

Exploring the potential for natural ventilation of very tall buildings

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ABSTRACT

Tall buildings have traditionally been sealed and mechanical ventilated. In recent years advances have been made allowing the natural ventilation of tall buildings for a part of the year. The motivation has been both energy savings and occupant comfort. The projects realized thus far work on the mixed mode principle. Natural ventilation is employed for a proportion of the annual period. However under certain wind and external temperature conditions mechanical systems take over. Whilst this means of operation allows energy savings in operation and improves occupant comfort, recent research has shown that there are in most cases no real savings in total primary energy consumption and that the economic viability of these concepts is poor; the reason being largely due to the fact that such concepts provide two systems essentially performing the same task; a situation which rarely makes economic or ecological sense. If a system of natural ventilation could be refined so as to perform in an acceptable way all year round and mechanical ventilation systems thus dispensed with, a paradigm shift in the ecological and economic viability of naturally ventilated tall buildings would occur. This paper illustrates a concept which allows all year round controlled natural ventilation of very tall buildings and outlines the implications for the architectural design of such buildings.

1. TALL BUILDINGS AND SUSTAINABILITY

The chief reasons for building tall buildings in European cities to date are status related or

economical. However recent research has shown that tall buildings could potentially be employed to increase urban density and contribute significantly to a sustainable development of our cities (1) (2). On first sight however high rise buildings appear to have a inherently low energy efficiency in their operation. This is mainly due to wind related issues. On account of the increased wind pressures due to height, external solar shading and natural ventilation with operable windows become difficult and thus all tall buildings to date employ mechanical ventilation and air conditioning. Therefore, strategies allowing natural ventilation of tall buildings offer significant potential to improve energy efficiency.

2. TALL BUILDINGS AND NATURAL VENTILATION

Research work has shown that natural ventilation via operable windows is more energy efficient than mechanical ventilation systems with heat recovery in most office building applications (3). On top of this there are the well known psychological benefits of natural ventilation to be considered. This research work has shown further that mixed mode systems do not make ecological or economic sense, as essentially two parallel systems are provided to perform the same task. The skyscraper or tall building type originated in the US and has been without exception equipped with a mechanical ventilation system and cooling from the postwar era onwards. Wind speed increases exponentially with height and high wind pressures at the upper level lead

to difficulties associated with operable windows; one of the major ones being the large force necessary to open internal doors which can result (other problems being windows and doors blowing closed, uncomfortable draughts and papers flying from desks). A double skin building envelope can provide a solution to the problems associated with tall buildings as outlined above. A shading device located in the cavity functions essentially as an external solar shading device. The wind pressure reduction provided can enable the use of operable windows for natural ventilation. Research work has shown however that the energy efficiency of such double facade concepts depends strongly on the potential to eliminate mechanical systems from the design (4).

3. CASE STUDIES

Within the last decade a number of tall office buildings have been designed and constructed which allow partial natural ventilation of the office spaces. Most of these are designed to operate in mixed mode and all are equipped with mechanical ventilation systems which are employed under certain weather conditions. In most cases the building designers claimed that natural ventilation can be used for between 50% and 70% of the year. An evaluation of these claims has not been reported. Examples of these buildings include the 56-storey Commerzbank headquarters building in Frankfurt, the 30-storey RWE tower in Essen, the 22-storey GSW-Tower in Berlin, the 20-storey Stadttor tower in Düsseldorf, the 30-storey Westhafen tower in Frankfurt, the 56-storey Main Tower in Frankfurt, the 41-storey Swiss Re tower in London and the 20-storey Deutsche Messeturm in Hanover. These projects use a combination of double facades, atria, sky gardens and special window elements. Strategies used include provision of additional resistance to air flow in the façade causing a reduction in wind pressure, control of the openings in facades of an atrium to reduce the wind pressure differential across the office floors, pressure equalization within corridor type double facades and double facades acting as solar thermal extract chimneys. Problems arising with the concepts include elevated temperatures in the facade cavity making natural ventilation unfavorable at times

and exasperation of the pressure differential across office floors connected by an atrium due to thermal buoyancy (particularly extreme in winter). Although the mitigating effect of the chosen measures in these concepts means that windows can be opened for longer periods in the year than otherwise possible, mechanical ventilation is still necessary for a substantial part of the year when external conditions do not allow the system to be operated.

The form of the new European Central Bank headquarters, currently under construction in Frankfurt, was strongly influenced by considerations to maximize energy performance and enable all year round natural ventilation of the office spaces. The environmental and energy concepts were developed by the author in collaboration with the architects Coop Himmelblau. Two (in building energy performance terms) optimally orientated towers with their main facades facing north/south were placed on the site, positioned so, that an effective shading of the first tower is provided by the second. Then an additional skin was wrapped around the two towers to create a central atrium and double-skin facades on the external sides of the towers. The form and construction of the buildings were then optimized, to employ wind, thermal and solar power to provide controlled natural ventilation of the offices.

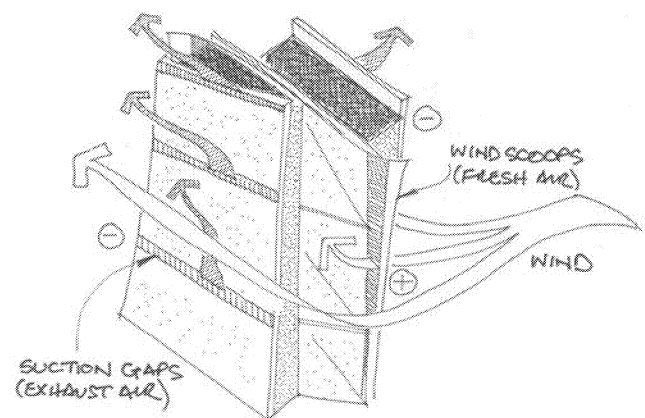


Figure 1: Natural ventilation concept for the ECB

The atrium facades were designed to act as wind scoops to channel wind into the atrium. In the external facades of the office towers the negative pressure at the specially designed

"suction gaps" ensures that the used air is drawn out of the building independent of wind direction (see figure 2). Air flows from outside into the atrium and from there across the office floors before leaving the office spaces on the external sides of the towers, thus ensuring effective cross ventilation of the office floors.

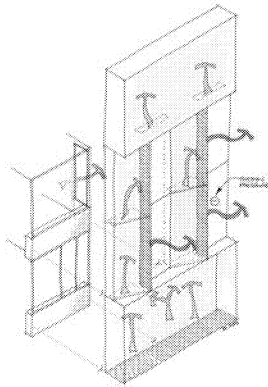


Figure 2: Natural ventilation concept for the ECB

The double façade on the external sides of the towers also acts as a solar thermal exhaust flue. The less dense warmer air rises up through the flue and is replaced by cooler heavier air flowing through the office floors. On account of the height of the building, the façade was horizontally divided up into 3 sections with a height of approximately 50 m each, in order to keep the pressure differences between floors manageable.

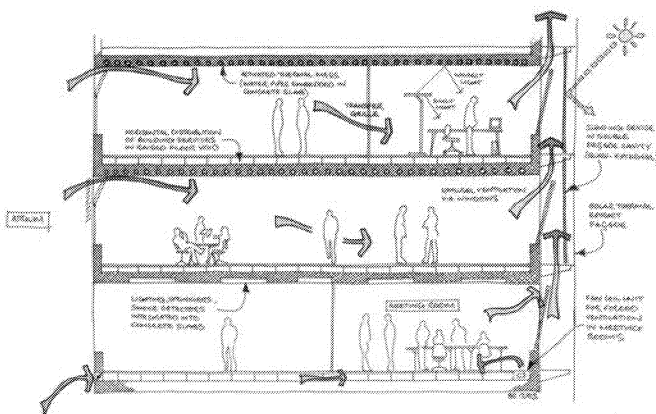


Figure 3: Natural ventilation concept for the ECB

Dampers in the external skin of the atrium and office facades are operated to control the pressure difference acting across the office floors and so regulate the natural ventilation of the offices (see figure 3). Due to the special design of the suction gap elements in the

external façades of the office towers the pressure coefficient at the air exhaust points is always lower than the pressure coefficient at the air inlet points on the atrium façade regardless of wind direction.

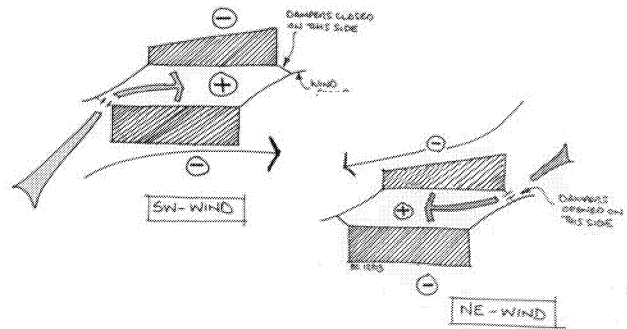


Figure 4: Natural ventilation concept for the ECB

Functional areas (meeting rooms, recreation zones, communication bridges, lifts etc.) were moved out of the office towers and into the atrium, in order to improve the relationship between gross and net floor area in the office towers. The dynamically formed atrium connects the two towers and improves communication within the building complex, so that a living vertical city is created. In contrast to the high rise buildings using natural ventilation built thus far, this concept eliminates the need for mechanical ventilation in the office spaces completely and thus offers enormous advantages in capital cost and grey energy terms (mechanical systems, plant rooms, shafts) as well as energy savings and maintenance costs.

In the design for the ÖVAG bank headquarters building in Vienna city a completely new typological solution for an atrium building in a European perimeter block development situation was arrived at as a result of a collaboration between Carsten Roth Architects in Hamburg and the author. We started with the idea of a compact building with an atrium as a central communication zone. Conventional solutions of this type provide office spaces facing the street and offices spaces facing the courtyard or atrium and experience in practice has shown that the perceived difference in the quality of the working spaces thus provided leads to problems.

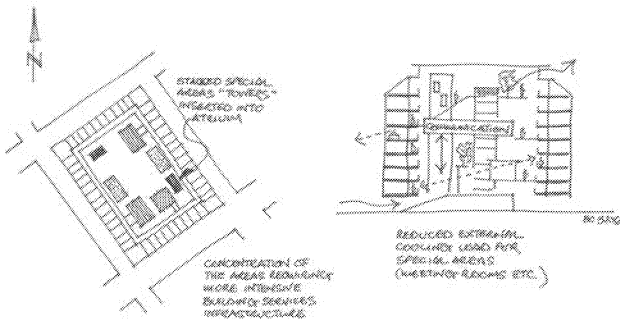


Figure 5: Concept ÖVAG Bank HQ

Experience has also shown, that with these types of solutions the interaction between the atrium and adjoining offices means that either the atrium works well as a communication zone and the adjoining offices less well or the atrium becomes a sterile space with little life and little communication so that the adjoining offices are allowed to function better. In these conventional solutions the spaces requiring more intensive building services infrastructure such as conference rooms, meeting points, communication and smoking areas etc. tend to be dispersed throughout the floor plan and thus necessitate a longer and more inefficient building systems distribution network.

In the proposed design, currently under construction in Vienna, the cellular offices form an external ring facing the streets. The special areas and the circulation elements (lifts and staircases) are independent structures which are inserted into the large interstitial atrium space within the office ring. The design offers the following advantages: equal quality for all work places, creation of a dynamic atrium space to showcase the banks business, informal communication encouraged and supported by the vertical atrium space with circulation elements and shared areas (meeting rooms etc.) contained within, special areas requiring a more intensive building services infrastructure grouped together and thus more efficiently served, the solar load for the special areas is significantly reduced and the compact design reduces the transmission heat losses of the building considerably (atrium roof area approx. 80% less than the area of the skin between offices and atrium). This new typology

combines the principle of the combi office originally developed in Sweden (concentrated working in small cellular offices and shared spaces in a communication zone in the interior) with the concept of an atrium as a vertical city and communication space.

4. DEVELOPMENT OF THE CONCEPT FOR NATURAL VENTILATION OF TALL BUILDINGS

The ideas developed for the two projects outlined above have been developed subsequently as a research project investigating concepts for year round natural ventilation of very tall buildings. A typical floor plan and a section of the concept design are shown below. The central principles of the improved concept are:

1. Use of wind and thermal forces to drive natural ventilation
2. Use of a central atrium in combination with an external double facade in order to create a controlled pressure difference
3. Use of equal height columns of internal warmer air and external cooler air to ensure equal pressure difference on all floors (the internal column is split into atrium and facade sections) – see fig. 8
4. Avoidance of excessive temperature stratification in the facade and atrium (to ensure equal pressure difference on all floors)
5. Opening all sides of the atrium to outside to allow maximum use of wind power using an automatic control system – see fig. 9

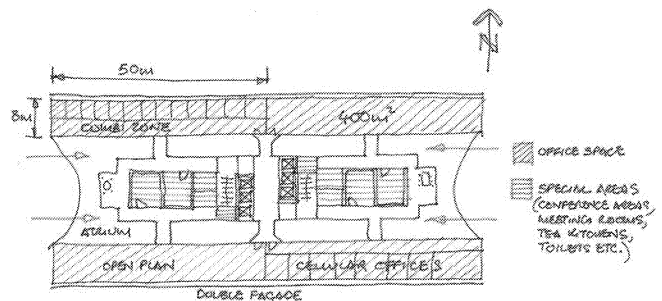


Figure 6: Floor plan of the model building

In order to reduce the pressure acting on the building skin in cold weather, the building is split into vertical sections of between 10 and 20 stories high. A heating and cooling system is

provided in the office spaces. Cooling without mechanical ventilation has been demonstrated to work effectively on several projects in Central Europe; see for example (5)

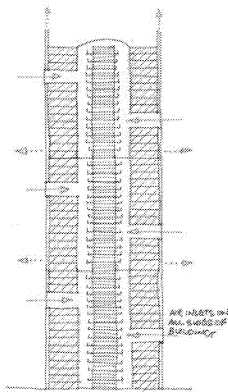


Figure 7: Building section of the model building

A virtual model of a representative part of the building with a combi office layout was built and dynamic thermal and CFD simulations carried out to test the concept. Normal occupancy and internal office loads are assumed. The location is Vienna city. Outside air enters the building via controllable openings in the atrium facades, passes into the combi zone via automatically controlled windows, then enters the office zone via a transfer grille, exits the office through windows into the double facade and finally leaves the building at the top of the extract flue.

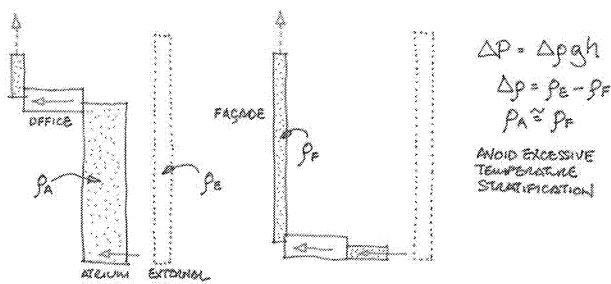


Figure 8: Strategies for optimizing use of thermal force

The largest resistance is given by the transfer grille between the combi and office zones on account of the sound attenuation requirements at this point and is approx. 2.5 Pa at the normal flow rate (2 air changes per hour in the offices). The set point temperature for heating in the offices is 22 °C and for cooling 24°C. The

atrium is heated to 15°C in winter and is not mechanically cooled in summer. The supply openings in the atrium facade and the extract openings at the top of the double facade are automatically controlled to maintain a constant pressure difference across the office floors.

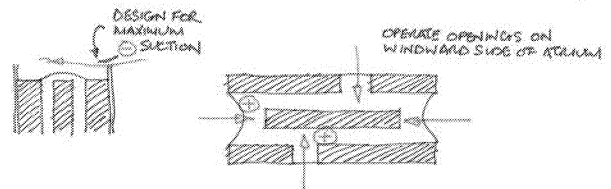


Figure 9: Strategies for optimizing use of wind force

In iteration steps various measures were used to optimize the performance of the model, including increasing the height of the flue above the top floor and introducing a controlled opening at mid-height of the double facade to allow reduction of the facade temperature on hot days. Both of these measures were necessary to stop reversed air flow on the upper floors. If the temperature in the atrium is lower than that in the facade then the available pressure drop at the top floor can drop below zero and cause reversed air flow on upper floors. The concept requires that the pressure at high level in the atrium is higher than external air temperature. This means that the envelope of the atrium needs to be airtight otherwise air flow through office floors will be significantly reduced.

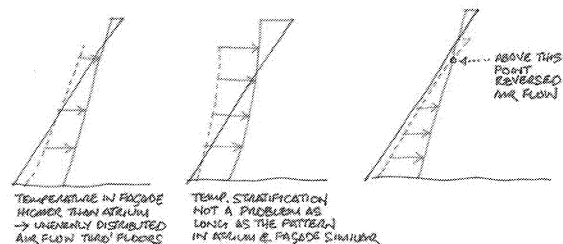
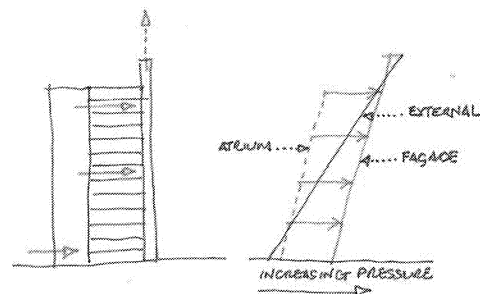


Figure 10: Pressure distribution diagrams

The study shows that if the pressure difference across the office floors is held at a constant value, varying path resistances due to opening doors to individual offices etc. do not cause major problems.

5. CONCLUSIONS

The provision of operable windows has the following advantages: psychological benefits (comfort), energy savings, less dependency on power systems (energy crisis, power failure, energy price crisis etc.) and more cost effective smoke ventilation. Mixed mode systems do not make ecological or economic sense since essentially two parallel systems which in principle fulfill the same requirement are provided. The benefits of the proposed concept are: increased energy efficiency in operation, reduced embodied energy (ventilation system, plant rooms, shafts), lesser risk of SBS, savings in running costs (energy costs, maintenance and operation) and savings in capital costs (system, plant rooms, shafts). Preliminary calculations show that the additional construction costs and embodied energy associated with the double facades and atrium can be largely offset by the savings on building volume due to the reduced need for plant rooms, shafts and suspended ceiling space as well as the ventilation system itself. Of course the ratio of net to gross floor area will be lower than that of a conventional high rise structure with a central core. This needs to be weighed up against the major benefits outlined above together with the spatial potential of the outlined concept and the psychological side effects associated with daylighted spaces and natural ventilation. The preliminary work shows that the concept is feasible. Further work on the following aspects needs to be undertaken: control strategies, optimization of the opening areas, investigations into the consequences of large pressure differences on skin construction due to high wind speeds and large thermal differences, the possibility of connecting double facades on both buildings sides together to provide pressure equalization, daylighting strategy for the atrium and adjoining spaces. By grouping a very tall high-rise building into vertical sections of between 10 and 20 stories each, it is possible to

enable natural ventilation of very tall buildings with the concept presented here.

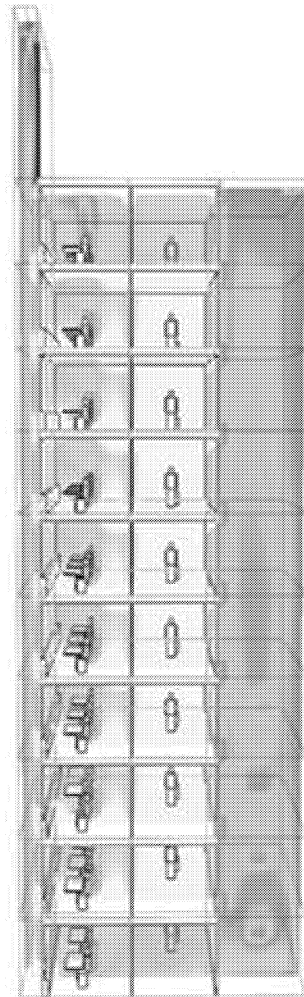


Figure 11: CFD simulation of part of the model building

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