Sustainable Schools: Their Passive Systems to Provide Comfort with Natural Means as an Educational Example for Pupils and Their Parents

Wim Zeiler

1 Introduction

> Architecture will, therefore, become more informed by the wind, by the sun, by the earth, by the water, and so on. This does not mean that we will not use technology. On the contrary, we will use technology even more because technology is the way to optimize and minimize the use of natural resources. (Richard Rogers)

As the results of the energy use of the built environment, which is around 40% of the total energy consumption [25], become more evident (depletion of fossil fuel and global warming), there is a demand for energy reduction. In order to reduce the high energy demand and pollution of greenhouse gasses, it is necessary to improve the performance of the buildings. In Europe, more than 64 million students and almost 4.5 million teachers work inside a school in preprimary, primary, and secondary schools [26]. School buildings represent a significant part of the building stock (17% of the nonresidential sector in Europe) and a noteworthy amount of total energy use (12%) [26].

Good education is an essential pillar for citizens' welfare and well-being. High-quality education infrastructure is one of the main pillars of economic prosperity and can put people on a path toward good health, empowerment, and employment. Evidence shows that, on average, each additional year of education boosts a person's income by 10% and increases a country's GDP by 18% [11]. Data from the Perry Pre-School Study, for example, show that every dollar spent on students when they were 4 and 5 years old had a benefit/cost ratio of more than 13 dollars by the time they were 40 [33]. Teacher recruitment, retention, absenteeism, and presenteeism are affected by poor indoor conditions [44], which also influences learning outcomes [12]. It is therefore of critical importance to ensure that schools enable

W. Zeiler (✉)
Department of the Built Environment, TU Eindhoven, Eindhoven, Netherlands
e-mail: w.zeiler@bwk.tue.nl

A. Sayigh (ed.), *Achieving Building Comfort by Natural Means*, Innovative Renewable Energy, https://doi.org/10.1007/978-3-031-04714-5_1

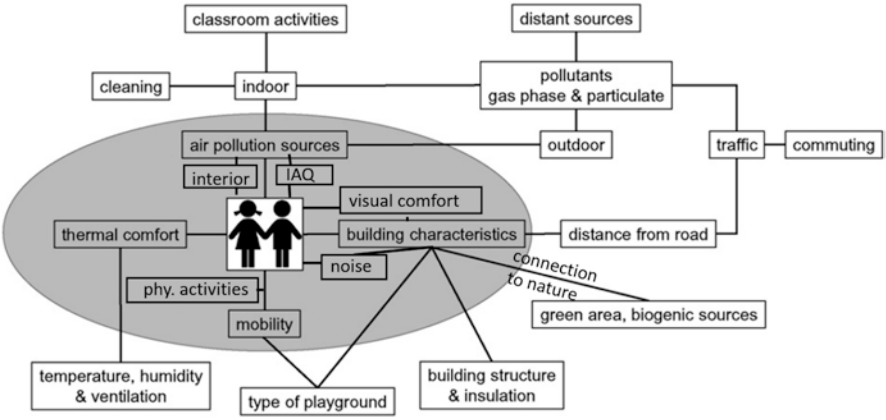


Fig. 1 Dynamic influence factors impacting the indoor climate in school classrooms [49]

children to thrive physically and mentally [49]. Despite this, inadequate ventilation is a common problem in school classrooms all over the world [2, 3, 36, 53]. A recent Dutch survey of August 2020 stated that from the more than 3386 schools that responded and performed a quick scan during summer conditions, 23% did not fulfil the minimum requirements for ventilation [40]. These outcomes are in line with the earlier outcome by van Dijken and Gelderblom [20], stating that in around 40% of the schools, classroom ventilation is seriously insufficient during the winter.

It is essential to create a healthy learning environment besides the sustainability aspects of schools [30] and to optimize the consistency of all dynamic influencing factors on the indoor environment (see Fig. 1).

2 Historical Perspective

It is important to learn from buildings of the past while still harnessing the opportunities presented by new technologies to think interdisciplinary and work collaboratively [19]. Since ancient times with the Greeks and Romans, the school plays an important role in the lives of children and their parents. But after the fall of Roman civilization, there was hardly any education in the middle centuries. Within a few years after the rise of Christianity, schools which were attached to churches and monasteries were built. These were intended for young people from the highest ranks to be formed into liturgy and church singers. Despite the fact that education was intended for the good, the situation in the big cities did not meet a healthy and comfortable climate at all. In rural areas, the condition of school buildings was even more dramatic, and school buildings were often compared with pigpens. The school from the beginning of the nineteenth century had only one classroom with sometimes hundreds of children. Old prints testify to these massive groups and give an idea of the housing. It was not until the nineteenth century that there was a

Fig. 2 Open-air school Dordrecht 1929 [13]

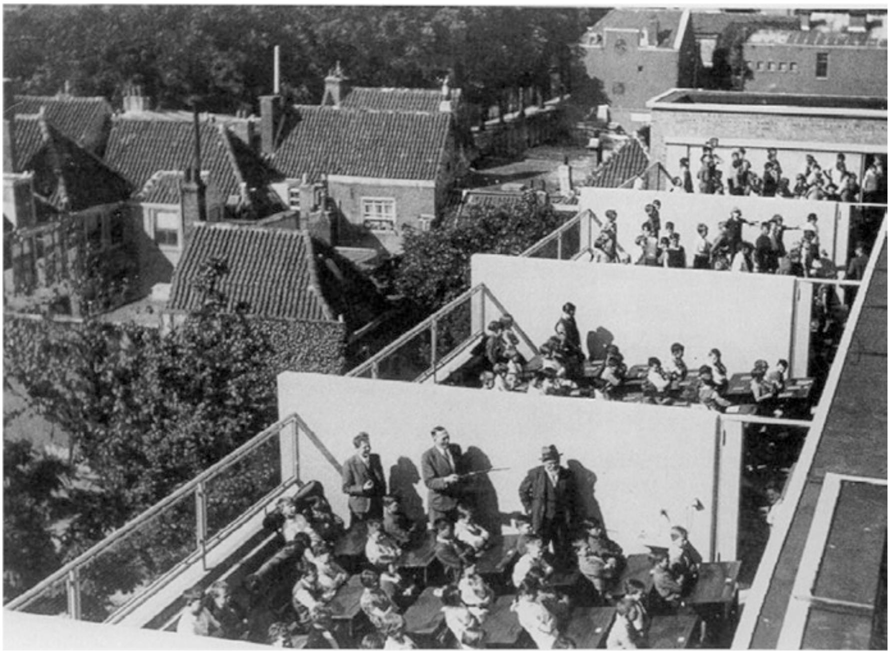


Fig. 3 Zuidwalschool Den Haag 1933 [13]

Fig. 4 Open-air school by Duiker and Bijvoet, Amsterdam 1930 [13]

turnaround; education laws proposed all kinds of measures to improve the situation. From the 1900s to the 1930s, due to all the health problems of pupils by the then prevailing tuberculosis, the concept of the open-air school was developed [13]. The phenomenon of the open-air school had a practical origin. Due to the significant health problems in industrial cities, such as tuberculosis, the solution was found in sanatoria. These were equipped with a lot of light and air as this was considered important for school-age children. The emphasis was put on ventilation and daylight entry intended for sick or weak children and usually situated outside the city or in a park-rich environment (see Figs. 2 and 3) [13].

The perhaps most well-known Dutch open-air school was designed by architect Jan Duiker in Amsterdam (1929–1930). This building is divided into the classrooms and terraces into the three-story structure in such a way that a maximum of light and air can be accessed here. The facades are located in one plane with the floor and a curtain wall with initially six large steel turn windows on the long sides of the rooms. The maximum openness, while minimizing construction, is in line with the principles of the new building style [6] (see Fig. 4). In 1994 the school was completely restored and adapted to the current educational requirements.

3 Use of Passive Strategies

With regard to passive strategies, architectural design elements, such as building shape, building façade, orientation, and window-to-wall ratio (WWR), can significantly influence the final energy use of a building. [32] made a complete overview of passive solar heating and cooling concepts and their effects on the performance of a building's thermal management. The concepts of Trombe wall, solarium, evaporative cooling, ventilation, radiative cooling, wind tower, earth air heat exchanger, roof pond, solar shading for buildings, and building-integrated photovoltaic and thermal panels are extensively covered in this review. Optimal combination of passive strategies can be analyzed, such as building shape, orientation, wall thickness and insulation, roof insulation, window orientation WWR, window-to-wall ratio, glazing, and overhang depth [31, 38, 42, 51] by applying building energy performance simulation (BEPS) such as [24]. These imply that the building's final energy can be significantly reduced through the use of passive and active strategies. However, excessive use of active strategies may be unproductive [46, 56]. Also, the effectiveness of passive strategies can vary depending on the individual thermal characteristics in a building [38].

4 Iconic Examples from the Past

Most architects dream about a school without installations, and many take St. George's County Secondary School in Wallasey as a great example (see Fig. 5).

The school designed by Emslie Morgan was built in 1961 and is considered the first English passive sun-controlled school to heat the school entirely with solar energy. However, the building has a heating system that only comes into operation under extreme outdoor conditions. Normally the sun, internal lighting, and the children themselves are a sufficient source of heat. The lighting plays a major role in heating the school, and lighting being reflected on the wall heats the room before the arrival of the children. The building has a two-story high transparent south façade,

Fig. 5 St. George's County Secondary School in Wallasey, Cheshire, England. (Photo: Jeremy Marshall [22])

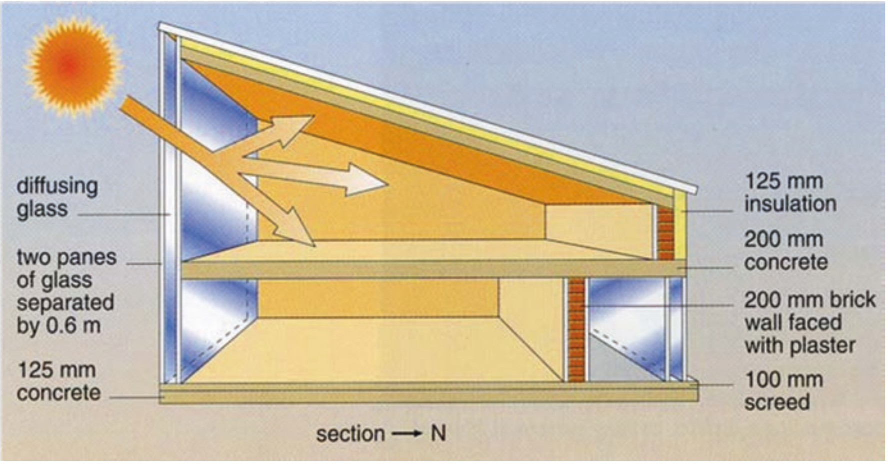


Fig. 6 Cross-section St. George's County Secondary School in Wallasey [22]

allowing the sunlight through a double skin façade consisting of two separate single glass windows with an intermediate distance of 60 cm. into space [23]. The walls and floors are made of heavy materials and thick to obtain a high buffering capacity of the structural construction (see Fig. 6).

A recent study into the current state of the building shows that due to new floor coverings on the concrete floors and the use of personal computers, the problems of overheating in the summer have increased sharply. Although the manually operated supply and discharge air valves function well in itself, it is not very user-friendly to operate in practice. As a result, the air valves are not always optimally adjusted, resulting in insufficient ventilation between 0.3 and 2.5 air changes per hour. The main problem of the building is the glare caused by the too much sunlight that enters through the all-glass south façade. This problem is very conflicting with twentieth century school equipment such as electronic whiteboards and computer screens. Although the school is an icon for the current designers of sustainable schools, one should also consider the critical aspects of the design. Nevertheless, the 1961 design with total energy use of 97 kWh/m^{2}a deserves praise and admiration, compared to the current English standard of 250 kWh/m^{2}a.

As the icon of a new generation of sustainable, low-energy, naturally ventilated sustainable educational buildings, the Queen's Building at De Montfort University, Leicester, was completed in late 1993. It gained a reputation with its stunning architecture using distinctive ventilation chimneys [18] (see Fig. 7). Architect Short Ford Associates worked on the building design alongside environmental engineer Max Fordham LLP, Cambridge Architectural Research (on the stack-effect chimneys), and Bristol University (on the physics of the airflow).

The building's operational performance was revealed in 1996 when a post-occupancy evaluation was carried out as part of the PROBE (Post-occupancy Review of Buildings and their Engineering) project. The assessment revealed a

Fig. 7 Queens Building, De Montfort University. [Photo Martine Hamilton Knight]

number of key shortcomings. Unresolved defects meant that for the first 2 years, the building operated with problems in critical mechanical and control systems [18]. The survey of its occupants showed dissatisfaction with high summertime temperatures and stuffiness in both winter and summer months [18].

The first energy-neutral sustainable elementary school of the Netherlands [58] made clear what the focus on sustainable school design should be [57]:

> A sustainable school is a sustainably designed, built, and used school building in which sustainable education is developed and provided. The building and its surroundings serve as an educational tool for illustration, demonstration, exploration, experimentation, and discovery. The concept of the sustainable school and its practical realization must be 'CONVINCING':
>
> **C** ONTEXTUAL, **O** RIGINAL, **N** EED, **V** ISIBLE, **I** NTEGRATED, **N** ATURAL, **C** LEVER, **I** NSTRUCTIVE, **N** ETWORKING, **G** LOBAL
>
> The whole concept of a sustainable school building is based on principles of sustainable development which deal with the limited availability of natural resources, the interdependence with nature, the fundamentals aspects of interdependence with nature, the fundamentals aspects of production and consumption, and the issue of equity within, between and among generations.

5 Methodology

Traditionally, the potential for energy reduction in the Netherlands was mainly determined by the applications of building energy reduction measures according to the Trias Energetica method (see Fig. 8). In the first design step, the energy demand is reduced as much as possible by avoiding waste of energy, applying high

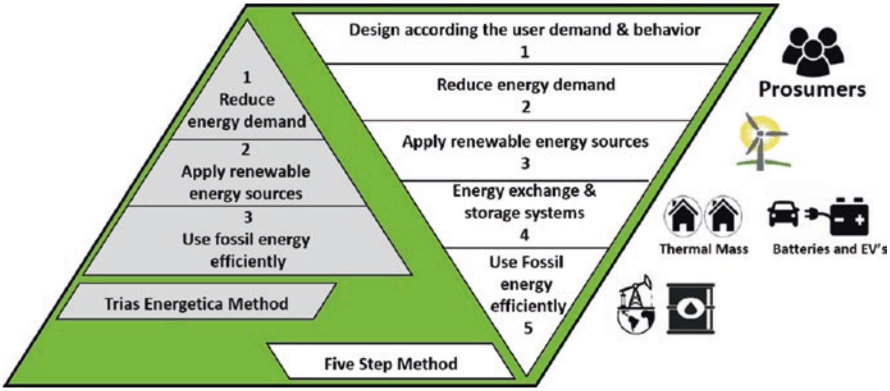


Fig. 8 The Trias Energetica method and the five-step method [55]

insulation levels, and implementing energy-saving measures, such as lowering the setpoint temperature in winter or increasing the setpoint temperature in summer slightly. In the second step, all possibilities to apply renewable energy sources are investigated. In the third step, the remaining energy demand is covered by using fossil energy solutions as efficiently as possible. An adapted version of the Trias Energetica method, the five-step method, has been developed [60] by adding the integration of user behavior, their capability to produce energy locally, as well as energy exchange and storage systems (buffer tanks, Aquifer Thermal Energy Storage) (see Fig. 8) [55].

More specifically, the first step to minimize the energy demand is to look at the actual behavior and occupancy in relation to the ventilation need, which is directly related to the number of pupils in a specific classroom. So this demand-driven ventilation is a good step to reduce the energy demand by the ventilators. A similar measure in this step is occupancy detection for the control of the lighting and daylight. This measure minimizes the use of artificial lighting, thus reducing the electricity demand. The second important step to reach nZEB is the application of the passive house strategy. This leads to energy savings on heating of 80% compared to conventional standards of new buildings. To reach these goals, the passive house concept focuses, first and foremost, on reducing the energy demand of the building through high insulation of walls, roofs, floors, and windows/doors, thermal bridge free construction, and airtightness.

In 2009, the Dutch government started their so-called UKP NESK program to stimulate innovation for energy-neutral buildings. UKP means unique chances projects, and NESK means “toward energy-neutral schools and offices” (Naar Energie neutrale Scholen en Kantoren). The published results by the Rijksdienst voor Ondernemend Nederland (RVO) showed the top 15 most energy-conscious schools in the Netherlands for 2014 and 2016 [47, 48]. The total energy consumption was determined by the energy use for heating, hot water, cooling, ventilation, and lighting. The number one school in the top 15 of the combined 2014 and 2016 list [62] is a primary school, where high thermal conductivity is obtained in the structural

Fig. 9 Overview energy generation by PV panels of school 1 [50]

elements to prevent large heat losses. The open façade parts consist of frames with three-layer glass. Solar screens are provided in order to avoid overheating. Besides, the school building generates a lot of energy due to a large number of solar panels on the roof, with an amount of 135 kWp in total: 41% of the generated energy is used by the school, the rest is delivered to the grid (see Fig. 9).

In Table 1, an overview is provided of the different HVAC concepts of the Top 15 schools. It is pretty remarkable that besides the five schools which are connected to a district heating system and the only one using a biomass pellet boiler, all other schools are using a heat pump. All Dutch projects are all applied with a balanced ventilation system and heat recovery [62].

Schools typically have a high internal heat load (heat generated by people, lighting, and buildings). As a result, the required amount of cooling is significantly higher than the average building. Nowadays, modern school buildings have reached the insulation quality at which the amount of cooling needed during the summer roughly equals the amount of heating required during the winter. Hypothetically, if all heat could be stored within the building, no external heat source would be needed throughout the year. An increasingly popular solution is energy storage in the groundwater below the building: aquifer thermal energy storage (ATES) in porous sand layers, called aquifers. These systems work in combination with a heat pump in order to ensure the required temperature difference for cooling and heating is reached. The principle of an ATES system is based on transferring groundwater between two separated storage wells. During summertime, water is extracted from the coldest well and used to cool the building (see Fig. 10).

During cooling, the water temperature increases from approximately 8 °C to 16 °C and is injected in the warmer well and stored until the winter season. During winter, the extraction/injection flow is reversed, and the heated water (which still has a temperature of approx. 14 °C) is pumped back to the building. With a heat

Table 1 Overview of different techniques used for heating/cooling and ventilation

School	HP	ATES	Pellet boiler	Borehole HE	District heating	HR boiler	Ventilation system	CO_2 control
1			X				MS+ME+HR	+
2	X	X					MS+ME+HR	+
3	X					X	MS+ME+HR	+
4	X						MS+ME+HR	+
5					X		MS+ME+HR	+
6	X	X	X				MS+ME+HR	+
7	X	X					MS+ME+HR	+
8	X	X					MS+ME+HR	+
9	X	X					MS+ME+HR	partly
10	X			X			MS+ME+HR	+
11	X		X				MS+ME+HR	partly
12	X						MS+ME+HR	partly
13					X		MS+ME+HR	+
14					X		MS+ME+HR	+
15					X		MS+ME+HR	-
16	X	X					MS+ME+HR	+
17					X		MS+ME+HR	partly
18	X	X					MS+ME+HR	partly
19	X	X					MS+ME+HR	-
20							MS+ME+HR	-
21	X	X					MS+ME+HR	-
22						X	MS+ME+HR	+
23	X	X					MS+ME+HR	-
Total	15	10	3	1	5	2	23	

pump, the heat is extracted and converted to higher temperatures to heat the building. The water is cooled to approx. 6 °C and is injected back into the cold well. A heat exchanger between the groundwater and the building system water is used to avoid water contamination. An optimal performing ATES system can deliver very efficient cooling: coefficient of performance (COP) of 12 compared to a regular (compression-based) cooling system which reaches a COP between 4 and 6 [8, 9]. Because of the favorable soil conditions, the use of ATES systems in the Netherlands has become increasingly popular since the first installations in 1990 and became an important sustainable alternative to conventional chillers. In the Netherlands, the number of ATES applications could rise from 2500 to 20,000 in the next decade, but it also has a high potential for other coastal areas throughout the world [10, 29]. The concept is suitable for residential complexes and small offices up to large-scale clusters of buildings like business neighborhoods or university campuses.

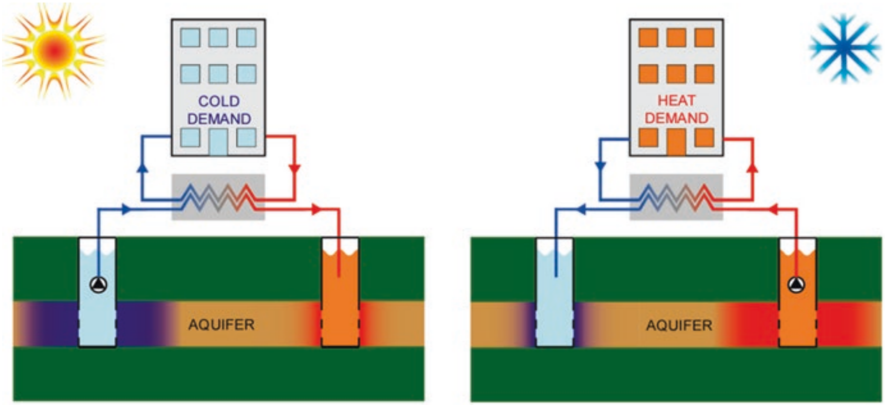


Fig. 10 Doublet ATES systems [21]

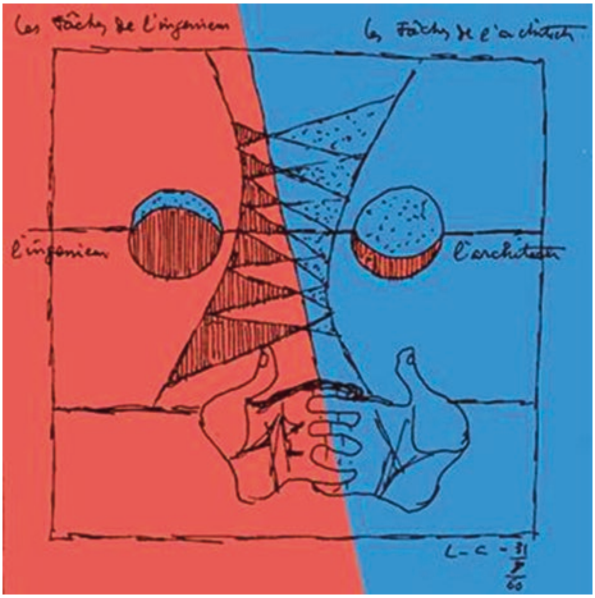


Fig. 11 Science et Vie [41]

Form and function should form a synergy instead of being sometimes in conflict with each other. Already many years ago, Le Corbusier showed how the interaction between architect and engineer should look like (see Fig. 11). Fortunately, more and more integral approaches are becoming common practice to find the optimal solution between passive and active energy elements and between architecture and building services.

Le Corbusier explains the roles of the architect and the engineer [45]: “Under the symbolic composition I have placed two clasped hands, the fingers enlaced horizontally, demonstrating the friendly solidarity of both architect and engineer engaged, on the same level, in building the civilization of the machine age” [41]. The architects and the engineers should work together from the very start of a design project and must aim to reach synergy by combining the knowledge and the experience of all disciplines already in the early stages of the conceptual design. An integral approach is needed to make this possible, which represents a broad view of the world around us that continuously needs to be adapted and developed from sound and documented experiences that emerge out of an interaction between practice, research, and education [61]. In the Netherlands, some very interesting examples show that architects and engineers can design as an integral team. These will be described next.

6 Dutch Iconic Examples from the Present and Near Future

> “Finally, it is not only a matter of methodology; it is much more. It is the urgent, and unconditional call for spirituality, and for a poetic mind, which would be able to recognize, respect, and support the beauty that nature offers for free. No methodology, no number, in fact, can be sufficient alone, as there is no technical layout for beauty.” – Alessandra Scognamiglio, ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Fig. 12 North facade of the EAE building with solar chimney visible [54]. (Photo: Egbert de Boer)

6.1 Energy Academy Europe- Groningen

The Energy Academy Europe (EAE) building (see Fig. 12), in Groningen, provides education, conducts research, and fosters innovation in the field of energy while working toward the transition to a sustainable energy future. The key energy themes of the EAE are the energy of tomorrow (such as wind and solar energy), energy efficiency, cost savings, and CO_2 reduction:

- Zero emissions (after 40 years, incl. construction)
- BREEAM-NL outstanding
- Energy performance coefficient = 0 or less
- 51 kWh/m^2 per year (which is extremely low for an education-related building)

The unique design demonstrates how a building can make optimum use of the natural elements of earth, water, air, and sunlight as a primary energy source.

The main external feature of interest on otherwise straightforward flat, triple-glazed facades is the wavy vertical *brise soleil* made from Siberian larch (from Dutch forests) [43]. They are the result of calculations on controlling solar gain to particular areas and keep the building as cool as possible on hot days. The ratio of glazing to a wall is 50% to the offices on the east- and west-facing facades but around 80% to the south winter garden side, and the north, which doesn't have direct sunlight.

A 200-meter-long air vent under the building uses the earth to cool and heat the air (see Fig. 13). The design connects outdoor air, collected on the lower south side, to the air demand on the buildings' higher northern side. Pushed through a "thermal labyrinth" and assisted by natural powers such as thermal buoyance caused by the sun and wind stream, the airflow due to occurring pressure differences is optimal for cooling the building in summer.

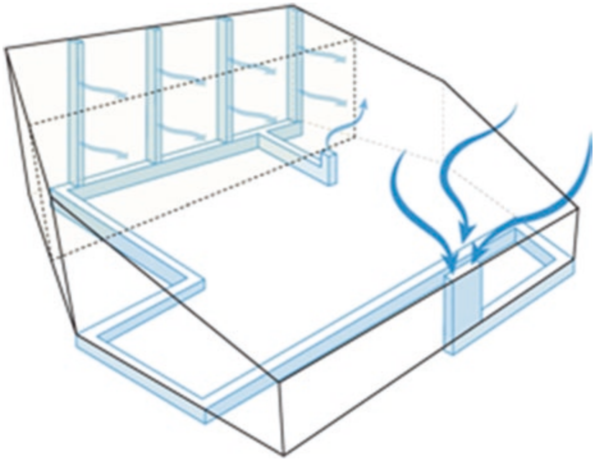
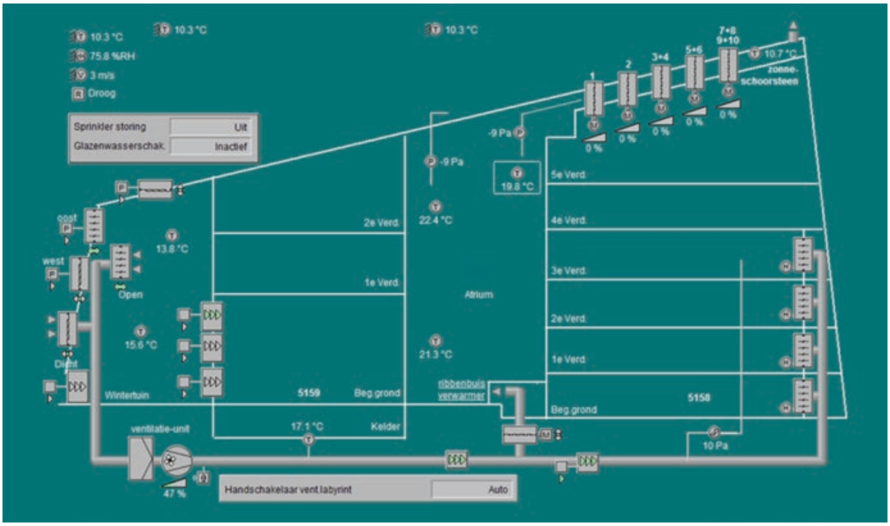


Fig. 13 Air supply through a "thermal labyrinth." [Source: Arch20]



Sprinkler storing Uit

Glazenwasserschak Inactief

Handschakelaar vent.labyrint Auto

Fig. 14 Hybrid ventilation system with process control by building management system [54]

The north side (the highest point of the building) has a solar chimney, which stimulates the airflow using solar energy and controls the flow of the return air out of the building. The controls are quite complex as all weather conditions and internal conditions have to be taken into account (see Fig. 14). This natural ventilation saves approximately 20% in energy. On warm summer nights, there is additional cooling through a natural process that requires no power. Cool night air flows through the interior winter garden via the atrium and through the entire building so that the next day occupants can start their day in a cool working environment.

The atrium connects two sections; the north side is the research area with laboratories and related workspaces, and on the south side, there are workspaces, a winter garden, and the teaching areas. Via wide stair ramps, users will feel a natural preference to take the stairs rather than the elevator (see Fig. 15).

The building does not have to rely on natural ventilation alone; if the weather conditions are not good enough, the mechanical ventilation system will step in. The building has three air handling units with a total capacity of 81,000 m^3/h (see Fig. 16).

In addition, the building will be heated and cooled through concrete core activation combined with aquifer thermal energy storage (ATES). The heating and cooling sources mainly come from the stored energy within the ground. However, the total cooling capacity of the heat pump is 830 kW and the heating capacity is 550 kW. Two deep wells dug near the building will use geothermal energy of the ATES to keep the building at a comfortable temperature. Two water reservoirs are located at a depth of 100 m – one for heating and another for cooling. In summer, the cold water is pumped up and absorbs heat in the building. This now warmed water is then pumped back into the second reservoir. In winter, this process is reversed. The water

Fig. 15 The atrium as a central connection to the different building parts. [Source: Arch20]

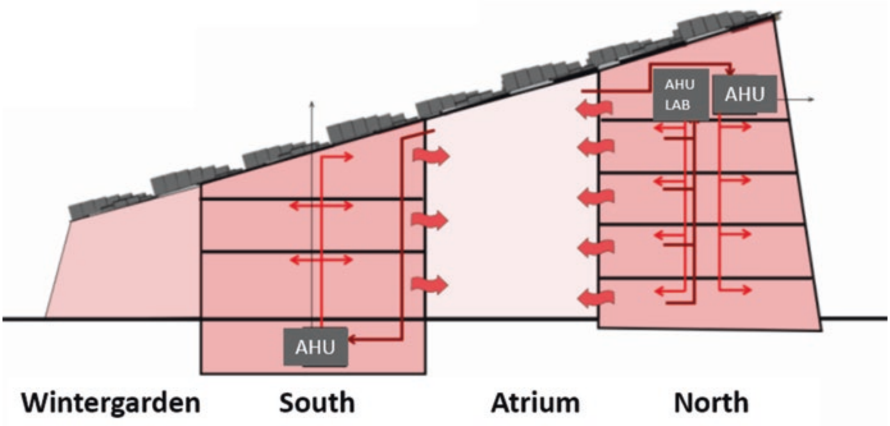


Fig. 16 The three different air handling units for the mechanical ventilation. [Source: Arch20]

is further heated by a heat pump which efficiently turns electricity into heat which is distributed throughout the building for underfloor heating (60% of the heating), to heat the airflow through climate ceilings, and to heat tap water. When needed, cold water can also be used from the nearby pond.

The building has an extraordinary energy roof (see Fig. 17). The energy roof has an optimal orientation toward the south with an unusual design of a large, slanted roof of 1600 solar panels. The panels are arranged in triangles (133 in total) so that

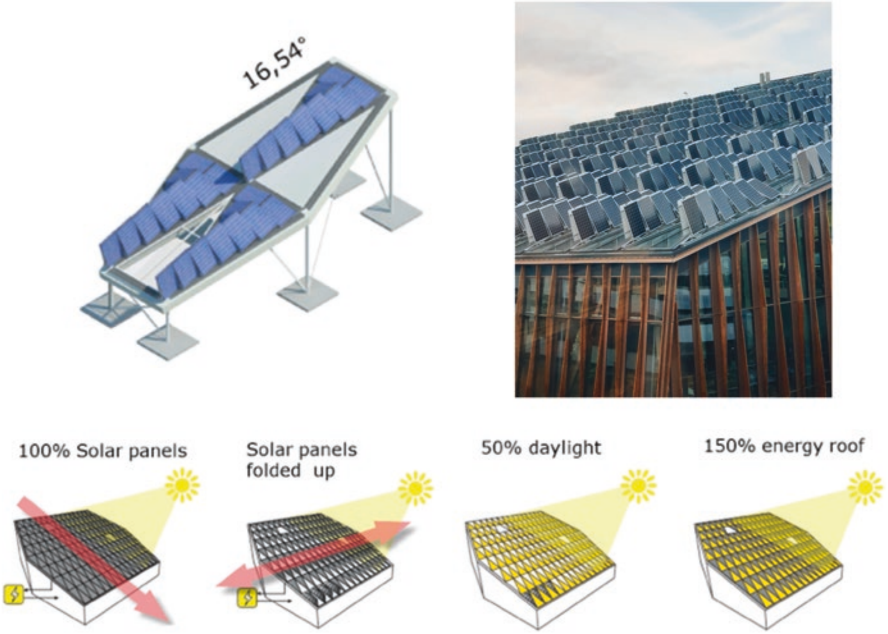


Fig. 17 Solar panel roof with windows for daylight. [Source: Arch20]

they cover 100% of the roof surface. At the same time, the design allows daylight to pass through, making it effectively a 150% energy roof.

Such a striking, effective exterior leaves no room for doubt: the building is a place with innovative passive and active energy efficiency. A team of experts worked together to achieve this, consisting of Broekbakema, pvanb architecten, ICS, Arup, Structural consultant Wassenaar, and building physics consultant DGMR.

6.2 Ecological Primary School De Verwondering Almere

The design of the primary school De Verwondering of 1900 square meters and 14 classrooms (see Fig. 18) is inspired by nature Architect Daan Bruggink, who suggested biophilic principles should be translated into all kinds of buildings levels and spatial context. The school consists of clusters of classrooms that form the biotopes for pupils of different age groups. These are so oriented toward each other that a natural gap is created that encompasses the central space. The school design is made as circular as possible in a dry and demountable system, with local materials and local wood. Natural and biobased materials are dominant, and wood is the primary building material for the school. In the classrooms, the interior walls are made of clay stones to get thermal mass into the building. Nowadays, airtight construction and good insulation are two key concepts that are becoming increasingly important

Fig. 18 Primary school De Verwondering Almere. [Photo: Ronald Auee]

in building design. However, this also means the need to cool a building increases as the indoor temperature can become too high during the warmer (summer) months. Therefore, each room is equipped with large ventilation hatches combined with large roof hatches in the roof of the central area to provide natural ventilation and night ventilation to cool the school in summer. Solar collectors on the roof (see Figs. 19 and 20) absorb the heat from the ambient air, and then the heat is stored in an underground ice buffer (see Fig. 21).

A heat pump transfers the water from the buffer to the desired temperature to heat the building. If it gets colder, that water in the ice buffer is cooled to below freezing. When cold water transitions to ice, energy is released, the crystallization heat. This heat can then be used to meet the heat needs. The ice can cool the building in the summer; the heat of the building is then used for heating again in winter. From the end of the heating season, the reverse process begins. The ice buffer is a form of thermal energy storage, and such can be an alternative for the earlier discussed ATES.

On the roof of the lowest cluster, there is an open-air classroom, partly covered and surrounded by the vegetation roof, on which even chickens walk. This outdoor room (see Fig. 22) is used all year round so pupils can experience the weather, the seasonal changes, the environment, and all other natural aspects that play a role in teaching. It is possible to teach within the covered classroom approximately 300 days a year. It was already “fully booked” during the first year of operation. Indeed, based on natural and biophilic considerations, this is a modern version of the old and earlier discussed open-air schools’ principle.

Fig. 19 The green and energy roof of the school with solar thermal collectors and PV panels. [Photo; ORGA architect]

Fig. 20 The solar thermal collectors to feed the heat pump ice buffer system. [Photo: TDS Engineering]

Fig. 21 Ice buffer. [Source ORGA architect, Gemeente Almere, Heko Spanten]

Fig. 22 Open-air classroom on the top floor of the school. [Photo: Ronald Auee]

Design team: Architect Daan Bruggink-Orga architects, Structural engineer Lüning, Building Services consultant Bart Ruijs TDS Engineering, Building Physics consultant Nieman, Plant design Well Planted, Contractor Van Norel Bouwgroep. Special thanks to Daan Bruggink and Bart Ruijs for their collaboration.

6.3 Erasmus University Rotterdam: MFO II

The Erasmus University Rotterdam's (EUR) new multipurpose educational building MFO II (see Fig. 23), covering some 8500 m^2 (91,500 sq ft), is currently being built and will become one of the most sustainable university buildings in the Netherlands. It will house lecture halls, teaching rooms, a lounge area, and plenty of study space for around 3000 students from various faculties. Energy neutrality, circularity, and vitality are the main goals while simultaneously inspiring and stimulating, sustainable, and aesthetically appealing surroundings for students and staff. The following minimum requirements for its sustainability were formulated [27]: BREEAM opens external 1 rating as "outstanding," building circularity performance (BCP/CPG 2) score is 8, and energy performance coefficient (EPC) is 0. The design, development, and construction contract was granted to a consortium made up of Paul de Ruiter Architects, Halmos Building Services consultants, and LBP|SIGHT building physics consultants together with BAM as construction partner. Their design will actually generate more energy than it will use, thanks to roof-mounted solar panels, heat pumps, and ATES. One of its unique features will be a revolutionary new ventilation system using wind and solar energy. This "powered by nature" air-conditioning system was developed by Ben Bronsema [14–17], the Earth Wind and Fire (EWF) concept (see Fig. 24) in collaboration with the Universities of Technology of Delft and Eindhoven [[7, 34], Hooff et al. 2021] and first applied at the end of 2018 in hotel BREEZE in Amsterdam [15–17]. The design

Fig. 23 Erasmus University Rotterdam MFO II Building. [Photo: Paul de Ruiter Architects]

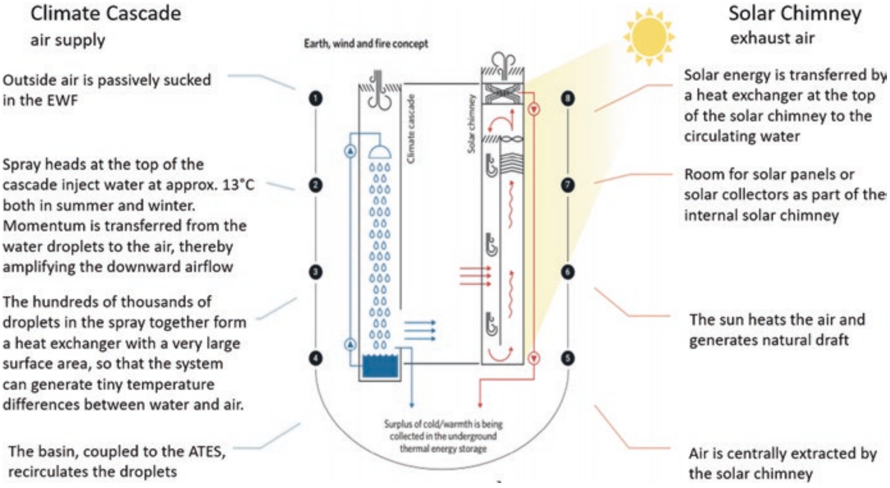


Fig. 24 The EWF concept [37]

requirements of the EWF concept have been meticulously applied, and multiple optimizations have been implemented on the system, such as energy recovery between the air from the solar chimney, and to the climate cascade, variable airflow by application variable volume controls with low resistance and application of multichannel heat exchangers (MCHE) as low resistance heating coils. Two EWF ventilation systems are applied with a total air quantity of 135,000m^3/h and a resistance of 140Pa in supply and in the exhaust of 80Pa (normal for air handling units is approximately 900 and 600Pa). With this system, energy savings of more than 50% are achieved compared to air treatment cabinets, of which 90% are on fan energy.

7 Conclusion

Building comfort by natural means is about finding the right balance between architecture and engineering, form and function. The goal is not to minimize the use of external or additional building services systems but to aim for the most optimal combination of natural means and other efficient systems, that is, the right balance between passive and active systems. In particular, when designing schools, this is of utmost importance to create a healthy and effective learning environment. There are a growing number of examples where the building itself becomes part of the education, not only to facilitate it alone. The focus of this chapter is especially placed on schools as they offer possibilities to include elements in the education of the pupils and involve their parents and therefore show the new generation what the possibilities to create a more sustainable built environment are. Some of the most inspiring Dutch examples are presented in this chapter. They are a good promise of even better things to come by a new generation more aware of the necessity and the possibilities that nature and technology offer.

References

1. Aa A. van der, 2002, Pilot study report: School building Waterland, International Energy Agency, Energy Conservation in Buildings and Community Systems, IEA ECBCS Annex 35 HybVent, report date 01-02-02.
2. Almeda R.M.S.F., Freitas V.P. de, 2014, Indoor environmental quality of classrooms in Southern European climate, Energy and Buildings 81: 127–140.
3. Almeda R.M.S.F., Freitas V.P. de, 2015, IEQ assessment of classrooms with an optimized demand controlled ventilation system, Proceedings 6th International Building Physics Conference, June 14–17, Turin, Italy
4. Almeida M.G., Ferreira M., Rodrigues A., 2015, CO2 zero schools School building renovation towards emissions neutrality REHVA Journal – December 2015: 34–38
5. Arch20, 2021, Energy Academy Europe (EAE) | Broekbakema + De Unie Architecten, https://www.arch2o.com/energy-academy-europe-eae-broekbakema-de-unie-architecten/
6. Architectureguide, 2021, http://www.architectureguide.nl/project/list_projects_of_tag/tag_id/15/prj_id/362
7. Blocken B., Hooff T. van, Aanen L., Bronsema B., 2011, Computational analysis of the performance of a venturis shaped roof for natural ventilation: venturi-effect versus wind blocking effect, Computers and Fluids 48(1): 202–213
8. Bloemendal, M., Hartog, N., 2018. Analysis of the impact of storage conditions on the thermal recovery efficiency of low-temperature ATES systems. Geothermics 17, 306–319.
9. Bloemendal, M., Olsthoorn, T., Boons, F., 2014. How to achieve optimal and sustainable use of the subsurface for Aquifer Thermal Energy Storage. Energy Policy 66, 104–114.
10. Bloemendal, M., Olsthoorn, T., van de Ven, F., 2015. Combining climatic and geo-hydrological preconditions as a method to determine world potential for aquifer thermal energy storage. Science of the Total Environment 538 621–633.
11. Brandt Y., 2015, Education: the most powerful investment in our future, https://blogs.unicef.org/blog/education-the-most-powerful-investment-in-our-future/
12. Brink H.W., Loomans M.G.L.C., Mobach M.P., Kort H.S.M., 2020, Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: a systematic literature review. Indoor Air. https://doi.org/10.1111/ina.12745
13. Broekhuizen D., 2005, Openluchtscholen in Nederland, Architectuur, onderwijs en gezondheidszorg 1905–2005, Uitgeverij 010, Rotterdam 2005.
14. Bronsema B., 2013, Earth, Wind & Fire – Natuurlijke Airconditioning, PhD thesis TU Delft, https://tudelft.on.worldcat.org/oclc/845637529.
15. Bronsema B., Bokel R., Bruggema H., Luijk R. van, Mook A. van, Potter M. de, Meerstadt O., Quist M., 2018c, Earth, Wind & Fire: The Evolution of an Innovation (2) – 'Fire': Natural ventilation and air-conditioning using the climate cascade, REHVA Journal October 2018: 65–73
16. Bronsema B., Bokel R., Bruggema H., Meerstadt O., Quist M., Spoel W. van der, Swier P., Veerman J., Vermeer J., 2018b, Earth, Wind & Fire: The Evolution of an Innovation (1) – 'Earth': Natural ventilation and air-conditioning using the climate cascade, REHVA Journal June 2018: 65–79
17. Bronsema B., Luijk R. van, Swier P., Veerman J., Vermeer J., 2018a, Natural air conditioning: what are we waiting for?, REHVA Journal April 2018
18. Bunn R., 2007, Live and learn: Queens Building, De Montfort University, Building ServicesJournal , April 2007
19. Clements-Croome D.J., 2020, Designing Building for People: Sustainable Liveable Architecture, Crowood
20. Dijken F. van, Gelderblom A., 2016, Performance of mechanical ventilation systems in primary schools in Rotterdam, the Netherlands, Proceeding Indoor Air, Gent, Belgium
21. Drijver B., Willemsen A., 2015, Groundwater as a heat source for geothermal heat pums, International summer school on direct application of geothermal energy, https://www.

researchgate.net/publication/267300619_GROUNDWATER_AS_A_HEAT_SOURCE_FOR_GEOTHERMAL_HEAT_PUMPS

22. Elsadig A.K., 2005, Energy Efficiency in Commercial Buildings, PhD-thesis Faculty of Engineering department of mechanical Engineering Energy Systems Research Unit, University of Strathclyde, June 2005, pp. 42–43.
23. Energie-Cités, 2006, Bringing sustainable energy into your school, A Handbook for teachers and school managers, produced by Energie-Cités as part of the School Buildings Integrated Energy development Operation (SchoolBIE-DO), pp. 36–40
24. EnergyPlus, 2021, EnergyPlus Manual; Department of Energy: Washington, DC, USA. https://energyplus.net/documentation
25. EU, 2020, https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-feb-17_en0
26. EU, 2021, EU Buildings Factsheets, https://ec.europa.eu/energy/eu-buildings-factsheets_en
27. EUR 2020, https://www.eur.nl/en/campus/tomorrows-campus/ongoing-projects/multipurpose-educational-building/sustainability
28. EWF-Lab, 2021, Earth, Wind and Fire, https://www.ewflab.nl/literatuur/
29. Fleuchaus, P., Godschalk, B., Stober, I., Blum, P., 2018. Worldwide application of aquifer thermal energy storage – A review. Renewable and Sustainable Energy Reviews 94, 861–876.
30. Golshan M., Thoen H., Zeiler W., 2018, Dutch Sustainable Schools towards Energy Positive, Journal of Building Engineering 19: 161–171
31. Gong X.Z., Akashi Y., Sumiyoshi D., 2012, Optimization of passive design measures for residential buildings in different Chinese areas. Build. Environment 58: 46–57
32. Gupta N., Tiwari G.N., 2016, Review of passive heating/cooling systems of buildings, Energy Science and Engineering 4(5): 305–333.
33. HighScope, 2021, Perry Preschool Project, https://highscope.org/perry-preschool-project/
34. Hooff T. van, Blocken B., Aanen L., Bronsema B., 2011, A venturi-shaped roof for wind induced natural ventilation of buildings: wind tunnel and CFD evaluation of different design configurations, Building and Environment 46: 1797–1807
35. Hooff T. van, Blocken B., Aanen L., Bronsema B., 2012, Numerical analysis of the performance of a venturi-shaped roof for natural ventilation: influence of building width. Journal of Wind Engineering and Industrial Aerodynamics 104–106: 419–427.
36. Hou Y., Liu J., Li J., 2015, Investigation of Indoor Air Quallity in Primary School Classrooms, Proceedings 9th ISHVAC & 3rd COBEE conference, Tianjin, China
37. Huijbers K., 2021, ABT en EWF-Lab, https://www.ewflab.nl/wp-content/uploads/2021/02/ABT-en-EWF-lab.pdf
38. Kang J.E., Ahn K.U., Park C.S., Schuetze T., 2015, Assessment of Passive vs. Active Strategies for a School Building Design Sustainability 7(11): 15136–15151
39. Kolokotroni M., Perera M.D.A.E.S., Azzi D., Virk G.S., 2001, An investigation of passive ventilation cooling and control strategies for an educational building, Applied Thermal Engineering 21 (2001) 183–199.
40. LCVS, Landelijk Coördinatieteam Ventilatie op Scholen, 2020, Eindrapportage, Beeld van ventilatie op scholen in het funderend onderwijs in Nederland, 1 oktober 2020.
41. Le Corbusier, 1960, Science et Vie, August.
42. Nguyen A.T., Reiter S., 2012, Passive designs and strategies for low-cost housing using simulation-based optimization and different thermal comfort criteria. J. Build. Perform. Simul. 7: 68–81
43. Parker J., 2017, Intellectual Energy, Energy Academy Europe Groningen, Netherlands, ADF December 2017, www.architrctsdatafile.co.uk
44. Plotka E., 2016, Better spaces for learning, RIBA.
45. Popovic Larsen O., Tyas A., 2004, Conceptual Structural Design: Bridging the Gap Between Architects and Engineers, American Society of Civil Engineers, Thomas Telford Ltd.
46. Ramesh T., Prakash R., Shukla K.K., 2010, Life cycle energy analysis of buildings: An overview. Energy Build 42: 1592–1600
47. RVO, 2015, Top 15 energiezuinige scholen onderzoeksrapport 2014, Rijksdienst Voor Ondernemend Nederland, Utrecht

48. RVO, 2016, Top 15 energiezuinige scholen onderzoeksrapport 2016, Rijksdienst voor Ondernemend Nederland
49. Salthammer T., Uhde E., Schripp T., Schieweck A., Morawska L., Mazaheri M., 2016, Children's well-being at schools: impact of climatic conditions and air pollution, Environ. Int., 94: 196–210
50. SCX Solar, 2014, https://www.scx-solar.eu/projecten/zonnestroominstallatie-op-mfaschool-hart-oijen/
51. Soussi M., Balghouthi M., Guizani A., 2013, Energy performance analysis of a solar-cooled building in Tunisia: Passive strategies impact and improvement techniques, Energy Build. 67: 374–386
52. Spring M., Dazzling achievement, Building connect, 8 June 2007, www.building.co.uk/story.asp?sectioncode=583&storycode=3088489&c=1
53. Vilecekova S., Kapalo P., Meciarova L., Burdova E.V., Imreczeova V., 2017, Investigation in Indoor Environment Quality in Classroom – Case study, Procedia Engineering 190: 496–503
54. Vos A., Groep W. van de, Türkcan O., 2021, Hybride ventilatie met natuurlijke bronnen, TVVL Magazine 01 Februari 2021
55. Walker S.S.W., 2021, Sustainable energy transition scenario analysis for buildings and neighborhoods: Data-driven optimization, PhD thesis TU Eindhoven.
56. Wang Q., Zhang Y., Ahuja S., Augenbroe G., 2014, Re-evaluation of passive design measures in the BASF house in recognition of uncertainty and model discrepancy, Proceedings of the 30th International PLEA Conference, Ahmedabad, India, 16–18 December 2014.
57. Weenen H. van, 2000, Passive Solar Schools International Expertise in Support of the First Sustainable Elementary School of The Netherlands International Workshop, 3–5 March 2000, Castricum, The Netherlands.
58. Weenen H. van, Dettmers W.J.M., Overtoom M.S.J., Poldermans H.G.J.M., 2000, Development of the First Sustainable Elementary School of The Netherlands, Proceedings International Conference Sustainable Building 2000, 22–25 October, Maastricht, the Netherlands.
59. Woodger H, 2017, Energy academy provides a low-tech lesson for the future, Future Constructor and Architect, fc&a, https://www.fca-magazine.com/features/greenhouse/941-breeam-energy-academy-provides-a-low-tech-lesson-for-the-future
60. Zeiler W., Gvozdenović K., Bont K. de, Maassen W., 2016, Toward cost-effective nearly zero energy buildings: The Dutch Situation, Science and Technology for the Built Environment 22(7): 911–927,
61. Zeiler W., 2017, Dutch academic Building Services design education: Integral Design to connect industry and university, essential for nZEB design, REHVA Journal: 01/2017:57–62
62. Zeiler W., 2018, Dutch efforts towards sustainable schools, Proceedings WREC, July 30th – August 3th, Kingston, London, UK

Wim Zeiler started in the building services industry in 1983 and is since 2001 Full Professor of Building Services at the Department of the Built Environment, Eindhoven University of Technology (TU/e), the Netherlands. In addition, Zeiler is still a part-time building services technology specialist at Kropman Building Services contracting. He was awarded in 2009 a gold medal by TVVL, the Dutch Technical Society for Building Services. In 2014 he received a professional science award from REHVA, the European Federation for Heating, Ventilation and Air-conditioning. His research is on integral design, intelligent buildings, and flexible smart grid integration.