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EARTH, WIND & FIRE – NATURAL AIR-CONDITIONING

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SUMMARY

The invention of air-conditioning in the early 20th century and its development since then has brought many advantages to mankind. In spite of this many people are not very satisfied with the indoor environment at their workplace. They complain about the air quality, the cold draught they experience, fan noise and dry air, causing dry eyes and throats, notorious elements of the so-called Sick Building Syndrome.

As an experienced HVAC designer I asked myself if we could do better. Looking at termite hills, where termites closely work together, build their dwellings with natural air-conditioning but high Indoor Environmental Quality, a doctoral research was started. This implies a building designed as a "climate machine", activated by gravity and the ambient energy of the earth mass, the wind, and the sun, metaphorically referred to as Earth, Wind & Fire.

After 5 years of modelling, simulating, testing and validating it was demonstrated that natural air-conditioning in buildings is feasible. An air-conditioning without fans, nevertheless able to maintain an excellent indoor climate. This paradigm shift in air-conditioning not only promises an excellent Indoor Environmental Quality, but also an improved relationship of architect and engineer and much lower energy use of buildings.

INTRODUCTION

The invention of air-conditioning in the early 20th century and its development since then has brought many advantages to mankind. Comfortable indoor environments have increased the wellbeing and productivity of office workers and improved production processes in factories. Buildings could be developed in climates where such a comfortable indoor environment would have been difficult or even impossible without air-conditioning.

In spite of this, at the moment many people are not very satisfied with the indoor environment at their workplace. They complain about the air quality, the cold draught they experience, fan noise and dry air, causing dry eyes an throats, notorious elements of the so-called Sick Building Syndrome.

On the other hand there is a gap between the artistic, intuitive and creative mind and method of working of architects and the more rational and logical approach of the engineer, making their cooperation often troublesome. Many architects dislike the ducts and pipes which are visible in the building or take up space hidden in shafts and above false ceilings. HVAC systems increase the building volume, increase investment costs, require a lot of maintenance and consume a lot of energy.

As an experienced HVAC designer I asked myself if we could do better. Could we design simpler air-conditioning systems which do increase the user's satisfaction? Could we, at the same time, improve the building process by involving the architect in the design? And could we, by doing so, also reduce maintenance costs and energy use? Could we kill four birds with one stone?

The strategic set-up of this research is focused on the development of *Climate Responsive Architecture* in which climate design, building physics and HVAC systems are interwoven with the architectural assignment. This strategy gives the architect a major role as co-designer of the air-conditioning system, an air-conditioning system as an element of architectural expression, making the architect also partly responsible for the indoor environment and energy consumption of the building.

BIO MIMICRY

Termites in Africa build huge hills inside which they farm a fungus that is their primary food source. The fungus must be kept at 30^{0}C, while the temperatures outside range from 0^{0}C at night to 40^{0}C during the day in bright sunlight. The termites achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the course of the day.

As far as we know termites don't split up the design of their buildings into architecture and engineering. And as far as we know termites are very satisfied with their dwellings. So why not try to copy termite architecture in the human world?

Then, at the border of two worlds, the disciplines of architecture and engineering, a great idea was born. Could we, like termites, design a building as a climate machine with natural air conditioning? Could we, by doing so, also bridge the gap between architect and engineer? And would we, doing so, be able to design zero energy buildings with a natural healthy and productive indoor environment?

A new term was born: "Climate Responsive Architecture". A building designed as a "climate machine" would be activated by gravity and the ambient energy of the earth mass, the wind and the sun, metaphorically referred to as Earth, Wind & Fire.

EARTH, WIND & FIRE IN BRIEF

Figure 1 shows a cross section of a multi-storey office building. The wind blows against the wall and at roof level is caught by the roof overhang and is used for natural air conditioning via the climate cascade.

Ventec roof

The Ventec roof utilizes positive wind pressures for the supply of ventilation air to the building via an overpressure chamber and the Climate Cascade. Negative wind pressures are used to extract used ventilation air from the building through the Solar Chimney and a Venturi-ejector. This concept takes advantage of the relatively good air quality at higher altitudes. Furthermore, the horizontal separation between supply air and exhaust air prevents short circuiting between the two air flows. The Ventec roof can in principle also be used for the generation of wind and solar energy, in this way making an important contribution to zero energy buildings.

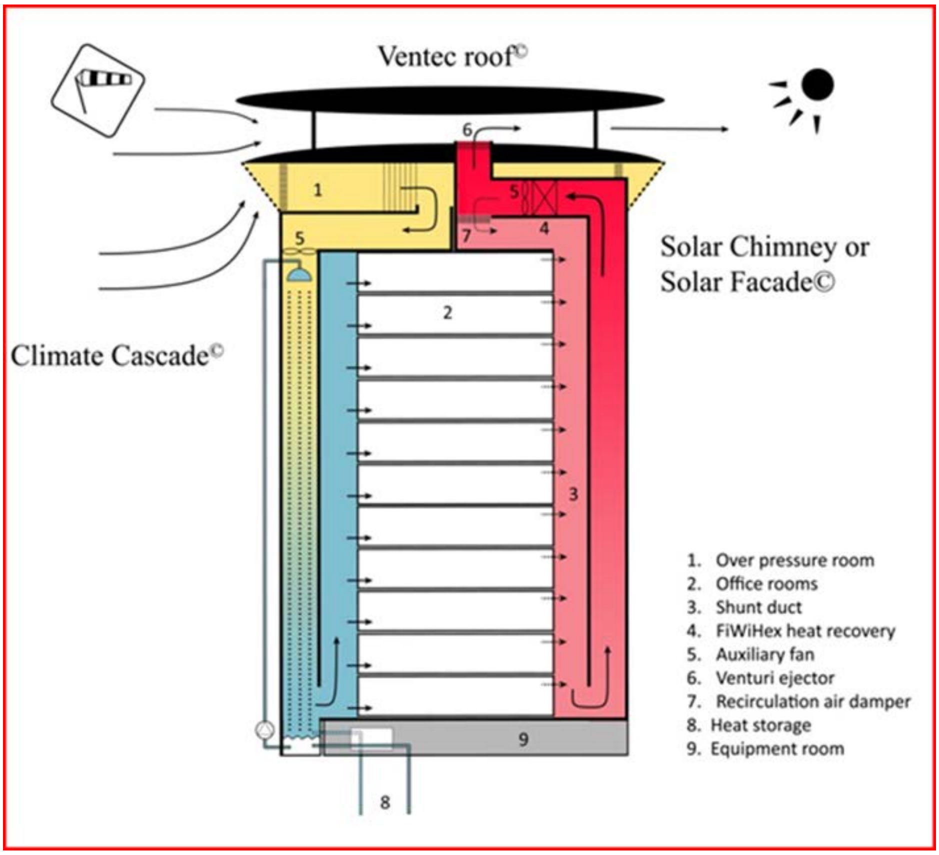

Figure 1 - The Earth, Wind & Fire principles

Climate cascade

Core of the climate system is the Climate Cascade, a gravity-activated heat exchanger for conditioning of ventilation air, designed as an architectural shaft.

At the top of the Climate Cascade water is sprayed in at a temperature of 13^0 C by which the air is cooled and dried in summer and heated and humidified in winter. Due to the mass difference of the water-and-air-mixture and the surrounding air, pressure is built up at the bottom of the Climate Cascade, so that the air can be distributed into the building via the supply shaft. In summer the air can be cooled from 28^0 to 18^0 C. The required cooling, provided by the 13 ^{0} C water, is extracted from the soil underneath the building, and heat is directly or indirectly supplied by the solar chimney.

Solar chimney

The Solar Chimney is situated on the south side of the building. In the Solar Chimney the air is heated by solar radiation creating an under pressure which extracts the air from the rest of the building at the foot of the chimney. With the aid of a heat exchanger in the top of the Solar Chimney, solar energy can be harvested and transferred to water, transported to the heat storage in the ground under the building to be used for the building heating system in winter.

The air leaves the building through the venturi-ejector where under pressure is created by the locally increased wind speed. The venturi-ejector compensates for the pressure drop of the heat exchanger.

THE RESEARCH METHODOLOGY

The research and development of the Ventec Roof, the Climate Cascade and the Solar chimney are developed according to the method of modelling, simulating and validating, see figure 2.

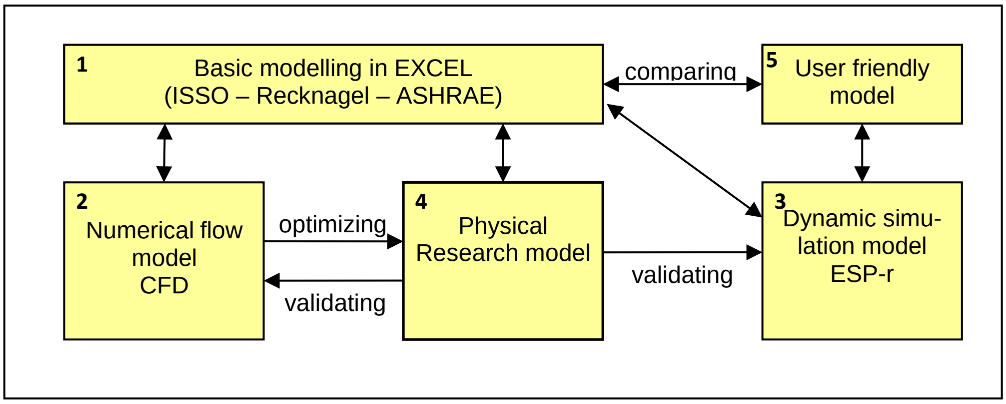

Figure 2 – Modelling, Simulating and Validating

Basic modelling (1)

The development of the three sub concepts was initially carried out by means of simple computational models which gave a first impression of the feasibility and the potential of the concepts. Using scientific and technical data from the repertoire of the climate engineer, mathematical descriptions of the heat transfer and flow at macro level were formulated.

Detailed modelling (2)

The sub concepts, analysed by basic modelling, were worked out into virtual prototypes using Computational Fluid Dynamics (CFD), which gave insight into the heat transfer and flow patterns at micro level. Using simulation techniques, the physical effects could be analysed in detail in order to determine whether and to what extent models could be scaled up to full size components.

Dynamic modelling (3)

The basic computational model and the CFD model are used as a tool for the computation and the design of the Climate Cascade and the Solar Chimney under stationary conditions. For the study of the dynamic behaviour and estimates of the annual energy performance of these responsive components the dynamic simulation model ESP-r is used.

Validation in experimental mock-ups (4)

Based on the basic and detailed models, experimental mock-ups of the Solar Chimney, the Climate Cascade and the Ventec roof were built. With these mock-ups, the actually occurring heat transfer and airflows were measured real time under various conditions. Although the mock-ups were scale models, their dimensions were such that the processes could reliably be monitored. Based on the measurement data from the experimental mock-ups, the basic and the detailed simulation models were calibrated and validated.

Computational model for practice (5)

For the Solar Chimney, a dominant architectural building element, a user-friendly computational model has been developed. In the conceptual phase of the building design, the architect can vary the dimensions of a solar chimney and with a mouse click directly see its matching performance.

RESULTS AND DISCUSSION

Ventec roof

The aerodynamic performance depends on the wind speed at roof height, which is primarily determined by the height of the building and its surrounding buildings. Through CFD modelling, validated by wind tunnel measurements, it was demonstrated that the Ventec roof is wind direction independent. An elegant formula has been developed to calculate the performance of the venturi-ejector. Boundary conditions have been formulated for optimizing the Ventec roof in an urban context.

Climate Cascade

The basic computational model and CFD model are validated by the experimental mock-up. Both models can predict the psychrometric and aerodynamic performance of a Climate Cascade in all seasons with a high degree of accuracy.

The Coefficient of Performance (COP) of a Climate Cascade depends on the water / air ratio and the height of the building and may vary from 50 to 15 in buildings of 4 to 20 stories.

Solar Chimney

The experimental mock-up is used during four seasons for measurements of temperatures and air velocities as a function of the incident solar radiation and the outside temperatures. The measurements gave a good view of the complex thermodynamic processes in a solar chimney. Due to uncertainties in the dynamic heat transfer coefficients, CFD modelling was not very successful. The basic thermal- and flow models however are validated by means of measurements in the experimental mock-up, and proved accurate enough to provide a base for a computational model for practical use. A dynamic simulation in ESP-r, calibrated and validated in the experimental mock-up delivered a reliable calculation model for the energy performance of a Solar Chimney.

The thermal efficiency of a Solar Chimney, defined as the ratio of the heat absorbed by the airflow and the incident solar radiation is mainly determined by the properties of the glass wall. A good choice can yield an average annual efficiency of around 60%.

From autumn to spring solar heat can be used directly or through short-term storage for heating the building. For the summer months, long term storage is needed to use the solar heat in the heating season. Several systems for heat storage are briefly and conceptually investigated..

Summary

Using computer simulations which have been validated with physical test models it has been demonstrated that all elements of the Earth, Wind & Fire concept, the Ventec roof, the Climate Cascade and the Solar Chimney perform excellent. Reliable calculation models for the design and performance analyses are available.

APPLICATION OF THE EARTH, WIND & FIRE CONCEPT

The developed Earth, Wind & Fire concept is a central air-conditioning system for buildings, which can replace the building's central mechanical system. Decentralized systems for heating and cooling at workplace level, such as climate ceilings, fan coil units, radiators etc. guarantee optimal thermal comfort in a perfect combination.

The precondition for an optimal operation of Natural Air-conditioning according to the Earth, Wind & Fire concept is that the influence of wind and sun on a building is not substantially impeded by the surrounding buildings. Ideally, the wind should have free access to the Ventec roof and the Solar Chimney should not be put in the shade by other buildings.

ENERGY AND INDOOR ENVIRONMENT

The measurement of energy efficiency, the Energy Performance Coefficient (EPC), has been an instrument of the Dutch climate policy since 1995 and requirements for the EPC of a building have been periodically tightened. In order to achieve the required EPC value, it is often easier and cheaper to score with less durable building services then more sustainable structural facilities, which are therefore often omitted (Shaviv, Edna 2011). Focusing on building services results often in increasingly complex and maintenance sensitive HVAC systems. Such systems do not always deliver the healthy indoor climate that may be expected, and a simple and intuitively understandable operation is hampered by their complexity (Mendell 2000, Juricic et al 2012). Moreover research shows that there is no statistically significant correlation between the predicted and the subsequently measured energy performance of buildings in the use phase.

Worrying scenarios in lowering the EPC requirement are further reduction of the ventilation flows, threatening the indoor air quality (Seppanen 2012) and avoidance of air-conditioning by application of natural ventilation often resulting in deterioration of the thermal comfort in the workplace during the summer. (Olesen et al 2010). A building with a high score on sustainability and energy efficiency may have neglected the most important aspect of architecture, namely providing a pleasant, healthy and productive workplace, a combination of well-being and design quality (Chen et al 2011).

EW&F – BENEFITS FOR THE INDOOR ENVIRONMENT

No air filters

The pressure loss of filters in traditional HVAC systems is significant, making them not applicable for natural air conditioning in the Earth, Wind & Fire concept. Moreover, such filters suffer from the so-called filter paradox: Particulates are removed from the air but, after some time the collected dust emits a smell that people perceive as unpleasant. P.O. Fanger called this odor emissions the *"hidden olfs*". This effect is further enhanced when filters become moist, for example, in the event of foggy weather when small water droplets are separated in the filter. In this case, air filters can form an excellent host for microbial growth, which entering the room may cause allergic reactions in susceptible people. In short, dust filters in HVAC systems can be considered a necessary evil to prevent contamination of the air handling unit and duct system. Because the Earth, Wind & Fire concept operates without these components, and also due to the favourable location of the air intake at top of the building, air filtration is in principle not necessary. If nevertheless air filtration is required, electrostatic air filters can be applied.

Air cleaning in the Climate Cascade

The Climate Cascade also operates as an air washer, because a part of the particles > ≈ 5 mm are "*washed*" from the air by the water droplets. Greasy dust and soot particles are not absorbed by the water droplets, and, unlike the name suggests, an air scrubber cannot be considered a full air purifier. However, for buildings in an industrial or urban area where the outside air is sometimes heavily polluted, it is an advantage that many soluble gases, SO_2, NO_x, Ozone, NH_3, formaldehyde, fragrances and smog are absorbed by the water droplets of the Climate cascade.

Air humidity

Moisture in buildings and humidification using air washers brings certain risks on the indoor environment such as corrosion and frost damage. The Climate Cascade during the heating period, consciously brings moisture into a building, and it is important to recognize these risks.
Humidification in traditional HVAC systems may entail risks, mostly due to incorrect design and unhygienic operation. Humidification is therefore not very popular in the Netherlands and is often omitted because of fear of the negative health effects.
Maintaining a minimum humidity of the air in the indoor environment, however, has many positive aspects (Bronsema 2002) which the multifunctional Climate Cascade can provide. Potential risks are limited by the low temperature and good accessibility for inspection and cleaning. Compared with traditional spray humidifiers, the coarse droplet spectrum allows limited moisture penetration in the form of aerosols.

Legionella prevention

A notorious pathogen is the legionella bacterium which, when inhaled, can cause infection through the respiratory tract. Because the Climate Cascade operates at water temperatures between 10^0C and 20^0C the risk of the legionella bacteria's survival can be excluded. In other words, the concept is intrinsically safe.

EW&F – POTENTIAL BENEFITS FOR THE INDOOR ENVIRONMENT

Waterfall Effect and Ionization

A possible positive effect of the physical process in the Climate Cascade is the production of negative ions by the waterfall effect, also known as Lenards effect. In a waterfall, water droplets become fragmented due to mutual collisions. This would allow most positive ions in the droplet to remain as free ions and emit negative ions into the air. In metal ducts negative ions precipitate on the walls, as the result of which the natural ion balance in the air is disturbed. In the Climate Cascade, an architectural element, this effect does not occur improving the ion balance in the air.

> *"It has been suggested that the ion balance of the air is an important factor in human comfort in that negative ions tend to produce sensations of freshness and well-being and positive ions cause headache, nausea and general malaise. Present evidence on the effects of air ions and, in particular, the effectiveness of air ionizers is inconclusive and hence no design criteria can be established".(*CIBSE 1999).

The Climate Cascade may, therefore, by improving the indoor air quality, have a beneficial effect on the indoor environment. This reasoning is speculative but interesting enough for further research.

Ozone

Ozone is a strong oxidant and biocidal, and among others, used for water treatment and legionella prevention in cooling towers. When added to the spray water in the Climate Cascade, the positive properties of ozone may be combined. Oxygen enriched water potentially has a positive effect on the air quality. In addition, any micro-organisms in the cooling water will be killed. Ozone emission of an electrostatic air filter will be absorbed in the cooling water where conversion takes place from O_3 to O_2. This reasoning is also speculative but interesting enough for further research.

CONCLUSIONS

The Earth, Wind & Fire concept for natural air-conditioning is an important contribution to low- and high rise zero-energy buildings and an important step towards healthy, comfortable and productive indoor environments.

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