A COMMENT ON STUDYING THE VENTILATION REQUIREMENTS FOR BUILDINGS IN THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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ABSTRACT

A comment is made on the works that should be done in a recent consultancy project on reviewing the ventilation requirements for local buildings initiated by the Buildings Department (BD), Government of the Hong Kong Special Administrative Region (HKSAR). It is suggested that indoor air flow should be studied carefully for developing codes related to ventilation requirements for buildings. Local air speeds, turbulence, and their effects on thermal comfort are the key factors in determining criteria for providing better ventilation. Correlation relations among the key macroscopic design parameters and thermal comfort indices should be derived. Also, it is worthwhile to consider the application of Computational Fluid Dynamics (CFD) as this technique is more feasible and relatively cheaper than other methods. The use of CFD to study natural ventilation in a small flat is illustrated. Further, research activities on indoor air flow at The Hong Kong Polytechnic University (PolyU) are briefly reviewed. It is pointed out that local higher education institutions such as the PolyU would be in a very good position to help BD on working out appropriate codes on ventilation requirements in buildings. Results from this study will be useful not only to the HKSAR, but to other sub-tropical countries as well.

1. INTRODUCTION

The Hong Kong Special Administrative Region (HKSAR, formerly Hong Kong) is a dense urban area. Natural ventilation provided in a building is not properly considered [1]. This can be reflected by having so many buildings built closely together, which allows only limited natural ventilation. There are many illegal structures built in older highrise buildings in the past 30 years. Those structures not only block the normal and emergency access to the buildings, but also create problems on structural stability and fire safety, and have the risks of falling down of external finishes materials. A Building Safety Inspection Scheme (BSIS) is going to be implemented by the local Buildings Department (BD) of the SAR Government to solve those three problems [2]. For ventilation, those illegal structures would affect the air flow pattern and hence limit the supply of fresh air to buildings. Separation distances of the buildings would be much shortened by the illegal structures. In such case, heat rejected from air-conditioners would transfer to their neighbours easily. Even worse, large quantities of flue gases would be discharged if the illegal structure is used as a kitchen in restaurants. As a result, most of the windows in a building have to be closed. In addition, the quality of outside air would become worse, especially in those days with stagnant air movement, or when strong winds blowing from the north. Therefore, building occupants cannot rely on natural ventilation to provide fresh air for survival or for thermal comfort. Sometimes, opening windows might be very dangerous because large neon light advertisement panels are constructed over the whole building envelope without caring about the people staying inside. The BD had taken action to dismantle those panels several times, wasting lots of public money.

Because of the above and many other reasons, local citizens are likely to stay most of their time indoor in spaces with little natural ventilation. As a result, mechanical ventilation and air-conditioning (MVAC) systems are installed [3,4]. This is not only for getting sufficient fresh air for survival but also for thermal comfort. Bearing in mind that HKSAR has a very long hot and humid summer, and a 'warm' winter in most of the time. Window units are found in almost all residential buildings including temporary resettlement areas. Central air-conditioning systems are found in commercial buildings, shopping malls, industrial buildings, railway stations, halls, stadiums and theatres. Even passenger train compartments [5] and most buses and cars are air-conditioned.

However, both the design and operation of the MVAC systems for buildings in the HKSAR are not quite satisfactory as demonstrated by the survey on the indoor environment in different buildings including libraries, offices, shopping malls, education institutes and car parks [6-9]. The incident in 1996 [10] demonstrated well how inadequate ventilation design would lead to chaos, though that case was happened in train compartments but not in buildings.

A consultancy project [11] on studying the lighting and ventilation requirements for buildings in the HKSAR is just funded by the BD. The main objective is to review the current regulations, codes and recommendations [12-19] and identify the areas that requires improvement. Now, the SAR government is very open and public opinions are openly seeked through consultation papers. Views from academics are well taken care of before imposing regulations. BD and Fire Services Department (FSD) are the two government departments demonstrating this kind of good practices. In response to that consultancy project which might have long-term impact to the entire construction industry, this paper gives a brief summary on ventilation requirements in buildings under the current situations. The importance of studying indoor air flow is pointed out.

2. VENTILATION REQUIREMENTS

Generally, people need a minimum amount of oxygen for survival. However, carbon dioxide generated would cause the sensation of stuffness and 'bad air', therefore both oxygen depletion and carbon dioxide accumulation must be considered. Further, physicians would prefer more fresh air for minimizing the spread of disease, especially in crowded spaces. Thermal effects, both temperature and humidity, would also affect human sensation in a ventilated space. Following the recent review by Janssen [20], minimum ventilation rates were worked out based on physiological needs and comfort factors. The values ranged from a minimum of 4 cfm (2 ℓ/s) per person for the first estimation made in the history by Tredgold in 1836, to a maximum of 30 cfm (14 ℓ/s) per person, and then 15 cfm (7.5 ℓ/s) in ASHRAE Standard 62-1989 [21].

After releasing ASHRAE Standards 62-1989, lots of arguments arose on the ventilation rates, particularly in the smoking areas. This standard was withdrawn for some time for further reviews. A revision was proposed in 1996 in Standards 62R. An addendum with lower ventilation rates for most spaces was proposed which will go through a public review very soon [22].

Lots of efforts (e.g. as reviewed by Sherman [23]) were paid on studying the ventilation requirements in commercial buildings overseas. There had been conflicts between fresh air requirement and the associated energy use on heat or cooling the outside fresh air. Relatively speaking, ventilation in residential buildings was not studied so much as in commercial buildings. A main reason is because opening windows are believed to provide adequate ventilation. However, with the new style of living in using ventilation, more fresh air is required for diluting the indoor pollutants such as volatile organic compounds. Thus, the existing ventilation requirements for residential buildings have to be reviewed.

Studying building ventilation, both 'for physiological needs' and 'for human comfort', in the HKSAR is necessary. At the moment, codes and design guides for building ventilation dated back years ago, when Hong Kong did not have so many highrise buildings. Those codes had not been revised for a long time. Further, before smooth reunification to the Mainland, MVAC systems guides follow those available overseas [e.g. 21,24-26]. Whether those guides are applicable to sub-tropical regions and to the local territory is a big question. The recent ventilation design guide for underground car park [27] came basically from Australia, though very few large enclosed underground car parks are found in there. Another example is on quantifying air draught on thermal comfort using the percentage of dissatisfied (PD) equation [28,29]. This came from subjective survey in Scandinavian countries which should only be applicable to Europeans under cold climates. As reported by Chow and Fung [30], local Chinese prefer to have elevated air speed in summer! Many people felt sick while staying inside the train compartments in the big delay incident in 1996 [10]; and the unsatisfactory ventilation provisions in libraries, offices, shopping malls and car parks as surveyed [e.g. 6-9] are obvious examples of paying insufficient attention to the ventilation design, or just copying the overseas guides and codes without understanding the local conditions.

In view of these, the BD had decided to review the current situation and take appropriate actions to improve the ventilation provision in buildings. A consultancy project [11] was set up with a Steering Group chaired by the Director of BD himself to take care of the progress. The objective of the study was to make a comprehensive review of the ventilation requirements for local buildings. All the deficiencies and areas for improvement on the existing regulations, codes and recommendations [12-19] should be identified. A new set of standards is targeted to set up for protecting the health aspects of occupants and ensuring satisfactory indoor environment quality for local buildings which would have modern architectural features such as curtain-walled buildings, atria or multi-purpose complexes.

As pointed out by Chow [31,32] in applying for financial support, new ventilation design criteria for indoor spaces in the HKSAR should be developed scientifically. Current ventilation guides for those indoor spaces should be urgently reviewed so that new proposals to the HKSAR government can be recommended through advanced scientific investigations. The study should be a long-term project with the first stage focused on local air speeds, turbulence and their effects on thermal comfort. Research proposals were submitted to the HKSAR with those objectives to recommend, through scientific studies, new indoor ventilation design criteria related to local air speeds. However, the applications were not supported.

3. REVIEW OF CURRENT SITUATION

There are two key parameters specified in most of the standards and design guides for building ventilation [12,21,22,24-27]: the number of air changes rate and the ventilation rate. Both parameters were derived from the total ventilation flow rate through air inlets $\dot{Q}_a$ (in $m^3 \cdot s^{-1}$).

- Air Changes Rate

  The number of air changes rate N_{ACH} (in number of air changes per hour) is determined from $\dot{Q}_a$ and the space volume V_{room} (in m^3):

$$N_{ACH} = \frac{\dot{Q}_a \times 3600}{V_{room}} \quad (1)$$

- Ventilation Rate

  The ventilation rate VR (in $dm^3 \cdot s^{-1} \cdot m^{-2}$) is expressed in terms of $\dot{Q}_a$ and the floor area of the room A_{room} (in m^2):

$$VR = \frac{\dot{Q}_a \times 1000}{A_{room}} \quad (2)$$

  VR can be expressed in $m^3 \cdot hr^{-1} \cdot m^{-2}$ as:

$$VR = \frac{\dot{Q}_a \times 3600}{A_{room}} \quad (3)$$

  VR specified in the standards are normally determined from nominal occupant density and carbon dioxide emission from human beings.

Local regulations concerning ventilation provided in buildings appeared in Building (Planning) Regulations, Chapter 123 Subsidiary Legislation [12]. There, minimum requirements of windows for natural ventilation are specified clearly, though there is no explanation on how those dimensions (e.g. aggregate of window area should be at least 10% of floor area) are determined. A minimum requirement of 5 air changes per hour (i.e. $N_{ACH} = 5$) is also required in mechanically ventilated spaces. There is another set of Building (Ventilating Systems) Regulations, Chapter 123 [12] which is basically on ventilating system for buildings. Neither guidelines on determining the required minimum ventilation flow rate nor on how a desirable working environment can be provided were clearly described. However, the construction requirements of the system and personal responsibilities of the system owners, contractors and inspection officers were mentioned in there.

There are not any design codes or standards on assessing the spaces with MVAC, though the Environmental Protection Department is issuing a consultancy paper [19] on managing indoor air quality, looks like based on an earlier consultancy study [14]. However, neither local air speed limits nor turbulence were discussed. Also, there are some data on the minimum windows area (5 to 10% of floor area) for naturally ventilated spaces and minimum fresh air supply rate for air-conditioned spaces specified [15,16] by the Occupational Safety and Health Branch, Labour Department. Therefore, international standards and codes developed elsewhere were followed for designing environmental control systems. However, those standards should be used with careful consideration as they might not be applicable to local situations. An obvious example [e.g. 30] is the desire to have elevated air speed in crowded spaces.

There are some reservations in using the two parameters N_{ACH} and VR:

- Local buildings such as shopping malls used to be crowded with occupant density much higher than the nominal value. Therefore, the ventilation system might be undersized under such crowded conditions.
- For buildings like car parks where more air is required, much higher concentration of carbon monoxide might be discharged from a vehicular queue that formed near the entrance during rush hours. The ventilation system might not be functioning well under those vitiated ventilated environments.
- The ‘well-mixed’ model was commonly assumed. However, this might not be the condition in many buildings like atria where thermal stratification occurs.

As a result, there were many complaints on feeling discomfort in places with MVAC system [6-9]. Another example was that incident at the train compartment of a local railway where some people believed that the ventilation system was not operated properly [e.g. 10]. Consequently, in-depth investigations were made on how to improve the ventilation systems.

Preliminary summary on the local practice of MVAC systems design was reported by Chow and Fung [3], Chow and Yu [4]. It was found that most of the ventilating systems were installed to satisfy the local building regulations for obtaining the occupation permit. The primary objective of providing fresh air into the occupied space was generally not studied. For instance, Computational Fluid Dynamics (CFD) [1,33-35] was only used in several projects. Surveyed results also showed that installation of an air-conditioning system was to satisfy the thermal comfort requirement. This is obvious for those office buildings with high rental prices but this is only one of the purposes of providing air-conditioning system. The primary objective of an air-conditioning system is to provide occupants with a healthy and comfortable indoor environment for carrying out their activities [36]; or to provide the required indoor environmental control for manufacturing (e.g. textile mills, electronic factory), product storage, or other development processes.

Good design of the air diffusion system gives better satisfaction to building occupants. A 'gap' was found between the design and the preference of MVAC systems. Macroscopic numbers such as N_{ACH} were specified in designing those systems.

Buildings should be designed with adequate ventilation for comfort, health and satisfaction of building occupants. If natural ventilation is not adequate, MVAC systems with desirable end-product on the above three items should be provided [37]. Alternatively, another approach is to use a 'mixed mode' by providing a comfortable internal environment using both natural ventilation and MVAC system, but using different features of the systems at different times of the day or seasons of the year [38,39]. The preference on comfort of building occupants is closely related to the local conditions in the occupied zone. Physical parameters affecting thermal comfort are air speed, air temperature, humidity and radiant temperature. If a natural ventilated-building fails to give satisfactory conditions, the MVAC systems installed should have the first three parameters (air speed, air temperature and humidity) well controlled. For example, temperature and humidity in the occupied zone would be dynamically controlled by placing sensors in representative locations in the occupied zone. Usually, there are no sensor designed for MVAC systems to measure local air speed, so the local air speed was not controlled by the system automatically.

Air speed is a significant factor in evaluating the thermal comfort but it was not considered in the current building codes for natural ventilation. For instance, the window area, shape and location with respect to the local wind environment were not considered. Description of the building leakage is not found. Air speed is seldom taken as a control parameter in operating the MVAC systems (fan speed was specified)! Specifying the local comfort conditions in the occupied zone of buildings is difficult at design stage although it is one of the solutions to bridge the 'gap'. Relating the macroscopic numbers to the local human comfort conditions is an alternative choice.

4. PRELIMINARY WORKS TO STUDY

Indoor spaces cover residential buildings, commercial buildings, halls, theatres, car parks, tunnels and railway stations. However, vehicles such as trains, buses and car compartments which are also regarded as indoor spaces though they are not included in the current consultancy project [11]. The following works related to indoor aerodynamics should be specially studied at the first stage of understanding the ventilation requirement in buildings.

- To review the ventilation requirements including the air speed limits imposed by building ventilation design guides, standards and regulations overseas.
- To study the airflow in selected samples of all local building types with natural or mechanical ventilation.
- To study the effect of air turbulence on thermal comfort criteria for people in the HKSAR.
- To apply the technique of CFD [1,33-35] in simulating the airflow pattern in buildings of various types, both relying on natural ventilation or on MVAC system.
- To propose relevant macroscopic design parameters for both naturally and mechanically ventilated spaces.
- To derive correlation relations among the proposed macroscopic design parameters and the human comfort indices.
- To verify the above results by experimental field measurements.

Recommendations should be made on ventilation design criteria related to air speed and turbulence for indoor spaces in the HKSAR. The 'health' aspect of buildings must be improved by maintaining acceptable indoor air quality so that disasters due to inadequate understanding of ventilation, similar to the big incident [10] in 1996, will not happen. Care must be taken on discriminating between the outdoor air flow rate and the total supply rate.

- Air Speeds at Occupied Zones

Upper and lower limits of air speed at occupied zones are specified in different ventilation standards [e.g. 21,24]. The values should not be too high for giving draught effect nor too low to give air stillness. Results came mainly from cold countries where air speed V(t) (in ms^{-1}) at time t (in s) is required to be low.

- Air Turbulence

Common MVAC design for places under hot climate is to provide lower indoor air temperature and higher mean air speed at the occupied zones. In this way, higher installation and operation cost of the mechanical systems are required for cooling the incoming air at a large flow rate. Air turbulence was proposed to be another factor to be considered [28,29]. To quantify that, a turbulence intensity Tu (in %) was defined in terms of the mean air speed u and the mean velocity fluctuation u′, both over a period of time of measurement from t_0 to $t_0 + t_1$ as:

$$Tu = \frac{u'}{u} \tag{4}$$

where

$$u = \frac{1}{t_1}\int_{t_0}^{t_0+t_1} V(t)dt \tag{5}$$

and

$$u'^2 = \frac{1}{t_1}\int_{t_0}^{t_0+t_1} (V(t)-u)^2 dt \tag{6}$$

Maintaining suitable values of the turbulence intensity Tu in the occupied zones will give the same comfort level even at higher temperature and lower air speed. This phenomenon must be studied in detail before determining the comfort range of turbulence intensity. Suitable air distribution for naturally and mechanically ventilated spaces can then be designed. Field measurement and thermal comfort survey in different indoor spaces should be carried out. Macroscopic parameters for design purposes are to be developed using theories on turbulences. Note that both local air speed limits and turbulence intensity were not discussed in the proposed code of practice for the management of indoor air quality [14,19]. However, those two parameters would affect the mixing of pollutants with fresh air.

- Thermal Comfort due to Draught or Elevated Air Speed

A parameter known as Percentage of Dissatisfied PD (in %) [28,29] was proposed for assessing the thermal comfort by quantifying the air draught effect. This is given in terms of u, Tu and the air temperature T_a:

$$PD = (3.143 + 0.3696\ u\ Tu)\ (34 - T_a)\ (u - 0.05)^{0.6223} \tag{7}$$

In the above equation, u is taken as 0.05 ms^{-1} if u is less than this value, and PD is taken as 100% if it is greater than 100%. Note that many effects such as these due to adaptation, cultural differences, climate and seasons, age and sex differences are not considered [40].

Recent studies by Chow and Fung [30] suggested an opposite view in sub-tropical countries. Local Chinese prefer to have higher air speed, or at most, feeling less comfort only instead of feeling dissatisfied with the imposed elevated air speed, under hot and humid seasons. Studies by de Dear and Fountain [41] confirmed that office workers in warm humid climates prefer more indoor movement.

A new parameter known as percentage of feeling less comfort PLC due to elevated air speed was proposed by Chow and Fung [30] using a climate chamber. This parameter is taken to be either positive value of PD, negative value of PD or somewhere between the two, depending on two critical air temperatures θ_1 and θ_2 which were determined empirically. Equation for PLC is given by:

$$PLC = \begin{cases} -PD & \text{for } T_a > \theta_1 \\ f(T_a)\cdot PD & \theta_2 \le T_a \le \theta_1 \\ +PD & T_a < \theta_2 \end{cases} \tag{8}$$

The function $f(T_a)$ is given by:

$$f(T_a) = \frac{2(T_a - \theta_1)}{(\theta_2 - \theta_1)} - 1 \tag{9}$$

This parameter should be investigated more thoroughly in actual sites for covering the wide range of buildings.

- Turbulence Measurements

Hot wire anemometers allow measurement of airflow and turbulence at very low velocities. However, the single wire probe response is affected by the flow direction. With turbulent flow varying in directions, crossed wire types of probes would be used for high frequency response in velocity and turbulence measurements. Further, omnidirectional heated sphere types are suitable for low frequency response mean omnidirectional airflow. Collaboration projects on studying ventilation requirements in railway stations with the local industry [42] on using similar types of instruments demonstrated the technique is adequate for thermal comfort studies.

- Correlation Relations

Experimental studies in big spaces with mechanical ventilation were carried out extensively. Correlation relations were derived among macroscopic flow parameters and thermal comfort indices and key concentration of pollutants. For example in railway stations [43], the median value u_{50} (in ms^{-1}) of mean air speed measured at different positions is related with N_{ACH}, VR and the modified jet momentum J* for the air diffusion devices as:

$$u_{50} = 0.0483\ N_{ACH} \quad (10)$$

$$u_{50} = 0.0235\ VR \quad (11)$$

$$u_{50} = 288 \times 10^{-6}\ J^* \quad (12)$$

It was proposed that J* is an important flow parameter in spaces with MVAC. The mean age of air A_{50} (in s), with the concept reviewed in the literature [44], and the mean carbon dioxide concentration C_{50} (in ppm) are related to it as:

$$A_{50} = -2.75 \times 10^{-4}\ J^* + 74.2 \quad (13)$$

$$C_{50} = -5.19 \times 10^{-2}\ J^* + 570 \quad (14)$$

5. APPLICATION OF CFD

Good understanding on air distribution in the building is important for deriving ventilation standards. CFD [1,33-35] is a common technique applied for predicting the microscopic picture of the mixing mechanism. The air flow patterns, temperature contours, dust particles and contaminants distribution achieved are useful to evaluate the performance of the mechanical ventilation and air-conditioning systems. Better design of the selection, spacing and operating conditions of the air diffusion devices [e.g. 45] is obtained.

However, there are problems in CFD simulations [e.g. 46-48] and at least three points have to be reviewed:

- turbulence models;
- discretization schemes for solving the set of partial-differential equations while using finite difference methods;
- algorithms for solving the pressure-velocity linked equations.

These three points will be studied in-depth with experimental verification [e.g. 49].

Very few studies were made on extracting relevant macroscopic parameters for design purposes from CFD results. A more practical approach is to derive a simple model based on the macroscopic flow parameters determined from a database derived from CFD. Macroscopic flow parameters included N_{ACH}, VR, J* and others which were specially defined for this purpose. For example, correlation equations with the median of mean air speeds u_{50} and median value PD_{50} (in %) of PD were derived [50] for a mechanically ventilated space as:

$$u_{50} = 0.018\ N_{ACH} \quad (15)$$

$$u_{50} = 0.017\ VR \quad (16)$$

$$u_{50} = 252\ J^* \quad (17)$$

$$PD_{50} = 0.46\ N_{ACH} \quad (18)$$

$$PD_{50} = 0.44\ VR \quad (19)$$

$$PD_{50} = 6191\ J^* \quad (20)$$

Other examples are on relating the ‘throw’ of air diffusers to the mean age of air, as criticized in the preliminary analysis on the ventilation design of a train compartment [5].

For natural ventilation, a small flat of size 10 m by 10 m, height 3 m with two windows A and B (both of width 1 m) as shown in Fig. 1 is taken as an example. Driving forces for natural ventilation included stack effect due to temperature differences between indoor and outdoor, buoyancy of warm or cool air, and wind action. The wind effect and the relative positions of windows are considered in this paper as an illustration on how CFD can be applied. The commercial package PHOENICS 3.1 [51] was taken as the simulator.

Four cases are considered with window B at different locations and opening conditions.

- Case A:
  Window B fully opened at 3 m away from the top left corner of the flat as shown in Fig. 1a.

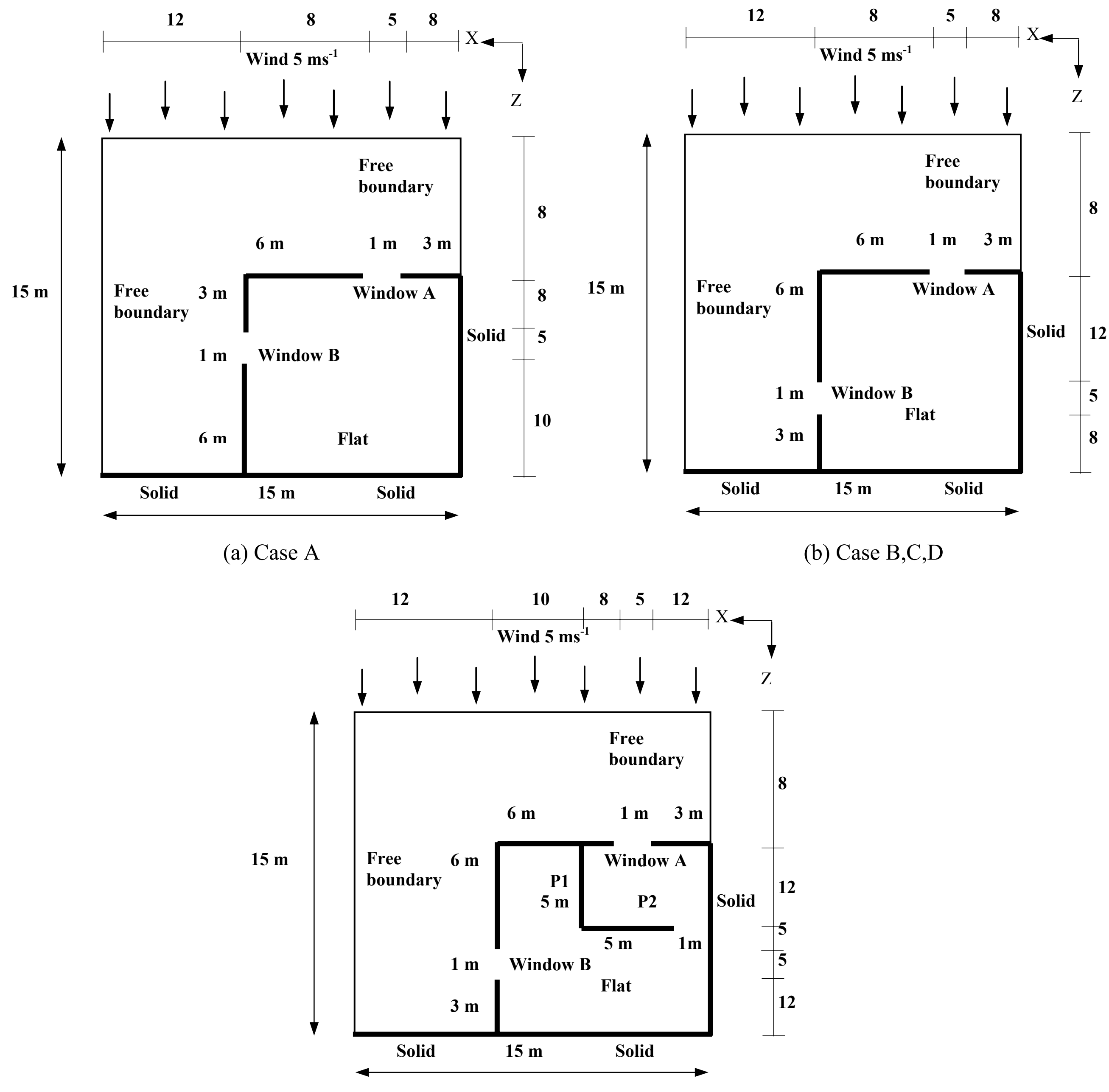
- Case B:
  Window B fully opened at 6 m away from the top left corner of the flat as shown in Fig. 1b.

- Case C:
  Same as case B but with window B closed.

- Case D:
  Same as case B but with window B half-closed.

Another case on the effects of internal partitions is also considered:

- Case E:
  Windows at positions same as in case B, both fully opened but there are two partitions P1 and P2 as shown in Fig. 1c.



(a) Case A

(b) Case B,C,D

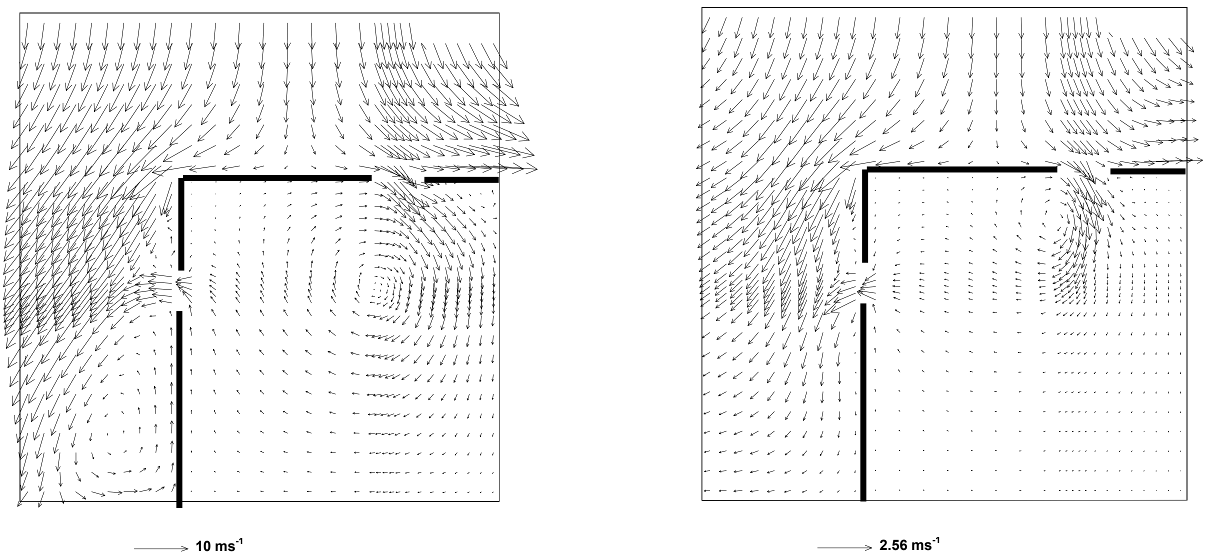
(C) Case E

Fig. 1: Geometry of a small flat

Predicted air velocity vectors for the five cases are shown from Figs. 2 to 6 due to very strong wind of ms-1 blowing in direction as shown in Fig. cases A and B shown in Figs. 2a and 3a illustrated that higher indoor air speeds will be found if window B is designed further away from the corner. Results for case C shown in Figs. 4a and 4b demonstrated that closing window B will not give a good path for air motion. Opening the window partially for case D as shown in Fig. 5a would give better air movement. The importance of opening a window in providing indoor air motion is clearly demonstrated.

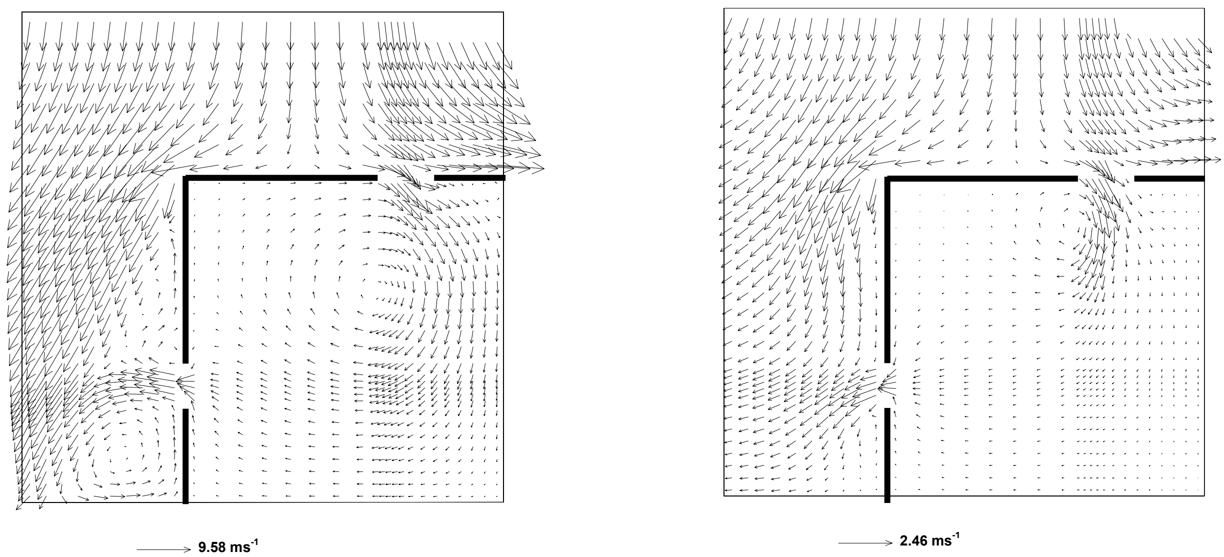
Further, results on the effect of partitioning the room is shown in Fig. 6. Air flow in the space next to partition P1 will be quite 'still'.

In addition, lower wind speed of 1 ms^{-1} was also considered with results shown in Figs. 2 to 6. Results on the air motion are similar to the stronger wind except that the magnitudes of the air velocity were reduced.



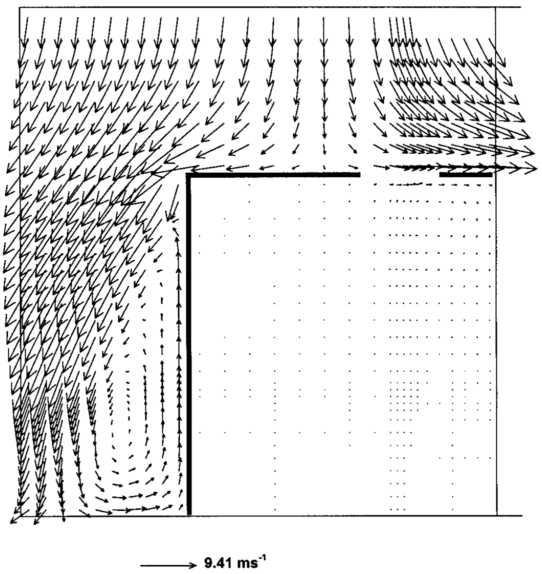
(a) Wind speed 5 ms^{-1} (b) Wind speed 1 ms^{-1}

Fig. 2: Results of case A

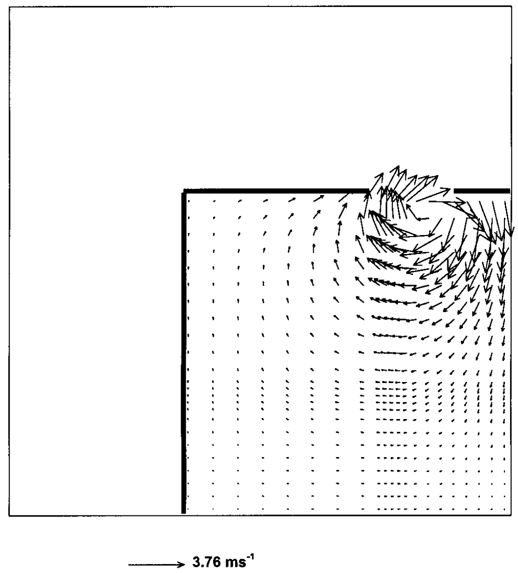


(a) Wind speed 5 ms^{-1} (b) Wind speed 1 ms^{-1}

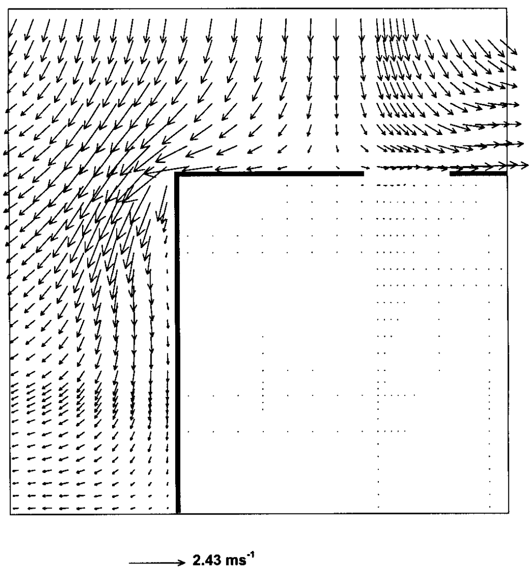
Fig. 3: Results of case B



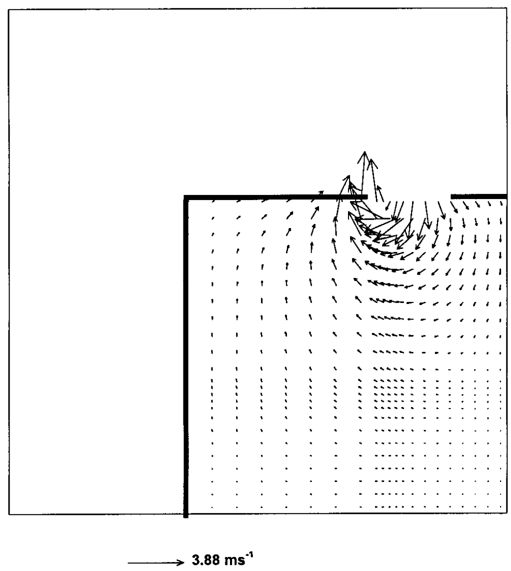
(a) Overall, wind speed 5 ms^{-1}



(b) Inside the flat, wind speed 5 ms^{-1}

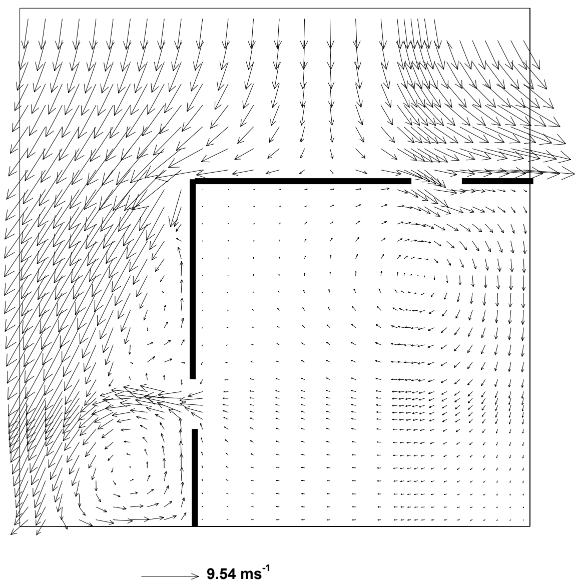


(c) Overall, wind speed 1 ms^{-1}

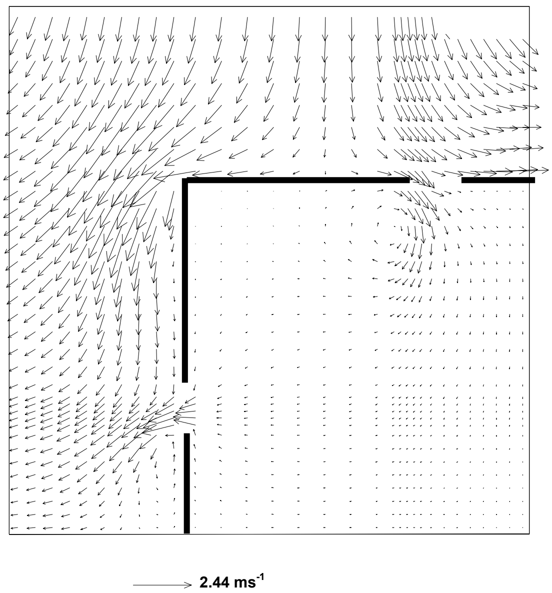


(d) Inside the flat, wind speed 1 ms^{-1}

Fig. 4: Results of case C

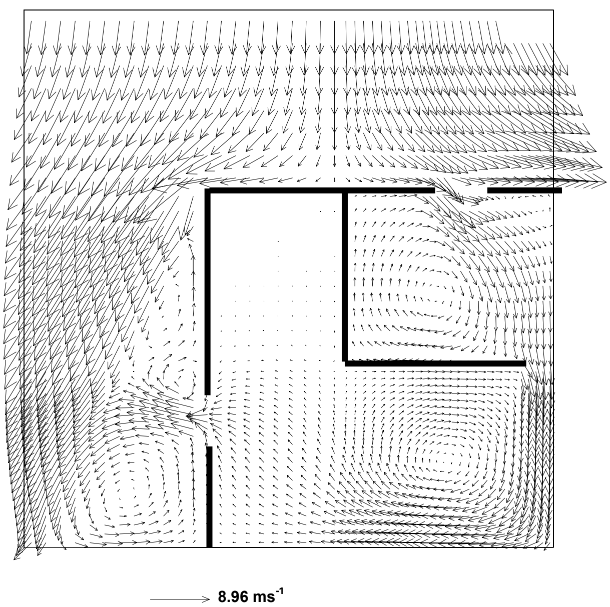


(a) Wind speed 5 ms^{-1}

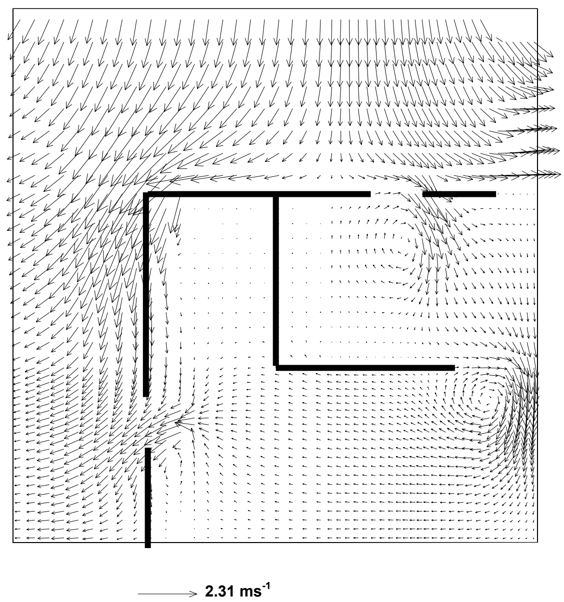


(b) Wind speed 1 ms^{-1}

Fig. 5: Results of case D



(a) Wind speed 5 ms^{-1}



(b) Wind speed 1 ms^{-1}

Fig. 6: Results of case E

6. REVIEW ON PREVIOUS STUDIES AT POLYU

There are many papers, reports and books on ventilation and indoor aerodynamics in the literature which had been reviewed extensively [e.g. 44]. In fact, research on indoor air quality engineering at the PolyU was started since 1987. Quality Teaching', i.e. teaching supported by research, is offered at the PolyU. High-level research projects [e.g. 6-8] included application of CFD for MVAC systems design, field measurement on indoor environment, thermal comfort assessment, air speed measurements and air diffusion devices. Different buildings such as old and new offices, car parks, vehicular tunnels, electric cable tunnels, railway stations, atria, shopping malls and the PolyU buildings were studied.

A summary of the academic works, excluding those routine field measurements which are regarded as 'home-work assignments', is listed below:

- Development of CFD modelling technique [1,33-35] for simulating the indoor airflow pattern in spaces with MVAC systems. Both a 'self-developed' CFD package and application of commercial and academic packages were made.
- Development of surveying method for subjective feeling of occupants [6]; and field measurement techniques on indoor environmental parameters in big sites [8].
- Development of technique for analyzing large volume of collected data [42].
- Preliminary studies on the macroscopic parameters for designing MVAC systems and correlation with thermal comfort criteria [e.g. 5].
- Improvement of indoor environment by modifying the MVAC systems. A good example is installing the new 'partial air-conditioning system' at several railway stations, which is an outcome of a PhD project [42].

All the above should be applied in developing optimum codes related to ventilation requirements in the HKSAR. The above studies will be continued under financial support of the PolyU Area of Strategic Development (ASD) in Advanced Buildings Technology in a Dense Urban Environment: Fire Engineering Contingency. Two journals, International Journal on Engineering Performance-Based Fire Codes and International Journal on Architectural Science are launched under this ASD activity.

7. CONCLUSION

The ventilation requirements in buildings are briefly reviewed. The new consultancy project [11] to review the current situation and identify the areas of improvement should cover at least the following key points:

- Reviewing the air speed limits imposed by standards employed from overseas [e.g. 21,22,24-26], and investigating whether this would give draught, preferred elevated air speed or air stagnant regions.
- Analyzing the effect of air speed and air turbulence [28,29] on thermal comfort criteria for local citizens.
- Deriving design equations relating human comfort indices with macroscopic design parameters with the aid of CFD, and verification by experimental studies [e.g. 1,33-35,46-48].
- Parameters related to ventilation effectiveness [52] must be clearly identified. The concept of using the age of the air is very important [44].

This project [11] is an extensive study and so the plan for investigation must be worked out carefully so that resources and time would not be wasted. Further, demonstration of using a CFD package [51] on assessing the natural ventilation due to different window position is illustrated.

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