04

SMART ENERGY TECHNOLOGY

04.01 Basic introduction to energy

04.01.01 Energy in and around the house

Energy in the built environment in relationship to people is simultaneously complex and simple. It is complex because we deal with different forms of energy and conversion factors. Yet it is also simple because energy equals power times time. Therefore, we need to understand energy and its basic units. First, energy is the unit of Joule, J. One Joule is one Newton.metre (N.m, or kg.m^2/s^2). So energy is used when a force (accelerated mass) has moved something over a certain distance. Power is energy used by unit of time, Joule/second (J/s), or simply Watt (W).

Table 04.01: Energy and power units

kJ	kilojoule	10^3 J
MJ	megajoule	10^6 J
GJ	gigajoule	10^9 J
TJ	terajoule	10^{12} J
PJ	petajoule	10^{15} J
EJ	exajoule	10^{18} J

kW	kilowatt	10^3 W
MW	megawatt	10^6 W
GW	gigawatt	10^9 W
TW	terawatt	10^{12} W
PW	petawatt	10^{15} W
EW	exawatt	10^{18} W

Table 04.01 gives energy and power units.
Table 04.02 presents conversion values for energy and power.

Table 04.02: Energy and power conversion factors

1 kWh	kilowatt hour	3.6 x 10^6 J = 3.6 MJ
1 kWh	kilowatt hour	0.1022 m^3 nge[9]
1 kWh	kilowatt hour	864 kcal

1 m^3 nge	natural gas equivalent	35.2 MJ
1 m^3 nge	natural gas equivalent	9.78 kWh
1 m^3 nge	natural gas equivalent	7980 kcal

1 cal	(small) calorie	4.18 J
1 Cal or kcal	(large) calorie, food calorie	4.18 kJ

1 hp	Horsepower	0.736 kW
1 hph	horsepower hour	2.647 MJ

fir wood		10.5 MJ/m^3
domestic fuel oil		40 MJ/l (appr.)
diesel		36 MJ/l (appr.)
petrol		33 MJ/l (appr.)

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[9] Natural gas equivalent. This only concerns the energetic content. In the generation of electricity losses occur. The efficiency of power generation is approximately 50% with gas-fired plants. This implies consumption of 0.205 m^3 of natural gas for 1 kWh of electricity.
The value mentioned for 1 m^3 of natural gas is high caloric value (HCV), so condensation of exhaust gases it is 35.1 MJ/m^3. At low caloric value it is 32 MJ/m^3.

All human activities cost energy. Table 04.03 gives an overview of the power of these activities. A human being typically performs 130 W x 24 h = 3 kWh per day. Table 04.03 also gives approximated values for power of domestic appliances.

Table 04.03: Human activities (left) and technology around us (right)

Sleeping	75 W
Sitting	115 W
Walking	230 W
Race walking	345 W
Cycling	475 W
Swimming	550 W
Running	670 W
Judo	1150 W

Lamp	25-100 W
Computer	200-300 W
Television	100-120 W
Vacuum cleaner	1200-1800 W
Small car	75 kW
Big car	80 kW

Let us take the Dutch as an average for Western European countries. By 2010 an average Dutch household used 3,500 kWh of electricity and 1,500 m^3 of natural gas. Together this is 65.4 GJ or 16.7 MWh. With an average distance of 20,000 km a year by a moderately efficient car, the energy used for transport is no less than 14 MWh, almost as much as normal living needs. And this does not include flying trips…

An empty Boeing 747-400 weighs 180 tons. A typical arrangement of the aircraft with three classes transports 416 passengers [www.airliners.net]. With 50-65 tons of cargo and 170 tons of kerosene it weighs 400 tons.
End of June 2012 the price of a gallon of kerosene was $ 4.00 [www.nyserda.org]; this equalled 4.00/3.8*1.25 = € 1.32/l of kerosene. Note that in the same period the price of petrol for cars in Northern Europe varied around € 1.75/l.
It is a 13 hour flight from Amsterdam to Singapore. With an average occupancy of 85% our Boeing 747-400 will carry 354 people. Fuel consumption is around 12 tons of kerosene per hour (3.3 litre per second – some figures state a gallon per second, which would mean 3.8 l/s), so 156 tons of kerosene in total. 156.000/354= 441 l/passenger, or 882 l after returning. In total this costs € 1,164 per passenger. With European car fuel prices the expenses would have been € 1,544.
Aviation does not pay excises on fuel so we can travel wherever we want…

Now, all of this energy used needs to be generated somewhere. At the moment, most of this is established through fossil energy resources, which will gradually deplete and have a serious impact on anthropogene climate change in the meantime. So we have to find sustainable alternatives, for which the New Stepped Strategy is helpful:

1. reduce the demand
2. reuse waste energy
3. generate energy from renewable sources (sun, wind, water, earth and life itself).

The following sections will explore in detail energy saving and sustainable generation, so let's first have a look at the human aspect to it: how to we keep ourselves supplied with energy? By food and drinks, of course. Table 04.04 presents the energy we as human beings absorp, provided by food we eat and beverages we drink. These are approximate values.

Table 04.04: Energy in food and beverages

Sugar	one tea spoon	13 kcal	55 kJ
Ketchup	one portion	15 kcal	60 kJ
Broth	one cup	20 kcal	85 kJ
Knäckebröt	one piece	35 kcal	150 kJ
Jam	one soup spoon	44 kcal	185 kJ
Rye bread	one slice	55 kcal	230 kJ
Whole milk	one glass (¼ l)	69 kcal	290 kJ
Cola	one glass (¼ l)	80 kcal	335 kJ
Red wine	1 glass (120 ml)	85 kcal	355 kJ
Coffee garnish	one portion	90 kcal	380 kJ
Fries	50 g	130 kcal	550 kJ
Peanuts	20 nuts	140 kcal	590 kJ
Trout, cooked	one piece	150 kcal	630 kJ
Grape juice	one glass (¼ l)	160 kcal	670 kJ
Roast beef	one piece	175 kcal	735 kJ
Beer	one pint	182 kcal	761 kJ
Ice cream	one portion	200 kcal	840 kJ
Apple pie	one piece	300 kcal	1260 kJ
Creme pastry	one piece	400 kcal	1680 kJ
Farmer’s sausage	125 g	515 kcal	2160 kJ
Chocolate	125 g	680 kcal	2850 kJ
Butter	100 g	750 kcal	3300 kJ

04.01.02 Exergy next to energy

In the building industry we should not use high-caloric energy to produce low-caloric heat at the end of the process.

> It is a problem that a gas heating flame of 1200-1500°C
> should keep our homes at a level of 20°C. ‘Waste’ heat is not used.

Energy companies and building utility manufacturers must come to their senses. It is inevitable that the essential temperature for heat demanded on one side, on an energetic base, must be aligned with the heat sources that are available on the other side.
This has far-reaching consequences for buildings that use low-caloric heating in floors and walls, especially when larger building surfaces are becoming more common.
A large variety in types of energy supply is needed.

There are two important reasons why we consume so much unnecessary process energy.

1. There are profits to be made by inefficient energy use, that is to say: fossil energy is too cheap.
2. We lack the knowledge and facilities to apply sustainable heating.

Let's assume that the last reason is the most important one. It is not hard to make a product fit for its circumstances (1 to 9) looking at the environmental conditions and composition (atmosphere, hydrosphere, lithosphere).

The definition of the exergy of a product (flow) is the maximum amount of labour that is available within this product (flow), per mass unit, based on the differences according to the environmental condition in terms of pressure, temperature and chemical composition.
For example, natural gas of 175 bar and 60°C (as in a reservoir) is not equal to the environmental circumstances, in all three exergetic parameters[10]:

- natural gas (CH_4) $\neq$ N_2, O_2, H_2O, CO_2
- 175 bar $\neq$ 1 bar
- 60°C $\neq$ 15°C

It appears that despite this definition energy and exergy can be easily confused.
When I look at my energy saving projects in the past, in which mainly exergy was applied for ventilation systems and heat exchange, the energy possibilities can be counted on 10 fingers.

Low-exergy design principles

- Small isolated core
- Bike-shed
- Rain water collector and storage (e.g. in bags)
- Combined solar boiler
- Heat exchanger in foundation piles
- Sequence of energy utilization: from electricity, process heat to low-caloric heat

04.02 Thermal insulation

04.02.01 Wrapping up the building

Insulating foundations
We were the first to introduce thermal insulation of foundations in the Netherlands and probably also one of the first elsewhere in the world. Today it seems logical but around 1980 it was far from common. Our work changed the direction of construction forever.

The idea was born with a simple calculation.
When foundation beams have the same temperature as the ground in winter (appr. 6ºC), heat losses from a dwelling with a typical 38 m^2 of concrete beams will be approximately 500 kWh per heating season (corresponding to a consumption of around 80 m^3 of natural gas). To avoid these thermal bridges an interruption in the concrete can be made by for instance foam glass.

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[10] Source: Prof. J. de Swaan Arons, TU Delft

Another option is covering the foundation beams with 100 mm thick polystyrene insulation panels (figure 04.01).

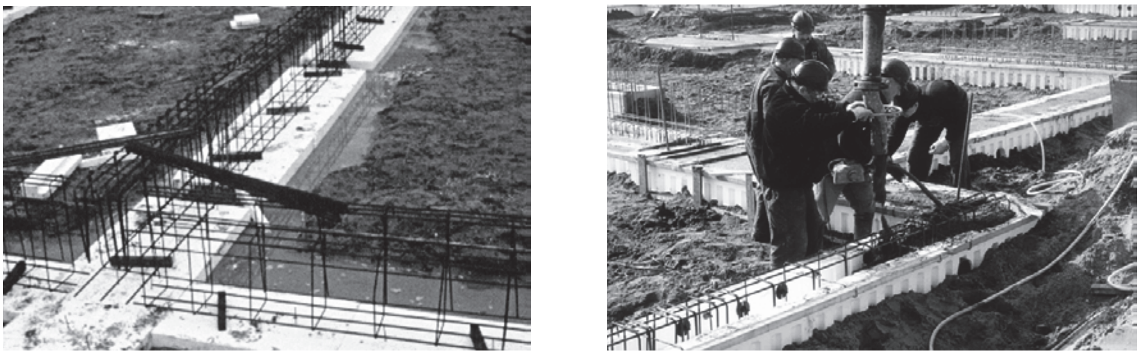

Fig. 04.01: Permanent polystyrene insulation underlayer for foundation beams (1982, left) and casting of the concrete inside the foundation insulation (2010, right)

For ground floor insulation above the crawl space, polystyrene cushions can be placed between and under pre-stressed concrete beams (figure 05.02). These cushions function both as thermal insulation and as permanent formwork for the floor on top. The concrete finish floor then functions as a compression zone together with the pre-stressed concrete beams.

The permanent polystyrene insulation formwork for foundation beams was once innovative but has become standard since. Among others, this system is being recommended by labour inspection because the minimal weight of the product, leads to less worker back problems during installation. The concrete reinforcement cages are delivered on site prefabricated.

Fig. 04.02: Polystyrene cushions placed between pre-stressed concrete beams

Insulating walls

Thermally insulated walls had become a habit already long before the insulated foundation. We built the very first Dutch house with thermal insulation in the roof and cavity of the gable in 1967. This soon became the standard after the oil crisis in 1973.

Fig. 04.03: *The plasterers are working outside one of our well-insulated houses in the 1980s. Extra reinforcement was applied in fragile places at the edges of the window-frames. One had no experience, so everything was done as safe as possible.*

In the 1980s we introduced PUR sealings between precast concrete wall elements to optimise the energy performance of buildings. This of course was combined with thick façade insulation and air-tight wooden Swiss window frames with triple glazing. These were sealed by intumescent strips. On the construction site, polyurethane (PUR) has become the preferred resolution for minor mistakes in detailing. Seams are usually sealed with polyurethane foam. PUR has various negative environmental properties, but since 1990 Freon as propellant is substituted by gases that do not damage the ozone layer.

Fig. 04.04: *This is how the facade of the dwelllings eventually turned out.*

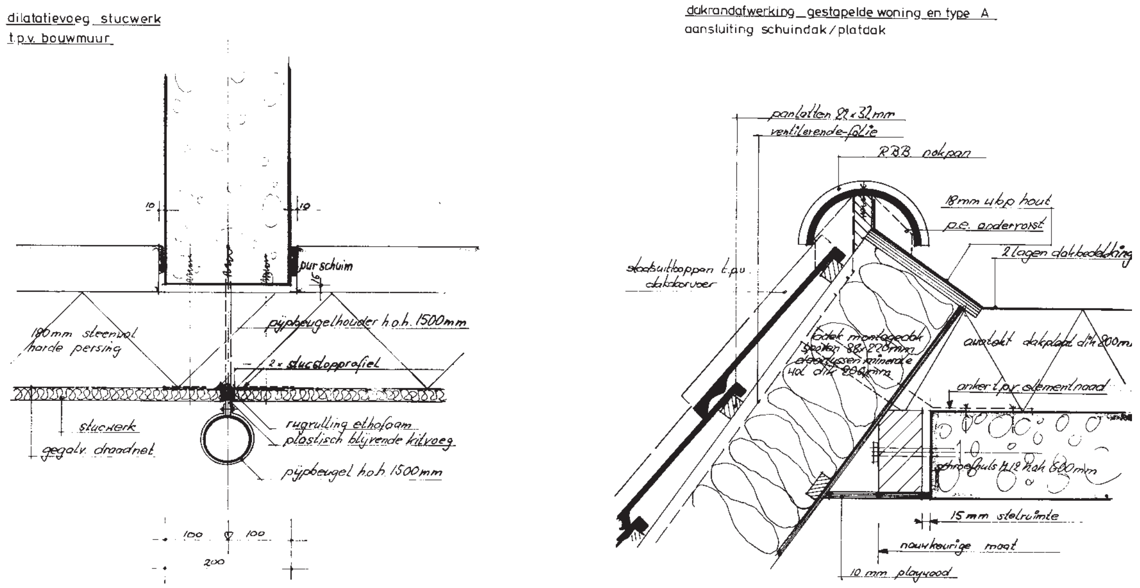

Fig. 04.05: *Old details of a well-insulated house: horizontal section of a plastered gable (left) and vertical section of the connection of a slanted roof to a flat roof part (right)*

Insulating roofs

Another novelty to the building industry was the use of prefabricated rafter roof elements. In the earliest versions these had a 10 mm bottom multiplex board. A package of 200 mm of mineral wool lay between the rafters. Under the tile laths a man-bearing ventilating foil was placed. On top of it, ceramic or concrete roofing tiles finished the structure. Danish Velux windows were often placed in the roof elements during fabrication. These windows were chosen because of their uncomplicated use and maintenance.

Fig. 04.06: *The piled-up rafter roof elements with thermal insulation (left) and the roof with integrated Velux windows just before the roof tiling works*

This was all done long before the introduction of the passive house principle, including a heat-recovery system to be discussed further on. According to measurements the average air-tightness of the dwellings was generally good. The system was not disturbed with the opening of windows during night-time.

04.02.02 Thermally insulating shutters

Introduction
The ability to minimise heat flows, into or out of the building according to the season, is an energetic factor of great significance. in a well-insulated dwelling with a façade that is adaptable to the seasons, we can win solar energy in winter and prevent its entry in summer:

- In the heating season thermally insulating shutters in front of windows, for the evening and at night.
- With the use of a narrow and wide window strip, shutters in front of the wide strip of bedroom window can stay closed in winter.
- Optimal daylight access: high and wide for maximum light admittance (possibly diffuse), adjustable in summer.
- Exterior sun protection, against over-heating in summer, preferably adjustable, transparent and storm proof.
- Deciduous climbing plants, not attached to the façade, or knotted lime trees.

In this way we can make a summer and winter house in one, but also a night and day house.

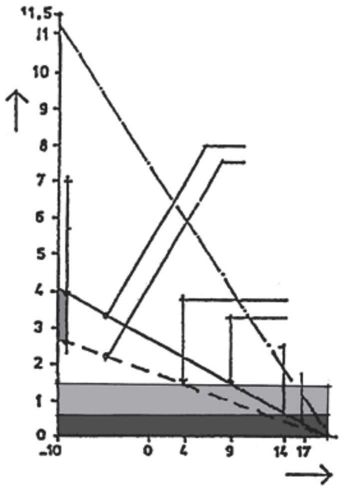

Fig. 04.07: Changes to the heating season as a result of the internal heat production, and the difference of having shutters or not. Vertical are heat losses in kW, horizontal the outside temperature in ^{o}C; the dark grey area is a house uninhabited, the light grey area inhabited. The crossing sloped lines depict at which temperature heating is required when they cross the light or dark barrier: the dashed line is with shutters closed, the full line with shutters open.

The winter house of Frank Lloyd Wright in Taliesin West, near Phoenix (figure 05.07), is a beautiful example of a winter house that was kept at temperature by a roof of milk glass. In summer this house was empty due to overheating. Yet the house is also used in summer months due to its architectural significance, made possible thanks to a large air conditioner as we see more often in “Gods own country”.

Fig. 04.08: Taliesin West, by Frank Lloyd Wright: meant as a winter palace, nowadays used as museum and air-conditioned all year round.

Insulating shutters are rarely seen on buildings. They do sometimes function as sun protection, as slats and for security. It is obvious to use thermally insulating shutters as elements that form the architectural image, but this happens sporadically.

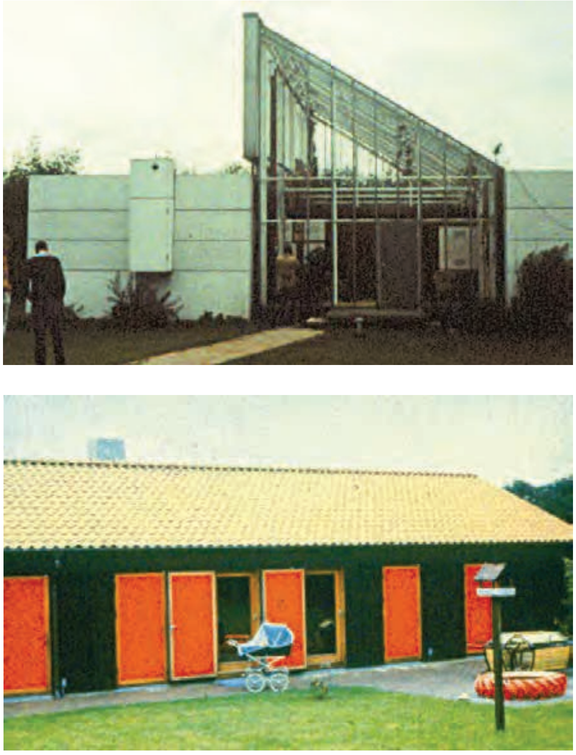

Fig. 04.09: The Danish 'zero'-energy house: simultaneous development of shutters at the Technical University of Copenhagen (above) and Hjortekjear, also in Copenhagen – dwellings with outside shutters that set the architectural scene (below)

In theory the thermally insulating shutters can be shut for two-thirds of the time in schools and offices, since they are closed during that time. For bedrooms and/or study rooms in dwellings the period of required daylight is equal to or less than in offices. For an average room (T_i = 21ºC) the shutters reduce 30 m^3 nge/m^2/year with single-glazed windows and 10 m^3 nge/m^2/year with double-glazed windows.

Fig. 04.10: Test of thermally insulating shutters in the Beijum district of Groningen (left) and the ones applied in the neighbourhood of Woudhoek-Zuid in Schiedam (right)

Examples from practice insulated shutters

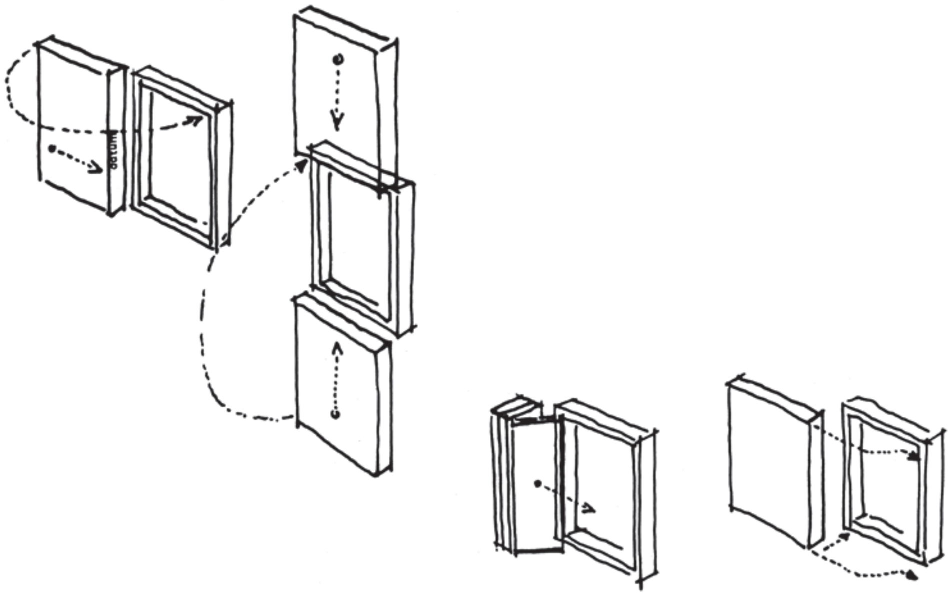

Fig. 04.11: Various examples of thermally insulating shutter principles

A thermally insulating shutter can (in principle) be operated in three different manners: sliding, rotating and folding. A reliable operating system for rotating shutters that can be opened and closed from the inside took 1.5 years to develop.

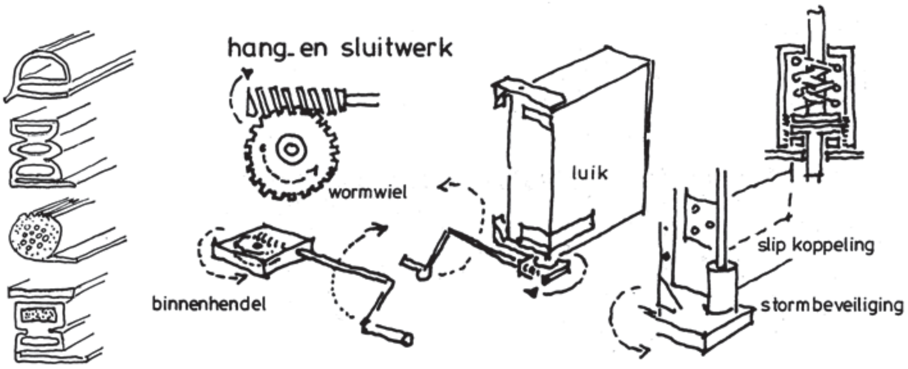

Fig. 04.12: Examples of sealing rubber gaskets for insulating shutters (left) and the original sketches of worm wheel for operating shutters (right)

The combination of a worm wheel with a warranty (coming from sunscreens) with a steel spring to bear wind forces and to ensure a good sealing, appeared to work well for the Minimum-Energy Dwellings in Schiedam. The operating system had to be as easy as possible.

Later, in the working-class district of Klarendal in Arnhem, the small windows with rotating shutters were replaced by folding shutters after which the window had to be opened to adjust the shutters. Sliding insulated shutters of large dimensions (2 x 2 m) at ground level are adjustable by a rail and a hinge system, known from mini-vans. A sliding shutter on the outside of a façade is a very effective solution with a stark architectural expression.

Fig. 04.13: Folding shutters, operable by hand, in the Klarendal district in Arnhem

For the internal orientation in a house it is important that part of a window, for example the operable part, is not completely closed by insulating shutters. If nine tenth of the window is covered, a large energetic effect will already be accomplished whilst ensuring daylight access.

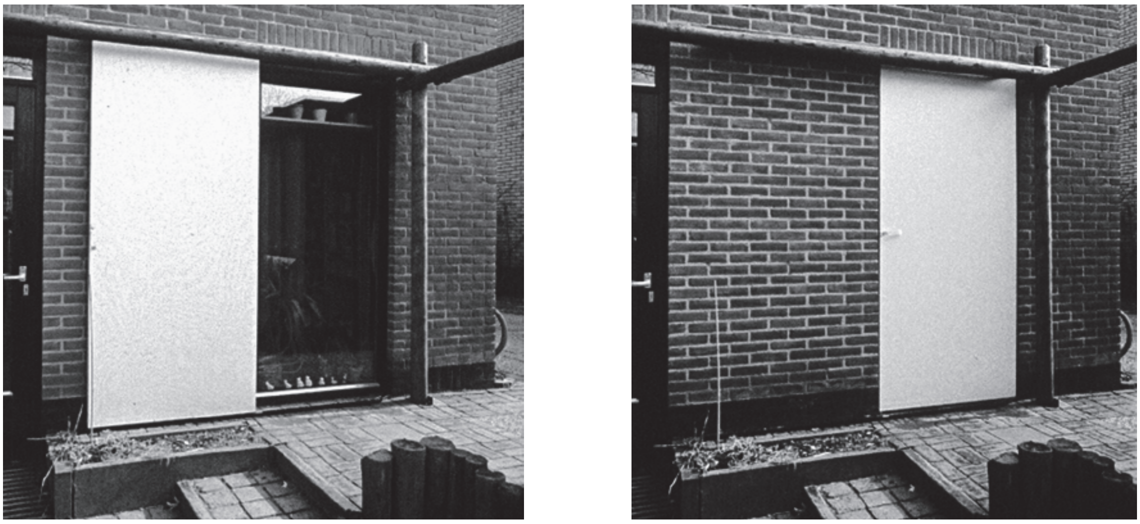

Fig. 04:14: Sliding shutters with the rail system of a van

Another option is the use translucent insulation materials in shutters: good for daylight inside and insulation in winter. In summer these shutters provide little cooling. This can be rectified by applying white reflecting material or colloidal foil that turns white at high temperatures on the translucent shutters. An option is a combination of insulating shutters and PV cells on the south as a new architectural element.
The implementation of interior shutters is less complicated. In most cases magnetic locking is used, also when the shutters swing open to a ceiling or 180º against an indoor wall.
Condensation against the strongly cooled glass in winter is inevitable, but in the space between the shutter and the glass there is little air. Suppose 0.2 m^3 with a relative humidity of 50%. That is 1 m^2 x 0.2 m^1 x 50% x 17 gr/m^3 = 0.2 x 0.5 x17 = 0.17 gr of condensate. When the shutters are opened this condensate appears to be evaporated in 2 to 3 minutes. The shutters will have to be air-tight.

Fig. 04.15: Translucent insulating shutters seen from the outside and inside

A sliding alternative, where insulation grains are captured between two layers of glass, is difficult to establish in the building industry, when a warranty of ten years cannot be given.

Are there more possible applications for insulated shutters? Yes, certainly. For low-rise buildings a wooden terrace in the form of the old portcullis, such as castles have, can also form a thermal insulation part of the façade. In the upright position it can function as a security system against burglary.

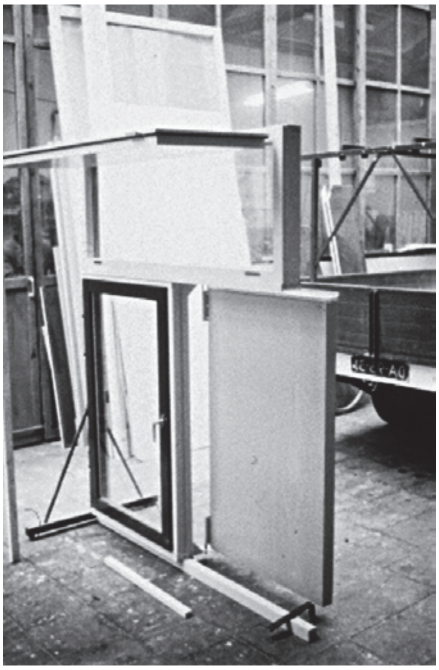

Fig. 04.16: Pre-manufacturing an insulating shutter

Other useful applications of insulated shutters for example are not thermal, but acoustical, as noise insulation. For instance, for discos and youth societies at inner-city locations that do not close at 11 PM. Sound insulating shutters enable a double use of space. It also makes the city livelier when housing and recreation go hand in hand. These shutters can be fixed on the inside, with a hinge. They have a double rabbet and are made of heavy plated material filled with sound-absorbing filling. In case an even higher insulation is needed, an extra external shutter can be considered. The strength of the chain is determined by the weakest shackle. Sound-tight ventilation cannot be forgotten.

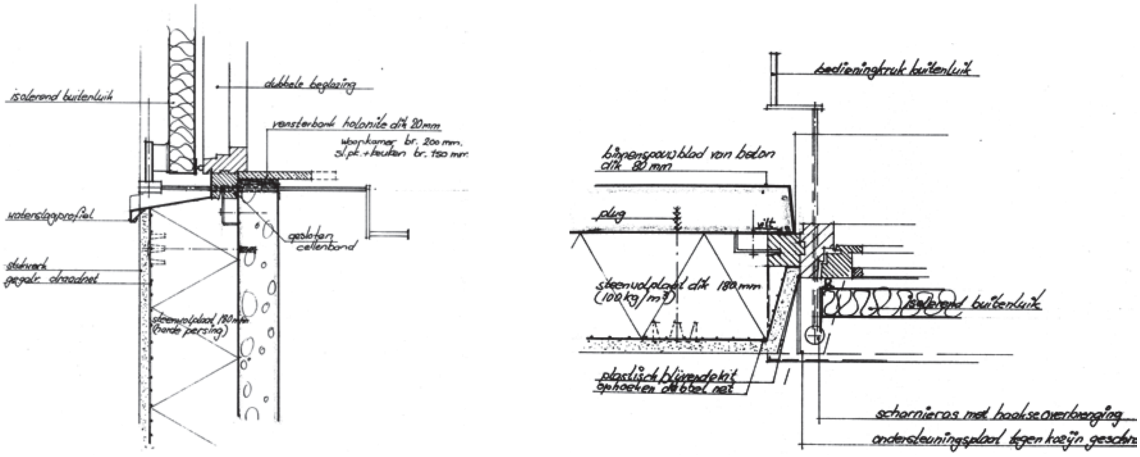

Fig. 04.17: Detail of the sill at the parapet, with external shutter (left), and of a window-frame connection with external shutter controllable from the inside

Rough results for thermally insulating shutters by TNO in 1983
Accomplished measurements of thermally insulating shutters determined the following:

1. The practical heat resistance measured at panel shutters is 35 to 40% higher than the resistance of the best insulating window surfacing (reflecting roller-blinds).
2. The selection of cover and core material for the panel shutters is hardly of influence on the practical heat resistance. Wooden shutters are a fraction better than metal or synthetic ones.
3. The maximum practical heat resistance measured for the total façade element appears to be approximately 1.25 m^2K/W, i.e. a U value of 0.8 W/m^2K, with insulation glass.
4. Fastening or totally sealing off of the rubber strips does not lead to major improvements in heat resistance.
5. The window-frame onto which the shutter is fixed appears to be an important thermal bridge. An important heat resistance improvement of the total construction can only be realised with a totally separated internal and external window-frame, also interesting for the costs and benefits.
6. The operational system with a turning-arm instead of a turning-axis for wind control is recommended with external shutters, in which the wind control should better not contain cast-iron parts.
7. Load-bearing tests indicate that users need to be instructed not to operate the shutters at a wind force of 6 Beaufort or more.
8. Shutters with large dimensions should be avoided. Up to 1 m^2 a shutter can operate with normal driving-components and connection parts. For larger shutters the double folding shutter principle with guard bead, or sliding shutters should be applied.

Concluding remarks
Fortunately we can determine that the thermal quality of double-glazing has improved with large steps each time against little extra costs. The float glass technique where melted glass floats seamless on tables filled with tin, instead of the large rollers used in the past, is a revolution in the production process (of the first order). In this way glass has become relatively cheap and has had many possible functional applications. Glass is manufactured from material that is nearly unlimited and that can be recycled through a melting process.
The thermal improvement of 'cheap' glass prevented the expensive shutters from competing. Moreover, the window-frame has become the thermal bridge and not the glass pane, as around the time of the Schiedam Minimum-Energy Dwellings for example. The next energetic measure is to improve the window-frames. In second instance the insulating shutters can, as adjustable façade, have a great influence on the dimensions of the building heating and cooling services.

04.02.03 Energetic renovation of 448 tenement flats, Schiedam (1989)

448 tenement flats, spread over 15 blocks in the neighbourhood Nieuwland in Schiedam and dating from 1956, were due for renovation. After 32 years of intensive use this was (also in regards to comfort and the new energy reduction programme of the government) desperately needed. Our office got the honour to provide an answer. We started with one building block of 32 flats.

Fig. 04.18: *Font side of the tenement flats in Schiedam after renovation*

Old situation

The tenement flats each contain apartments with three or four rooms, divided over three or four storeys. The type is representative for many apartments from that period. The storage rooms are situated in the basement of the buildings. The size of the flats was originally derived from requirements and suggestions dating back to 1951; according to current criteria they are small, especially the kitchens. The balconies partly protruding from the building are small (1 x 1.85 m) and therefore limited in their usage.

The thermal bridges at the balconies caused moisture problems, condensation, mould, etcetera. There was of course no mechanical ventilation. The ventilation mainly occurred through chinks, by opening windows and via the ventilation shaft in-between shower and toilet.
In the beginning the flats had been heated by coal stoves. Later these were replaced by gas heaters put in the living room. Thermal comfort in these flats was poor. The disadvantage of stoves and gas heaters is an uneven distribution through dwellings without thermal insulation.

Fig. 04.19: *Old kitchen*

Deduced from measurements by TNO (a Dutch building investigation institute) the temperature gradient between floor and ceiling within one space turned out to be $\Delta T = 17°C$ (in the case of an outside temperature of -3°C). Especially the dwellings above the basement had very little comfort. Next to the stove at the floor in the living room the temperature was 14.5 °C, at the ceiling 31°C and next to the window respectively 11.5 °C and 29°C. In the unheated bedroom the temperature measured was 6.5°C. The average energy consumption, including all energy needed for cooking and hot water, was 1,830 m^3 of natural gas per year for upper and lower dwellings and around 1,130 m^3 of natural gas for the dwellings in-between.

Fig. 04.20: Impression of the new balcony, removal of the balconies and a new one in place

Improvements

- Enlargement of the balcony at the front side and the application of extra sliding windows
- Enlargement of the kitchen and a new kitchen block
- A new façade surrounding the new balconies at the backside
- Reduction of the glass area at the shadow side
- Installing 150 mm thick thermal insulation on the outside
- Replacement of the wood windows and window frames
- Replacement of single glazing by double glazing
- Applying roof insulation and new roofing
- Heating the whole apartment instead of just the living room
- Insulating storage boxes in the basement to prevent heat loss from the lower dwellings
- Seamless all around finishes

New situation

The main goal was to improve the indoor climate. As a test-case one dwelling was renovated and the air-heating installation was tested. The residents were informed at an early stage. The façade placed around the balconies led to disappearance of thermal bridges and moisture.

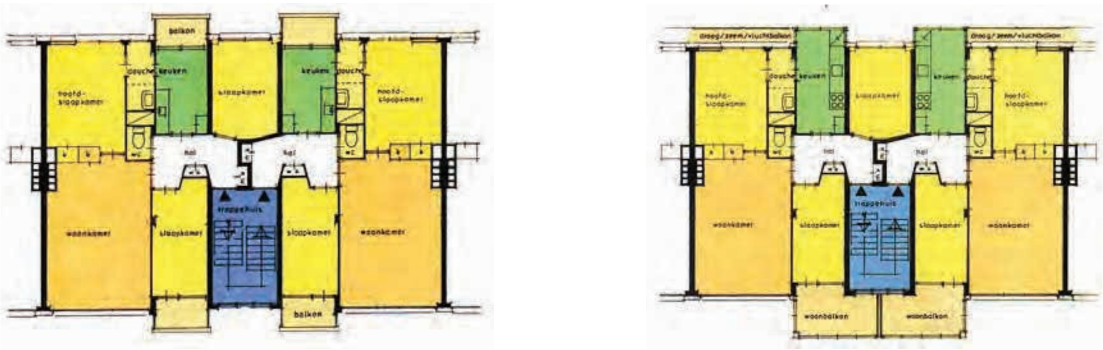

Fig. 04.21: *Floor plan, old (left) and new (right)*

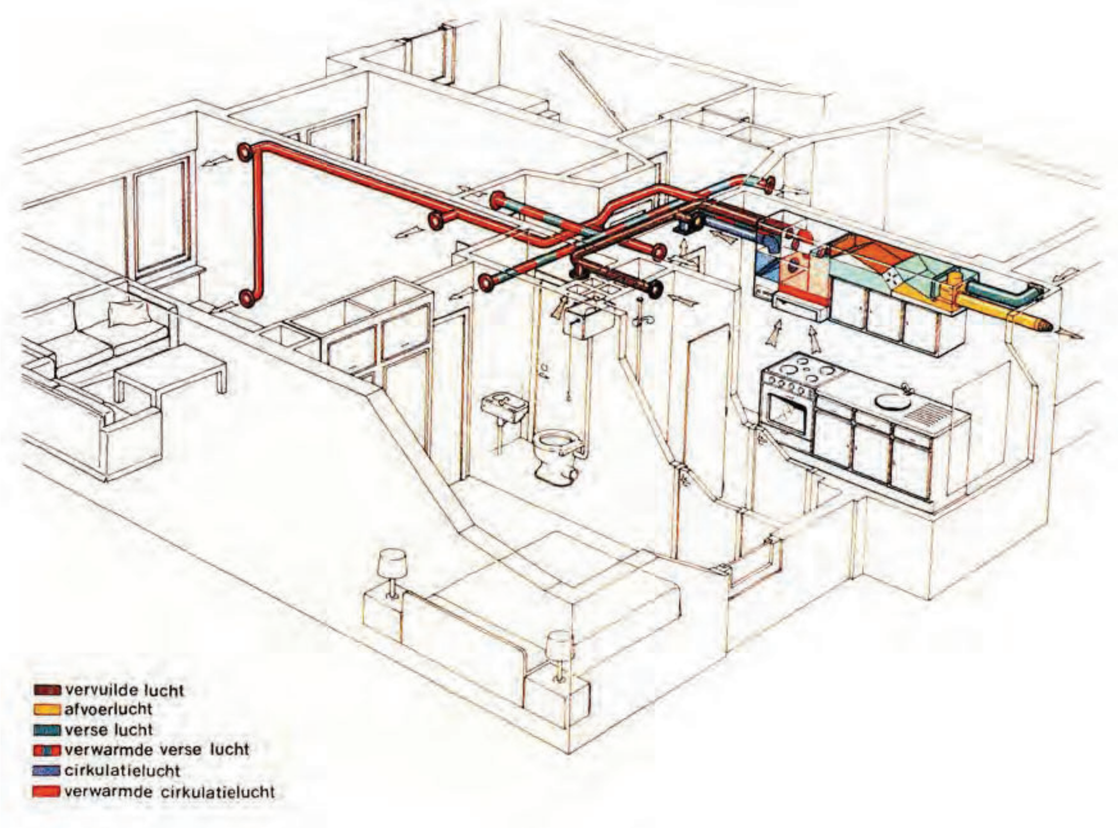

Fig. 04.22: *'Combiduct' installation of the energetic renovation in Schiedam*

For the tenement flat renovation an efficient use of energy, a good living comfort and letability on the longer term were the main issues. Due to the adjustments to the dwellings a traditional central heating system would lead to increased energy costs in contrast to the low energy costs of the former gas stoves. This would come on top of the higher rent. That is why we developed something new.

The 'Combiduct' air-heating installation had been designed especially for apartments, where space is scarce. The Combiduct was placed in the kitchen above the cooking-stove. It bundles four functions in one machine: balanced ventilation, heating, hot tap water and heat exchange from flue gasses and exhaust air. The machine had an outlet-valve that when pulled out gave the ventilator extra acceleration. The heating of air and the ventilation system had two compartments: the bedrooms and the compartment of the living room, kitchen and shower. In the bedrooms only fresh air was added. The temperature in the main bedroom could be adjusted through a thermostat, independent from the living area. Living room, kitchen and shower received recirculated air and had their own thermostat.

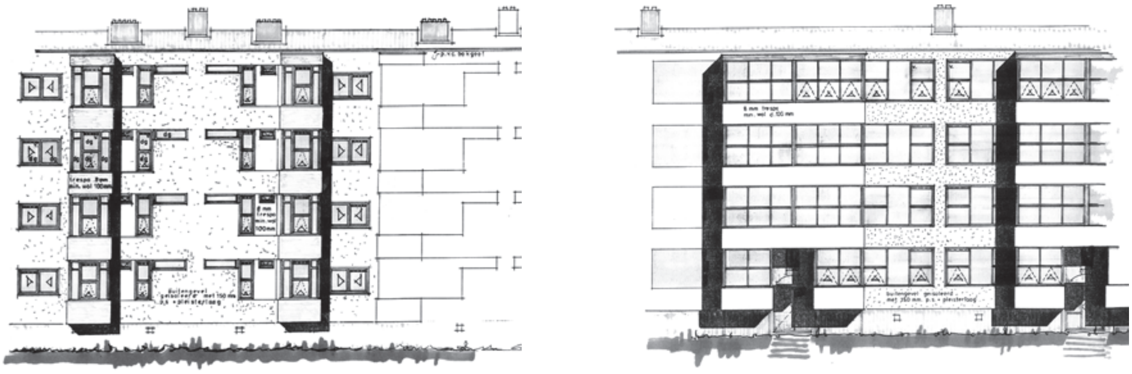

Fig. 04.23: Proposal of new facades, front (left) and back side (right)

Thanks to the balanced ventilation system it was possible to completely seal the apartment, without the risk of moisture problems. When the installation was set for summer operation, only the out-blowing ventilator functioned. The air inlet in that case needed to be through open windows.

Energy consumption and climate in the living area

Calculations indicated that the new energy consumption needed for the heating of an in-between apartment was approximately 400 m^3 nge/year, and about 570 m^3 nge/year for an upper or lower apartment. The extra use of electricity for the ventilators was 540 kWh/year. As a result of this a large part of the energy reduction would be lost. The consumption of natural gas for cooking and such was estimated at approximately 80 m^3 nge/year, and 250 m^3 nge/year for hot water. 100 m^3 nge/year could be reduced by a heat exchanger. The expectation was that 70% of the flats would not deviate from more than 20% this value.

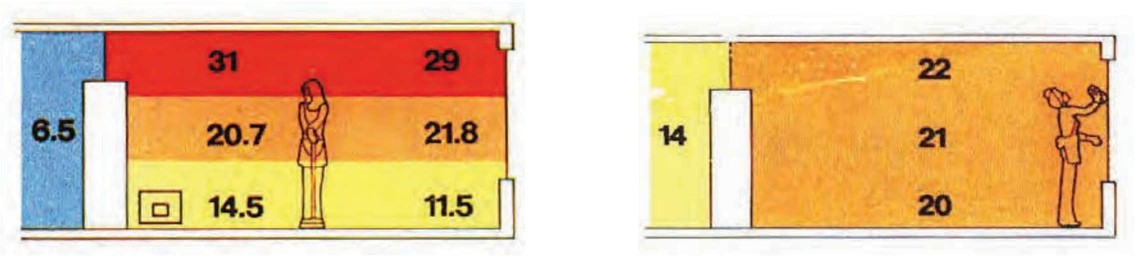

Fig. 04.24: Temperature distribution before (left) and after renovation (right)

It has to be pointed out that the living comfort had improved enormously. These improvements become apparent when temperature differences in one space at the floor and ceiling are compared with each other (at an outdoor temperature of -3°C). Before the renovation it was impossible to keep your feet warm, with a floor temperature of 11 to 14°C, while the temperature at the ceiling was around 30°C. The spaces were apparently heated in favour of the neighbour above.

After the renovation the temperature difference between floor and ceiling did not exceed 2°C. Moreover, the entire apartment was heated, in contrast with one room in the old situation. The energetic renovation, the new heating system and the hot tap water facility led to a maximum increase of the rent of only € 20.42 (lowest storeys) or € 15.18 (middle storeys) per month per apartment, while this merited a monthly energy reduction of € 59.45.

It became one of the renowned projects of the National Renovation Prize of 1989, awarded by the Ministry of Economic Affairs.

The expenses for the improvement of the first 32 buildings were € 21,345 per dwelling excluding VAT: residents had a better apartment and the neighbourhood was preserved – the functional lifespan was prolonged. Later, with a subsidy of the European Community the other 416 buildings were renovated as well.

04.03 Ventilation with heat recovery

04.03.01 The Slootweg Unit

The 'Slootweg' heating and ventilation unit that was installed in the tenement flats of Schiedam has never been developed further than the 0-series. This is extremely regrettable because it had a simple operating system, was small and compact, with no electronic high-tech and easy to produce in quantity.
Nevertheless there were problems with the Fasto geyser boiler (not enough warm water and undesired lowering at night, set for energy savings by the Ministry of Economic Affairs). The connection of the Fasto geyser and the Slootweg unit eventually caused the designer/fitter, after whom the system was named and who was responsible for the total contract installation, to go bankrupt.

It is clear that the possibilities for architects to build ‘Minimum-Energy Dwellings' was ever more reduced; the government and housing corporations speculated wrongly on cheap natural gas (as long as it is available!).
Nowadays, the development of the successful Fasto geyser and Nefit heating boilers could be traced back to the original 'Slootweg' unit, then without balanced ventilation with heat recovery and fresh air heating.
With the current energy performance requirement for small dwellings a simple air heating system would be much more appropriate. Apparently, one still considers the traditional radiator heating system – old-fashioned but familiar – the safest option. Meanwhile, the convectors needed for the bedrooms became unnecessary!

04.03.02 The fine-wire heat exchanger

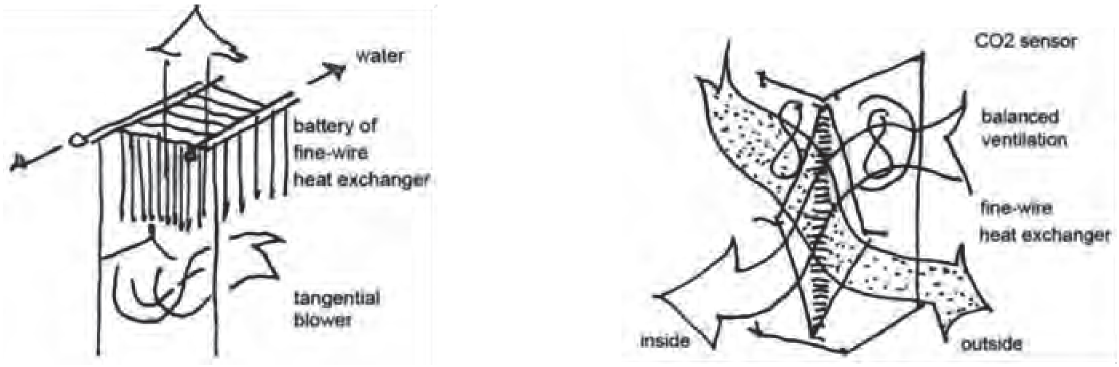

Fig. 04.25: Water/air Fiwihex heating/cooling (left) and air/air Fiwihex balance ventilation (right)

Introduction

Why did it take such a long time to make the fine-wire heat exchanger suited to the market when the calculated output raised such high expectations? How air had to be led through or along the Fiwihex device was unknown, various prototypes were tested.

The knowledge of weaving textiles had disappeared to developing countries. A weaver had to be found who was willing to invest in an expensive, complicated loom that could weave 1/10 mm copper wire.

Why is greenhouse horticulture so slow in switching from natural gas to solar energy?

There are at least three reasons:

1. Natural gas is very cheap for market gardeners.
2. When burning natural gas, CO_2 arises, which the plants use as fertilizer (yielding 20% more output).
3. The unfavourable investment climate does not allow much innovation.

A foreseeable breakthrough and application is at hand. Seasonal heat and cold storage is generally situated at a depth of 20 to 50 m in an aquifer, a wet layer of sand enclosed between impervious layers of clay. These soil conditions are often found in the Rhine delta of The Netherlands. In brief: This new technology will be applied on a large scale, as it allows Dutch greenhouse horticulture to change from being a wholesale natural gas consumer into a solar energy supplier using seasonal storage in aquifers. The late eminent innovator Dr. Noor van Andel, a retired director of corporated research of Akzo Nobel, advanced experiments into fine-wire by acquiring the skills of Gerard ter Beek, the only skilled textile weaver and employer to be found in the eastern part of the Netherlands. Beek was willing to accept the challenge to develop a new loom capable of weaving copper wire.

How to make a fiwihex?

The Fiwihex devices for heating and cooling are woven with a warp of ø 1/10 mm tinned copper wire and a weft of ø 2 mm water-conducting tubes of 9,5 mm centre to centre (Figure 04.27). The dimensions of every heat-exchanging mat are: 2 mm thick, 150 mm wide and 300 mm high. Side by side with an in-between distance of 10 mm the mats are soldered to thicker pipes at top and bottom. The final air-heating element measures 200 x 1050 mm. To this a tangential ventilator is added between the plant tables. This appears to function well in practice and the plants are not hindered by draught. When applied in factories and workshops the Fiwihex fans are mounted high. The shafts have become higher and at the lower end equipped with a streamlined outlet of water-absorbing material to catch possible condensation water collected during the cooling process. The soldered components are now glued (with hot melt glue) including the synthetic main tubes, shortening assembly time. These Fiwihex devices are tested in practice at max. 2 bar (20 m head of water).

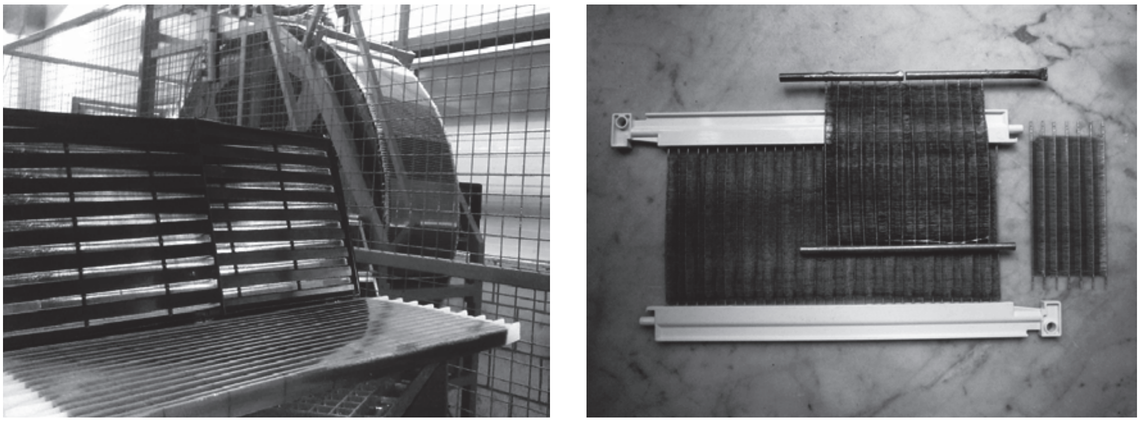

Fig. 04.26: Three steps of Fiwihex elements, showing the twinning machine for the ø 0.1 mm copper wire at the back, an air-to-air heat exchanging element at the front and an element with air conductors behind it (left) and three steps for an element with heat transmission from air to water or reverse, including interwoven thin water pipes (ø 2 mm) (right)[11]

Industrial ventilators have to be transformed for use in private houses. In this phase we go back to an approved very low temperature decentralized air-heating device on the ceiling. Inside a round woven fine wire heat exchanger of ø 0,6 m and 0,2 m high, slowly rotates a fan which keeps moving 1000 m3/h of air. This ceiling air heater has proved to operate free of dust. The first large-scale application will be the new Kramer-laboratory at TU Delft. Fresh outside air is led to the offices through fans in the lowered ceiling. Laboratories require highly controlled, extremely well ventilated spaces; therefore cheap heating is critical.

A combination of basic radiation heating and lower temperature air heating may be a better solution. We can postulate that when the demand for it arises. In the longer-term smaller and more silent running fine wire air heating elements are in the process of developement.
When this paper was written in January 2009, experiments were being carried out with small Fiwihex transparent convectors, driven by small LTV-tangential ventilators.

First application of the greenhouse technology of tomorrow
After many years of development the ‘fine-wire heat exchanger’ has now reached its first phase of application. In Dutch greenhouse horticulture studies has been presented that show that by using fine-wire heat exchangers greenhouse energy consumption can be reduced from

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[11] Photos by Trudy Veldhof

approximately 50 m^3 natural gas/m^2 per year to zero (though electricity is used to power the pumps).

Fig. 04.27: Fiwihex hanging in a rose greenhouse for heating and cooling

Excess solar energy can be stored in an aquifer. On an annual basis at our latitude of 52° north, about 7 times more solar heat enters the greenhouse than leaves it due to transmission losses. It is clear that cooling is no less important than heating. It is customary to whitewash glass roofs to keep out the heat and to open skylights to outside fresh air. In the case of the energy-producing greenhouse such as the one described here, it is taken for granted that the greenhouse is kept closed all year round and in hot sunny weather is cooled by the same water/air heat exchanger which heats up the green-house during the night. Keeping greenhouses closed all the year round has three advantages. Firstly, the relative humidity inside the greenhouses can be kept at a steady level (for example 80%). Secondly, vermin is kept to a minimum. The third advantage is vegetation stimulation. In further developments of the energy-producing greenhouse all organic waste matter will be collected and anaerobically converted by means of biogas fermentators, the fuel to be used in micro turbines or diesel engines to generate electricity. The filtered CO_2 will be blown into the greenhouse to manure the plants. CO_2-neutral greenhouse horticulture arises when the CO_2 concentration of 500 ppm in open greenhouses is increased to 1,000 parts per million (ppm), resulting in a productivity increase of 20%.

Villa Flora, a greenhouse with a 25 m high landscaped office, located in The Horticulture world exhibition Venlo, The Netherlands, will be discussed in more detail in chapter 09.
The inside climate of Villa Flora's greenhouse, with 35,000 visitors on peak days, is mainly controlled by Fiwihex air cooling and heating. The fine wire heat-exchanger already works at very low temperatures. Insulation, concrete core activation (cooling floors with water), can also influence radiation heat. The perceptible temperature range for humans is the average temperature of air and radiation. There is a clear relation between the inside climate of the greenhouse and the heat and cold storage in the aquifer. A greenhouse of 2 ha (150 x 150 m) is large enough for seasonal heat storage (aquifer) to function with edge losses. The heat excess from the greenhouse can provide 8 ha. (i.e. a maximum of 200 passive houses) with heating and cooling. The cooling water from the diesel engine provides the houses with hot tap water. This new greenhouse technology will be introduced into dwellings and offices.

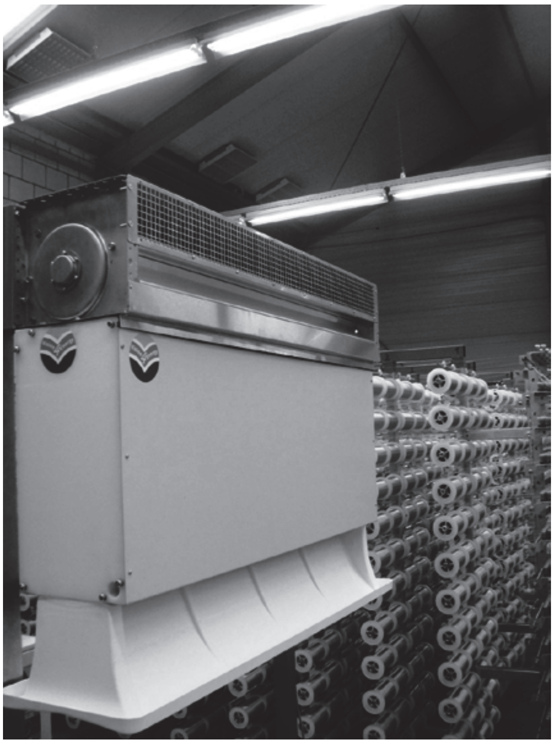


Fig. 04.28: Fiwihex box in a factory

Greenhouse technology for private houses
The translation of greenhouse horticulture technology to private houses has not yet been realised. In some houses an aquifer cannot be installed. A minimum roof collector surface of 1 ha. is necessary, assuming that a simple version of a roof collector is twice as efficient than a closed greenhouse. Often there is also excess heat of 25 to 30˚C in various forms e.g. cooling milk at a dairy farm. This is a new technology, a minimalist approach without the aid of heating pumps and fossil fuels.
The electricity consumption of pumps with little resistance can be reduced if the diameter of the pipes is wide enough and the conveying height small. The temperature level inside the house is bound to limits of comfort. Most Europeans find 17˚ to 23˚C comfortable.

Now we have to consider radiation heating, air heating and the localised preferences of the building occupants. Low radiation heating in floors and walls is based on a constant temperature of 19˚C in the living area/room, to which the option is added to use ∆T 3˚C air heating to heat up or cool down the house individually/automatically. Heating and cooling follow the same procedures.

Is greenhouse air heating suitable for private houses? The air heating installation is too big, makes too much noise and the living room is not free of dust. There are two main types of fine-wire heat exchangers that can resolve these issues: the fine-wire water/air heat exchanger and the fine-wire air/air heat exchanger.

Breathing Window
When you as a university professor at the end of your professoriate unexpectedly receive the Royal/Shell Award in person, what do you do with the tax-free money? According to the chief author of this paper the ventilation in buildings is the weakest link in the building industry. Much money has been spent on this. The list of conditions did not require extrapolation, improving existing techniques, but devising from scratch an optimal ventilation system that is small, user-friendly, intelligent, with hygienic CO_2 control and inaudible. In the meantime, in the course of a parallel search for a smart effective decentralized room ventilation device, a new type of fine wire heat exchanger was developed, with the same partners as Fiwihex. We call it a “Breathing Window”, and the technique will be discussed in the following section.

This air/air fine wire heat exchanger is not woven but wound with ø 1/10 mm copper wire on a big rotating drum. This new air/air heat exchanger measures 16 x 200 x 400 mm. Each heat exchanger consists of a warp of 15 km of ø 1/10 mm diameter copper wire weighing 500 gr. The weft is glued nylon thread with a centre-to-centre distance of 12.5 mm. Its small size making it easier to remove the heat exchanger from its casing for cleaning. The stacked wefts must be mutually airtight, forming 13 small air-channels of 2 x 220 mm, each having a width of 16 mm. Due to two counter-current flows evenly distributed by conical air ducts, the channels are alternately hot inside and cold outside.

04.03.03 The Breathing Window

Background
The annual Royal/Shell Prize for Science (new style) was awarded to me in 1998.
I was nominated for the award by The Dutch Society of Sciences and the Royal Dutch Academy of Sciences for a scientific break-through in technological innovation in the field of sustainable development and architecture. The prize (*ƒl*. 200,000 ≈ € 90,000) provided me with financial and technological opportunities, as well as social obligations. Therefore I thought seriously where the gaps are in sustainable building knowledge. From my point of view the ventilation in buildings is the weakest link in the chain. Due to regulations the natural ventilation in houses is more and more mechanically controlled from a central point with heat recovery.

Koninklijke/Shell Prijs
1998

groot ƒ 200.000.=
(zegge tweehonderdduizend gulden)

toegekend aan
Prof. ir J. Kristinsson

uitgereikt te Rotterdam,
29 oktober 1998

Fig. 04.29: Certificate of the Royal Shell Prize for Science

What we had in mind is a decentralised high-tech breathing skin of buildings, a 'Breathing Window'. The ventilation system is often over- or under-dimensioned, mostly with an incomprehensible control system. The central ventilation ducts are hidden behind thermally insulating suspended ceilings, as a result of which the thermal mass of the floors contributes only very little to a balanced indoor climate.

The search for an optimal high-efficiency heat exchanger lasted for two years. It was finally descovered in a company named Fiwihex, located in Almelo, 40 km from Deventer where I live.

Fiwihex had a fine wire heat exchanger under development. Together with the inventor, Noor van Andel, and his son Eur, we set up a three-year research and development project for Breathing Windows, with additional financial support from Senter, part of the ministry of Economic Affairs.

The aim is to create a healthy indoor climate in buildings, by ventilating every room through a Breathing Window, each according to its needs. Technically translated this meant a computer-controlled, compact and efficient system for air ventilation and heating.
Often it is extremely difficult to develop something simple. The development of the Breathing Window was a challenge with a high level of complexity.

Indoor-air quality

An investigation into the indoor-climate quality of private houses in the Netherlands has yielded some remarkable results. Research worker ir Evert Hasselaar attached to OTB of the Delft University of Technology investigated 500 houses in various categories. Two thirds of the housing stock had mechanical ventilation. Non-subsidized houses had balanced ventilation with heat recovery to reach a low EPC. After some years the ventilation capacity was halved, a reduction of some 10% per year due to dust. In additon, because of the excessive noise caused by the fan, sometimes the whole mechanical ventilation had been simply shut off. Another discovery was that in 4/5 of the houses with natural ventilation the occupants did not open their master bedroom windows, not even at night, due to traffic noise. This leading to adverse levels of CO_2 concentration, fine dust and house mites. The bathroom, which was used for showers three times a day, generally had too little ventilation to get dry resulting in black spots of mould. There was no significant difference between built-in bathrooms or bathrooms with a window in the outer wall.

Fig. 04.30: Breathing Window fine-wire heat exchanger element: 7.5 km of 0.1 mm copper wires (400 g in total) run left to right; plastic partitions separate the canals where ingoing and outgoing air flows in turns exchange heat

Present installations

Ventilation studies in house-building, commercial and industrial buildings in the Netherlands show a large disparity in results expected and those observed in practice. Factors are: concept, design, saving, execution, control, adjustment, use and maintenance. At every phase calculation errors may be concealed by over-dimensioning. Fig. 1. In the conceptual (draft) phase the architect should design the overall indoor-climate in a crosscut fashion, write his ideas down and explain them to the principal and the installation consultants. In practice it usually does not work out this way. The help of experts is called upon. Without affecting the layout, all heating, ventilation and air-conditioning systems are drafted by consultants and usually concealed in lowered ceilings. The internal thermal mass of the building is for the greater part put out of action. Lowered ceilings conceal air ducts claiming 15% building volume.

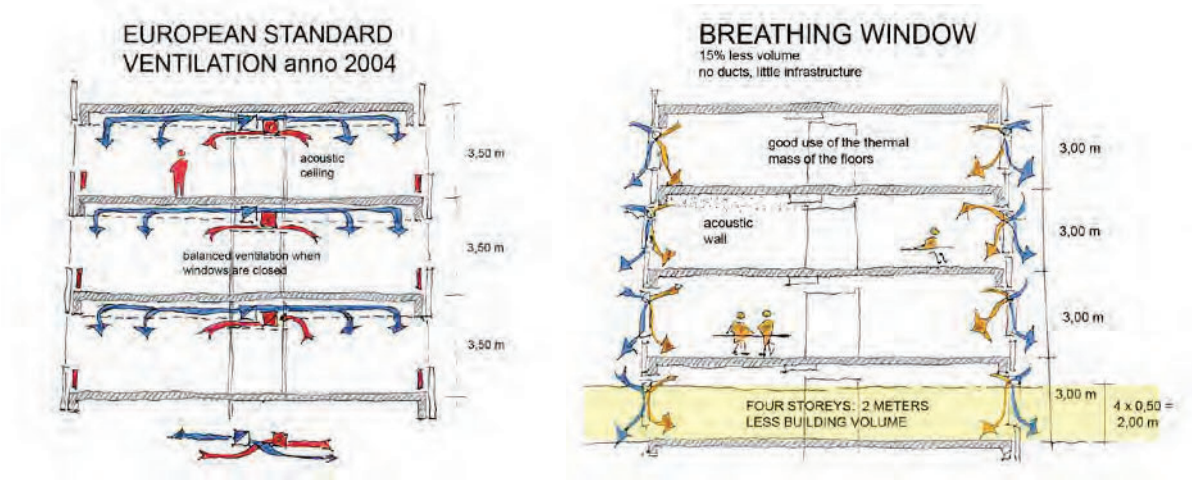


Fig. 04.31: Standard ventilation system – cross-section of lowered ceilings = 0.6 m (left) and ventilation in the skin of building –15% less volume built (right)

At the building-costs estimate before or after public tender the ventilation is sometimes curtailed. The suddenly required extra fire compartmentalizing is a well-known phenomenon in the last phase before the building permit is granted.

Installations reviewed

Gradually we have arrived at a turning point in thinking about installations. The current installations in houses appear in practice not to be appreciated by its inhabitants.
The main reasons are noise nuisance and the easily clogged heat exchanger behind a steel hatch in the attic. It belongs to another world compared with the familiar thermostat of the central heating installation. The bigger installations are usually maintained, but take up a lot of space and render much thermal mass of buildings useless by lowered ceilings and insulation. This means less comfort, higher building costs and higher peak loads of cooling and heating. Installations have a short writing-off period and are thus relatively expensive.

Use and maintenance

When installed correctly, a long period of use and maintenance follows. According to research it appears that heat exchangers in houses with a balanced ventilation system are hardly maintained and get clogged up with dust. It also appears that two thirds of the mechanical ventilation as prescribed in the regulations is not achieved in draught-free newly built houses. The average user generally has no idea of technical installations. In large buildings, which are mechanically ventilated, the sick-building syndrome has been found; people felt locked up in non-compliant technology. This complaint is sufficiently remedied by opening windows, but the question arises: shouldn't we look for fundamentally different ventilation systems?

New highly efficient ventilation

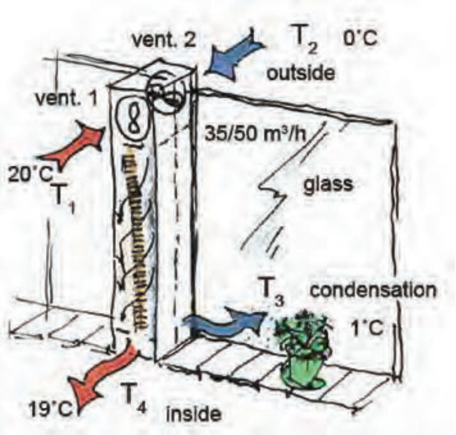
Albert Einstein said: "We cannot solve problems with the same thinking that created them".
Let us begin again at the very beginning – the building is sustainable architecture – installations are supposed to be silent and smart. As an architect I have been hypothesing for years on the idea of constructing a Breathing Window. How this is to be achieved and what form it is going to

have is at this moment (February 2005) not yet entirely clear. Optimization of heat recovery to around 95% seems to be feasible.

As mentioned previously, the search for the best heat exchanger took many years, and to my surprise ended on a website showing a fine-wire heat exchanger designed by someone who worked only 40 kilometres away from where I live. The inventor, Noor van Andel, needed only a few months to convert the original water/air heat exchanger into an air/air heat exchanger (In 2006 Noor received an honorary doctorate from the University of Amsterdam). To test the design I chose the dimensions of a window-frame with a standard cavity wall depth.

The Breathing Window has 3 main components:

1. Balanced ventilation system with two fans
2. Smart control system
3. Fine-wire counter-current heat exchanger



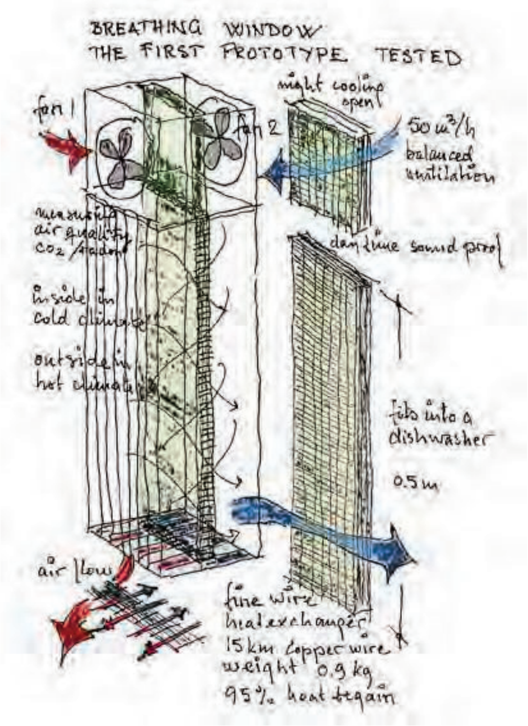


Fig. 04.32: The Breathing Window can be a jamb, mullion or built in a wall (above); the first generation prototype design (right)

The prototype has a compact semi-transparent synthetic counter-current heat exchanger consisting of 15 km (length) and 0.1 mm (diameter) copper wire weighing 1.05 kilogram. The winding of the prototype in 26 vertical layers on a washing drum takes three days to prepare. For the purpose of worldwide applications we assumed an inside air temperature of 20°C. To a heat exchanger it is indifferent whether to pre-heat cold outside air or to pre-cool hot outside air, the efficiency stays the same.

Cold climate: outside air of 0°C enters at 19°C. The Dutch building regulations state, that the height of a ventilation opening is allowed to be lower than 1.80 m, if the temperature difference between the incoming air and the inside air is less than 2K. The Breathing Window meets these regulations up to an outside temperature of -20°C, when the incoming air temperature will be 18°C. Hot climate: outside air of 40°C enters at 21°C. Fig. 6. In combination with moderately chilled surfaces, e.g. floors, walls or ceilings, the traditional air-conditioning may be reconsidered.

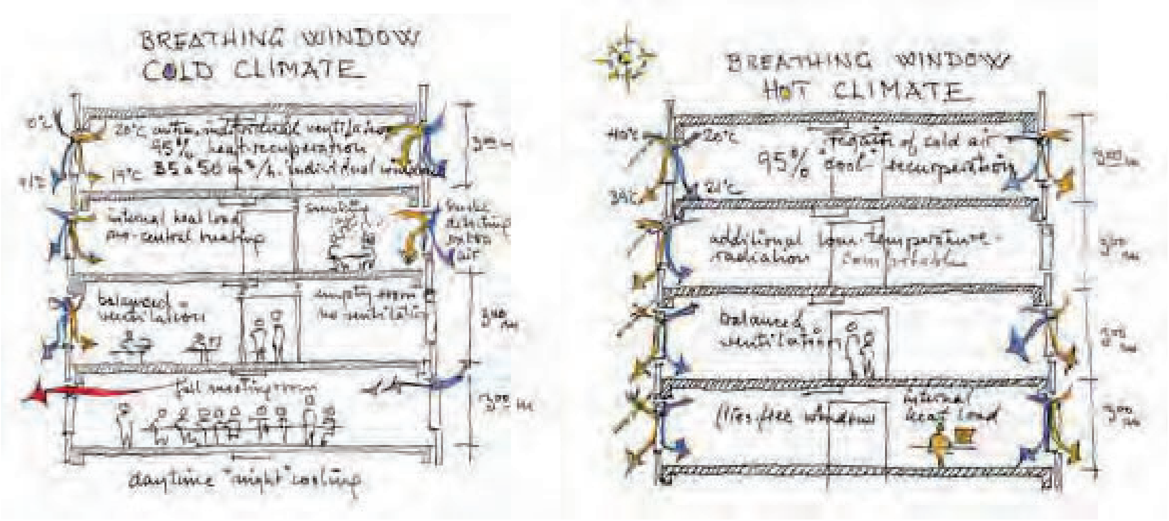


Fig. 04.33: *Schematic cross-section of a building with a the Breathing Window principle in a cold climate (left) and a warm climate (right)*

Technical specifications

To make a Breathing Window prototype preliminary draft agreements must be made regarding dimensions, outward appearance and ventilation capacity. The dimensions of the first-generation prototypes are 750/200/180 mm. The fine-wire heat exchanger can be cleaned under the shower and easily fits into a standard dishwasher. The first prototypes were made with a transparent synthetic casing in order to detect pollution in the fine-wire heat exchanger. The Breathing Window functions well alongside natural ventilation, hybrid or completely mechanically balanced ventilation. The CO_2 sensor (Sense air Sweden) starts automatically at 500 ppm (parts per million) when an addition to natural ventilation is needed, but also gives a light signal at 1200 ppm (MAC value). On reaching 1700 ppm CO_2 a sound signal will be heard. This means that doors and windows have to be opened to keep a healthy indoor climate.

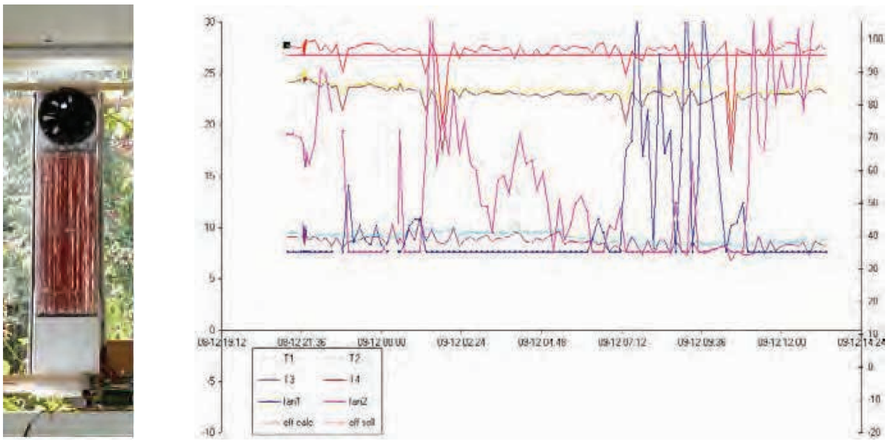


Fig. 04.34: *Test results in Iceland 2003 with reverse ventilators as the wind direction changes 180°; result is approximately 50 % less geothermal hot water needed for heating in the dwelling*

What should the driving force be, what energy consumption is reasonable and which noise level belongs to a certain air velocity? Analysis indicates that the ventilators need to have a 12-Volt capacity of 2 Watts each, and the 12-Volt transformer another 2 Watts. At 50 m^3 of air per hour the noise level can stay below 30 dB. The larger the vent hole, the lower the air velocity, the noise production decreases, but the wind effects increase in high-rise buildings.

Two small reversible computer ventilators could not cope with the extreme differences in air pressure (100-150 Pascal). The ventilation systems in large tall buildings also tend to lose their balance during a storm, the manufacterers advise closing the horizontal air supply and exhaust ducts when there are heavy winds, because in these circumstances there will be enough natural ventilation anyway. According to calculations the prototype should have an average heat recovering efficiency of 95%. The prototype tested in a kitchen window on the coast of Iceland in 2003 usually had a heat-recovering efficiency of over 95% - the uppermost line. The four thermometers, which regulate the temperature of the two balanced airflows by means of the reversible ventilators, work well. One can notice the extreme rotation speed (and noise) during storm peaks, both windward and later leeward. And thus we have arrived at the realisation aspects.

Realisation

The basic idea behind the Breathing Window is a smart local ventilation system, which has almost all the qualities of large centralised ventilation systems with a minimum of disadvantages. To re-design and minimize most parts of a ventilation system is an achievable task. It is my personal opinion that minimum technology can always be realised. A second, redesigned prototype is devised from the point of view of a producer and a consumer.
The industrial-design student, Yannic Dekking, of the Delft University of Technology, received this assignment as his final project. In broad outline the dimensions of the second prototype were similar to its predecessor. Dekking succeeded in optimising the feeder channels of the fine-wire heat exchanger and fitting them into a winding machine. In the space left vacant a handle could be made to take out the heat exchanger in order to clean it. All types of ventilators were included in this research.

There are three different construction possibilities in several types of building; as part of transparent glass, as a vertical window frame, or, which seems to be the most probable solution, as part of a closed panel/wall in existing buildings. The Breathing Window functions well besides natural ventilation, hybrid or completely balanced mechanical ventilation (air-conditioning).

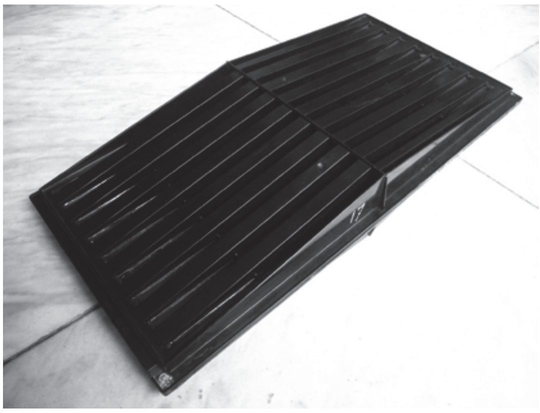


Fig. 04.35: Compact counter-current fine-wire heat exchanger fits into a dishwasher

Use as decentralised room ventilation

The main characteristic of every Passive House ventilation device is that it must be very well balanced because of the perfectly airtight exterior wall. The decentralized Breathing Window – one in every room – is characterized by perfectly balanced ventilation in every room with a high percentage of heat recovery. The control system measures the CO_2 concentration of the indoor air in parts per million and reacts on it immediately by adjusting its ventilation rate. The relative humidity of the indoor air in relation to the outdoor air temperature makes an optimum heat exchange possible without any condensation. Good indoor-air quality in each separate room is ensured. Low occupancy rooms are minimally ventilated. One can adjust (programme) the maximum and minimum CO_2 concentration. In the countryside the ventilation stops at 450 ppm and in urban areas at 550 ppm. When a room is not occupied or when a window is opened the Breathing Window also stops ventilating. When a room is used more often the BW will rotate faster to refresh (exchange) more air. Whereas at 50 m^3 air/hour (master bedroom) the BW is not audible (< 30 dB), the noise level in the occupied living room can reach 40 to 45 dB at a high rotating speed and 250 m^3 air/hour, however the perception of this noise level is reduced to background activities in the house or outdoor traffic.

The CO_2-controlled ventilation system is highly efficient, unoccupied rooms are not permanently ventilated. However, regular ventilation is desirable in connection with radon and paint smells. Generally decentralized ventilation as compared to central ventilation can lead to a 2/3 saving in energy with the same indoor air quality. In summer, when doors and windows are likely to be open, the BW will not rotate. The relation between humidity and the outdoor temperature ensures that the heat exchanger will never get frozen. By adjusting the rate of recirculation of the indoor air through the ‘bypass’ the highest possible efficiency is always reached.

Some calculations

Calculating energy saving

There are 5080 degree hours in the heating season in the Netherlands. Between October and May the outside temperature is 4.8˚C, the inside temperature 20˚C. The ‘Breathing Window’ ventilates on average (ranging from 15 to 50) 40 m^3/hour with a heat recovery efficiency (85 to 95) of 90% volume metric heating capacity, that is 1212 joules/m^3 K.
Saving, 5080 x 40 x 1212 x (20 - 4.8) x 0.9 = 3.37 gigajoules/’Breathing Window’ per year.

Heating cost reduction per house

Expressed in energy equivalents: one m^3 natural gas is 32 MegaJoules in the heating efficiency of a 90% High Efficiency boiler, that is 3,370,000,000 / 32,000,000 x 0.9 = 117 m^3 natural gas/’Breathing Window’ during the heating season. With 3 to 5 Breathing Windows in one house, its average multiplied by: 4 x 117 = 468 m^3 natural gas or 13.5 gigajoules. At the end of 2004 the price of natural gas was € 0.416/m^3.
Thus the calculated saving is 41.6 x 468 = € 195/year per house.

Electricity consumption

Besides the savings of the heat exchangers the primary energy consumption of the two ventilators should be deducted. At an outside temperature of 0˚C and an inside temperature of 20˚C and 50 m^3/hour ventilation per ‘Breathing Window’, the two ventilators use 8 Watts, but now with 95% heat recovery efficiency. The thermal (low-calorie) energy saving is now: 50 x 3600 x 1212 x [20-0] x 95 = 320 Watts.

The high-quality 8-Watt electricity is produced by a traditional power station (not connected to district heating), with 40% efficiency amounting to 8: 0.40 = 20 thermal Watts. The energy saving is 320 – 20 = 300 thermal Watts, therefore the net efficiency of the 'Breathing Window' is 300 / 320 x 0.95 = 89%, which is close to the 90% average efficiency assumed earlier.
The electricity consumption of the CO_2 meter and the intelligent control is negligible.

Air resistance and noise

Even when two ventilators work reversibly to control an even air current, they can be very inefficient. The heat exchanger in the 'Breathing Window' has an air-pressure resistance of 18 Pascal at 50 m^3/hour ventilation. The two ventilators produce a net energy of: 2 / 3600 x 50 x 18 = 0.5 Watt ventilation energy. Due to this modest air resistance in the heat exchanger little electricity appears necessary, but even so the indoor ventilator produces a 30-decibel noise and that is audible in the silent hours of night. We aim at 25 decibels. The simplest solution: when you halve the depth of the heat exchanger, the heat recovery will still be 85%. A sirocco type ventilator with a spiral case underneath is also an option.

Fig. 04.36: The test version of a double Breathing Window: two Fiwihex elements in a compact box

Conclusion

Although the Breathing Window is still in the making (statu nascendi) it seems to be the right answer to the question of desired customized ventilation. Time will show. A coincidental, unforeseen advantage compared to the usual plate heat exchangers is that the fine-wire heat exchanger hardly freezes up. The explanation is not simple. Is it sublimation? Is the frost evaporation time so short that the forming of ice does not take place?

Applied in hospitals the fine-wire heat exchanger can easily be renewed to prevent infection. The range of applications is wide. For instance, it fits into a specific small mounting space in boats, caravans and mobile homes. The CO_2 meter is also a very accurate smoke detector, which signals fire even before any smoke develops.

After more than 10 years of product development the first Zero-series of Breathing Windows went into production in 2010. Brink Systems became the manufacturer, but to our great disappointment by early 2012 no application had been made yet, in spite of various expressions of interest from the market.

At the time of finalising this book, a slimmer, longer, more façade integrated Breathing Window is now ready for the market.

04.03.04 The Air Mover

Definition of a problem
If you have to point out the weakest link in the building trade, it is ventilation. It is often insufficient and too noisy. Too much ventilation does not exist, because the maximum ventilation level is the outside air. However, draught caused by an air velocity that is too high, can be detrimental.

If we consider the CO_2 concentration of inside air in ppm (parts per million), its most important quality standard, 500 to 600 ppm is a good air quality with 30 to 50 m^3 fresh air per person per hour. The problem of draught-proof buildings is that the same quantity of air that is removed must be supplied. This balanced ventilation is common knowledge; what is new and unknown so far, is that there is a special ventilator that can produce two balanced air flows. This special ventilator, which we call air-mover, can, by itself, even replace two ventilators rotating slowly. During rotation the Air Mover ventilates six times its volume.

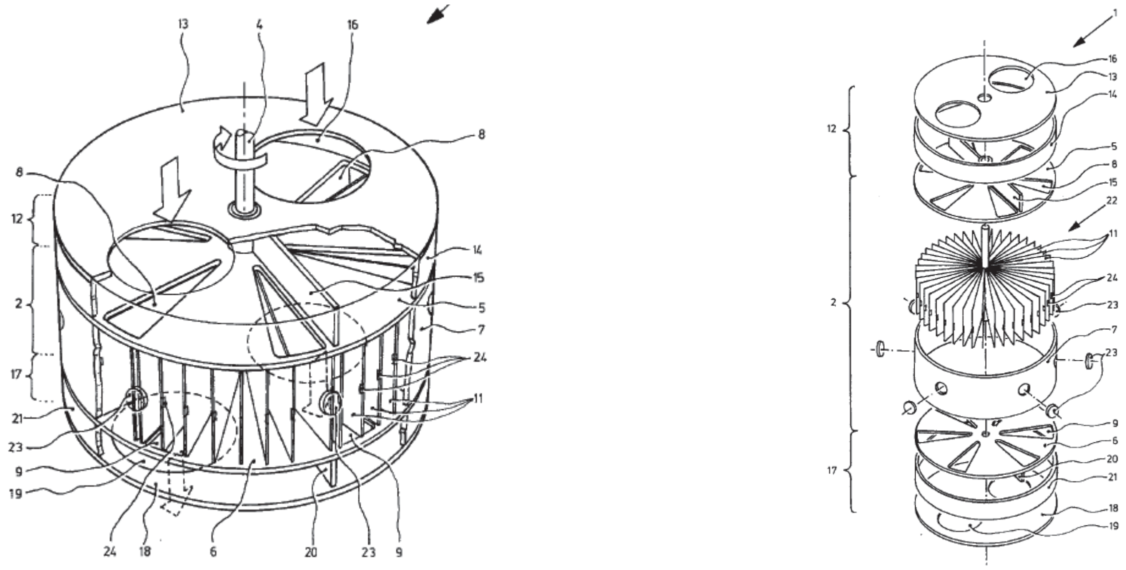


Fig. 04.37: Drawings of the Air Mover (prototype no. 1) magnetic blades principle, from the patent application[12], 19 m^3/h with 1.5 rotation per second (parallel principle)

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[12] Image by Björn Kristinsson

The Air Mover

The air-mover can achieve not only two balanced parallel airflows, but also reach an over pressure which has not yet been measured. Therefore without air valves the air-mover is suitable for applications in high rise buildings, in ocean-going vessels or in the changeable stormy polar climate. The over pressure is produced by small magnets fixed to the cylinder wall and by small magnets fixed to the flexible ventilator blades, which slowing down a little, lag behind untill the next ventilator blade moves up and the whole procedure starts all over again. See figure 04.40 below.

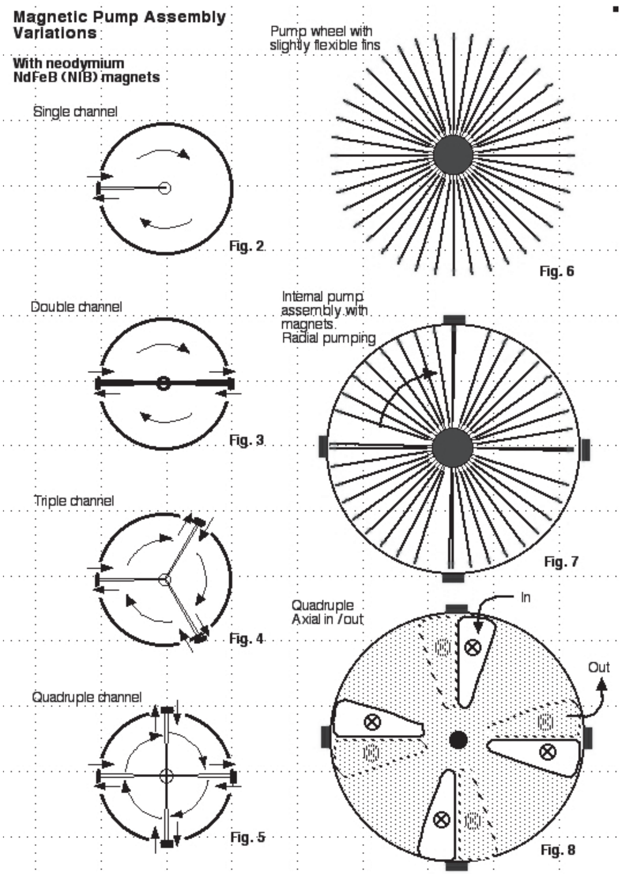
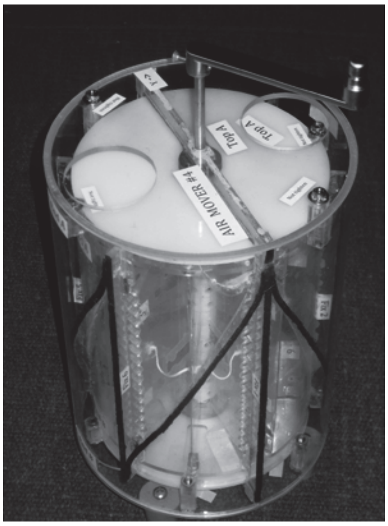


Fig. 04.38: Principle of the Air Mover [drawing by Jón and Björn Kristinsson]



A prototype has been made and a second robust type has almost been completed. The first prototype with a diameter of ø 250 mm, an opening of 60 mm and a height of 125 mm can displace two times 2 x 20 m^3 air per hour, at a rotation velocity of 1.5 per second. The rotation test at a forced higher velocity led to the damage of weak glue connections to the core of the rotor blades. A second, more successful prototype – diameter ø 200 mm, opening ø 520 mm – proved to move 2 x 15 m^3 of air at a speed of 2 m/s with 1.0 rotation per second. The noise level at 3 m distance of the open installation was no more than 38 dB.

Fig. 04.39: Plexiglass model of the Air Mover (prototype no. 2)[13]*, double cylinder, 16 m^3/h at 1 rotation per second (reverse principle)*

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[13] Photo by Björn Kristinsson

Application
The first thing that comes to mind when thinking of the application of Breathing Windows is balanced room ventilation. It stands to reason to connect a compact heat exchanger direct to this room ventilation. This small air/air heat exchanger, made of 7.5 km wound 1/10 mm copper wire, exists in the Netherlands under the name 'Fiwihex' (fine-wire heat-exchanger).

The size of this Breathing Window is not determined by the air-mover, but by the heat exchanger developed at great cost. The most favourable proportion between width and height of the 'air-mover' has not yet been investigated. The second prototype will be higher than it is wide. Due to this the magnetic ventilator blades will be a little less burdened. Thus we see that, even before the new air-mover has been put on the market, a new application field has already been found.

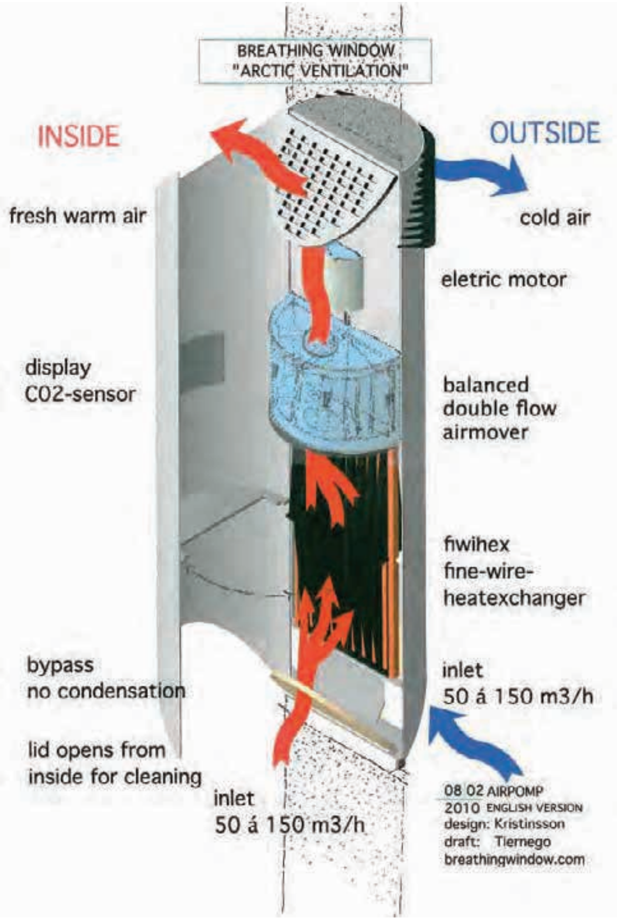

Fig. 04.40: Technical scheme for a heavy duty Breathing Window for highrises and arctic ventilation

04.04 Light

04.04.01 Daylight and roof lights

When we observe the projection of sky luminescence, we immediately see the difference between the quantities of light provided by roof windows in comparison with a window in a façade. Generally the amount of light is 5.5 times larger! Therefore a reduction of 60% on artificial light can be achieved when using this principle.

When using layered plate glass with colloidal foil (non-crystalline) in a roof, the transparent foil turns white and starts to reflect light when the temperature exceeds 30°C. It thereby prevents a surplus of irradiation and unwanted temperature increase. This automatic sunblind reduces around 50% of the solar irradiation. The incoming shortwave radiation remains quite constant, both with a clear and a cloudy sky.

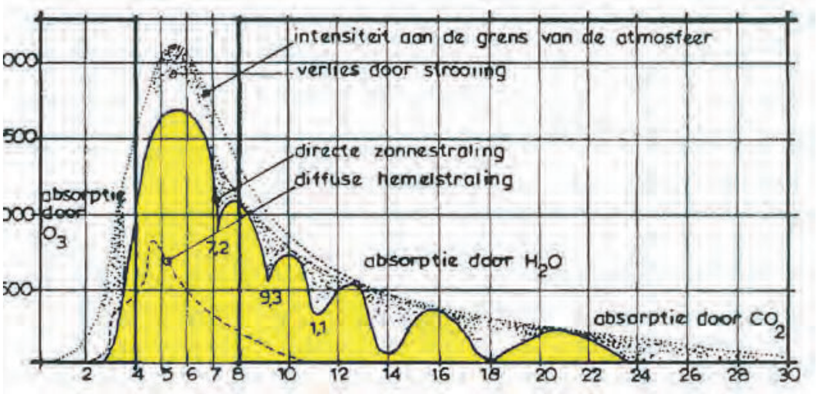

Fig. 04.44: *The spectral capacity of the solar radiation*

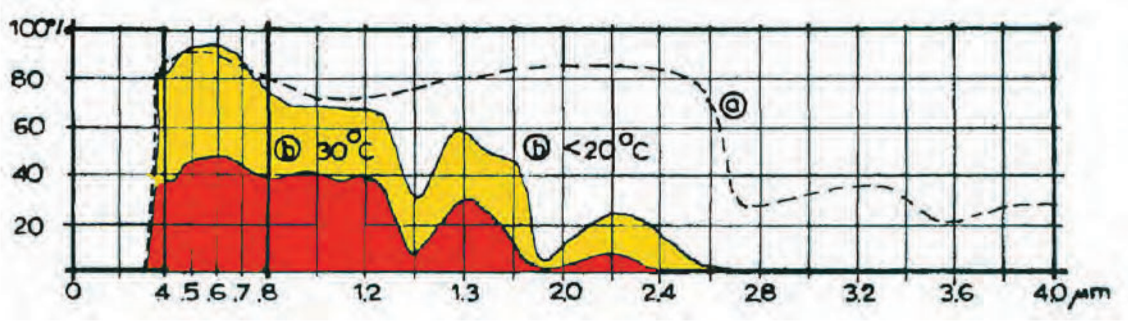

Fig. 04.41: *Spectral permeability of double pane glass with colloidal foil as automatic sun blind in the roof windows (b), compared to 6 mm of polished plate glass (a). The colloidal foil turns white in sunlight (red area: incoming solar radiation heat when the foil is white).*

As well as the prevention of overheating, this light control is of a particular benefit to office workers, reducing direct daylight and glare that would ordinarily affect their tasks.

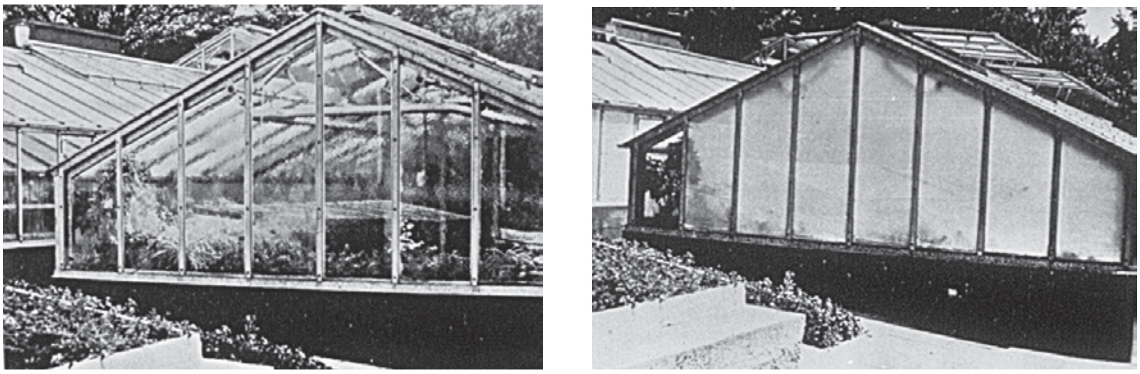

Fig. 04.42: *Image of a greenhouse with colloidal foil during cold weather (left) and warm weather (right)*

04.04.02 Parabolic roof shells

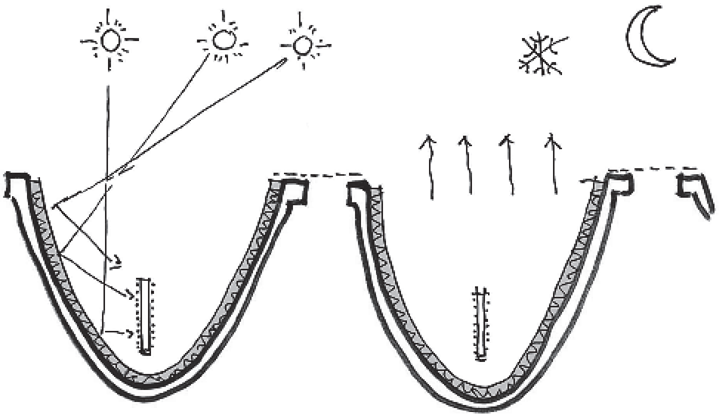

Fig. 04.43: Functions of parabolic roof shells: collection of solar heat, PV, nocturnal cooling and water collector (from rain and condensation at night)

Parabolic roofs can provide environmental advantages over normal roofs. When covered by stainless steel sunlight will be concentrated on focal point. This focal point could be filled with a flat plate solar collector filled with water. The warm water can be guided through tubes, possibly situated next to the rainwater discharge, to a solar boiler or to the ground for interseasonal storage.

Another solution could be PV in the heart of the parabolic shell, producing electricity, but without further measures the cells would possibly overheat, detrimentally affecting their performance and therefore gaining no advantage on typically positioned photovoltaics.

Apart from reflecting light, the parabolic shells could also have a function as a solar collector (irradiation from the sun) or cold collector (eradiation to the clear night sky) and as a collector of rainwater, to be used as water for washing, flushing and rinsing. These functions could all be integrated with a PV array in the parabolic centre.

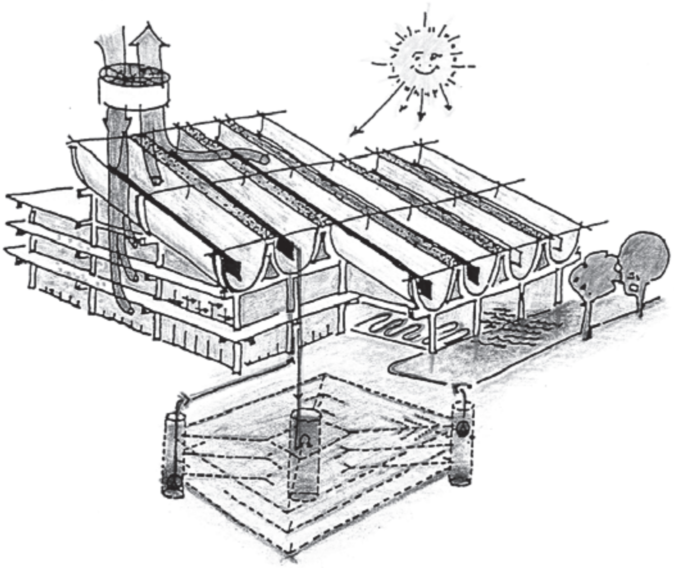

Fig. 04.44: Parabolic roof shells as designed for the Lelystad town hall (to be discussed in chapter 09)

Parabolic roof shells can also play an acoustic role. The reverberation time for several sound frequencies can be determined according to the Law of Sabine.

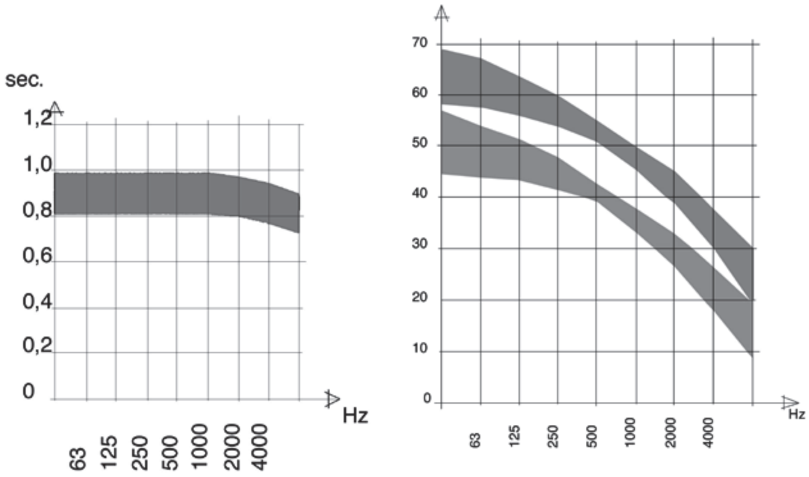

Fig. 04.45: *Resonance period in the bandwidth of 0.8 to 1 second from the lower to the higher tones of 2000 Hz (left), and the desired background noise (right) in a fully occupied office space (band above) and for the building services (band below)*

Parabolic roof shells were first proposed for the 1976 Lelystad town hall. Parabolic sun boilers were recommended on the ISES (International Solar Energy Society) congress in Hamburg, 1989. It is only since 2008 that they have found a renewed purpose in Villa Flora, the greenest office in Europe.

04.04.03 Artificial lighting

Artificial lighting as addition to daylight is inevitable. In offices the artificial illumination also needs to be efficient, functional and close to the user.

Artificial lighting in offices is a large subject that could warrant a chapter of its own. The thermal colour of artificial light goes from warm (bulbs) to cool efficient fluorescent lighting, which combines well with daylight. Bulbs have a light efficiency of 5 to 95% heat. For fluorescent lighting the capacity is 20 to 25%, so 4 to 5 times higher. What is remarkable, but understandable, is that in northern countries people choose warm lights (thermal colour < 3000 Kelvin) and in the tropics for cool white light (thermal colour > 3300 Kelvin). The light spectrum of fluorescent light is not complete and therefore often extended with halogen lamps.

In Western Europe fluorescent lighting was dominant in offices. The visual perception is based on variations in luminosity. Another aspect is the relationship with user age when it comes to the desired intensity of light. With every decade of age the desired intensity of light on the desk is doubled. In the Netherlands each working space is illuminated for a person near retirement age (that is 500 lux). Even more remarkable is that according to English criteria an employee needs only half, which is 250 lux. In Finland the illumination norm for new buildings is even 200 lux.

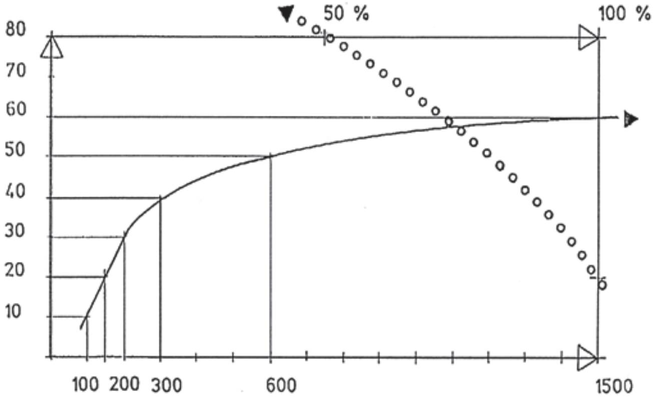

Fig. 04.46: Desired intensity of light related to ageing, in lux (lm/m^2)

Another aspect of artificial lighting is the quadratic decrease of light intensity with distance. So a seven meter tall lamppost may have an energy-saving armature, but a one meter tall lamppost principally consumes only 1:49 of the higher post with the same light intensity on ground level. Hence, from an energetic point of view it is more optimal to illuminate streets with low lampposts, instead of high ones, so that there is no illumination of an unnecessarily broad area.

04.05 Free-cooling roofs

04.05.01 The physical principle

Fig. 04.47: We all know this phenomenon: the misted up windshields of our car after a clear night. In wintertime a carport has its advantages…

When we study the spectrum of light that eventually reaches the earth's surface, we see a division in ultraviolet radiation, visible light and infra-red radiation. Free-cooling roofs consist of a spectrally selective membrane, which reflects most sunlight directly, however in a reverse way emits infrared heat radiation from the earth towards the sky. In this way an artificial night is created during the day.

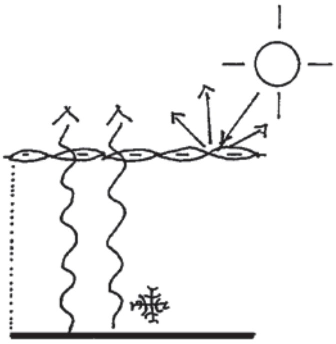

Fig. 04.48: Free-cooling roof: infrared emittance and light reflection

The free-cooling roof was originally an invention of TNO (report no. 86060, “Ice-rinks and Energy reduction”, by Mennink et al.). We used it for the first time in 1989, as part of a holistic concept for the competition of the ice-skating rink in the sports complex 'De Scheg' in Deventer. An outdoor ice-skating rink covered by a roof with 50% free-cooling foil consumes an equal amount of energy per m^2 as an indoor rink, resulting in an energy reduction of 75%.[14]

Fig. 04.49: Free-cooling test roof in Haarlem[15]

The structural inflated cushions cannot be damaged by material fatigue under the influence of resonance caused by wind. There is one disadvantage however, with a relative humidity of 100% (dew-point) a water film forms under the foil roof reducing the free-cooling capacity. A free-cooling roof in Haarlem has been tested and clearly demonstrated the influence of the roof cover: outside the ice was melting, whereas underneath the ice was still frozen.

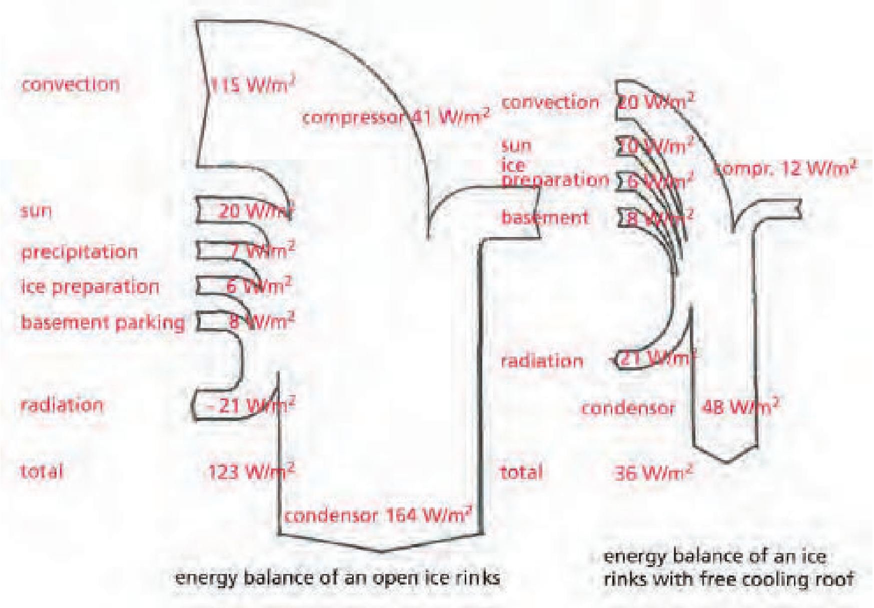

Fig. 04.50: Free-cooling test roof in Haarlem[16]*(left); energy balance of an open ice-skating rink (right) and an artificial ice-skating rink covered by a free-cooling roof (utmost right) – when compared a 75% energy saving!*

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[14] Only a 50% roof covering is one asset, the free-cooling a second, and fast cooling with thin, clear, rapid ice a third option for energy conservation. Very important is swabbing the ice efficiently. In order to avoid hoarfrost on the ice a lee needs to be created with a wire mesh partition.

[15] Photo by Bertus Butter, ice-master

[16] Photo by Bertus Butter, ice-master

For clarification a division can be made between three kinds of roof: the glass roof, the traditional insulated opaque roof and the free-cooling roof:

- A glass roof always functions as a solar collector: it allows 90% of the solar heat to pass. Once inside, the wave-length of the light changes at the moment it strikes a surface, transforming into infrared heat radiation that can no longer pass back through. This leads to the greenhouse effect, is a very important principle in passive low energy design.
- A traditional insulated 'cold' roof was once ventilated with fresh air. Due to use of new insulation materials, the damp tight 'warm' roof principle is now typical with no influence from outside air.

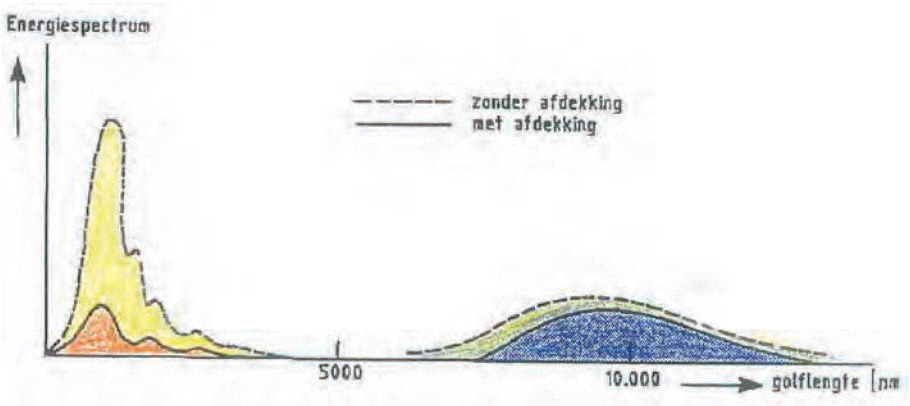


Fig. 04.51: Indication of the relationship between the short-wave irradiation of sunlight and the long-wave infra-red radiation of heat towards the sky: yellow is reflected sunlight; orange is the incoming light; blue is the radiation of heat through the roof foil; blue/green would be the radiation of heat without a free-cooling roof, i.e. in an open field.

- The free-cooling roof is made of a white membrane of polythene cushions that reflect direct sunlight. Some light enters, but with a clear sky during daytime and at night, the membrane allows infrared radiation from the earth to pass to the cold sky. This free-cooling comes down to approximately 100 W/m^2 which results in $-\Delta T$ = 3 to 5 °C of free cooling compared to the outside air temperature; a cooling performance comparable to air conditioning units. However, this principle only works under a clear and partly clouded sky, and preferably in full sunlight.

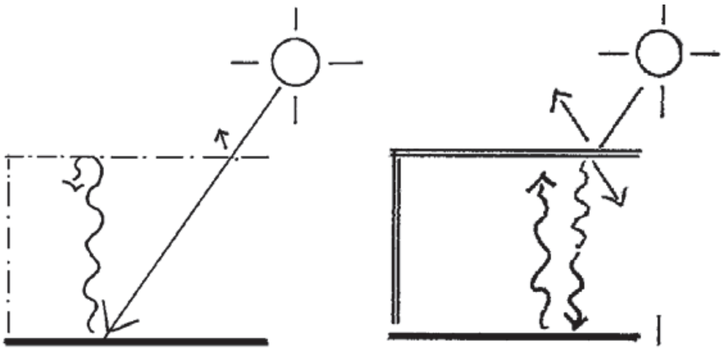


Fig. 05.52: Glass roof and a traditional insulated roof

04.05.02 Sports complex with innovative ice-skating rink, Deventer (1989)

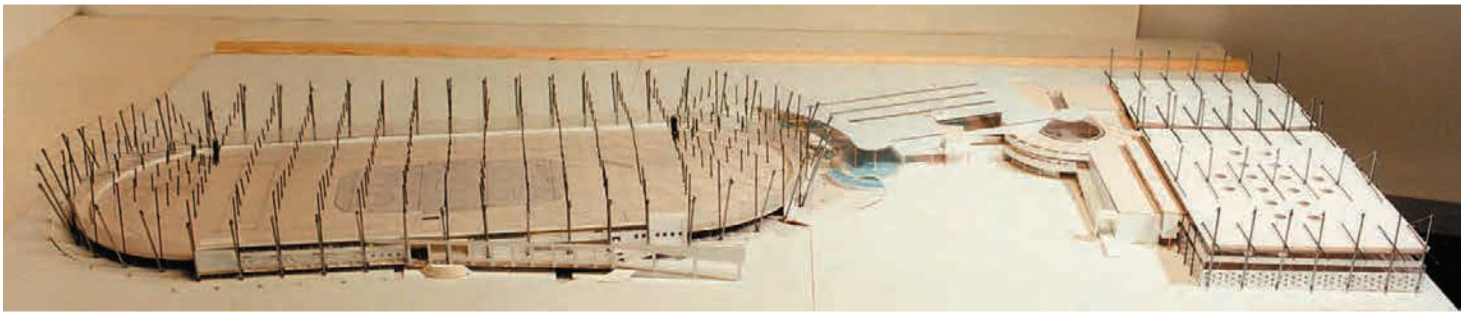


Fig. 04.53: Photo of the ‘De Scheg’ sports complex scale model

Three architectural offices, including our office, were invited to submit a conceptual design for a sports centre with a partly covered ice-skating rink. The location was near the Colmschate station, Deventer East. One of the interesting and challenging criteria for us was that it would be judged by its technical innovations.
Daan Josee worked on the multifunctional sports complex and Jón Kristinsson on the innovative ice-skating rink. In the design of the sports complex the focus was aimed at the larger functions: tennis hall, sports hall and swimming pool, organised in a triangle.
At the point of intersection in that triangle the large cylindrical hall had its centre-point. From this hall all sport activities would be accessible and to some extent visible. The central hall slicing through the entire building is adapted in a route parallel to the sports hall, tennis hall and squash courts. By sloping walkways, elevators and stairs this route over two building layers connects the large square at the front (at the level of the train platforms). In the long section of this route the intensity of passengers, visitors and spectators is at its maximum. In the large and high open space of the central hall this route continues over a bridge, from which the multiple visual axes reveal something of the diverse sport activities. Therefore the restaurant is situated around this open space.
The innovation consisted of the combination of a tension cable frame construction with vertical aluminium tubes as pushrod and slanting supports with grout anchors, designed by Bartels engineering office, and the free-cooling roofs by Netherlands Organisation for Applied Scientific Research (TNO), with Bertus Butter acting as consultant on wind and fast ice.

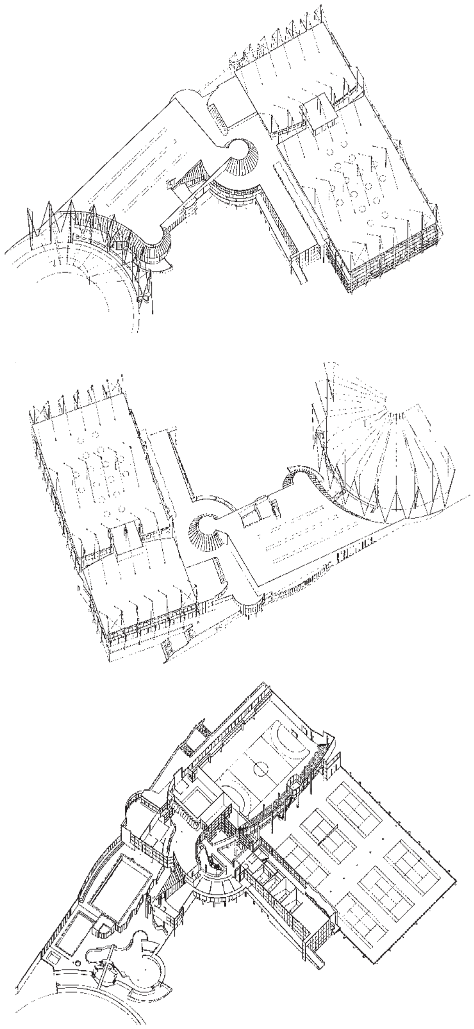
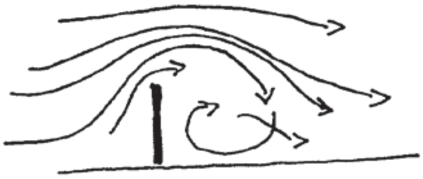


Fig. 04.54: Closed and open axonometric views of the Kristinsson design of the Scheg sports centre

The design features of De Scheg were:

- Energy consumption was reduced by 75%, with an environmentally sound design.
- The free-bearing insulated ice-rink had super fast ice and wind lee by a semi-transparent nylon wire mesh net.
- With the aid of an automatic infra-red temperature control system the track could be frozen in one night by a small compact cooling installation.
- The roof structure had been designed with an extra-light, maintenance free, Twaron tension cable frame.
- A synthetic free-cooling roof of inflated polythene cushions, with a reversed greenhouse effect and no condensation on the underside.
- No rain delays due to a covered 400 m track.
- Visitor-friendly: feet-warming grandstand, ice-skate-friendly finishing of wood and rubber.
- The basement was partly situated in the ground and offers space for 480 cars + 480 bicycles under the ice dome.



Due to far-reaching warranty requirements for new products, and a general lack of faith in the laws of nature, the free-cooling roof could not get off the ground and consequently the design was not selected.

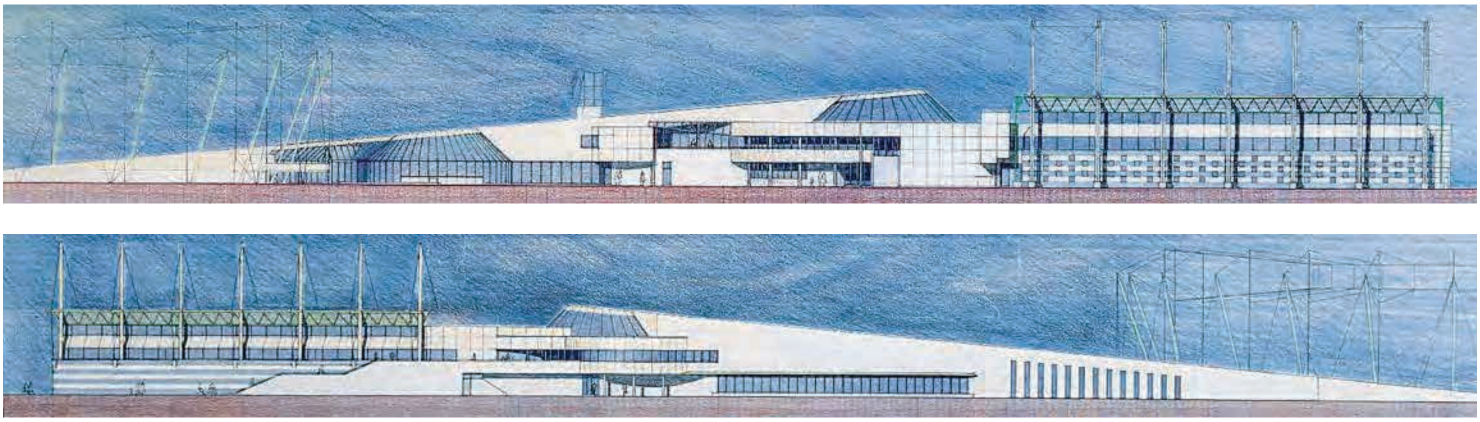


Fig. 04.55: View of the entrance side (above) and the station-side (below)

04.05.03 Free-cooling roofs in desert areas

How it is possible to jump from optimal ice-skating rinks in the Netherlands to deserts and arid areas? It is because the laws of nature transcend national and continental borders.
The principle of passive cooling can be implemented in hot and dry, semi arid zones of the world. It can be applied, for example, in tents, shelters for cattle, market roofs, car parks, mobile homes and existing roofs. It is an important option for fossil fuel reduction and the improvement of indoor and outdoor comfort globally!

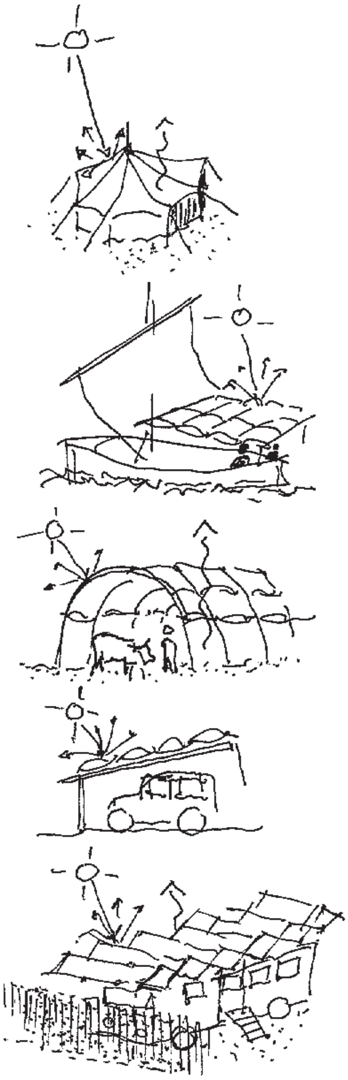


Fig. 04.56: Applications of the free-cooling roof (top to bottom): tents, sailing ships, stables, carports, campervans

04.06 Smart Skin

04.06.01 Introduction

With regard to energy consumption, sustainable building is often directed at energy-efficient use of fossil fuels and the generation of renewable energy through technical appliances. These measures may be considered adjustments to a traditional way of building, ignoring the fact that the building itself can be innovated to an intelligent, responsive or even proactive device. As a first step to the effective use of energy, a building needs to be fine-tuned to its environs and interact intelligently with local characteristics such as climate, soil type and context [Dobbelsteen & Linden, 2007]. The building skin most logically performs this interaction: the roof (mainly for the generation of energy in whichever form), the ground floor (for the exploitation of the soil) and the façade (mainly for a response to desired or undesired climatic conditions). In changeable climates the use of building mass or the thermally constant subsoil is an effective means to smooth large temperature differences.

The Smart Skin, a translucent (light-emitting) building façade, is a sophisticated integration of three-layered glass, three registers of water pipes and underground interseasonal heat stores. The heat stored has temperatures of 8 - 25˚C. The outer pane and the opaque white middle pane serve as a solar collector in sunlight. When desired, the middle pane can be transparent.

04.06.02 How to make a translucent Smart Skin

There are three qualities/aspects at issue in the design of Smart Skin; preventing sunlight transmission, gathering and storing heat and gathering and storing cold. Utilizing very-low-temperature heat > 25˚C and high-temperature cold < 15˚C elsewhere in the house is possible by means of new very-fine wire heat exchangers [Kristinsson et al. 2009]. The energy storage in the ground is more complicated than the smart skin itself. There are three temperatures to be stored and dynamically controlled for twenty-four hours a day, here the façade and the soil become interactive. The first prototype is based on triple-layered glass with pipes glued to each layer of glass, filled with water (Fig. 04.61).

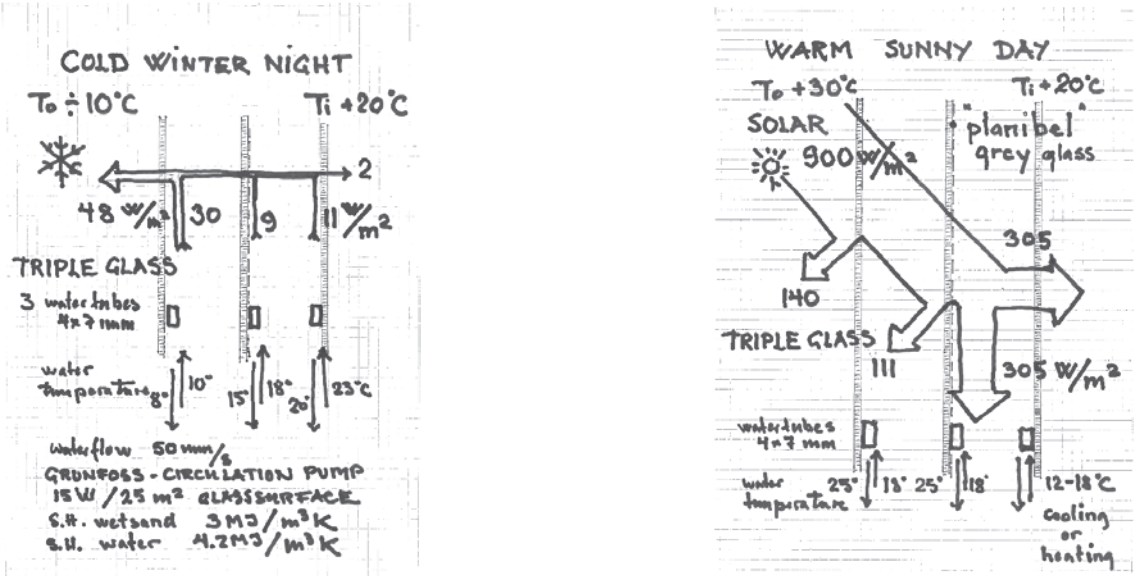


Fig. 04.57: *Smart Skin on a warm sunny day in connection with the groundwater heat and cold storage (left), and on a cold dark winter night: the inner glass plate is 21 - 22˚C (right).*

04.06.03 Every innovation creates a problem

The temperature of the outer layer of glass is highly dependent on the outside temperature, but in the Netherlands aquifer water of around 11˚C can be used at all times, without a license, in quantities of no more than 10 m^3 per 24 hours. In this way we can always keep the outer glass pane at a temperature of 10 - 12˚C, so that during freezing temperatures the heat loss is not larger than when it is +9˚C. The temperature of the glass in relation to the temperature in the water pipes (mounting bars, grills) is dependent on the quality of the connection of the tube to the glass and the glasses thickness. As the glass thickness increases the water pipes can be placed further apart, for example, from 150 to 250 mm centre to centre.

Fig. 04.58: The first 'Smart Skin' prototype with clear triple-layered glass, upside down.

Cold or 'coolth' harvested in winter at the outside pane is stored underground and used for cooling in summer. Heat harvested in summer at the middle pane is stored and used for heating in winter. Cooling and heating are generated from the inside pane. When a large part of the outer wall of a house consists of Smart Skin, the lack of radiation from the cold inner glass in summer, or the back radiation of the inner pane into the interior in winter makes a large contribution to comfort. We can cool with water of 12˚C, and heat with water of 18˚C because of this effect. By using heat absorbing grey-tinted glass, heat harvesting at the inner pane can be increased.

The great advantage of glass is that it is translucent making any leakages in the water system immediately visible. Leakages in the connections of the 2 x 3 = 6 water pipes (per pane) may be solved in the longer term, however waterproof glass sealing with dry, kit-free glazing, and a prefabricated standard bottom rail appears to be the best solution in the short-term. In this early stage of development the bottom rail is made of sustainable wood with a large trench.

04.06.04 Heat storage in the ground

One important condition has not yet been mentioned: the temperature control system. The water in the pipes in the 'Smart Skin' is dependent on orientation, radiation and the inside and outside temperatures. The following relates to an experimental bungalow with a 0.7 m thick insulating cellular structured 'floating' foundation (Fig. 04.63).

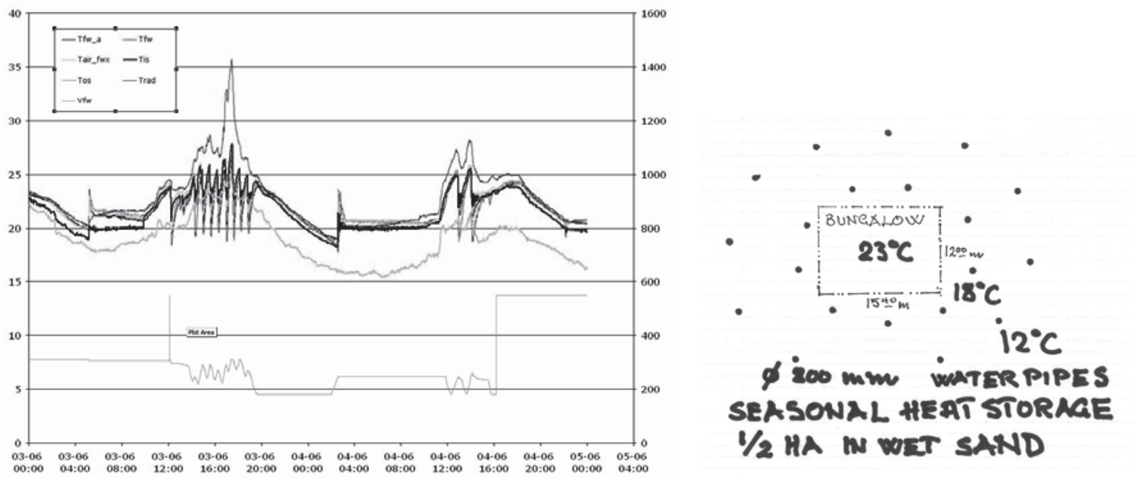
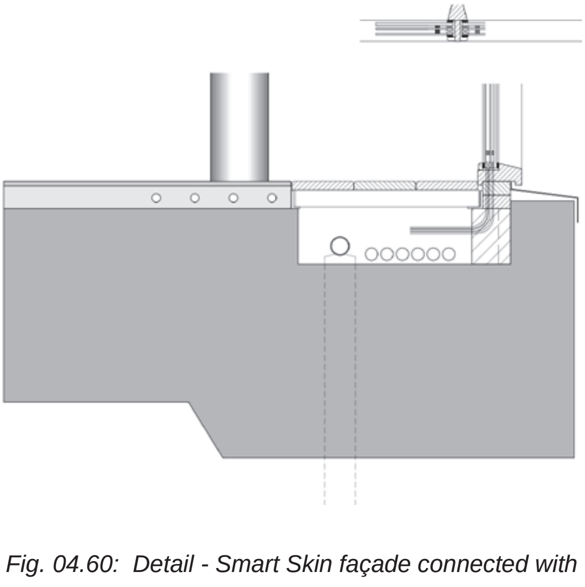


Fig. 04.59: The temperatures within 'Smart Skin' injection during a field test in sunny weather (left), and an oval configuration of pipes under the experimental building (right)

Pipes are connected in turn to water-collecting hoses in floor ducts along the façades. Such floor ducts are not common in the building industry, but here they are necessary to connect the water-collecting hoses with short vertical heat-exchanging pipes in the ground. The connection between these heat-exchanging pipes, which are shot in the sandy soil under hydraulic pressure, is unwieldy. As the 5 to 10 m long pipes must be injected before the ground floor is poured, dimensioning inaccuracies in location and height made at the initial stages of construction, make access to them difficult. It is much simpler and cheaper to allow a dimensional tolerance of 100 mm, for example. In view of easy mounting the floor ducts are extra deep (> 200 mm) and extra wide (> 300 mm).



Floor ducts make construction work more complicated. The floor heating is interrupted and the removable covering can cause noise. All the water pipes in the floor ducts finally end in a pump pit inside or outside the building. In this case a prefab pump pit has been chosen. It is a concrete pit outside the building with an insulated removable cover. Not only rows of small fountain pumps are mounted on the wall of the pump pit, but also all the switches, thermo-couples and thermostats required by control engineering. The temperature regulation is computer-controlled. Heat-exchanging pipes with three consecutive temperature ranges were injected in diamond formation into the ground under and around the building.

Fig. 04.60: Detail - Smart Skin façade connected with water pipes. The ground floor is of cellular concrete.

04.06.05 The design of an experimental Smart Skin building

The results of the first bungalow field test with a vertically mounted 'Smart Skin' (600 x 800 mm) did not match expectations. The heat output on a sunny day in May 2008 only fluctuated round 80 W/m^2, not enough for the building that requires a heat output of 200 - 300 W/m^2 (Fig. 04.65).

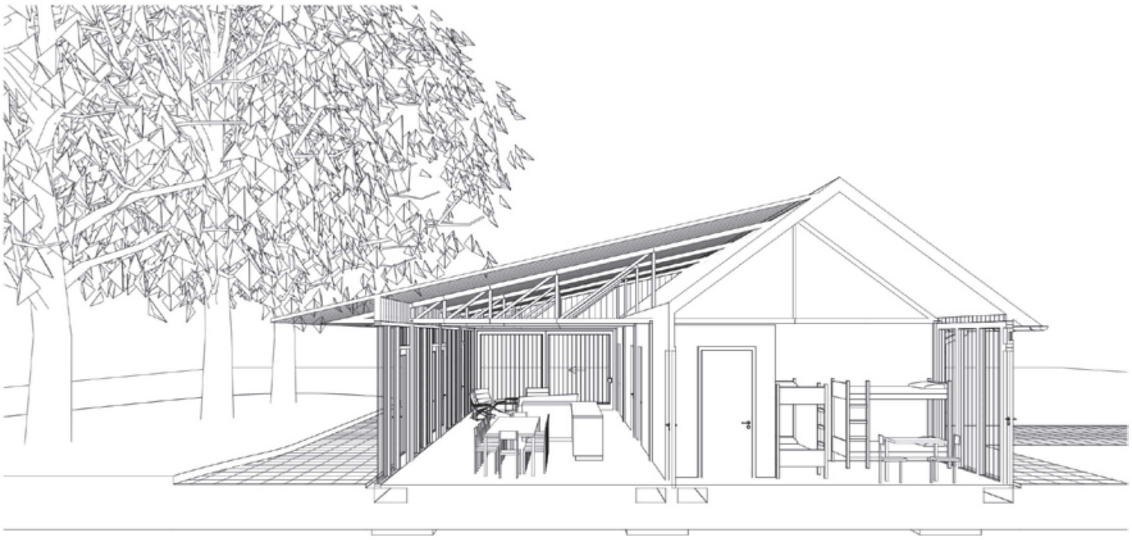


Fig. 04.61: The experimental building will be situated in an agrarian area near Enschede, the Netherlands. The building site is a water-logged meadow surrounded by solitary trees.

The outer walls largely consist of 'Smart Skin' with large glass doors. The design is derived from the traditional country barn. The short, south-orientated saddle roof has been fitted with thin-film Helianthos PV cells, while the north-orientated roof is made of clear 6-layered polycarbonate greenhouse sheets.

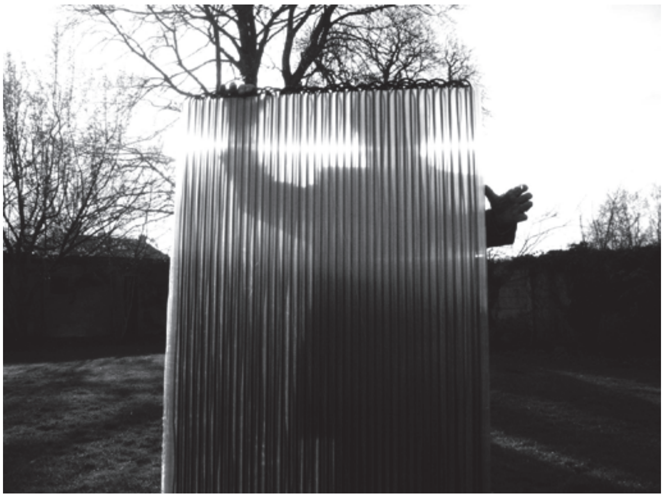


Fig. 04.62: Multi layered polycarbonate sheet applied as 'Smart Skin' roof

What is special about this roof is that it functions in a similar way to the ‘Smart Skin’ on the outer wall. Instead of metal pipes, black ø 6 mm synthetic tubes are pulled gradually through the polycarbonate channels. This roof also functions as a low-temperature solar collector, a heated roof and a cold collector. The technique applied to join the various diameters is often used in sprinkling devices for irrigation.

Fig. 04.63: An impression of a ‘Smart Skin’ zero-energy building. Panels of thin Helianthos PV cells on the south-orientated roof

04.06.06 Conclusion and discussion

‘Smart Skin’ is a perfect thermal integration of a lightweight building and a water-logged building site. The future use of ‘Smart Skin’ will have a profound effect on the building industry, for example, in the case of energetic renovation of historical buildings. ‘Smart Skin’ demonstrates that it is possible to generate very-low temperature heating (18˚C water) and high-temperature cooling (12˚C water). A Dutch glass producer ‘Betuwe Glas Groothandel’ believes in ‘Smart Skin’ and wants to supply it. The estimated production price of ‘Smart Skin’ built in an aluminium frame amounts to approximately € 700/m^2 to € 1,200/m^2, exclusive of VAT. It is inevitable that the handmade installation (the first of its kind), the control system and the constructional detailing will have to contend with and overcome various ‘teething troubles’.

The poor heat output performance of the first prototype can be improved by several measures, for example, the heat absorption properties of the outer-pane water pipes being enhanced by a darker back layer, or by spectral selective coatings (Polaroid principle). Another interesting application could combine the heat and cold functions with algae for water treatment. This concept was first explored by Luising [1998] and later elaborated on, and integrated into façade design by students and staff of the Manchester School of Architecture [Keeffe, 2008]. Of course these adjustments need to be tested before a working model can be presented. Needless to say that the first boilers, windmills and PV panels were not that efficient either. There is little practical experience yet, but we think that the innovative energy concept deserves every support for further development.

As a title, ‘Smart Skin’ does not cover the whole concept. The application of ‘Smart Skin’ technology in non-translucent constructions opens an entirely new outside-wall application in existing buildings and the renovation of listed buildings.

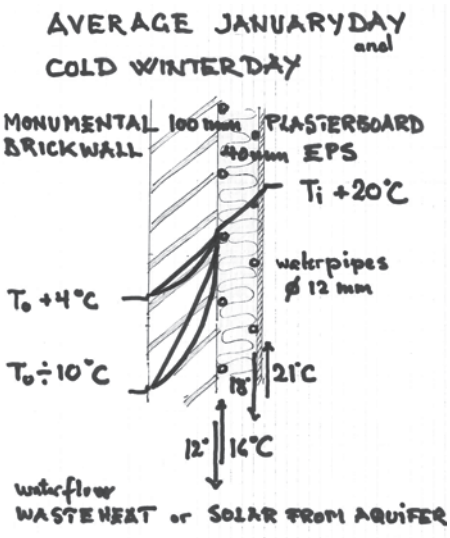


Fig. 04.64: Outline of an energetic Smart Skin renovation of 400 listed half-brick houses called ‘de Hoogte’ in the city of Groningen, the Netherlands.

04.06.07 Follow-up

The details for six water pipes for four orientations with accompanying pumps, management system and a seasonal storage for three temperatures, turned out to be too much technology for a small visitor building. Apart from a working prototype this translucent Smart Skin facade has not yet received a follow-up. One cannot say much about when and how these translucent facades will develop. In terms of feasibility and production, a study found that the Diamond Exchange building in Amsterdam could be heated and cooled without thermal insulation, by adopting a ‘Smart Skin’ concept of translucent glass facade and synthetic plated roof.

A simplified version of the aforementioned energy-producing translucent facade, has been manufactured with an opaque stone outer gable, cooled and heated by water of a very low temperature. Instead of the usual ∆T of 30˚C temperature difference between indoors and outdoors pumped into a building during the heating season, the main principle is to use 10˚C ground water on the inside of the outer gable, replacing thermal insulation. This energetic connection between the indoor climate of a building and the ground water temperature can be established relatively simply in renovation projects. Wall heating by water insulation is installed as floor heating with a water temperature of 18 to 22˚C.

If a building is to be cooled by a 'wall heating' system, it is advisable not to go below 18˚C to prevent internal condensation.

04.07 Soil energy

04.07.01 Introduction

Instead of a ventilation air inlet near the ceiling, drawing in the air through a set of synthetic tubes in the earth can reduce energy demand for air heating and cooling. This concept was demonstrated at the Poppe customs building in Oldenzaal, a project of the Dutch Government Buildings Agency.

At a certain depth the soil and ground water has a constant temperature: the local mean temperature. In the Netherlands this is 10 to 11˚C. It is possible to exploit this resource in summer and winter, without damaging the deeper watertight layer of clay. In summer the soil will be a natural pre-cooler, in winter a pre-heater. Through pre-heating ventilated air in winter, the capacity of a common heating installation can be reduced by 20%. The ventilation losses of the total heating capacity are around 40%[17]. With thermal mass and optimal isolation, the living areas will keep their temperature at night. Additional traditional heating is sufficient and air-conditioning will not be necessary.

Fig. 04.65: Piping required to harness soil energy

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[17] It must be noted however at night the outdoor temperature is at its lowest, while a lower indoor temperature can be tolerated. At this time building occupancy is typically low, and the ventilation can be switched-off.

To make this idea practical, pipes (rainwater pipes, ∅ 220 mm, will do) can be laid under the ground floor of a building. The space between the foundation structure and the grid of air pipes is filled with 1.5 m of sand. For cleaning and discharge of condensation water the tubes need to lay to falls towards an air collection pit, from whence the air is distributed in the building.

04.07.02 Hollow heat-exchanging foundation piles

Using the soil for seasonal storage of heat has become a proven method. There are three ways to establish this system.

1. Using an underground aquifer by drilling two tubes into a sand layer between two watertight layers of clay. Water is pumped in under pressure and pumped out a bit further in a closed cycle. In this way heat (from the sun) can be stored in the sand layers. One of the disadvantages of the method is the perforation of clay layers on a depth of 50 to 150 meters.
2. To inject double 10 to 20 meter tubes with water and to connect it to a heat pump. The disadvantage of this method is the need for anti-freeze and the subsequent risk of leakage into the ground/drinking water supply.
3. A shallow horizontal network of pipes or tubes in the ground or groundwater, of the type of soil energy discussed previously.

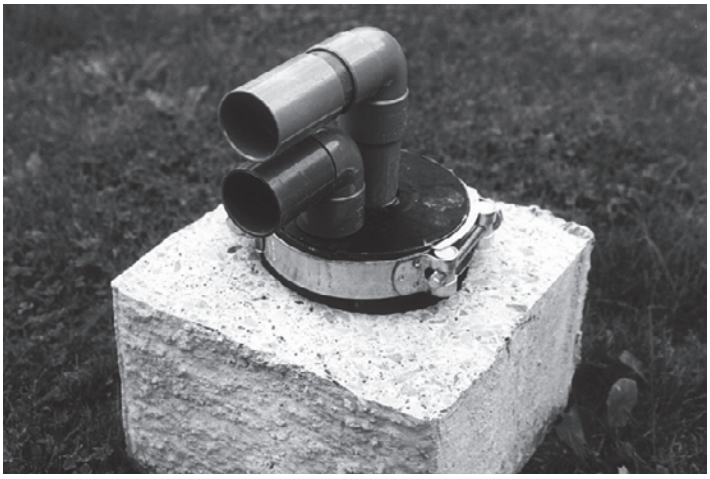

Fig. 04.66: Assembly of the water tubes for supply and discharge on the head of the pile[18]

Hollow piles
A new development applicable to countries like the Netherlands are hollow foundation piles. When filled with water the piles function as heat exchangers with the soil (at the first bearing sand layer), both pile and soil act as thermal mass.
With this system a low-tech, low-pressure water circulation is possible for the storage of low-caloric thermal solar energy. The system may be connected to a heat pump for domestic heating, or in reverse, for cooling of dwellings or office buildings.

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[18] Source: IEP, Almere

In 1999 a graduation project at the Faculty of Architecture of TU Delft by Pieter Geene studied the concept of 'thermal piles'. At that time hollow pile technology did not exist, three years later they were produced by Unibeton in Zeewolde. Pieter and myself were both involved in the completion of this innovation.

Fig. 04.67: Inventor Peter Peters and Pieter Geene in front of the storage of hollow piles

Foundation piles usually do not bear more than 10% of their loading bearing capacity. In the Netherlands 600,000 m^3 of concrete is annually processed into piles. A decrease of at least 100.000 m^3 of raw material is then possible with the hollow system. A consequent reduction in transportation removes some 2000 trailers off the roads. If we assume € 80 excluding VAT for one cubic meter of concrete, the savings are eight million euro per year.

Fig. 04.68: Driving piles with a diesel engine[19]

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[19] Source: Unibeton, Zeewolde

04.07.03 Deventer fire station (1990)

Fig. 04.69: South west elevation of the Deventer fire station

In 1988 we received the assignment for the design of the Deventer fire station. Two years later ground collector pipes for ventilation air were completed under the fire engine garage.

Although the predominant wind direction in the Netherlands is from the south-west, a decision was taken to allow ventilation air in at the north-eastern elevation preventing a neighbouring refuse transfer depot to the east having any adverse effects on air quality.

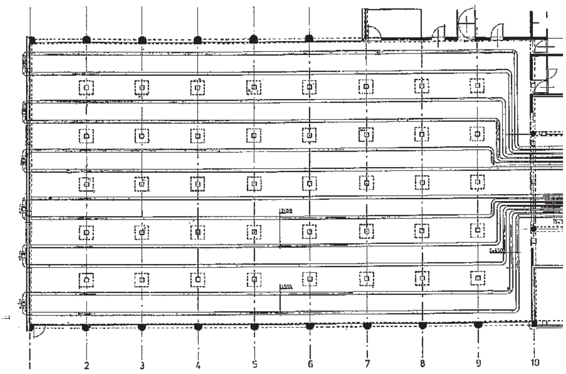

Fig. 04.70: Scheme of piping under the garage (left). The air-pipes fall 1.5 m underneath the garage floor and about 0.5 m above the highest groundwater level.

Measurements were incorporated in the National Energy Programme of the Dutch governmental energy institute ‘Novem’.

Fig. 04.71: *Garage (left) and north-west elevation (right). The air-pipes lay under the fire engine garage, which has a roof of steel Litzka beams. Grates for air inlet can be easily distinguished in the facade.*

Summer situation
Compared to the warm air outside, the cooling of air through the soil to approximately 18ºC indicates that underneath most low- and middle-rise buildings an effective environmentally sound alternative for air-conditioning is available. For large meeting rooms, which have to be extremely well air-conditioned, only additional top cooling may be necessary.

Autumn situation
This period demonstrates that there is no need for extra heating due to stored heat in the summer months.

Winter situation
In the Netherlands heating utilities are tuned to an air temperature difference ∆T = 30ºC between inside and outside, assuming -10ºC in winter and +20ºC in summer. The lowest and highest groundwater temperatures from the period 1961 to 1990 are used in computer simulations calculating heating requirement. This temperature is still rising.

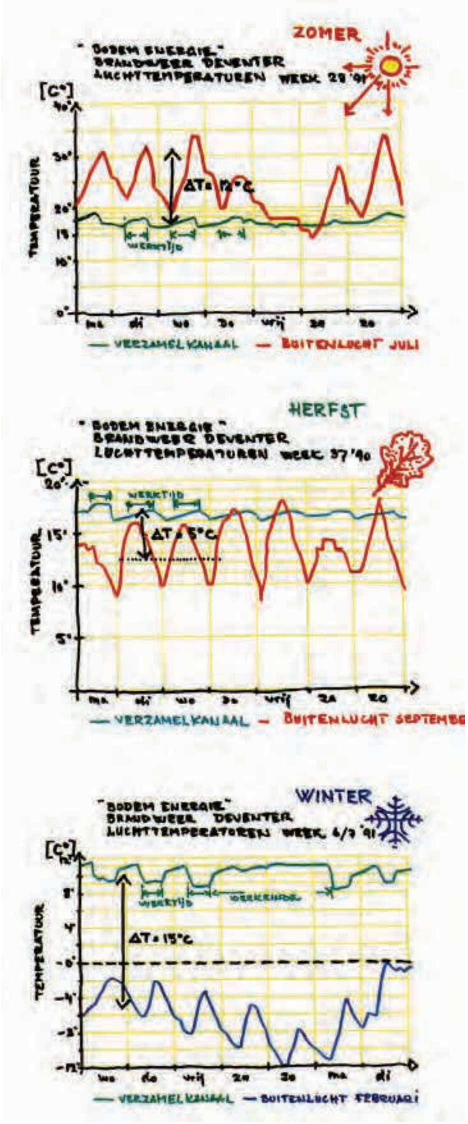

Fig. 04.72: *Summer: soil energy substitutes air-conditioning, free cooling, failure free, simple, cheap.*
Autumn: transition period, no heating needed.
Winter: smaller building heating service, heat exchange comparable to half the performance of a good air/air exchanger [20]

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[20] 1990 measurements were done by EcoEnergie Engineering from Velp

The incoming air is approximately 10ºC as the soil is still warm from summer. Since ventilation with soil energy is only applied during full occupancy during working hours [21], this relatively high inlet temperature is maintained for a long time. A ∆T of 15ºC means that by pre-heating fresh ventilation air with soil energy, the total building heating service system can be reduced by approximately 20%. This is very important for the energy performance of a building.

To summarise, soil energy can level out temperature fluctuations in summer and winter. Soil energy has almost the same effect as air-conditioning, but in operation it costs almost nothing. Unfortunately climate consultancy companies appear to be unconvinced of the obvious benefits this approach has to offer. At present they are paid in accordance with the costs of building services applied in a building, and not by the energy reduction they achieve.

The recommendation is clear: use the thermal mass under buildings. The capacity of an air-conditioning unit becomes redundant and the building heating service for winter can be reduced significantly. Extra costs are minimal and maintenance is nil.

04.07.04 Sustainable fire station, Soest (1998)

Fig. 04.73: The Soest fire station, designed by Jón Kristinsson[22]

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[21] The fan has a standard control with a weekly programme.
[22] Photo by Jan Derwig

Having seen the ‘soil energy’ Deventer scheme at the VIBA sustainable building exhibition in Hertogenbosch, the Netherlands, the municipality awarded us the contract for the fire-station in Soest. The project criteria were: use of passive solar energy, optimum daylighting and sufficient façade protection and minimal maintenance. The ground pipe concept at Deventer was repeated at the Soest fire station (figure 04.78) with the addition of a solar chimney (fire-hose tower) to induce the extraction of exhaust air.

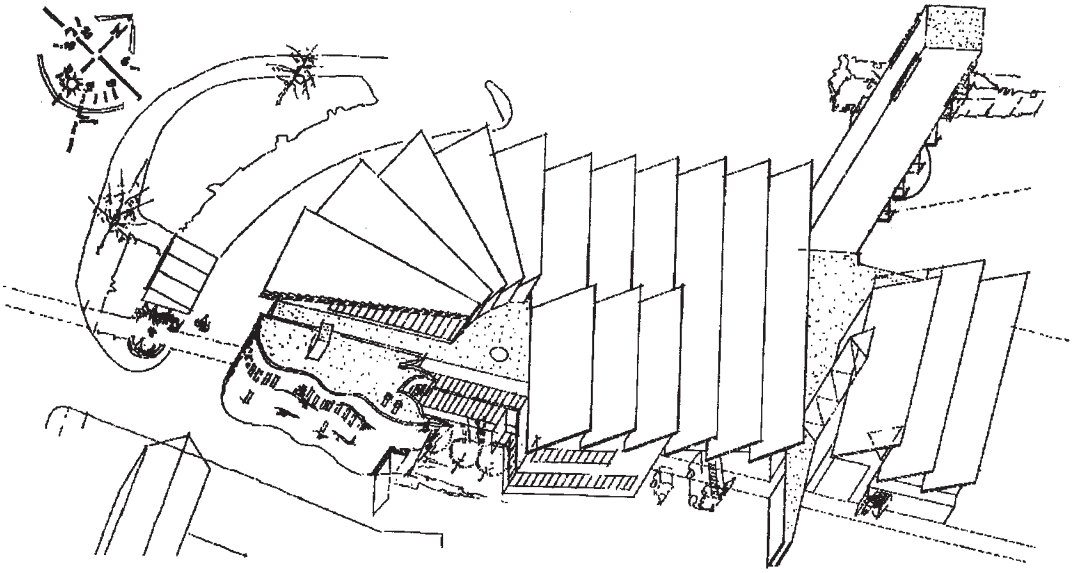


Fig. 04.74: Bird’s eye view of the fire-station, where a new fire hose tower is still drawn, which however was removed during the design process due to the substitution of the old hoses by light synthetic fire hoses that no longer had to be suspended.

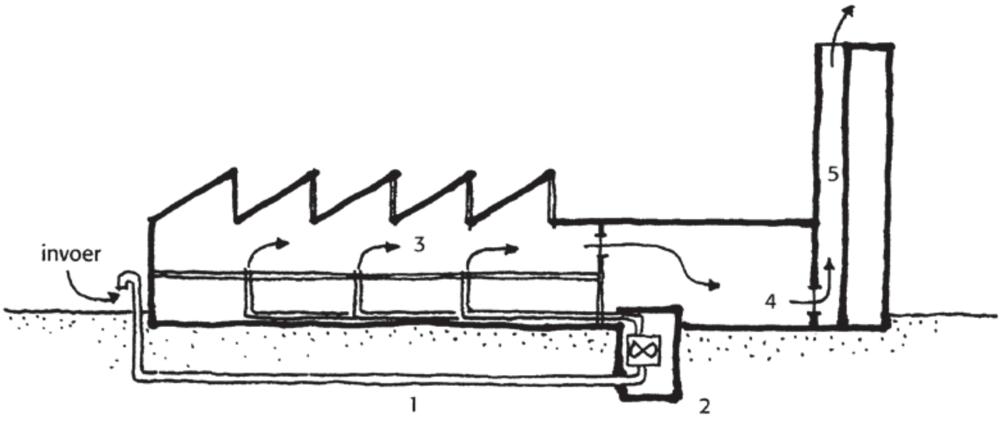


Fig. 04.75: Soil energy principle of the Soest fire station.

Energy measures

Energy-saving and sustainable measures include:

- The garage has natural ventilation by draught through the chimney-shaft in the existing fire hose tower.
- Soil energy cools air in summer and forms an extra heating source in winter.
- Rain water is collected for fire-fighting water, washing and rinsing.
- Passive-solar energy and natural light is received from the shed roofs.
- Light regulation and energy-saving armatures have been used.
- Water-saving taps, toilets and shower heads are used.
- 40% of timber has been saved through wood with 'Lignostone' connections.

Fig. 04.76: Canteen with light from above.

Although the original fire-station was demolished, the fire hose tower was preserved. No longer in use, the tower was to be utilised in the natural ventilation strategy following the principles of the ‘stack effect’. Here, natural draughts are induced by the height and the difference in atmospheric pressure between the indoor and outdoor climate.

Soil energy was applied with pipes running under the garage (see the section on the Deventer fire-brigade). These provide air-cooling in summer and auxiliary heating in winter. The offices on the ground floor have bare concrete ceilings promoting thermal mass. For the acoustics, a suspended modular ceiling was installed. General lighting was integrated into the ceiling panels, while desk lamps provided individual task lighting.

Material measures

Sustainable materials are:

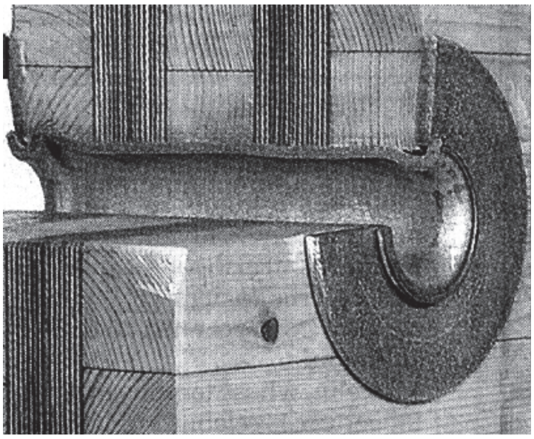
- Ceramic tile cladding
- Baked tile roofing
- Inner cavity wall of sand lime brick
- Windows and frames of finger-jointed and laminated larch (durability class two), transparent varnished on base of alkali (1 and 5), as well as the balcony and stairs partition.

Fig. 04.77: Backside of the fire-station in Soest.

The interior is also sustainable, with linoleum in the canteen and corridors, a cotton carpet in the offices and tiles in the wet spaces. The furniture is predominantly constructed of wood and steel. In the canteen a wall of glass building bricks surrounds the washroom block, allowing natural lighting to permeate during the day. In the centre of the building a large expressive timber spiral staircase forms the entrance to the canteen and the instruction area.

Awarded timber roof frame

The Soest Fire Brigade building (1998) is spanned with untreated (as placed inside the building) laminated framework beams. With a maximum length of 22 m, each beam cantilevers out to the exterior protecting the façade from adverse weather. A large canteen with balcony for the voluntary fire-brigade is located above the offices. The shed roofs catch the passive-solar energy and natural light.



Timber connections are made using the 'Lignostone' technique, originally developed in 1995, by Hylke Katsma and Ad Leijten from the Faculty of Civil Engineering at TU Delft. A galvanised thick-plated steel tube with a connective ring is pressed into the wood with tightly layered beech plywood between the joint parts. Although heavier with extra material, the frame becomes significantly stronger. Partly because the joints and tension members were made of rigid steel, the framework could be designed slimmer and lighter leading to a 40% saving in timber.

Fig. 04.78: Tube with connective ring and tight beech plywood pressed in-between the wooden joints.

Unlike the timber beams that span from the inside to the outside, the Lignostone beach-wood connections had to be located within the building envelope due to their high sensitivity to moisture. The frames exposed on the exterior would later be covered with ventilated transparent polycarbonate plates.

Fig. 04.79: Hammer-beam truss, covered with transparent polycarbonate plates and with the old firehose tower on the background.

In 1999 our architectural office received the European Glulam Award (for glued and laminated wood connections) thanks to this new and special construction.

Fig. 04.80: The European Glulam Award logo

04.07.05 Greijdanus, School of Fresh Air, Meppel (2011)

Fig. 04.81: Front of the Greijdanus School, the new build left to the original building,

Introduction
Fresh air is a major problem in schools across the world. There is strong scientific evidence that the learning performance of students significantly declines when the indoor air quality is compromised. This problem is aggravated by the limited budget of school building projects. For the Greijdanus School in Meppel we saw it as our challenge to solve this issue by integrated design, providing real-time physics lessons every year, including solar access and natural cooling. The building had to radiate its timelessness during all seasons and every hour.

Sunshading
The demand for cooling was minimised in the architectural design. Dynamics of the building were made visible from the outside by the strategic preservation and site relocation of deciduous trees. At the roof cornice a metal mesh foot-rack functions as a fixed sunshading device creating diffuse daylight. A large overhang at the north-eastern side provides a wind lee solar terrace. In addition, there is automatic external sunshading and a timber pergola.

Fig. 04.82: Mesh foot-racks act as sunshading device at the roof cornice.

Ventilation

It is a well known that ventilation is the weakest link in school design because of overheating, limited refreshment air, excessive draughts, ventilator noise and noise leakage through air ducts. The Dutch regulation for school ventilation is 12.6 m^3/h per m^2 of floor area, a figure that is hardly ever achieved. Normally, operable windows could solve this, but the Greijdanus School location next to relatively high levels of traffic noise demanded a building design combining natural ventilation with a closed facade. Breathing Windows therefore were an appropriate solution. These provide basic ventilation and heating. Breathing Windows permanently monitor the air quality on CO_2 concentrations. The ventilators could switch off at 600 ppm and give a warning at 1200 ppm. Mechanical exhaust is used in washroom areas.

Soil ventilation

Most notably, after successful installations at Deventer and Soest fire stations, and with the help of consultant Gosse Landstra, soil ventilation was utilised for the very first time at a school. Physical investigations proved that the air quality is better than in any other schools ventilated in the traditional way.

The Greijdanus School is entirely ventilated with air drawn in through a ground-air heat exchanger consisting of a soil pipe register (30 times 30 meter, ø 200 mm) at 1.2 meter depth in the ground. This provides sufficient, naturally pre-conditioned fresh air for 200 pupils. The capacity is 8200 m^3/h, which approximately equates to 50 m^3 per hour per pupil. In winter the air is pre-heated and humidified, in summer pre-cooled and dehumidified. The air coming in is around 18˚C at a 30˚C outdoor temperature. When it freezes, air is heated up in the soil ducts to around 10˚C. In that case a small afterburner provides the additional heating. In winter some recirculation takes place. The ducts lie at a gradient in order to enable annual cleaning by high-pressure sprayer.

Night cooling

The soil ventilation system offers simple, cheap, natural air cooling, and competes favourably in terms of efficiency against the much more expensive concrete core activation. Suspended ceilings were replaced by acoustic ceiling panels, exposing the thermal mass of the concrete floors. This helps to cool the structure on summer nights during 01:00 and 07:00. Thus, the system also provides night cooling that can be managed on each floor automatically.

In the classrooms, excess temperature hours of $T_i > 28$ºC were reduced from 41 to 13, 40 to 10 and from 29 to 6. Despite a superior air quality and comfortable indoor temperature, the installation costs are lower than traditional climate designs for schools.

04.08 Inter-seasonal heat storage

04.08.01 Working principle

The inter-seasonal heat storage was originally designed as a horizontal one-pipe system in three layers of wet clay. In a one-pipe system, in summer the heat is transported to the ground by the same method used in winter to extract heat. The ground area equals 40 m x 40 m = 1600 m^2. The solar heat spreads horizontally from the hot core to the surrounding edges. Vertically, stratification (layered temperature increase) is made possible through three vertical water shafts (Fig. 04.86).

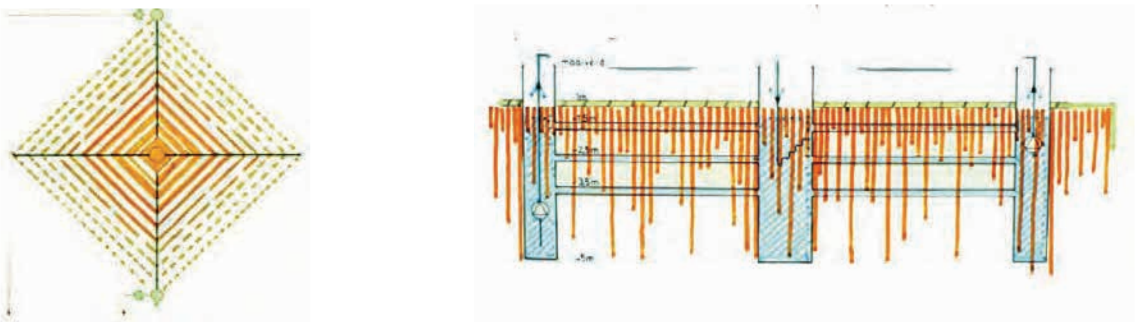
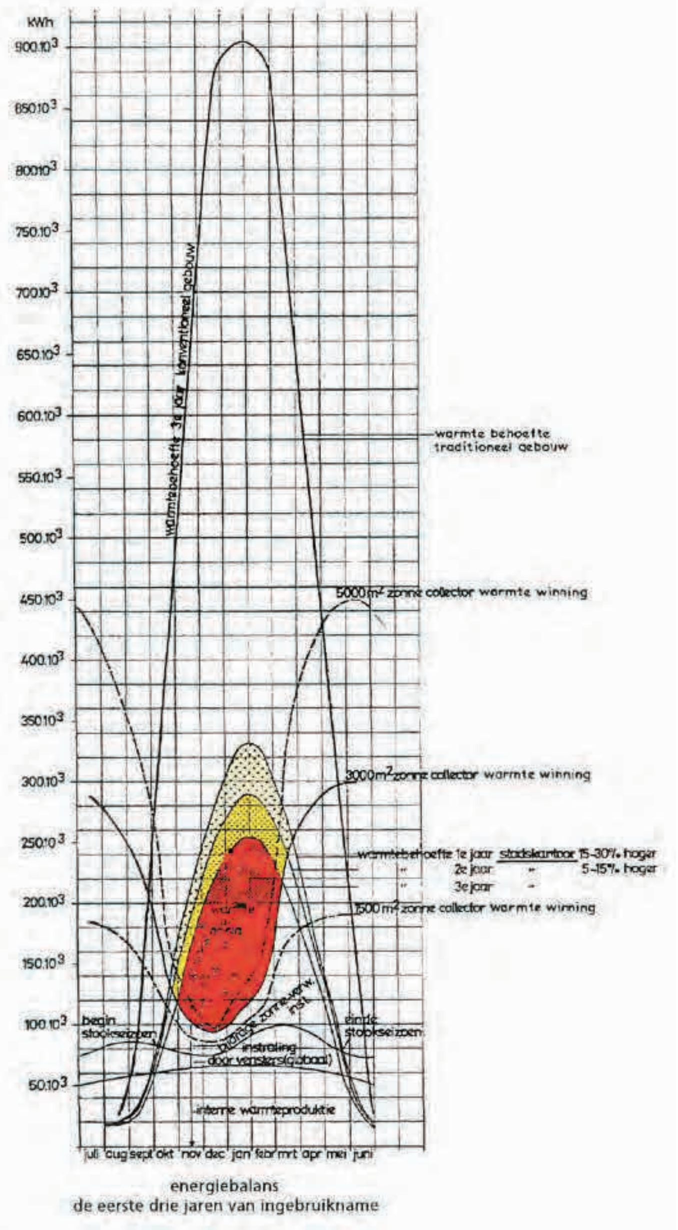


Fig. 04.83:Piping scheme of the inter-seasonal heat storage (analogue to the electrical resistance model), the charging occurs from the central shaft (above left). Section of the one-pipe system in three layers, connected to three shafts, and the temperature composition by stratification (above right).

Fig. 04.84 (right): An increasing amount of energy is stored in the 'battery'. In the second year neighbouring dwellings can also receive heat from the system.



Due to a bowl-shaped temperature profile there is no need for thermal insulation under the inter-seasonal heat storage. Following the principles developed by Prof. Van Koppen at TU Eindhoven the central shaft has a floating inlet composed of a light-weight sleeve. The inlet is filled with water of variable temperatures, this water eventually flowing to water of the same temperature and specific gravity. This principle prevents a mixture of temperatures in the shaft. The water with the highest temperature is obviously collected in the upper part. During the heating season solar heat is extracted from the inter-seasonal heat storage through the shafts on the outside. When there is a limited demand for heat the pump at the bottom of the lowest shaft is used. When the heat demand is high or when the storage is emptied, a pump at the top of the stratification extracts the heat.

Due to its ‘open’ character and little resistance this horizontal system with shafts enables the water to spread through the one-pipe system almost without any pumping, thanks to the different water levels or stratification in the shafts (communicating vessels). Because of the large dimensions of the horizontal water pipes that heat up the clay, gravity generates the circulation of water. An additional benefit to this strategy is that an open circulation system without pressure can have simple joints and connections.

04.08.02 Beijum, Groningen (1982)

An inter-seasonal heart storage system, partly funded by the European Community, was built for the neighbourhood of Beijum, in the city of Groningen (Fig. 04.88).

Fig. 04.85: Installation of solar panels to be combined with an inter-seasonal store, extension Beijum, Groningen, 1982.

For any inter-seasonal heat storage system it is important to connect the solar panels early in the process so the heat storage can be charged one summer before the building is in use. After a few years, when the storage is completely charged, the surrounding buildings can also be connected. The estimated efficiency of 50 to 60% has since been found to be accurate.

Fig. 04.86: Dwellings with solar collectors (left) feeding the inter-seasonal heat storage (right) for 100 dwellings in Beijum.

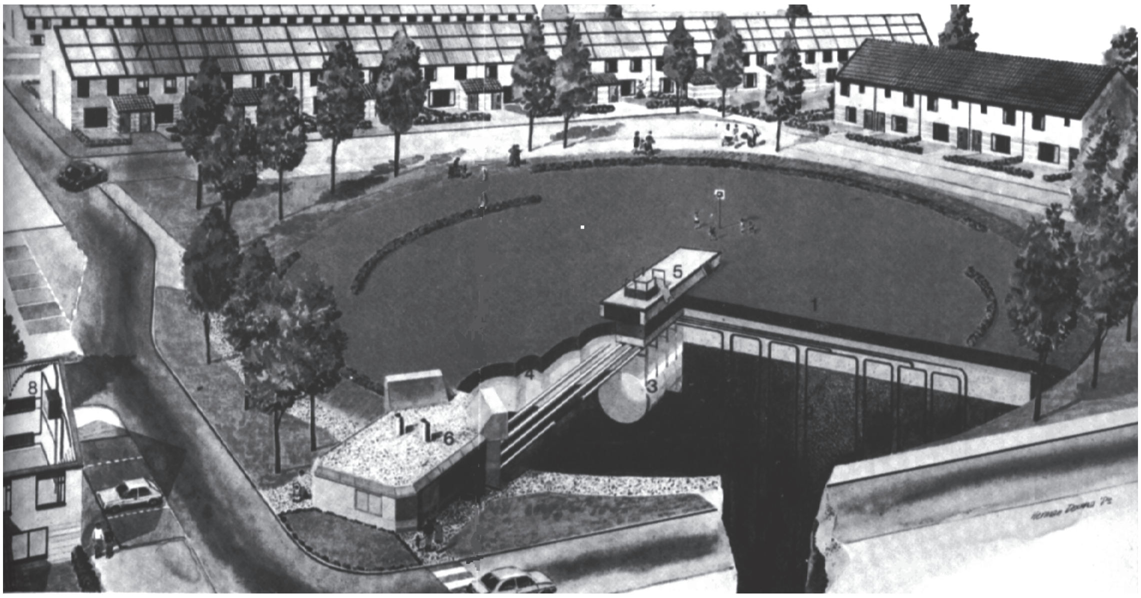


Fig. 04.87: Early illustration of the storage strategy at Beijum, built in 1982 and still in operation.

At Beijum, a one-pipe system was used with a vertical structure, water circulation relying on pumps and not temperature stratification as described in the previous section. For peak loads in summer a tank was added to balance day and night operations. For the solar panels, highly-efficient vacuum heat tubes were preferred, similar to those installed at the residence of Professor Van Koppen the year before - a technology way ahead of its time.

Fig. 04.88: Solar panels in-situ at the Prof. Van Koppen residence (Architect: A. Hoekstra), Eindhoven, 1981 (left), with high-tech vacuum collectors and warm water storage tank of 3.7 m^3. Detail of the vacuum tube heat pipe collector (right).