Earth, wind and fire
Towards new concepts for climate control in buildings

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ABSTRACT

The Earth, Wind and Fire concept means letting nature do its work in controlling the interior climate of buildings. It reduces the need for HVAC technology, minimizes energy consumption and boosts workplace productivity.

Since about 1900, architects have gradually lost the art of designing buildings as *'machines'* for climate control. Climate engineers remain fixated on HVAC systems. This trend will have to be interrupted if we are to achieve integrated designing of buildings plus their interior environment.

To break out of the trend, it is essential to have a reliable common base of knowledge, expertise and understanding. This common base, identified metaphorically as a *'Grammar of Integrated Design'* (henceforth *Grammar. I.D.*), will be developed in a research titled 'Earth, Wind and Fire'. The knowledge gained will enable architects to play a significant artistic and intellectual part in creating a sustainable built environment.

The study comprises the analysis, exploration of design alternatives, modeling and validation of various techniques that will let nature do its work again in a building. Principles and variants of the architectural design will be investigated by architectural students.

Keywords
Wind, sun, natural, ventilation, climate-control

INTRODUCTION (1)

The researcher is an experienced consulting engineer in building services, who has worked with many architects and knows this professional group well. Since many years he is also coaching, advising and assisting MSc students at the faculty of architecture. He observed that generally students, just like architects, dislike mechanical systems and often present quite surprising and sometimes amazing proposals for a more natural way of climate control. The exercise *Dream and Realization* of the chair *Constructional Integration and Coordination* appeared to be a breeding place for many fantastic ideas. The *Dreams* come from the students but the question if *Realization* is feasible has to be answered by the indoor climate consultant. The problem is that in many cases the consultant does not know how to answer these questions and also misses the tools for that; this problem is the immediate cause of the research program *Earth,* Wind *& Fire*.

The researcher wants to combine his knowledge, experience and power to draw up a *Grammar I.D.* which is intended to answer questions like these for the benefit of students, architects, the building industry and the environment. The study will be carried out as doctoral research.

So, this paper does not give solutions. It is intended to check if the right questions are asked, to gain the view of CIB experts to the problem as stated above, and to gather information on the state of the art in this field worldwide.

INTRODUCTION (2)

Building services have developed during the last 150 years to become a dominating factor in the built environment. All over the world, electromechanical services in buildings provide a comfortable, productive indoor environment, as well as hygiene, security, lighting and communications. Compared to past times, architects have won a much greater design freedom, and have accordingly changed the look of our world.

On the downside, electromechanical services place a heavy burden on the available energy, raw materials and financial resources. They have made society dependent and have made buildings more complicated. Is this trend reversible, and if so, how can that reversal be brought about?

DEVELOPMENT OF BUILDING SERVICE TECHNOLOGY

Building services systems as they are now have developed over about 150 years, roughly from 1850 to 2000. The main technical advances in this area took place in the latter half of the 19th century.

Climate control, or HVAC, is the building service that has done most to change the building world and architecture. For centuries, the architecture of a building was carefully gauged to the location. For centuries, too, buildings were carefully designed to allow the admission of light and air, and to repel or admit solar heat as appropriate. The development of technical systems made all these considerations superfluous. Electrical and mechanical equipment made buildings independent of nature and assured an unprecedented level of comfort. These systems also greatly enlarged the design freedom of architects, who have accordingly taken full advantage of them. The disadvantage has been that buildings have become wholly dependent on their electromechanical systems. They can no longer function without building services technology.

DEVELOPMENT OF BUILDING SERVICES TECHNOLOGY IN THE 20th CENTURY

The development of building services has meant an increase in the costs allocated to technology. Figure 1 represents the development of these costs over time. The building services costs in well-equipped office buildings have increased by a factor of 10 in 100 years. All kinds of technical systems have contributed to this development, but the cost of climate control systems (Health, Comfort and Hygiene) clearly dominates.

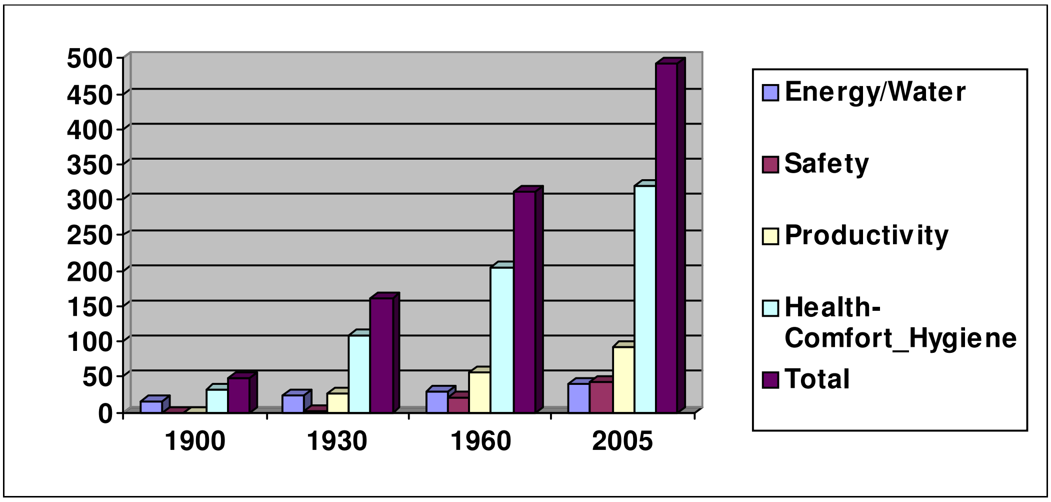


Figure 1 Building service costs in office buildings 1900-2005 in €/m^2_{gfa} (excl. VAT)

REASONS TO EXPECT A TREND TOWARDS MORE INSTALLED BUILDING SERVICES TECHNOLOGY IN THE 21st CENTURY

There are some ongoing developments which give grounds to expect further rise in the level of installed building services, for example:

- Architecture is using increasingly exuberant forms and masses, a trend not unconnected with increasing prosperity. Building services are increasingly necessary to obtain a satisfactory indoor environment in these buildings.
- Some areas of the world (for instance the Netherlands) experience an increasing shortage of building land. This fuels a trend towards taller buildings, building underground, building on water and multiple land utilization. Building services play an important part in such buildings.
- In buildings of the above kind, which have lost direct touch with the natural environment, increasingly high standards will be required for the indoor environment.
- The rising use of communication technology will entail enhanced technical facilities in buildings.
- The demand for luxury and comfort will increase.
- More mechanical ventilation will be needed in metropolitan and traffic-dominated situations because the poor quality of the outdoor air often makes natural ventilation undesirable.

REASONS TO EXPECT A TREND TOWARDS LESS INSTALLED BUILDING SERVICES TECHNOLOGY IN THE 21st CENTURY

On the other hand, developments have been noted pointing towards a lower level of installed services. Some examples are:

- Architecture is showing a perceptible trend towards controlling the indoor environment in a more natural way, with more reliance on natural daylight and natural ventilation.
- The integrated design of buildings and their indoor environment will reinforce the above trend.
- Sustainability is becoming an increasingly prominent political and social issue. Experimentation with low technology buildings, low energy and passive buildings is taking place worldwide.
- In the future, achieving a lower energy consumption in buildings will not be enough. Buildings will have to become at least energy neutral, and in the long run will have to become net suppliers of energy.

TOWARDS ENERGY NEUTRAL BUILDINGS

Buildings and climate control systems are normally designed separately rather than integrally, with the result that substantial HVAC installations are needed to create an acceptable indoor environment. The side effects of this are a suboptimal quality of the building, high failure costs in the building process, a high energy consumption for climate control, high running costs and a short building life span.

This situation will not change as long as architecture and climate engineering remain strictly separate domains. A different outlook on the design process is required, an outlook in which the conceptual distance between the architect and the climate engineer is reduced and they have confidence in each other's professional field.

The architect, with all his creativity and his influence on the building process, is largely uninvolved when it comes to matters of energy and the indoor climate. He must be persuaded to become a partner in the climate system design. As a technical and artistical co-designer of the climate system, he has an opportunity to excel in this area, thereby bringing to bear an unprecedented level of intellectual and artistic potential. Turning the building itself into a machine for climate control will allow the installed systems to remain simple and robust.

The climate engineer generally has a strong focus on the proper functioning of the installed systems. He sees them as independent elements and has little concept of the usefulness and necessity of integrating and coordinating all the building components into a single built whole, and of the potential beauty of that whole (Verheijen 2002). The climate engineer is not trained for that and lacks the requisite knowledge and tools.

To change this situation, a common base of knowledge, skill and understanding is needed. This is the objective of the Earth, Wind and Fire study. The direct utilization of natural elements for climate control brings the architect back to one of the fundamental aspects of his profession. For the climate engineer, it holds out a challenge to practice his profession at a higher level. The architect and the climate engineer will eventually be capable of designing architecture and the indoor climate in a truly integrated manner. This approach is a serious necessity in trying to achieve an energy neutral building. It will also substantially reduce failure costs in the building process, with their inherent and undesired consequences for the environment.

THE STATUS QUO IN 2005

Architects will probably need relatively little inducement to stop restricting themselves to shapes and masses and instead to put effort to optimizing the passive climate control of their designs. Proof of this is provided by the widely expressed admiration and appreciation of work by certain international architectural celebrities who have gained a name in this area.

Buildings designed this way adapt to their natural context. The sun and wind are utilized as natural phenomena to obtain an optimal indoor environment, and in some cases the ground is coupled interactively to the building mass. Electromechanical equipment is avoided as much as possible. In short: first class integration! (Luscuere 1992).

These buildings not infrequently cut across conventional boundaries, sometimes with striking results. Most of them have a ‘green image’, promise a lower energy consumption and offer an improved indoor climate. They often engage with a widespread public distrust of air conditioning. But are these buildings really all that good? This question arises because media publications pay considerable attention to the design but very little to the energy consumption and other performance aspects of such buildings.

The scientific basis of these designs is moreover often unavailable. Information about generic design methods or a design methodology cannot be extracted from the publications concerned, with the result that they remain incidental architectural performances. When design tools such as simulation and/or CFD analysis have apparently been used to put the architect’s intuitive design to the test, these tools are in most cases specific, highly specialized software applications. The essential research question to be addressed is as follows: Design a Grammar. I.D. which architects and climate engineers can use as a basis for the conceptual design of *“performative architecture”*. Once such a grammar is available, it will surely become possible to persuade climate engineers to abandon their fixation on fans, pumps, pipes and air ducts, and to devote their attention to climate control at a higher level.

NATURAL VENTILATION: DICHOTOMY OF THERMAL COMFORT OR PRODUCTIVITY

Applying natural ventilation is an important means towards energy neutral buildings. During hot summer weather, however, naturally ventilated buildings without cooling generally fail to satisfy objective comfort criteria as established by the PMV (predicted mean vote) model for thermal comfort (Fanger 1970, ISO 1994).

An extensive, worldwide study has demonstrated that people are often more tolerant towards the spatial conditions in which they work than would be expected from calculations based on the thermo physiological model of ISO 7730. Considerable differences are however observed between individual buildings.

Buildings with a central climate control and non-operable windows give people few options for adjusting their environment, and their tolerance towards the indoor climate proves much smaller under these conditions than in naturally ventilated buildings without cooling. Expectations undeniably play a part in this effect.

In naturally ventilated buildings where people can exert a greater influence on their thermal surroundings, the spread of acceptable space temperatures is much wider, and substantially exceeds the comfort limits defined in ISO 7730. Only 50% of this spread can be explained by the difference between the space temperature and the outdoor temperature, by clothing and by the relative air velocity in the interior. The rest of the spread must be ascribed to physiological and psychological adaptation processes which alter the *'set point'* of subjective thermal comfort.

Greater tolerances in the air temperature may thus be acceptable from a thermal viewpoint, but in combination with a high air humidity they may exert a negative influence on people's labor productivity, as shown by studies carried out by Fanger and co-researchers. The enthalpy of the interior air proves to have a significant influence on the perceived air quality, which in turn affects productivity. *"Serve the ventilation air cool and dry, lower the ventilation capacity, raise productivity and save energy"*. That in short is Fangers' maxim for the 21st century.

Toleration of a high room temperature, which could potentially yield a lower energy consumption and lower investment costs for climate control, must thus be paid for with lower productivity. It ought to be possible to combine the best of both worlds: a naturally ventilated building in which the ventilation air can nonetheless be supplied in cool, dry form. The Earth, Wind & Fire research aims to investigate the feasibility of a climate control system that meets this aim.

RESEARCH QUESTIONS

Earth

The earth is an almost inexhaustible source of heat and cold. When actively coupled to the building mass, it can provide heat to the building in wintertime and cooling in summertime. Thermal activation of the building mass, or slab activation, has become popular in some countries. The earth is also a constant source of gravitational force, which can actuate air currents required for natural ventilation.

Research issues are (see figure 3):

- How to heat up and possibly humidify the ventilation air in wintertime at the very low pressure losses typical for natural ventilation systems?

- How to cool and possibly dry the ventilation air in summertime in order to improve the indoor environment quality and obtain the required negative stack effect?
- Which pitfalls regarding moisture and condensation can be expected if natural ventilation is applied in a cooled building?
- How can gravitation be used for the transport of ventilation air? What are the psychometric, hydraulic and energetic properties and design criteria for vertical cooling washers?
- Is it possible and feasible to collect rainwater and to utilize it in a vertical cooling washer for conditioning the ventilation air?

Wind

As the wind speed increases with the height above the ground, the wind pressure on the top of buildings can be considerable, especially on high rise buildings. The research comprises the following issues (see figure 2):

- How can we make use of this effect by catching the wind at this level and duct it into the building at various wind directions?
- How will this approach influence the design of roofs? What can we learn from airplane wings?
- What are design criteria for roof hoods or special roof structures? Can commercial available wind catchers be useful?
- How much wind pressure is attainable for conditioning the air, taking into consideration the wind rose at the various location?
- How can negative wind pressure be used for air extraction, for example using cowls or special roof structures?
- Is it possible and feasible to use the ventilation system to generate wind energy, for example outside office hours and in periods of strong winds?
- What does this imply for the orientation of buildings?

Fire

The sun, like the wind, is an inexhaustible source of energy, but in office buildings solar heat is mostly kept outside as much as possible. Because of the high-quality insulation and the internal loads, solar heat has often to be dissipated by cooling, even in wintertime. Nevertheless, buildings receive an enormous amount of solar energy, which should be captured and used. Research issues are (see figure 4):

- How can solar heating be utilized to provide the natural draught for extraction of the ventilation air?
- Which are the design criteria for solar chimneys in buildings?
- What role could these solar chimneys play as thermal sources for heating a building during the

heating season?

- What is the performance of combined wind and sun ventilation systems taking into consideration their simultaneousness based upon weather data?
- What does this imply for the orientation of buildings and the design of façades?
- What are the implications for the architectonic design of buildings?

General

Natural ventilation in the Earth, Wind & Fire concept operates at very low pressures. As a consequence the size of the channels has to be increased compared to mechanical systems with sheet metal ducts. It is obvious to integrate the channels in the building design making them part of the construction. Research issues are:

- What does this imply for the architectonic design of buildings?
- What is the impact on the life cycle of buildings, financial and environmental?

The Earth, Wind & Fire concept uses mainly natural elements but, as these vary in time and power, supporting electromechanical and control systems will be necessary to fulfill the requirements of the indoor environment. This raises the following research issues:

- Which supporting electromechanical and control systems are necessary?

ENERGY AND SUSTAINABILITY

In the search for an energy-neutral building, the potential contribution of the Earth, Wind & Fire concept may be broadly quantified as follows:

- Reduction of energy consumption for heating through the use of heat pumps together with ground buffering and solar chimneys as heat sources and building components for heat delivery. The small temperature differential makes a heat factor in the region of 10 possible, so that the heat consumption on the basis of primary energy can be reduced to about 10 percent in comparison to a central heating boiler.
- The Earth, Wind & Fire concept makes use of natural ventilation, so that the ventilating fan power consumption is reduced to practically zero. Only the pump power requirement will increase, to a limited extent.
- The ventilation air and thus the building are cooled using cold stored in the ground, for which no external energy is required. Only the pump power requirement will increase, to a limited extent. Below I assume a residual consumption of 20% compared to the traditional situation.

Consider an office building with full climate control. The gas consumption is 10 m^3 per m^2 and the electric power consumed by HVAC equipment is 70 kWh/m^2.a. The energy consumption data before and after introduction of the Earth, Wind & Fire concept are as follows:

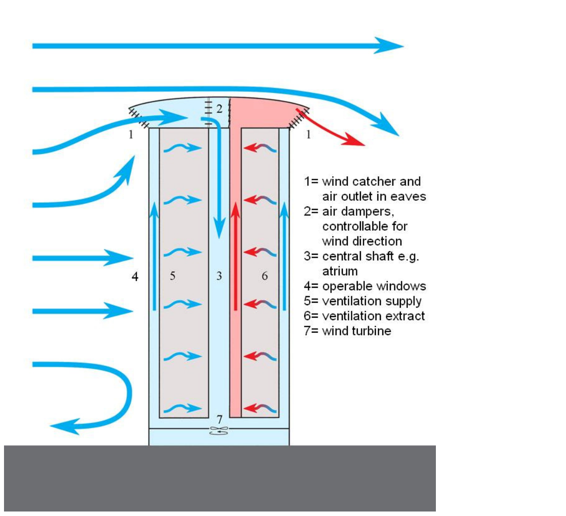
Energy MJ/m^2.a	Traditional		Earth, Wind & Fire	
	Primary energy	Final energy	Primary energy	Final energy
Gas	350 (: 1,4 =)	250	0	0
Electricity	210 (: 3,0 =)	70	42 (:3,0=)	14
Heat pump	0	0	75 (:3,0=)	25
Sun and wind active[1]	0	0	117 -/-	
Total	560		0	Energy neutral

[1] Active heat and power generation is not the main purpose of the study but will be regarded sidewardly.

The effective energy saving of (560-117=) 443 MJ/m2.a is equivalent to approx. 80%. It will therefore be considerably easier to generate the remaining electrical energy requirement from renewable sources. The study will include a broad survey of the potential opportunities for this at building level and at district level.

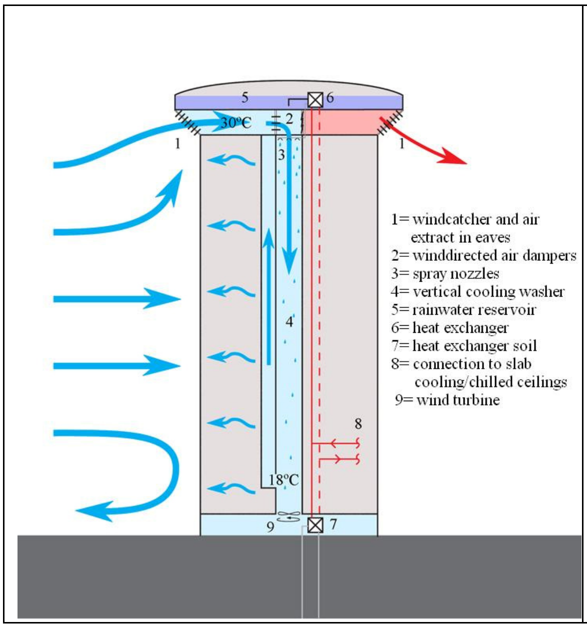
EARTH, WIND & FIRE – PRINCIPLES

The following figures illustrate the Earth, Wind & Fire concept in terms of a number of principles which will be addressed in the research.



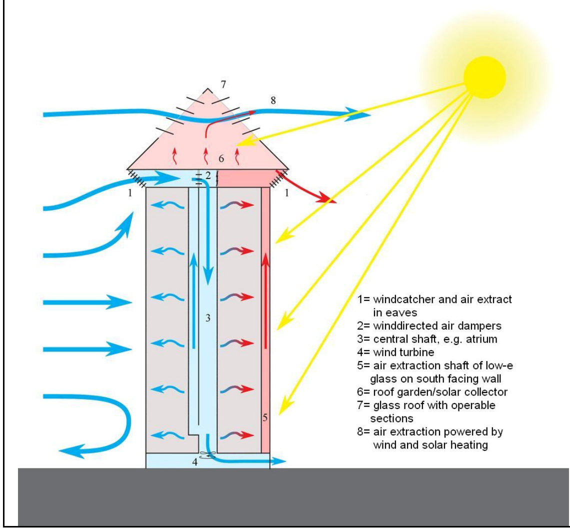
- The roof is carried out as windcatcher. The ventilation air flows through a central vertical shaft downwards, and is distributed at the foot e.g. via an atrium.
- At outdoor temperatures below the room temperature the shaft operates as a reverse chimney, providing additional pressure.
- Air dampers are operated to adjust the system to any wind direction.
- The ventilation air is extracted to the roof plenum and removed at the leeside
- The excess air is removed to the leeside through a wind turbine
- Additional low pressure filters (electrostatic) and heating is possible
- For operation in summer see figure 2

Figure 2 – Wind driven natural ventilation



- Starting point is an indoor temperature of app. 25^{0}C, to be realized by slab cooling.
- The roof is designed to function as a wind catcher. The ventilation air flows downwards through a central shaft, from where it is distributed through the building, e.g. via an atrium.
- The central shaft operates as a reversed stack which is carried out as vertical cooling washer.
- At the top cooled water is sprayed into the washer, as a result of which the warm outdoor air is cooled and dried.
- By the combined effects of cooling and induction of the falling water the ventilation air flows downwards.
- The feasibility to collect rainwater and use it as spray water will be investigated.
- Slab cooling and cooling of the spray water is done with cooling from the soil.

Figure 3 – Wind- and thermal driven ventilation in summertime



- The roof is designed to function as a wind catcher. See figure 3
- When the outdoor temperature is lower than the interior space temperature, the shaft operates as a reverse chimney, thereby supplying additional pressure.
- Air dampers are operated to adjust the system to any wind direction.
- The ventilation air is extracted to the roof plenum and removed at the leeside.
- Surplus air is transported to the lee side by a wind turbine.
- Electrostatic filters and heating can be incorporated.
- The above-roof solar chimney can be designed as a roof garden.

Figure 4 – Wind- and thermal driven ventilation + solar chimney with roof garden

THE RESEARCH

The research will be carried out in 3 phases:

1. Theoretical and analytical phase (2005-2006)
2. Development of software for simulation and modeling by experts from the Eindhoven university of technology (2006-2007)
3. Validation of the software by measuring and testing in physical scale models in a laboratory (2007- 2008)

The research will be guided by a group of prominent Dutch architects and engineers from the building- and the building services industry.

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