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Expanding Boundaries:
Systems Thinking for the Built Environment

FILTER FACADE

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Abstract
The *Filter Facade* research project has the goal of reducing air conditioning (air conditioner split units) usage in buildings by cooling the interiors of residential high rises (see fig. 03) in subtropical climate regions with natural cross ventilation by optimizing the wind-flow using architectural components with specific openings such as the *Filter Facade*.

Keywords:
Reduce A/C; air conditioning; thermal comfort; natural ventilation; subtropical climate regions; optimizing wind-flow; architecture components; specific openings; noise pollution; air filtering; controllable opening cross-section; Filter Façade

1 INTRODUCTION

The damp sub-tropical climate of the south-eastern Chinese coastal region has led to the use of air-conditioning systems ensuring a comfortable 50%-moisture indoor climate in combination with a temperature of 22 °C. The outdoor air moisture and temperature intensity are almost double these values. Compared with heating systems, air-conditioning systems require almost triple the energy input, and through their waste heat, they cause significant further warming of the urban space (40% of the energy is released in ambient air in the form of waste heat), while the systems themselves frequently overheat due to their excessively sealed surface areas (Heat Island Effect).

Air conditioning systems are exacerbating the urban heat island effect [1] in cities already suffering from overheating due to increasing ground sealing and the heat accumulating function of building substance [2].

The 150 million inhabitants in the south-eastern Chinese coastal region require 145 GWh per year to cool their homes by means of air conditioning [3]. If predictions regarding immigration to Chinese conurbations are to be believed, and if the current air-conditioning standards are maintained, energy demand will double [4]. Above all, this trend means an ecological challenge, which is directly linked to questions on energy production and the urbanization of major regions.

It is possible to optimize thermal comfort by using natural ventilation. Results from specific research projects [5] and from the dissertation at the Institute of Architecture Technology [6] have clearly demonstrated this. Scientific measurement has furthermore produced evidence that specific natural cross ventilation can optimize human behaviour for periods of up to 90 % of the year (e. g. Hong Kong) [7] (see fig. 1.1 and 1.2).

Should the possibility exist to provide natural ventilation for the inhabitants of an urban area, the question of possible polluted air in big cities arises together with the associated prohibition on the opening of windows. The search for solutions to these problems and also the problems of noise, air filtering, and sun protection are analysed in the case studies of this paper.

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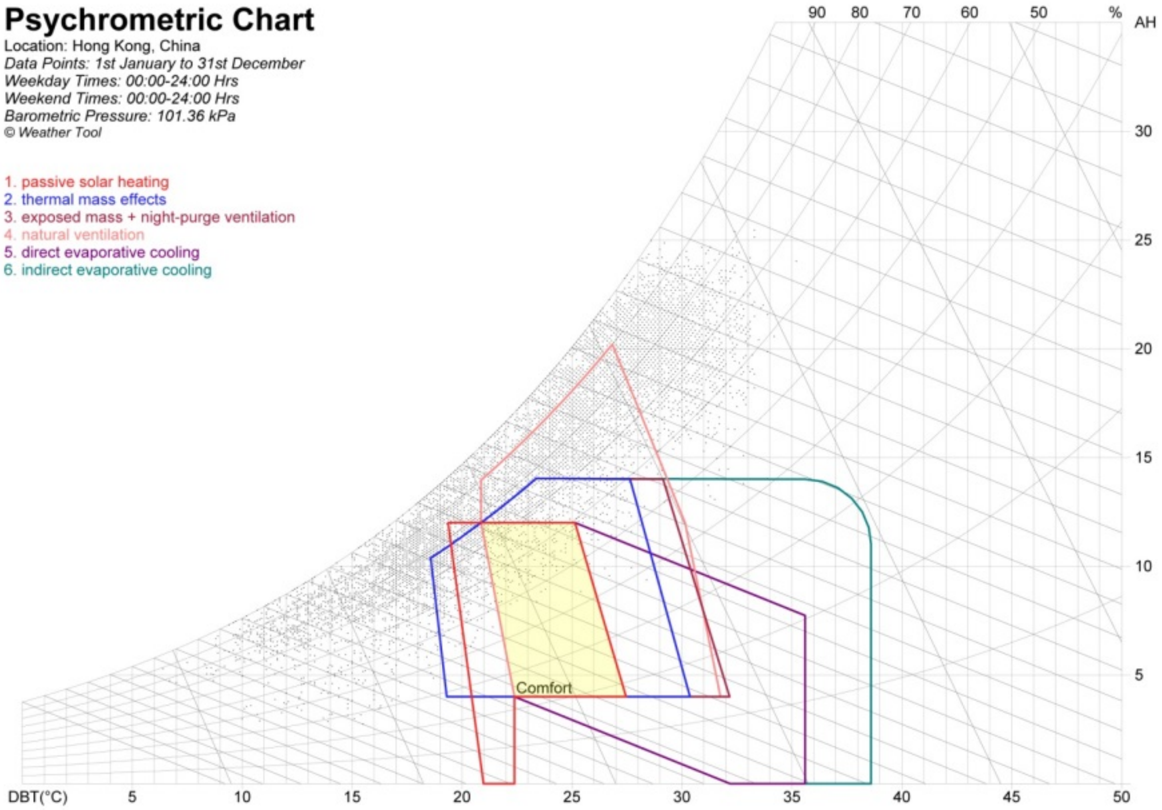

Fig. 1.1: Psychrometric chart of Hong Kong's comfort zone showing change due to natural ventilation (pink) and other methods of passive ventilation. Source: Weather Tool 2001, © Autodesk, Inc. 2010; Weather data Download, U.S. Department of Energy, report on the data (STAT) and ASHRAE Design Conditions Design Day Data file (DDY).

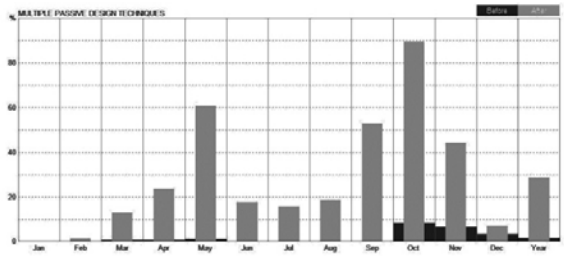

Fig. 1.2: Percentage of comfort throughout the year and per month achieved through natural ventilation in Hong Kong, data from psychrometric chart. Source: Weather Tool 2001, © Autodesk, Inc. 2010; Weather data Download, U.S. Department of Energy, report on the data (STAT) and ASHRAE Design Conditions Design Day Data file (DDY).

Fig. 3: Residential high riser Hong Kong, photo © Ferdinand Oswald 2013.

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2 METHODS

The methodology of this paper is, in a first step to analyse the locations and sites of air pollution worldwide. The second step discusses existing opening systems and their performance as a result of filtering and natural ventilation. The third investigative step points to solutions for problems resulting from traffic noise pollution and examines how natural ventilation performance can be optimised by making use of floor plan configuration and solar radiation. The conclusion presents a review of future research topics and examines potential solutions.

2.1 Inhalable coarse particles

Particulate matter (PM) is measured in micrograms per cubic metre. The size of the particles has a direct link to their potential for causing health problems. First among these are the particles of 10 micrometres in diameter or less, because these are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health problems. "Inhalable coarse particles," are those such as are found near roadways and in the vicinity of dust-intensive industries, these are larger than 2.5 micrometres and less than 10 micrometres in diameter.

2.2 Fine particles

The second group are the "fine particles," such as those found in smoke and haze, these are 2.5 micrometres in diameter and smaller. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

2.3 Existing openings systems

Current possibilities for filtering polluted air using different types of opening systems is an issue in need of discussion. I thus evaluate recently developed opening systems in terms of their efficiency in filtering polluted air, as also in achieving noise reduction, solar income and natural ventilation in residential buildings.

3 RESULTS

3.1 Air pollution in cities

The illustration shows the statistical range for air pollution worldwide from 2006. Particulate matter 10 micrometres in diameter is shown in yellow and the nitrous oxide emission in a thousand tonnes of CO2 equivalent is shown in violet. The bigger particulate matter with the size of 10 PM often occurs in developing countries in Africa, India and Middle East. This problem is further exacerbated due to the fact that these regions are frequently arid, sandy and have roads that are not asphalted. The Nitrous oxide emissions (NOE) shown in violet, are the "fine particles," such as those found in smoke and haze, they are 2.5 micrometres in diameter and less. These are more difficult to clean and are present to a significant extent in the following areas: The southeast costal region of China is heavily affected and European cities such as Paris, Stuttgart or Graz have high NOE values due to heavy automobile traffic and the special features of their locations. The results of this research are thus also suitable for use not only in the southeast costal region of China but also in European cities.

The inhalable coarse particles can be easily filtered by G1-G4 filter-systems (coarse dust filter class). The fine particles are more difficult to filter. This can be done using filters of the F5-F9 (fine particle filter class).

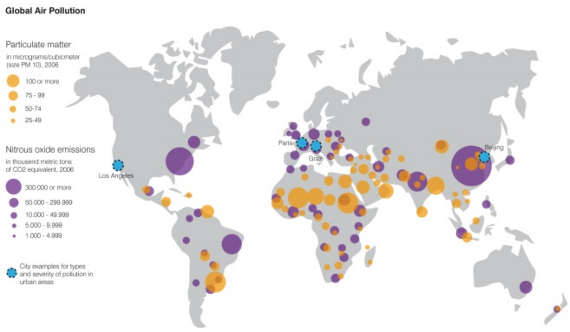

Fig. 3: Air pollution worldwide Source: © Institute of Architecture Technology, TU Graz, Austria, 2014.

4 DISCUSSION

We now move on to discuss existing opening systems and their performance in the contexts of filtering, noise pollution, floor plan configuration and natural ventilation.

4.1 Existing opening systems

A ventilation system is currently available on the market from the company Schüco *VentoTec* (see fig. 4). It uses filters of the fine particle filter class F7, and as a result can clean fossil fuels, forest fires and pollen pollutants from the air. The disadvantages of this ventilation system are as follows:

- The system is customized for office building usage and not for the residential use we propose to develop.
- It is a mechanical equipment set, which is powered by an electric motor and thus requires both an electricity supply and technical servicing and maintenance.
- A balustrade it is also required as housing for the equipment in a building.
- The air speed is not sufficiently high to ensure thermal behaviour inside the living space.
- The system is high-tech and thus cost-intensive.

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Fig. 4: VentoTec, © Schüco International KG, Germany.

Another existing window system which I would like to introduce here, is the conventional window system used in contemporary residential high rises in China (fig. 5). These have the following features:

- The system is customized for residential building usage in very high production piece numbers.
- The window wings are easily moved and can be fixed in different positions. This is a big advantage due to the different wind directions and wind speeds, which must be used for natural ventilation and it is an absolute "must" for the important possibility of controlling the opening cross section.
- They have single glazing only, a disadvantage due to solar heat income.
- The clientele for these units is working class, and as a result the openings are made cost-efficient and cheap to buy (low-tech).
- This window typology is thus lacking in the capability for the filtering of dirty air and reduction of traffic noise load features.

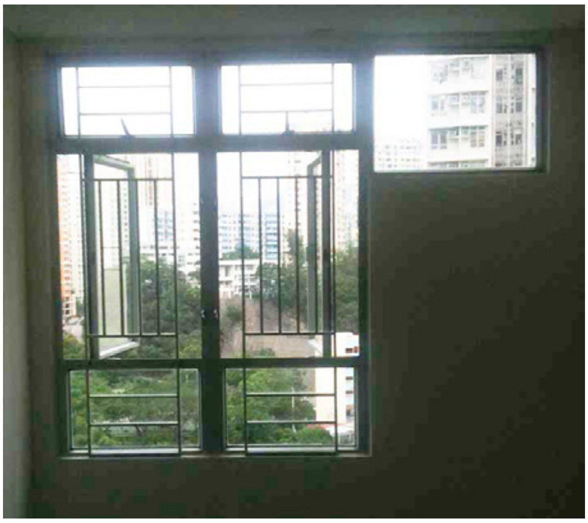

Fig. 5: Existing windows at Ngau Tau Kok Estate in Hong Kong, architect Hong Kong Housing Authority, Photo © Ferdinand Oswald, 2014.

4.2 Optimized Natural Ventilation

The natural ventilation performance (wind speed) also depends on the floor plan configuration. In figure 6 the modified floor-plan Harmony residential typology (architect: Housing Authority Hong Kong) from IAT can be seen. In the wind study and wind simulation conducted it has emerged clearly that effective natural ventilation is more efficient when cross ventilation is used throughout the complete living unit. This research was carried out by the Institute of Architecture Technology [8].

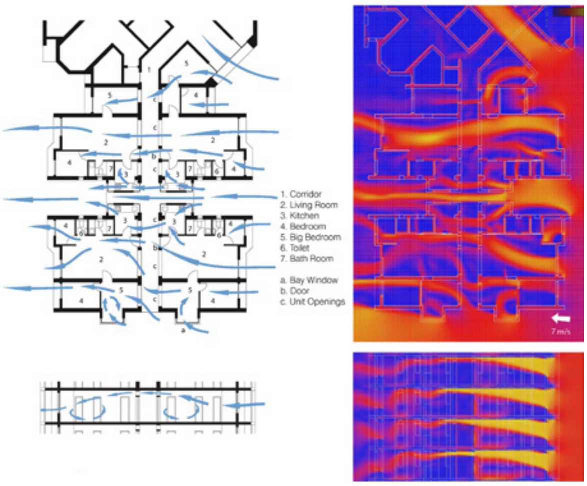

Fig. 6: Wind study and wind simulation for cross ventilation, floor plan and section © Institute of Architecture Technology, TU Graz, *Ferdinand Oswald, 2013.*

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4.3 Noise Pollution

Noise pollution is a serious problem when residential estates are located close to automobile infrastructure facilities, such as expressways, main city roads or highways. The illustration is a diagrammatic representation of the Acoustic Balcony which was developed by the Housing Authority 2013. Here the noise load is reduced using 3 different methods. These are:

- arc screens (glass fins)
- perforated acoustic wall panels in the winter garden
- diagonal, staggered opening configuration

The result of these three methods was reduced noise load income (Decibel = dB) into the living unit. The measured noise is outside 80.8 dB and within 56,0 dB which is a noise reduction of 24.8 dB. This has been worked out by an evaluation of the Institute of Architecture Technology in cooperation with the Hong Kong Housing Authority [9].

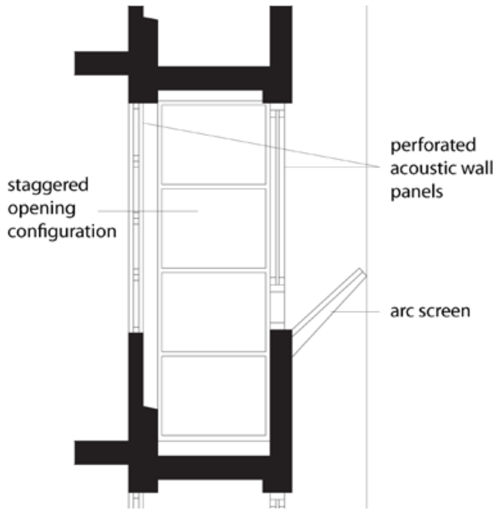

Fig. 7: Section Acoustic Balcony © Hong Kong Housing Authority, graphics modified by © Ferdinand Oswald, 2013.

4.4 Sun protection

The Met residential high rise project in Bangkok has no shading devices, although there is total glazing (from bottom to top) without significant solar heat income problems. This is explained by two main causes:

- The building openings are north and south orientated. Due to its location in Bangkok (13.8° latitude – Central Thailand) direct solar radiation here mainly from the west and the east.
- The building structure (reinforced concrete cantilevering elements) causes shadow to fall on the glazing in the openings (see fig. 8).

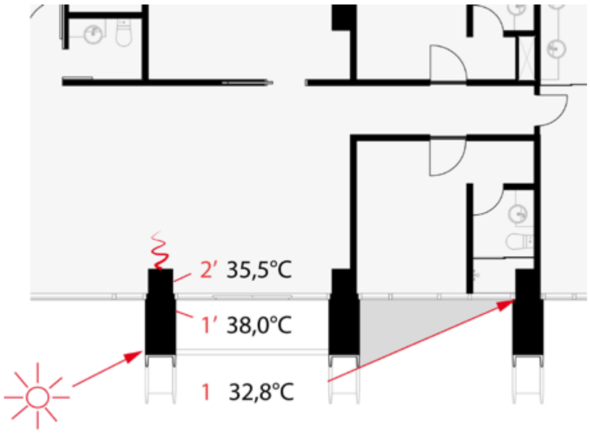

Fig. 8: The building structure causes shadow to fall on the glazing, the MET residential high rise Bangkok, floor plan unit 29th floor © WOHA architects, graphics modified by © Ferdinand Oswald, 2013.

4.5 Future research

The existing window opening system demonstrates that there is a significant need to develop a system which is both affordable for the working class client (cost efficient) and which can also fulfil the requirements as explained above. The fine particle filter class F7 air filter has the capacity to clean the air pollution encountered in big cities, but the problem of a massive air-flow filter resistance still arises. The wind speed is reduced significantly by the filter. It is thus necessary to optimize the natural ventilation by modifying the opening and façade system in a preliminary step. We can imagine one solution to this could be in the re-development of the box-type window. In combination with an intelligent façade structure the solution could result in the emergence of an entirely new *filter façade*.

The box-type window has good possibilities for:

- Optimizing natural ventilation including reaction to different wind directions and wind loads
- Reducing the traffic noise that can be heard
- Integrating a filter for cleaning polluted air

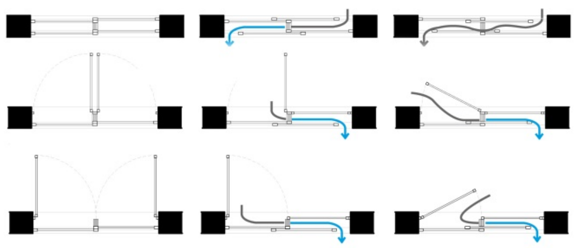

Fig. 9: Box-type window studies Source: © Institute of Architecture Technology, TU Graz, Austria, 2014.

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5 CONCLUSION

A single solution exists for each problem issue. The requirements of noise, air filtering, a controllable opening cross-section, as well as sunlight penetration, sufficient daylight and rain protection must all be achieved with this *filter facade*. This will require a *filter façade,* however, which is capable of meeting all of these needs simultaneously. The Institute of Architecture Technology is continuing this research in cooperation with the Hong Kong Housing Authority.

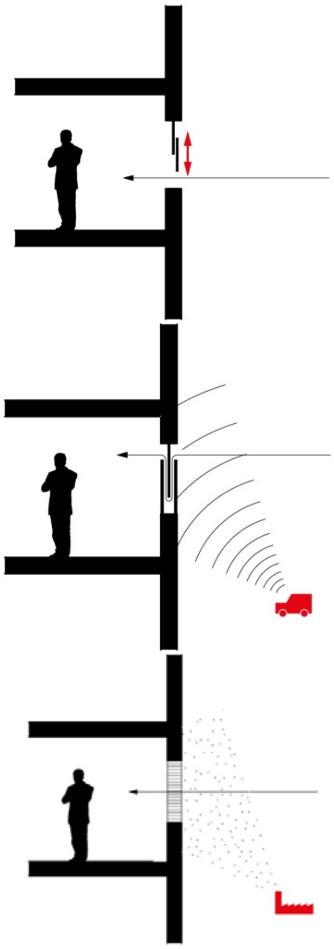

Fig. 10: Natural ventilation requirements for openings in urban area: optimized and controlled natural ventilation, protection for noise and air-pollution, © own diagrams by Ferdinand Oswald, 2014.

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