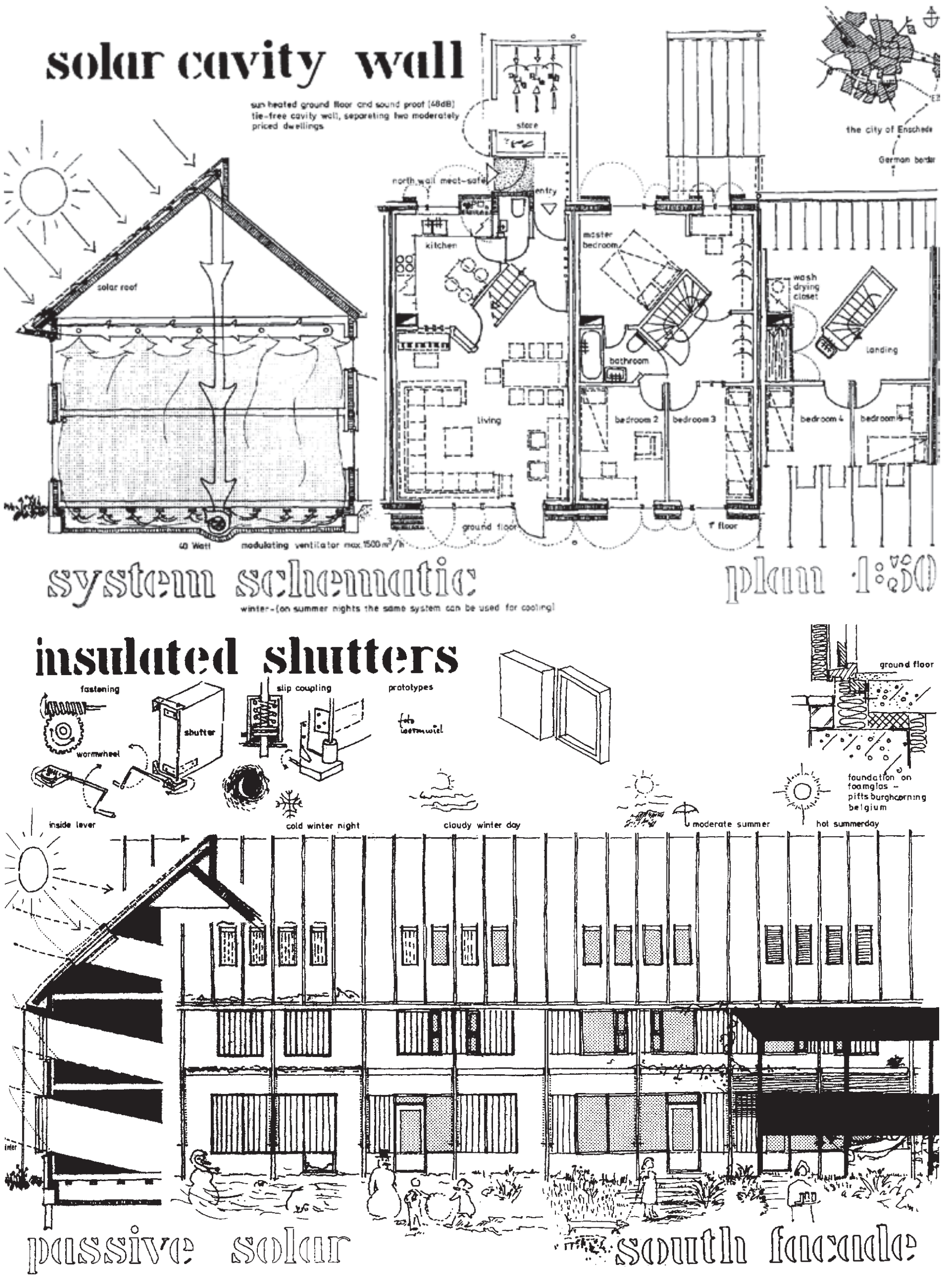


Fig. 05.32: Award winning contribution to the 2nd EEC passive solar energy competition (1982). An architecturally improved version of the Solar Cavity Wall Dwellings in Leiderdorp, with additional Slootweg type heating (Calculated heat consumption - 306 kWh per year).

In the second project design faults became apparent. The clients wanted a cool cellar in the heated crawling space, an extremely difficult design to execute. A further fault concerned the assembly of the air canals, which was confusing and the monitoring on leakages appeared not to be realisable. The programming of the temperature sensors, needed to control the ventilation of the air collectors, turned out to be too complicated. The high-tech electronic operating system was too ambitious.

This project taught us the need for simplicity and clarity in installation. After only three years following a heavy storm moisture problems occurred in the solar air collectors. Despite a life expectancy of 20 years, the collector suppliers refused to take responsibility. It was decided to cover-up the collectors and, unfortunately the experiment was terminated. The principles of the first generation Solar Cavity Wall Dwelling were however successful, and later repeated in Hoofddorp in 1984, this time with shorter air collectors that avoided excessive thermal expansion.

05.02.04 2nd generation: Drachten (1992)

Fig. 05.33: Morra Park glasshouse; roofing of the glasshouse consisting of transparent three-layered corrugated plastic sheets.

A 'creative' philosophy was adopted at solar garden dwellings at Drachten, one that provided the residents with the opportunity to develop their own environmental lifestyle. The idea being that when people have more influence on their immediate living environment, they are more likely to care for it.

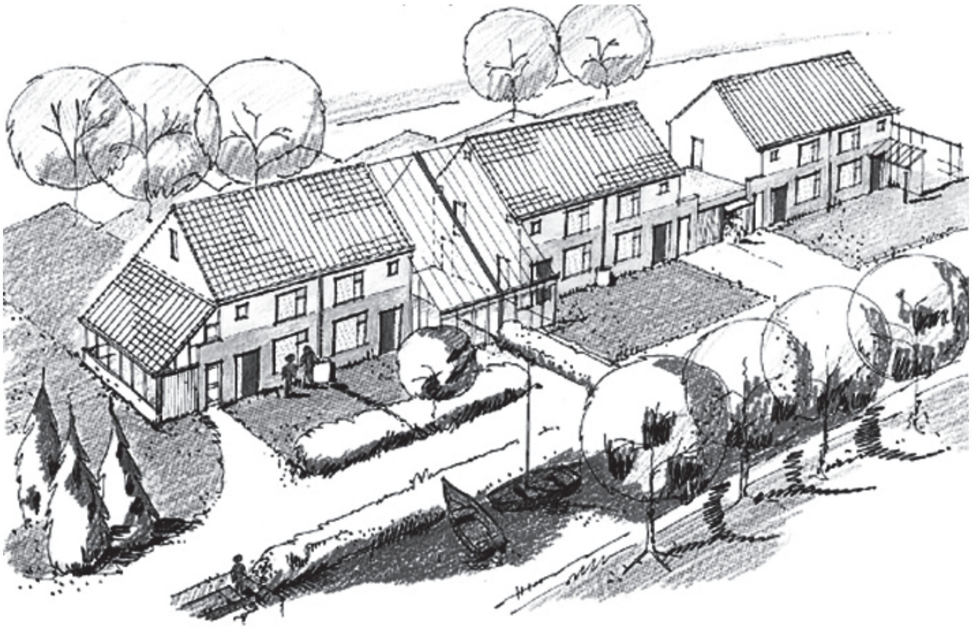


Fig. 05.34: Sketch of Morra Park in Drachten. Solar gardens between the dwellings function as air collectors. Clients choose if they want a solar garden, then size, height and depth are selected within the maximum boundaries.

The solar garden can have various purposes; greenhouse, work-out space, atelier, workplace, extra living space in spring, summer and autumn, etcetera. The housing strategy was to allow each resident to decide which to use. Occupants could also choose to install a balcony /mezzanine at first floor level.

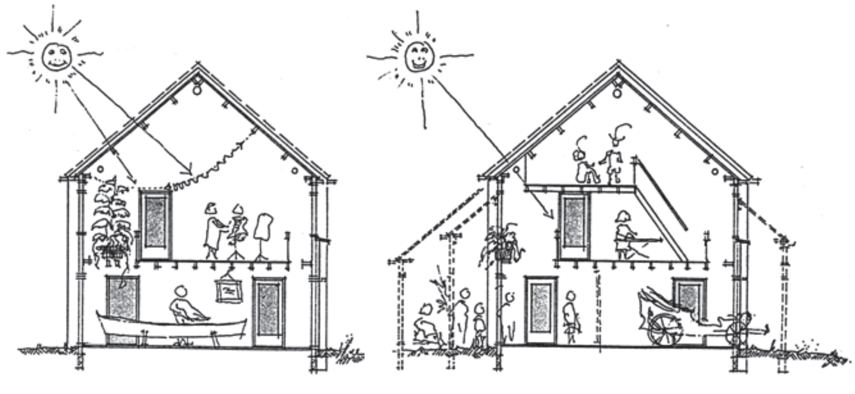


Fig. 05.35: Section of a glasshouse with a platform on the first floor (left) and extension of the solar garden on two sides (right).

The solar garden is not meant as a permanent living space, it should be regarded as covered external space or buffer zone. As with a conservatory, inappropriate usage will result in

disproportionately higher heating costs in winter. It is not practical to use the solar garden as a garage as extra facilities are needed such as fire safety and building permits.
The solar garden was delivered without an interior, with single glazing in the facades and covered with transparent corrugated plastic roofing. The northerly oriented glasshouse roof of three-layered 'Dobbelstek' slabs could in hindsight have been more effectively tiled reducing winter heat losses.

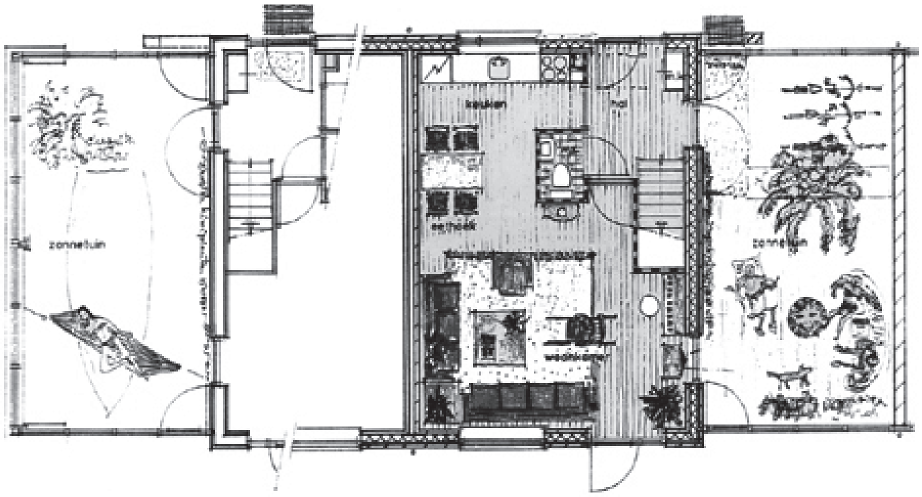


Fig. 05.36: Ground floor with glasshouse.

The 12 dwellings have a high Rc-value (floor 3, façade 4 and roof 4.5 m^2k/W) and all windows have insulation glass. Each dwelling is served by central heating with radiators and a high efficiency combi-boiler, as well as a 2.8 m^2 solar collector for hot tap-water. With the high efficiency boiler providing additional heating, the dwelling would be ventilated by a balanced system with heat recovery.

Five dwellings had a glasshouse constructed.
The environmental research and design office ‘BOOM’, in Delft, developed a method to test the environmental quality of the construction of dwellings and living environment for the municipality of Smallingerland. Observations concluded that the glasshouse radiated too much heat to the night sky; any future design developments should consider an insulated north and south roof would reduces these losses.

Fig. 05.37: Completed glasshouse dwellings in the Morra Park along the water front.

05.02.05 3rd generation: Ede (1995)

Fig. 05.38: South elevation of dwellings in the Rietkampen neighbourhood of Ede.

Realisation of Solar Cavity Wall Dwellings in the social housing sector was not possible without special financial measures, as we already described in the Groenekan example. The Municipality of Ede wanted to act, and the housing corporation Woonstede was willing to participate. By adding extra apartments the dwelling density was increased, extra capital generated allowing the municipality to lower the land price.

The solar collector was a bay design featuring a double façade integrated with rotating and lifting venetian blinds. A fan distributed air in the cavity wall between the dwellings. The cavity between the outer and inner façade was naturally ventilated outside of the heating season.

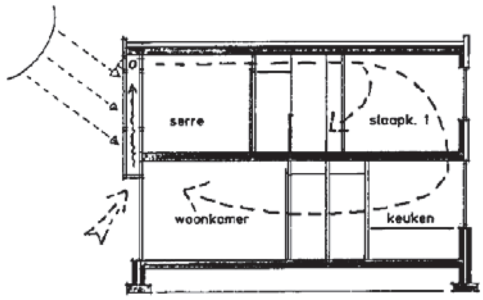


Fig. 05.39: Principle of the solar bay with the airflow in the cavity between the dwellings.