Earth, Wind & Fire – Natural Airconditioning
[1] Research objectives and Methods

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Abstract

Nearly zero-energy buildings cannot be achieved only by improvements to current technologies. A paradigm shift is needed to make the objective attainable. That paradigm shift is described in this paper.

The Earth, Wind & Fire concept transforms a building into a "climate machine" which is powered by the natural forces and energy of the sun, wind, the mass of the earth and gravity.

Ventilation air is cooled and dried, or preheated and humidified, by means of water droplets sprayed into the air contained in the Climate Cascade. The Cascade is a highly efficient heat exchanger housed in an architectural shaft. The spray water is maintained at a constant temperature of 13°C by cold or heat extracted from the ground.

Assisted by positive wind pressure, the Climate Cascade also serves as an air mover, making fans superfluous. Air is extracted through a solar chimney and by means of negative wind pressure.

At the top of the building, solar energy is recovered for heat storage.

The double roof, called the Ventec Roof, consists of an overpressure chamber provided with wind turbines and a Venturi- ejector for exhaust air.

The Climate Cascade, the solar chimney and the Ventec roof have been tested in physical mock-ups. Simulation models have been validated on the basis of real measurements. This work has resulted in the creation of reliable tools for design practice.

Keywords - Architectural Engineering; Energy conservation; Natural Air-conditioning; Natural Ventilation; Solar chimney; nZEB; Solar PV power; Wind Power

1 Introduction

1.1 Background

Energy saving in the built environment is a major challenge facing the building industry. The recast EU Energy Performance of Buildings Directive (EPBD Recast, Directive 2010/31/EU) formally describes the objective as follows:

"As of 31 December 2020 new buildings in the EU will have to consume "nearly zero" energy…Nearly zero-energy building means a building that has a very high energy performance….The nearly zero, or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on site or nearby".

It is improbable that nearly zero-energy buildings can be achieved by solely improved construction and HVAC engineering. Causes for concern associated with lower energy consumption include scenarios in which the ventilation capacity is reduced, or in which natural ventilation is used exclusively without use of an HVAC system. These scenarios would conflict with the EPBD, which further states that:

"(…) requirements shall take into account not just the energy performance but also general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation…
(…) measures should take into account climatic and local conditions as well as indoor climate environment and cost effectiveness".

1.2 A challenge for the construction industry

Energy saving in the built environment has hitherto been primarily the domain of building physics and HVAC engineering. Both these fields have shown excellent performance in recent decades. However, the end of this trend seems imminent: a declining return on the investment of additional effort is at least evident. According to the IEA (International Energy Agency) Energy Conservation in Buildings and Community Systems (ECBCS):

"Research into building energy efficiency over the last decade has focused on efficiency improvements of specific building elements like the building envelope, including its walls, roofs and fenestration components (windows, day lighting, ventilation, etc.) and building equipment such as heating, ventilation, air handling, cooling equipment and lighting. Significant improvements have been made, and whilst most building elements still offer some opportunities for efficiency improvements, the greatest future potential lies with technologies that promote the integration of active building elements and communication among building services"[1].

1.3 A challenge to architects and HVAC engineers

The integration of active constructional elements and building services advocated by ECBCS lies within the domain of building physics and HVAC engineering. Architecture, the discipline which has the greatest impact on the built environment, has however so far remained on the sidelines. Directly involving the architect, with his considerable creativity and influence on the building process, in the problems of energy and the indoor environment would open up substantially new possibilities based on a truly integrated design.

1.4 Climate- Responsive Architecture

Climate-Responsive Architecture, which forms part of the Earth, Wind & Fire concept, takes advantage of natural environmental energy. This makes it possible, in principle, to achieve an energy-neutral building while avoiding negative effects on the indoor conditions. Under this concept, the building is designed as a "climate machine" which is activated by the combined forces of the sun, wind and gravity.

Under the heading of Climate-Responsive Architecture, the Earth, Wind & Fire concepts couples HVAC system design, building physics and HVAC installations to an architectural task. The architect is axiomatically accorded a leading role in the climate control system design and the energy efficiency of buildings. Treating climate technology components as material for architectural expression will mean that HVAC is no longer subordinate to architecture, but becomes part of architecture. The design of a building as a climate machine hence becomes a job for the architect, who then inevitably takes joint responsibility for the interior climate and the energy economy of the building. This entails dedicating a considerable intellectual and artistic potential to achieving an intrinsically integrated design.

1.5 Paradigm shift

The research has demonstrated that Natural Air Conditioning in accordance with the Earth, Wind & Fire concept makes it possible to realize energy neutral buildings. But this requires an entirely changed mentality and a new design methodology for buildings. In this respect it merits description as a paradigm shift.

2 The Earth, Wind & Fire concept

2.1 Introduction

"Earth, Wind & Fire" is a metaphor for the natural force of gravity together with environmental energy resources such as geothermal energy, the wind and the sun. The innovative idea behind the Earth, Wind & Fire study lies in the use of these natural resources to control the interior climate of buildings. The principle question addressed by the study is whether is it possible to design a building as a "climate machine" which is activated by environmental energy together with gravity.

In a building of this kind, architecture, building mass, structure and building services respond jointly and interactively to the outdoor climate, thereby bringing about "natural air conditioning". The air movement in the building arises in principle through natural forces, and is thus much less dependent on technical systems compared to conventional HVAC.

Since the objectives of EPBD Recast require the building to be nearly energy neutral, the remaining energy requirement must be generated as solar and wind energy.

2.2 Earth, Wind & Fire in brief

A long career as a designer of climate control systems and years of collaborating with students of architecture and building engineering, gave me some intuitive ideas about the possibilities for combining climate control engineering, energy aspects and architecture.

The intuitive ideas were first elaborated in analytical and mathematical terms. A choice was then made of the most promising concepts. Three responsive architectural elements were adopted: the Ventec Roof, the Climate Cascade and the Solar Chimney/Facade. These elements were first developed, optimized and evaluated separately. Subsequently they were combined, in symbiosis with the architecture of a building, into a total concept for climate control – see Figure 1.

2.3 The Ventec roof

The Ventec Roof utilizes positive wind pressure to supply ventilation air to the building via the overpressure chamber (1) and the Climate Cascade. Negative wind pressures are utilized to extract air from the building via the Solar Chimney and the Venturi Ejector (6). The relatively good air quality at greater heights is turned to advantage in this concept [1, 2, 3, 4, 5]. Horizontal separation of the supply air from the exhaust air prevents cross-contamination between the two airflows.

The Ventec Roof can in principle also serve for generating wind and solar energy, thereby satisfying the second requirement of EPBD Recast (see Section 5 and 7).

2.4 The Climate Cascade

The core of the climate control system is the Climate Cascade, a gravity-actuated heat exchanger for conditioning ventilation are. It takes the physical form of an architectural shaft.

In the Climate Cascade, the ventilation air is cooled or heated, and dried or humidified, as needed. Spray heads at the top of the cascade inject water at approx. 13°C both in summer and winter. Momentum is transferred from the water droplets to the air, thereby amplifying the downward airflow from the overpressure chamber. This aerodynamic pressure combines with the hydraulic pressure and the vertical thermal gradient to make ventilation fans superfluous. Any necessary cooling is obtained geothermally, and heating is obtained directly or indirectly from the solar chimney.

The high coefficient of thermal transfer from the falling droplets, and the large active surface area of the millions of droplets resulting in the spray spectrum, allow the Climate Cascade to operate with a only very small temperature difference between the air and the water.

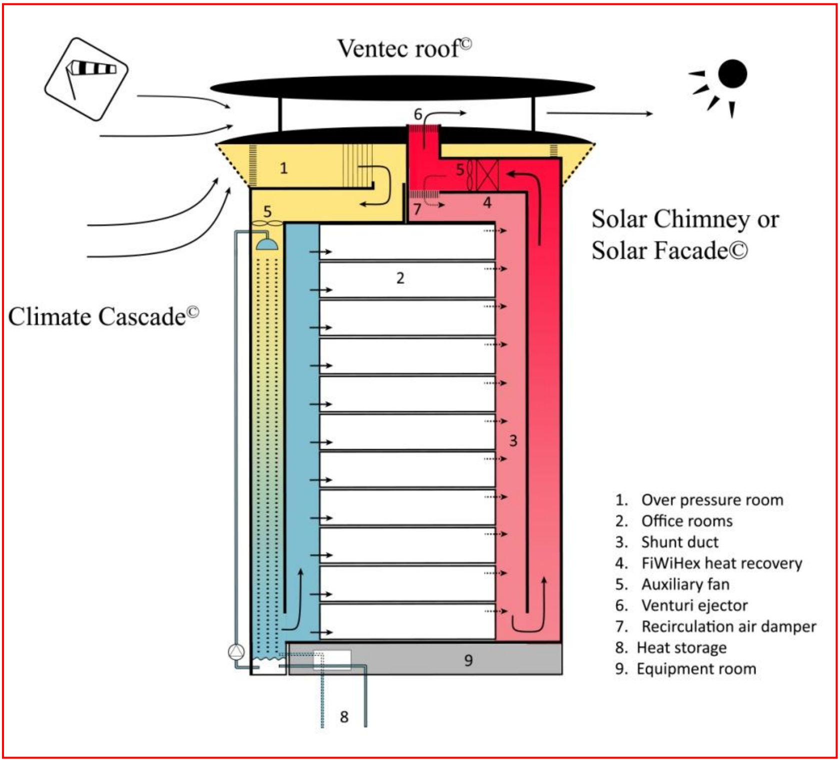

Fig. 1- Principles of Natural Air-conditioning according to the Earth, Wind & Fire concept

2.5 Solar Chimney or Solar Façade

Used air is extracted via the Solar Chimney or Solar Façade, which also collects solar energy for use in heating the building in the winter. The solar energy is transferred by a heat exchanger at the top of the solar chimney to the circulating water and then to the ground under the building. The same technique is widely used in horticulture for cooling and heating greenhouses. The Venturi-ejector in the Ventec Roof serves partly to compensate the pressure loss through the heat exchanger.

Many variants can be conceived for the morphology of a solar chimney. The Solar Facade, which extends over the whole facade of the building, is the variant with the best energy performance.

2.6 Application of the Earth, Wind & Fire concept

The airstreams required for supplying ventilation air through the Climate Cascade and extracting air through the Solar Chimney/Facade are the result of pressure differentials. These arise though density differences between warm and cold air, and are proportional to the height of the Climate Cascade and Solar Chimney/Facade. Since relatively small temperature and pressure differences are involved, a certain minimum height applies to the building. The research data relates to buildings of at least 4 storeys of 3.5 metres each (medium rise).

The Earth, Wind & Fire concept as developed must be considered as a centralized service for the air conditioning of buildings which is capable of replacing central mechanical HVAC systems. Decentralized measures for heating and cooling at the worksite level, such as chilled or heated ceiling, fan coil units, radiators etc. are easily combined with Earth, Wind & Fire.

The Earth, Wind & Fire concept is a total concept. This does not mean that the responsive building components developed in the study are usable only in combination. The stand-alone application of a Solar Chimney/Facade, a Ventec Roof or a Climate Cascade is possible.

The Earth, Wind & Fire concept can be combined with any architectural style: class, modern, international, postmodern, bioclimatic etc. It is the architect who determines the formal elaboration of the building as a climate machine.

New building projects can of course be completely designed with the Earth, Wind & Fire concept in mind. However, it is also applicable either partially or entirely to major renovation projects. Ventec Roofs and Solar Chimneys are both possible as additions to existing buildings. Existing facades can be converted to Solar Facades. An existing vertical service shaft can be converted into a Climate Cascade.

3 Research questions

1. What are the potential opportunities of the Ventecdak, the Climate Cascade and Solar Chimney for achieving a Natural Airconditioning in buildings?
2. What are the design criteria for the Ventecdak, the Cascade Climate and Solar Chimney for achieving the desired volume flow for a good indoor air quality and thermal comfort in the indoor environment?
3. What potential energy savings are possible by applying Natural Airconditioning according the Earth, Wind & Fire concept compared to traditional Airconditioning?

4. What are the potential opportunities for active energy generation with wind and sun in the Ventecroof?
5. To what extent can the Earth, Wind & Fire concept contribute to energy neutral buildings?
6. Which reliable design tools and / or calculation models can be developed for use in practice?
7. What are the preconditions for the implementation of this strategy in existing buildings?

4. Methods

4.1 Modelling → Simulatin → Validation

The Ventec Roof, Climate Cascade and Solar Chimney were developed according to the methodic sequence: basic modelling → detailed modelling with CFD → dynamic modelling with ESP-r → simulation → validation using physical test mock-ups. See figure 2.

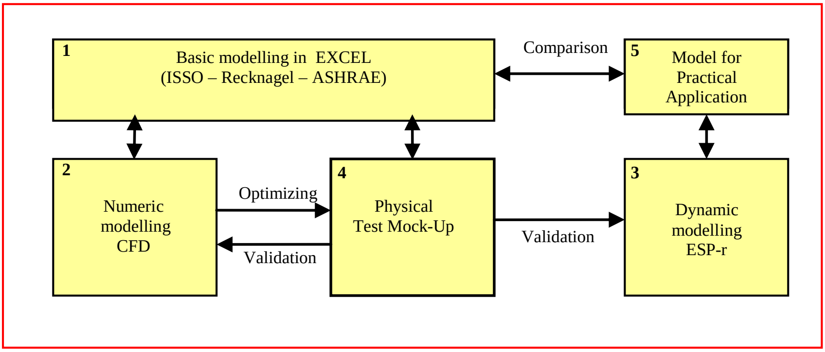

Figure 2 – Modelling – Simulating –Validation

4.2 Basic modelling [1]

The development of the various candidate concepts began with the construction of simple analytical models. A analytical model gives a first impression of the feasibility and potentials of the concepts.

The formulas used relate inevitably to stationary situations, but discretization enabled a pseudo-dynamic simulation of the processes, using MS-Excel. This approach yielded not only a satisfactory insight into the underlying phenomena of heat transfer and flow, and the combination of these; but it also disclosed many points of uncertainty, indicating the need for further simulations at a higher resolution.

4.3 Detailled modelling with CFD [2]

The concepts analysed with Excel models were further elaborated into virtual prototypes using CFD numeric flow models. The latter provided insight into the thermal transfer and flow patterns at a micro-level. This allowed further analysis of the physical effects, and simulation techniques could be used to check the scalability of the models to building at actual size.

In the Earth, Wind & Fire study, CFD was used to create virtual prototypes of the Climate Facade, the Ventec Roof and the Solar Chimney, and to analyse and optimize their performance. The virtual prototypes of these responsive building elements provided a basis for constructing physical test mock-ups for experimental study (see Section 5), which were used to validate the CFD simulations. The physical scale models served in turn as prototypes for real built elements in the real-world construction practice. CFD was used to check whether the tested scale models were representative for real built elements.

4.4 Dynamic modelling with ESP-r [3]

The basic Excel model and the CFD simulation model were used as input to the calculation and design of the Climate Cascade and the Solar Chimney under stationary conditions. To study the dynamic behaviour and to generate estimates of the annual energy performance of these responsive building elements, the dynamic simulation model ESP-r was used. This software offers designers a way to study complex relations between the outdoor and indoor climate on the bases of architecture, building mass, air flows and HVAC installations including control systems. It is flexible and powerful, and therefore well suited to the simulation of innovative techniques.

4.5 Validation by measurements on a physical test mock-up [4]

Physical test mock-ups of the Solar Chimney, the Climate Cascade and the Ventec Roof were constructed on the basis of the basic modelling in EXCEL and the study, verification and detailing of these using CFD simulations. The physical test mock-ups made it possible to measure the actual phenomena of heat transfer and airflows under various conditions and in real time. These were of course scale models, but they were large enough to allow reliable monitoring and recording of the processes.

4.6 Calculation model for real-world application [5]

A calculation model for real-world practice, based on the research results and using Rhinoceros and Grasshopper software, makes it possible for architects and engineers to broadly elaborate and dimension the concepts for actual building projects. A user-friendly calculation model for the Solar Chimney, a conspicuous architectural building element, was developed in the context of the study. The architect can use this model to vary the dimensions of a solar chimney, and with a mouse click read the resulting performance, while in the concept stage of a building design.

General design guidelines have also been developed for the initial design of the Ventec Roof and the Climate Cascade. The HVAC engineer of course remains responsible for the dimensioning of these elements in the definitive design.

Continued in Part 2