Earth, Wind & Fire – Natural Airconditioning

[2] Results of the research

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5. Results of the research

5.1. General

The complete results of the basic and detailed models, the simulations, the measurements on the physical test mock-ups and the validation process are reported in my doctoral thesis [6]. Below is a short summary.

5.2. Ventec roof – Overpressure room

See fig. 3 and fig. 1 in part [1]:

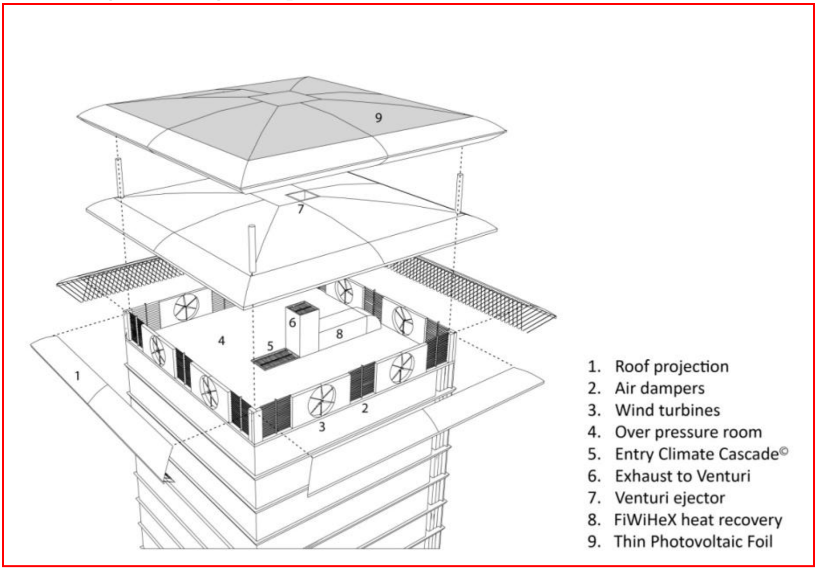

Fig. 3 – Ventecroof with wind turbines and venturi-ejector

Ventilation air is received on the windward side with the aid of roof overhangs (1) and routed via the overpressure chamber (4) to the Climate Cascade (5). The air thrust is determined by the local wind velocity and the wind pressure coefficient on the facade section concerned. A pressure coefficient of 0.8 was measured in the wind tunnel.

This means that in the overpressure chamber of a 25 high building in an urban environment with a moderate wind of 4 Beaufort, wind speed from 5.5 to 7.9 $m.s^{-1}$, an average positive pressure is built up of 20 Pa. For a breeze of 5 Beaufort, wind speed from 8.0 to 10.7 $m.s^{-1}$, the average pressure is 40 Pa. For a natural ventilation system these are significant values.

5.3. Ventec roof - Venturi-ejector

The venturi ejector terminates the airflow of the building exhaust system via solar chimney and the FiWiHEx (Fine Wire Heat Exchanger) system for heat recovery (8).

The aerodynamic performance of the venturi-ejector has been analysed using CFD simulations and validated by wind tunnel measurements [7,8,9,10] The pressure coefficient is independent from the wind direction but it is sensitive to the ratio of the air velocity in the ejector to the reference wind velocity $U_{ejector}/U_{ref}$ and the height c of the top channel (see Fig.4).

In the example above, with a moderate wind of 4 Beaufort, an upper channel with a height of 2m and a speed of U = 2 $m.s^{-1}$ in the venturi-ejector an average negative pressure of -8.5 Pa will be realized, increasing to -18,6 Pa at 5 Beaufort.

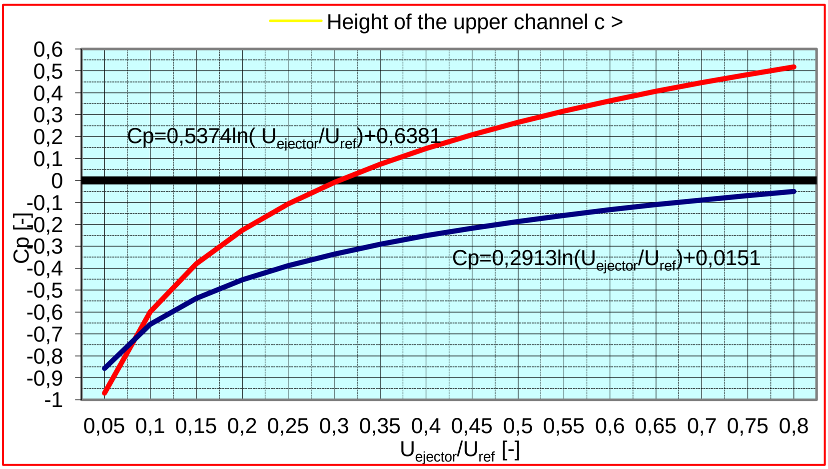

Fig. 4 – Pressure coefficient venturi-ejector als functie van $U_{ejector}/U_{ref}$

5.4. Climate Cascade

A unique property of the Climate Cascade is that the operative surface area does not have a fixed value as conventional heat exchangers do.

Varying the water/air ratio and the spray spectrum allows the heat exchanging surface to be enlarged or diminished. The mass flow and the temperature path of the cooling water can hence be adjusted for a specific cooling performance, making it possible to optimize the energy performance of the Climate Cascade.

To assist this adjustment, a user-friendly calculation model was created in which the user can adjust the many variables using the computer mouse in order to visualize the consequences for the design and dimensioning. Input parameters to the calculation model include the height of the Climate Cascade, the volumetric airflow, the air temperature and relative humidity. The airflow velocity, the water/air ratio, the spray spectrum and the relative air humidity can be chosen freely. Iteration of the variables makes it possible to set the desired exit condition of the air for circumstances optimized for energy or other factors. The hydraulic and thermal draught is calculated on the basis of this data.

The CFD simulations were carried out using the general CFD code of ANSYS FLUENT. Since this software package is not equipped as standard for modelling the process of cooling by condensation in a Climate Cascade, a special user-defined function (UDF) was developed for this purpose in collaboration with Fluent Germany. Simulations also assisted in the selection of sprayers for the physical test mock-up, see Fig 5 [11].

Fig. 5 – Test mock-up Climate Cascade

The calculation model and the CFD model were both validated using the physical mock-up – see figure 5.

Figure 6 shows the results of the calculated and measured thermal performance data across seasons, for which the following intake air conditions are assumed:

– B1 design summer condition 28°C - 55%RH
– B2 average summer condition 20°C - 80%RH
– B3 average winter condition 5°C - 90%RH
– B4 spring/autumn condition 10°C -100%RH
– B5 design winter condition -10°C - 55%RH

It can be concluded that the basic calculation model and the CFD model produce reliable results for the calculation of the sensible performance of a Climate Cascade.

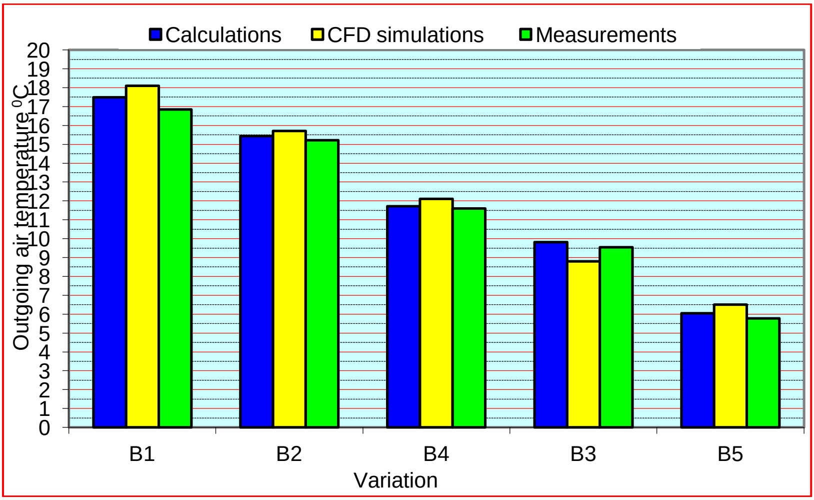

Fig. 6 – Validation of basic calculation model and CFD model against measurements

The pressure gradient in a Climate Cascade is composed of aerodynamic, hydraulic and thermal draught components. Given a water/air ratio of 0.9, the hydraulic draught is approx. 6.25 Pa per floor of 3.5m. The calculated values are confirmed by the measurements. At the minimum building height of 4 floors (see Section 2.6), the cumulative downdraught pressure in the Climate Cascade is approx. 25 Pa. The aerodynamic draught is difficult to model. The thermal draught varies from season to season and its value can be either positive or negative.

6. Solar Chimey

The airflow veocity and hence the volumetric flow in a solar chimney is determined by the upward thermal draught and the pressure losses, which must be in equilibrium. For this, a basic calculation model and a dynamic simulation model in ESP-r were developed. Both models have a thermal as well as a flow component.

The basic calculation model provided the basis of specifications for a physical test mock-up, in which among other things varying climatic conditions, actual temperatures and air speeds were measured – see Figure 7. The basic calculation model and the ESP-r model were validated in relation to the measurements.

Figuur 7 – Test mock-up Solar Chimney

The basic calculation model shows a reasonable level of reliability. The air temperatures prove to be calculable with good accuracy. Sensitivity to the entered heat transfer coefficient values appears to be limited. In combination with the given air velocity, this gives reasonably reliable information on the energy performance of a solar chimney.

The ESP-r model has several limitations, all of which affect the predictions to varying extents. Examples are:

- Margins of uncertainty about the volumetric airflow (+-20%) and temperatures (+-3.5%);
- Margins of uncertainty about the physical properties of glazing and the absorber;
- No allowance for wind effects;
- Non-uniform insolation due to the daily passage of the sun and the inherent shading effects.

Since the predicted values lie in most cases within the uncertainty margins, it may nonetheless be concluded that the ESP-r model offers a reasonable level of reliability.

When a good glazing type is used, the feasible annual efficiency is of the order of 60%. The total solar radiation on a south-facing surface is approx. 860 $kWh.m^{-2}$ in the reference year NEN 5060:2008. On this basis a yield of approx. 500 $kWh.m-^{2}$ may be expected per m^2 of solar chimney.

7. Energy generation

See Figure 3. Wind turbines are installed in the overpressure chamber for power generation. In principle, high power coefficients are achievable. Noise problems are soluble because of the situation interior to the building, and maintenance can be carried out inside the building. Since they are part of the technical building services, no environmental permit is required for these wind turbines.

The roof covering of the upper roof consists of a thin film of PV foil. Despite the lower yield of this foil, it is more cost-effective than solar cells.

Figure 8 shows the calculated specific energy performance per m^2 gross floor area for a building with a footprint of 20 x 20 m. The wind energy yield shows a slight rise from approx. 2 to 4 $kWh_e.m^{-2}$ for building height from 15 to 30 m., thereafter remaining practically constant. This partly compensates the declining yield of photovoltaic energy, which decreases from approx. 32 to 7.5 $kWh_e.m^{-2}$ as building height increases from 15 to 65 m.

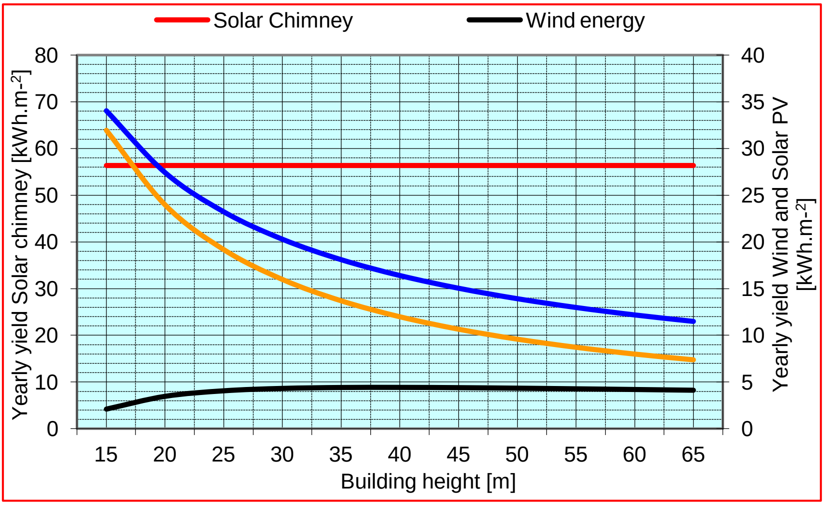

Figure 8 – Yearly specific energy performance Sun and Wind in kWh per m^2 gross floor area

8. Acknowledgement

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9. References

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