

Wind Effects

Wind Effects on Buildings and Urban Environment

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Annual Report of COE Research Projects

Project 1 : Wind Hazard Mitigation

The objective of research project 1 is to promote and develop many wind engineering technologies to mitigate wind hazards.

Wind load distribution to estimate maximum load effects

The gust loading factor method is useful for estimating the equivalent static wind load. Methods for estimating equivalent static wind load are mainly aimed at a certain load effect on a structural member or wind force. In practical design, innumerable maximum load effects can be considered. Innumerable equivalent static wind loads also have to be considered to determine these load effects. This makes it difficult for designers to choose a reasonable method.

This research project proposes an equivalent static wind load distribution that reproduces the maximum load effects on structural members. The method of deriving this distribution is hereafter referred to as the universal wind load (UWL) method. This method is applied to a cantilevered roof using wind tunnel test results. The bending moment induced by the equivalent static wind load is in good agreement with the maximum bending moment rather than the shear force in the members regardless of the structural system. The UWL method is applied to a high-rise building using the results of wind pressure tests to compare the wind load effects obtained from the Gust Loading Factor method and from the UWL method.

To confirm the effectiveness of the UWL method, the results of wind pressure data of an actual structure (large span roof) was used and the wind load distribution was reproduced using the UWL method.

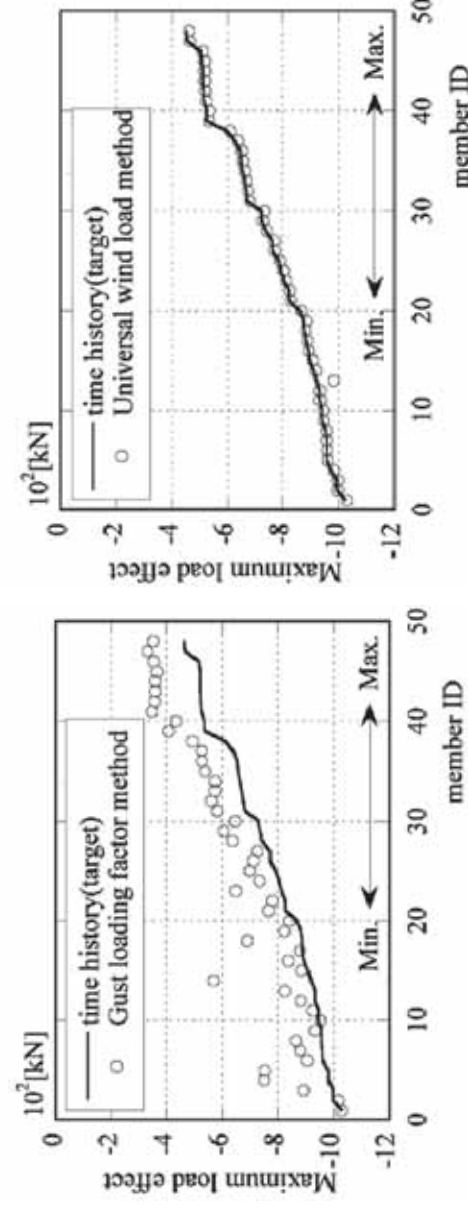
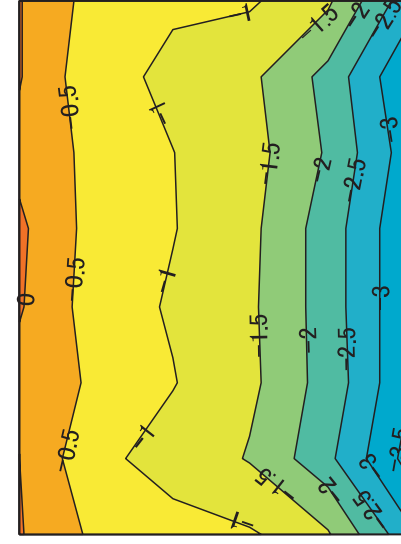


Figure 1. Example of UWL: comparison with conventional method.

Wind response monitoring, system identification and urban hazard mitigation system

The objectives of the research are to develop a wind-induced response monitoring system for buildings during strong wind using a Global Positioning System (GPS), to develop a health monitoring system for buildings by hybrid use of real-time observed data and FEM analysis, to develop a system identification technique for accurately estimating the damping ratio for predicting wind-induced response, and to develop a wind hazard mitigation system for urban buildings.

The following items were promoted in this research.

(1) Wind Response Monitoring System:

Basic studies were carried out to investigate the characteristics of RTD using an epoch-by-epoch algorithm. The accuracies of RTK-GPS and RTD using the epoch-by-epoch algorithm were compared. Response measurements using Multi-GPS were conducted of damped-free oscillation of two structural models. Wind-induced response measurement using Multi-GPS were performed on two structural models to investigate the possibility of response measurement for real structures.

(2) System Identification:

An ambient vibration measurement and a wind-induced response measurement were conducted on a transmission tower to identify its dynamic characteristics using Frequency Domain Decomposition and a Multi-Random Decrement technique. An ambient vibration measurement was conducted on a 3-story steel house to identify its dynamic characteristics and to estimate the stiffness of the secondary members.

(3) Hazard Mitigation System;

The feasibility of a multi-measurement system with

RTD using a Local Area Network was investigated to build a wind disaster prevention system.

Wind disaster investigation and design wind speed

The purposes of this research are to investigate the interaction of wind climates and structures including characteristics of extreme winds not only in Japan but also in other countries, and damage propagation processes of buildings; to develop a tornado-like flow simulator to investigate characteristics of extreme wind climates and their effect on buildings; to develop a wind climate database that contains wind speeds with their directions and information on tropical cyclones; to develop a tropical cyclone model for incorporation into the Monte-Carlo simulation technique for evaluating the probability distribution of wind speeds and design speeds of interested sites; and to develop a procedure for evaluating design winds that takes wind directionality and wind load effects into account.

Progresses of this research is as follows. A lot of post-disaster investigations of typhoons, tornadoes and downbursts were conducted. The results were published in the Journal of Wind Engineering and presented for discussion at some academic meetings. Wind tunnel experiments on a damage situation were conducted where a large roof was blown over a neighboring building. A larger-sized tornado-like flow demonstrator was developed. Tangential velocity fields were measured with a laser doppler velocimeter (LDV). The flow characteristics were visualized, and ground roughness effects were studied. Cyclones at Indian Gulf were studied. Wind speeds at the ground surface during a typhoon were modeled with modified Davis & Harris models. Wind directionality effects were studied. A concept for deriving

directional factor was proposed.

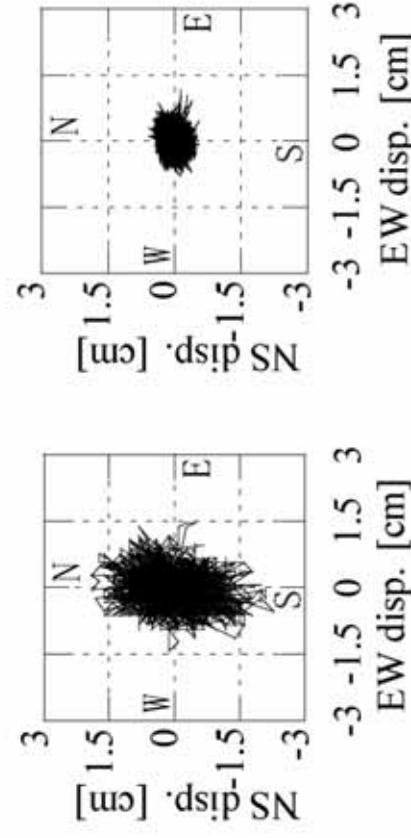
Numerical simulation of turbulent boundary layer flow over two-dimensional hills

This research aims to establish a numerical model for turbulent boundary layer flow over hills. Its characteristics depend strongly on hill shape, inflow conditions and hill surface conditions. These factors should be appropriately considered in the numerical model in order to obtain reliable simulation results. The proposed numerical model utilizes an LES approach that enables the time-dependent calculation of the unsteady flows including large-scale vortices, which are usually established in the wake of a steep hill. Surface conditions (smooth or rough) are modeled by changing the ground roughness density of the rectangular blocks. Furthermore, inflow turbulence corresponding to the hill surface conditions is generated from an additional simulation of the spatially developing turbulent boundary layer.

(1) The following items have been checked: data transfer form conventional staggered grid system to Maliska type grid system, turbulence model (Standard Smagorinsky model, Dynamic SGS model, Mixed SGS model), and validation of the numerical model. These were done on the NEC SX-5 Supercomputer of TIT, together with the T.Tamura lab.

(2) A PC Cluster Computer System (4 CPU as Intel Xeon 2.8Ghz with 512MB*2 of discrete memory for each node) was established. Modification of the program using MPI is in progress in order to conduct parallel calculation.

(3) For numerical simulation of the flow-structure interaction (Flow-induced vibration), inflow turbulence has been generated. An alternative numerical model has been



(a) RTK-GPS(conventional) (b) RTD-GPS(new method)

Figure 2. Measurements of stationary points with GPS

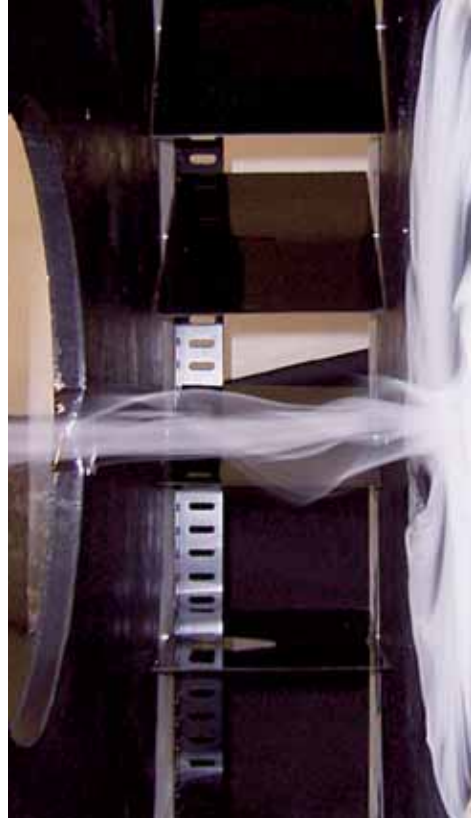


Figure 3. Tornado like flow induced by tornado demonstrator

programmed (in progress). A generalized curvilinear coordinate system has been developed with a corocate grid system rather than a Maliska staggered grid.

Establishment of aerodynamic database

The objective of establishing an aerodynamic database is to provide the community with access to wind tunnel test data for use in the preliminary design of various kinds of structures. This interactive database will provide users with values of aerodynamic data for various kinds of structure, e.g. low-rise buildings with different roof types, high-rise buildings, dome structures etc. The mean and fluctuating pressure/force coefficients are provided together with the raw pressure/force data measured in the experiment.

Wind tunnel experiments on the following structures have been conducted. The aerodynamic statistical and raw data have been uploaded on the COE website and can be browsed and downloaded.

- Wind pressure database on low-rise building with gable roof
- Wind pressure database on rectangular cylinder
- Wind pressure database on shell structure



Figure 4. Wind pressure database on Web.

Wind resistant design of tiled roofs

To evaluate the wind resistance of residential house roofs, wind tunnel experiments and field measurements for distributed wind pressures were conducted considering realistic situations such as the mechanism of peak forces on roof tiles. The following results were obtained. The largest negative peak pressure for all directions occurs at the corners of roofs regardless of roof shape. Large negative peak pressure coefficients exceeding -6.0 occur only at the corner areas of hip roofs. However, these large negative peak coefficients occur at the tips and edges as well as the corners of gable roofs. Temporarily wind force distributions were evaluated from temporary

internal pressures estimated from the temporary external pressure obtained from wind tunnel tests at the base of the above results without tiles lifting. Loading modes, which are the ratio of load on surrounding tiles to that on a target tile, were decided from the results of the wind tunnel experiments.

A static loading system has been developed. The capacities of this system are as follows. There are 9 simultaneous loading points. The load on each point is controlled by a PC monitoring the load through a load cell automatically and separately. The maximum individual load is 2kN.

The loading models of a roof tile are made by the conventional method of roofing with underlay and battens. The loads act on a target tile and the eight tiles around the target tile according to a loading mode. In addition, the model, with tiles added on the overlapping side, was investigated to confirm the fixing effect of overlapped tiles. It was found that the test should be carried out for the target tiles with the surrounding tiles.

Wind-resistant self-sufficient housing system

The purpose of this study is to develop a building system and a construction method for residences that will not only survive strong winds like typhoons, but also obtain energy from the wind and solar radiation, and drinking water from the rain. This will save large-scale infrastructure for distribution, creating a housing system that is independent and self-sufficient. The following items were studied.

- 1) General data of weather in the Southeast Asia area were collected by the Japanese Meteorological Agency affiliated organizations.
- 2) Basic data on the production system and a typical building system for residences were collected from the literature.
- 3) Several data on governmental organizations and regulations relating to building systems and construction methods for residences were collected from researchers and published reports in this area.
- 4) General data on culture and typical life-style were collected from Japanese guidebooks.
- 5) A building sub-system considering resistance to wind pressure in southeast Asia was investigated according to field studies in Thailand and Vietnam.

Project 2: Design Method for Natural/ Cross Ventilation

The aim of research project 2 is to develop a guideline for a cross-ventilation design method and to hold a workshop on the guideline in the final year of the COE project. The main works in this research in 2004 are as follows.

Analysis of airflow structure in cross-ventilated building by RANS turbulence model

Previous research has indicated that LES could reproduce wind tunnel results fairly well, but the calculation load is very large. To reduce the computational load and to thus improve CPU performance, several RANS turbulence models, containing standard $k-\epsilon$, RNG $k-\epsilon$, standard $k-\omega$, and SST $k-\omega$, have been verified and compared to wind tunnel results for the flow field around and within a cross-ventilated building. A commercially available CFD code, Fluent 6.1, was used to solve the governing equations of the simulated flow field. Figure 5 shows that the location of the standing vortex and the flow separation at the roof simulated by the SST $k-\omega$ model were in good agreement with the wind tunnel results. The un-

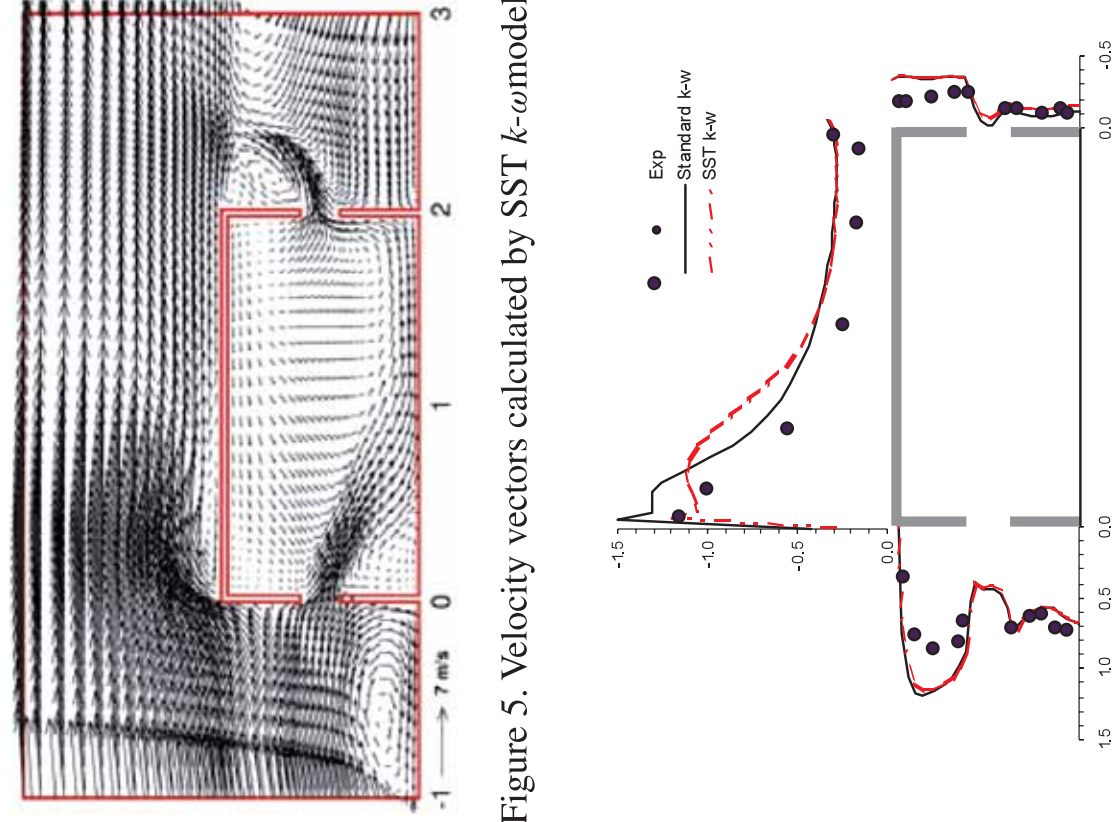


Figure 5. Velocity vectors calculated by SST $k-\omega$ model

derprediction of wind pressure on the building edge in Figure 6 was due to a large increase in kinetic energy at the upwind edge. However, the general pressure distribution trend was depicted satisfactorily and the pressure coefficients near the openings were accurately predicted.

Analysis of airflow structures in training institute from field experiments

Thermal comfort in buildings is increased by cross-ventilation in hot and humid climates. Residents usually open windows to achieve cross-ventilation for a long time each day. Therefore, these openings are equipped with insect screens, and are occasionally closed by lace curtains, fabric curtains etc. to block out incident sunlight, to moderate glare and to prevent persons from looking in. Residents are accustomed to being exposed to airflows through these window configurations. The airflow features through these window configurations were investigated to precisely evaluate the thermal comfort of residents. The air velocity was measured last summer at a training institute using four ultrasonic anemometers. The mean air velocity was decelerated at the center of the room by the resistance of window configurations in the upwind opening. The characteristic length scale of eddies through the room became gradually smaller at three points other than the path point. The fabric curtain influenced the contribution of energy spectra in the low frequency range and characteristic length scale of eddies at the center of the room. The negative slope and the power spectrum ratio in the low frequency range were highest at the path point where the airflow contracted.

Establishment of high-precision model for ventilation flow rates

The currently used method for calculating ventilation flow rates is a conventional orifice flow model that assumes a constant discharge coefficient independent of the approaching flow angles. The influence of wind direction is not taken into account in the ventilation calculation formula. However, the discharge coefficient at the opening is highly dependent on wind direction angle. Most actual wind directions are not normal to the opening. Thus, the prediction accuracy of ventilation flow rates by the conventional orifice flow model may greatly decrease.

Figure 6. Pressure coefficient distribution

The proposed local dynamic similarity model expresses the relative pressure balance between the cross-ventilation driving pressure and the interfering cross-flow dynamic pressure in the vicinity of an opening. It selects a discharge coefficient that adequately matches the approaching flow angle. Previous work has indicated that the model improved the prediction accuracy of ventilation flow rates compared to that of the conventional orifice flow model even when the discharge coefficient greatly decreases with change in wind direction.

In 2004, wind tunnel experiments were conducted with the opening positions and the building arrangement changed in a more complicated manner, and the applicability of the local dynamic similarity concept was evaluated in detail. It was found that the discharge coefficient C_d can be predicted accurately from dimensionless room pressure P_R^* for most opening positions, even if the approaching flow angle is varied or there is another building near the opening. It was also found that there are no substantial problems in predicting C_d from P_R^* when the direction of the interference flow is changed or there is a wall/floor near the opening disturbing the diffusion of incoming airflow. However, it should be noted that the C_d prediction accuracy is lowered when these conditions occur simultaneously.

Project 3: Control of Indoor/Outdoor Air Pollution

Project 3 deals synthetically with the atmospheric problem in the field of indoor space to urban space. The atmospheric problem in the field of indoor space has a microclimatic problem around the human body or indoor air pollution such as sick house syndrome. The atmospheric problem in the field of urban space has many problems caused by contaminant discharge near the building, gaseous contaminant discharge from district heating plants, etc. This project is divided into two fields, the indoor and outdoor air environments, and research on air pollution in both fields is being carried out. Some of the results of research in 2004 are shown below.

Control of indoor air pollution (indoor air chemistry, biology and physics)

Objectives of research in indoor air pollution are:

- To develop a fundamental model for predicting emis-

sion, ad-/desorption and chemical reaction of VOCs (Indoor Air Chemistry)

- To develop a numerical model for predicting micro-organism growth and MVOc emission by taking into account the influence of moisture and temperature (Indoor Air Biology)
- To develop a procedure for coupled analysis of flow, temperature, moisture and pollutants (Indoor Air Physics)
- To establish a paradigm for the integrated design of the indoor environment that takes into account the Indoor Air Chemistry, Biology and Physics (Public Health Engineering)

Progress of research in indoor air pollution (2004FY)

Indoor Air Chemistry;

- A flat-plate-type test chamber was developed and the mass accommodation coefficient of ozone and sticking coefficient of HCHO were measured for various building materials.
- A medium-scale-type test chamber ($V=1.5 \text{ m}^3$) was developed and the VOC emission rate from DIY furniture was measured.

Indoor Air Biology;

- A micro cell type test chamber was developed and the MVOc emission rates from various fungi (Alternaria, Eurotium and Aspergillus) were measured taking into account the influence of moisture and temperature.

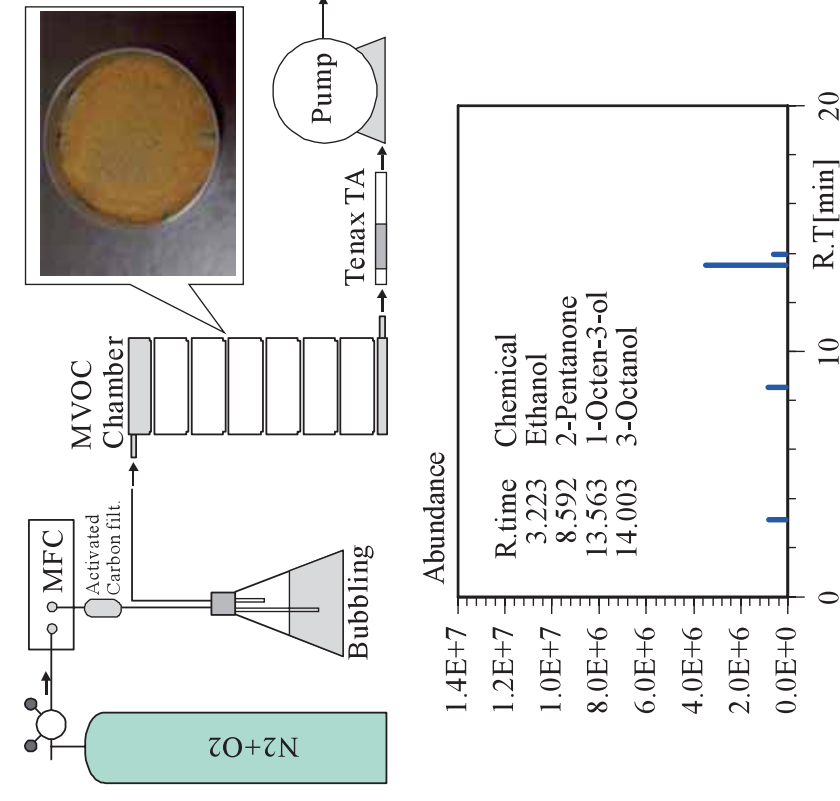


Figure 7. MVOC Sampling System & Total Ion Chromatogram of MVOC Components (Eurotium)

Indoor Air Physics;

- Coupled simulation of emission, diffusion and wall surface deposition (uni-molecular reaction) based on CFD simulation was carried out and correspondence with experimental results was verified.
- A gird library of Virtual Manikin, which takes into account attitude, gender and comfort model is being developed for coupled CFD simulation around the human body (Analysis for micro-environment).

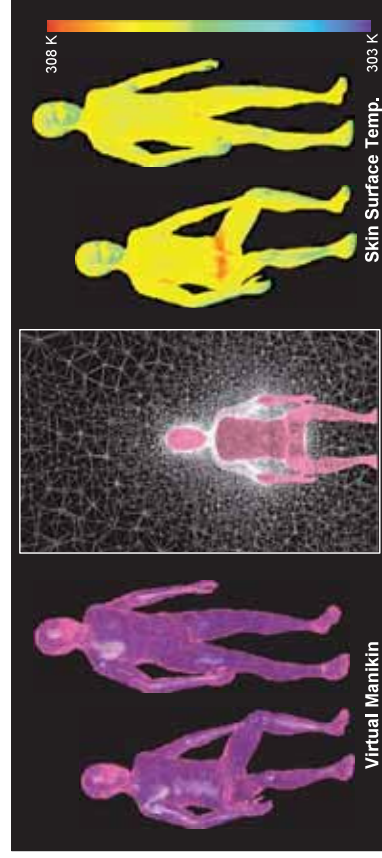


Figure 8. Virtual Manikin (Child model)

Control of outdoor air pollution

We aim at developing an accurate CFD model to predict pollution concentration in urban space as a practical analysis procedure. As the first step, we carried out CFD simulations with RANS turbulence models using the standard k - ϵ model and modified k - ϵ models (Launder-Kato (LK) model, Renormalization Group (RNG) model), to verify the results of past wind tunnel tests and evaluated the prediction accuracy of pollution concentration.

In unsteady conditions using the standard k - ϵ model and the LK model, the pollution concentration on the rear surface of the building tended to be estimated as higher than those from the wind tunnel test. However, in unsteady conditions using the RNG model that reproduced periodic vortex shedding in the boundary layer flow, the pollution concentration on the rear surface of the building obtained from the RNG model was comparable to the wind tunnel test results.

In future, we will carry out wind tunnel tests (Simultaneous measurement of wind velocity fluctuation and concentration fluctuation, fluctuation of temperature) to measure the precision diffusion phenomenon of concentration under stable atmospheric conditions and clarify the structural system of turbulence and heat transfer, and concentration transfer that constitutes the numerical

model. We will also clarify the applicability of the RANS turbulence model by comparison with wind tunnel test results. Furthermore, we will develop a high precision LES model and verify its predictive accuracy. Finally, we will use the developed numerical model and wind tunnel tests together, and examine a method for removing air pollution in urban spaces.

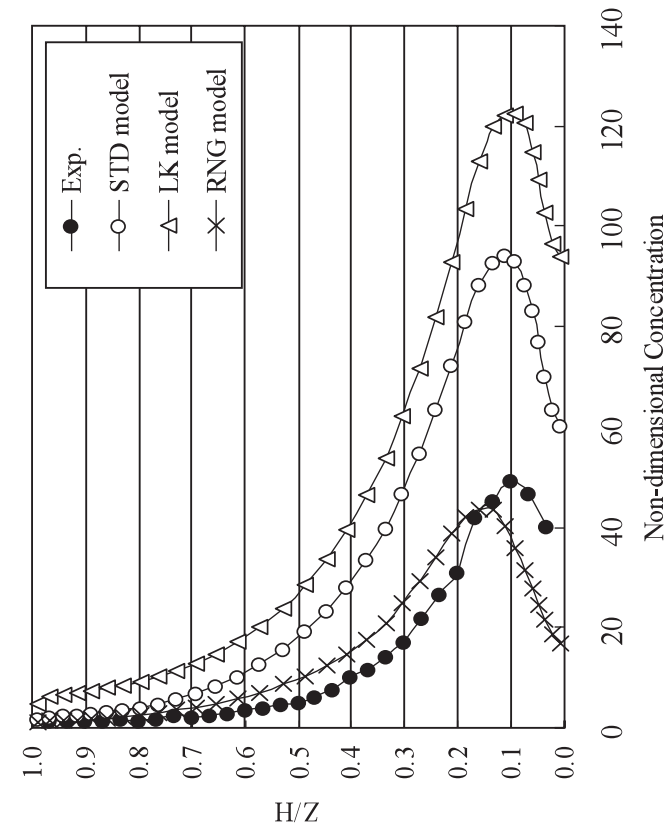


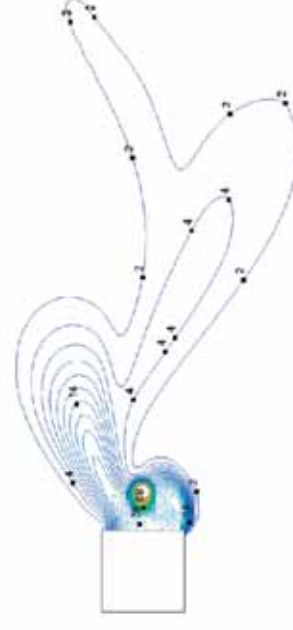
Figure 9. Mean concentration on rear surface of building in vertical center plane



(a) STD k - ϵ model



(b) LK k - ϵ model



(c) RNG k - ϵ model

Figure 10. Instantaneous concentrations behind building in horizontal plane

Invited Article

Wind-Induced Fatigue Damage of Structures

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Aerodynamic wind actions may produce large vibrations of structures at moderate and frequent wind velocities. Thus, structures may undergo a great number of stress cycles leading to damage accumulation. Several damages have been observed for different kinds of structures such as urban light poles (Figure 1), guyed masts and chimneys.

The importance of wind-induced fatigue was first emphasised by Davenport (1966). Despite that paper, however, there was a quite lack of contributions until the last 80's. Ditlevsen (1985) analysed the crosswind-induced fatigue of elastic bars, due to vortex shedding. Dionne and Davenport (1988) introduced a simple relationship between the alongwind gust factor and the fatigue damage. Then, since the 90's, the interest for wind-fatigue increased, and several papers were published following two main lines of approach: the first makes recourse to traditional time domain cycles counting procedures; the second applies frequency domain methods in a probabilistic environment.

The time domain approach was mainly adopted for engineering applications, using Monte Carlo simulations of turbulence (Kumar & Stathopoulos 1998), or measured pressures in wind tunnel tests (Flamand et al 1996), or responses recorded in full-scale experiments (Peil and Nolle 1994). This approach is very burdensome since it needs a series of samples for any loading condition, later processed by numerical algorithms such as the Rainflow Counting (RC) method. However, it is truly appropriate to evaluate fatigue damage induced by non-Gaussian processes, or for non-linear structural behaviours.

The frequency domain approach is mostly focused on alongwind-induced fatigue, applying basic principles of random dynamics. Relevant contributions to this matter were given first by Mikitenko and Perelmuter (1998) and by Petrov (1998), under the hypothesis of narrow-band stress processes, later by Deoliya and Datta (2002) and by Holmes (2002), analysing the broad-band nature of the stress processes using the semi-empirical method of Wirsching and Light (1980).

Since 2000, the author coordinated a wide research program, in co-operation with Maria Pia Repetto, aimed

at formulating and calibrating a general procedure for determining the mean fatigue damage and the mean fatigue life of structures under general wind loading conditions.

Initially, a method for evaluating the alongwind-induced fatigue was proposed, under the hypothesis that the response is dominated by the fundamental mode of vibration [1]. Parallely, using the same hypothesis, the crosswind-induced fatigue was analysed, taking into account also lock-in effects [2]. Joining and generalising these methods, the simultaneous alongwind and crosswind-induced fatigue was examined, considering wind directionality and upper modes of vibration [3]. Such procedure takes into account the joint probability distribution of the mean wind velocity and direction at the structural site, considers stress processes as narrow-band, provides the cycles histogram, the mean fractions of damage, the mean total damage and the mean fatigue life in closed form. However, the comparison between theoretical and time-domain numerical results points out that the narrow band hypothesis is appropriate for the resonant crosswind-induced fatigue, but can lead to large overestimates of the alongwind-induced fatigue, especially when the quasi-static part of the response is relevant.

Based on this remark, a second phase of this research project was carried out, with the aim of establishing an advanced broad-band formulation. Applying the cycle counting method based on the classic narrow-band assumption, two discrete cycles histogram expressions were first proposed, which approximate the Peak Counting (PC) method and the Peak Valley Counting (PVC) method [4,5]. The PC method takes into account all local maxima above the mean value of the stress history, and pairs them with fictitious local minima of the same size under the mean; so, it gives rise to an upper bound of the fatigue damage. The PVC method identifies the ampli-

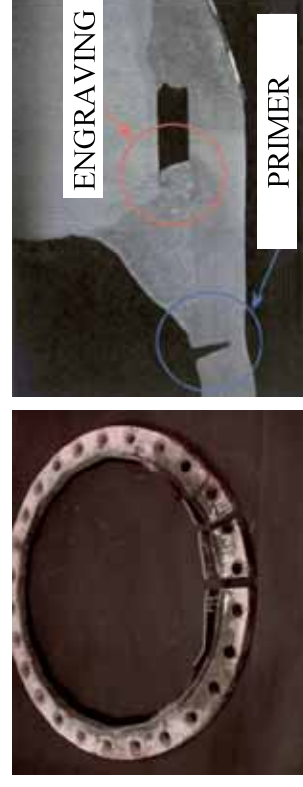


Figure 1. Wind-induced fatigue damage suffered by the base plate of an urban light pole.

tude of each cycle with the difference between two successive local extremes; so, it gives rise to a lower bound of the fatigue damage. However, depending on the spectral properties of the stress process, the gap between the two bounds may be very large.

Therefore, starting from the Bi-Modal Counting (BMC) method developed by Jiao and Moan (1992), a more refined counting method was introduced [4,5] which relates the low-frequency and the high-frequency spectral content of the stress to the background and to the resonant part of the response, respectively. Such aim was pursued by approximating the cycle hystogram furnished by RC method by two distinct groups of cycles: the first includes the large amplitude cycles and is related to the pseudo-envelope of the stress process; the second includes the small reversals due to the high frequency resonant stress process and to its envelope. All the obtained solutions are in closed form, and their results are very precise when compared with RC method.

As an example, the above procedure was applied to evaluate the alongwind-induced fatigue of a steel urban light pole, 14 m high, with a shaft 4 mm thick; the lighting device at the top has a mass of 145 kg. The fundamental frequency of the pole is 0.54 Hz, its structural damping is 0.005. The terrain surrounding the pole has a roughness length of 0.1 m [4].

Figure 2 shows the damage distribution as a function of the reference mean wind velocity, i.e. the mean wind velocity at 10 m height on a flat homogeneous terrain with a roughness length of 0.05 m. The black line corresponds to Monte Carlo simulations processed by RC method, and is referred to as the rigorous solution; $T_{RC} = 40$ years is the mean fatigue life. The red line corresponds to BMC method ($T_{BMC} = 35$ years); the blue and the azure line correspond, respectively, to PC ($T_{PC} = 20$ years) and to PVC ($T_{PVC} = 63$ years) method. The results provided by BMC method are good approximations, on the safe side, of those obtained by RC method. PC and PVC methods furnish, respectively, an upper bound and a lower bound of damage.

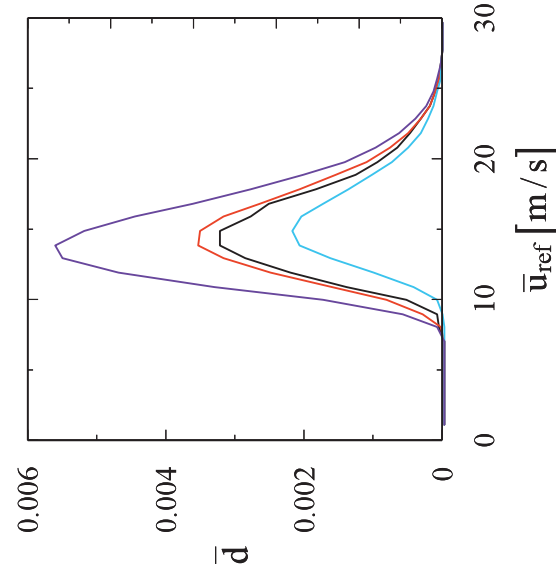


Figure 2. Alongwind-induced fatigue damage distribution at the base of an urban light pole.

It is worth notice that all methods and analyses reported above were carried out hypothesising the atmosphere as neutrally stratified, as it is typical of ultimate loading conditions. However, results showed that wind-induced fatigue is often sensitive to moderate wind speeds associated with stable and unstable conditions. Such occurrences may be very important for critical vortex shedding effects. Based on this remark, previous methods were recently generalised to take into account non-neutral atmospheric stratifications [6].

As a second example, the above procedure was applied to evaluate the crosswind-induced fatigue of a steel chimney, 30 m high, with a constant diameter of 1 m and variable thickness between 6 and 10 mm. The fundamental frequency of the pole is 1.27 Hz, its structural damping is 0.005, the Scruton number is 8.6 [6]. Since fatigue damage is concentrated close to the critical shedding of vortices, the stress process becomes narrow-band and using RC, BMC, PC and PVC methods leads to almost coincident results.

Figure 3 shows the damage distribution as a function of the mean wind velocity at 10 m height. The red and blue lines correspond, respectively, to neutral and non-neutral stratifications. Despite the relevant difference between these two diagrams, however, at least in this case the mean fatigue life does not change and assumes a value close to 5 years. Of course, considering other wind climate conditions, results may be very different.

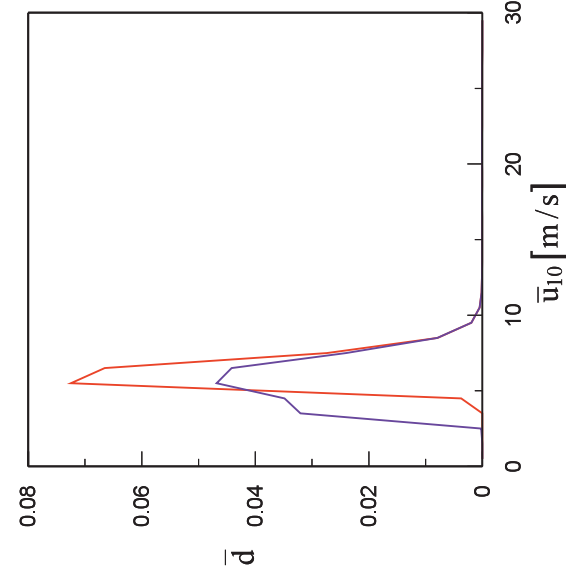


Figure 3. Crosswind-induced fatigue damage distribution at the base of a steel chimney.

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Invited Article

Wind Effects on the Measurement of Building Leakage

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Summary One of the current research projects in the School of the Built Environment is the development of a pulse pressurisation technique for the measurement of the adventitious leakage of building envelopes at low pressures [1]. As part of this project it has been necessary to investigate the effect of wind (and buoyancy) on the measurements. This article briefly describes the investigations and some of the results.

Background Ventilation openings take two forms i.e. purpose-provided and adventitious. To avoid unnecessary energy consumption in winter it is desirable for the adventitious leakage of a building to be small. Many countries now have standards for adventitious leakage and this has led to the requirement for measuring leakage of buildings. In practice it is unlikely that such measurements will be made in still-air conditions and it is necessary to examine the effect of wind on the measured leakage.

There are two effects of wind that are considered here, namely

- the indirect effect of external flow on the discharge coefficients of openings
- the direct effect on the pressure measurements.

Wind effect on the discharge coefficients of openings

If the discharge coefficient C_z of an opening is altered by the presence of an external flow at the inlet or the outlet of the opening, the leakage measurement will be affected. As part of another project on the design of naturally ventilated buildings, we have carried out an investigation into the effect of external flows on the discharge coefficient of purpose-provided openings [2]. Two types of opening were investigated – sharp-edged openings and

long narrow openings, such as chimneys. With leakage measurement the interest lies in adventitious openings. Adventitious openings will typically be narrow with significant depth i.e. they have similar shapes to a chimney. It is therefore argued that the effects of wind flow on the discharge coefficients of long narrow openings can be applied to adventitious openings. Figure 1 shows the variation of C_z with Reynolds number (based on flow rate through the opening) for the still-air and wind-on conditions. These results were obtained at model scale, so the Reynolds numbers are representative of adventitious openings.

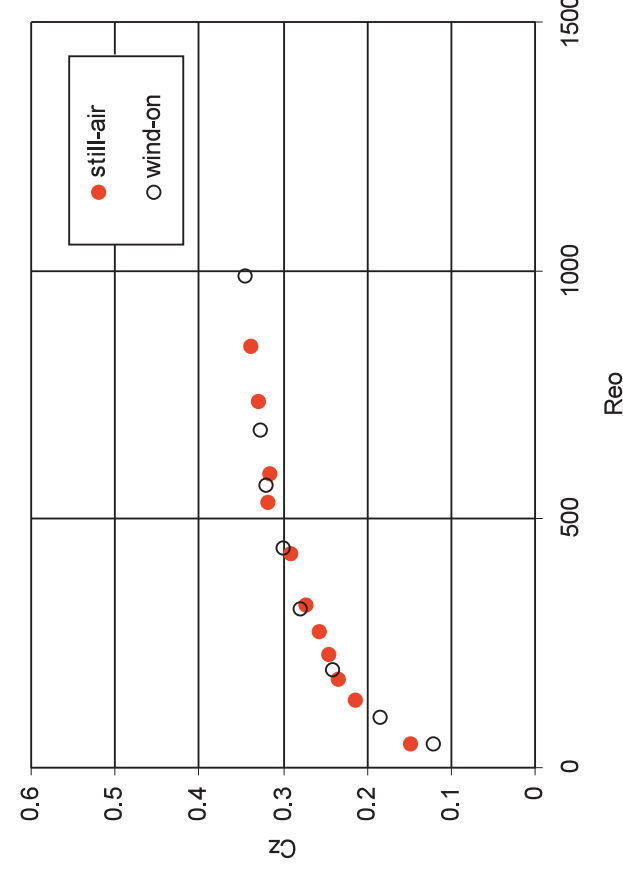


Figure 1. Effect of wind on the discharge coefficient of a long narrow opening

It is clear that the effect of wind is negligible. For the results shown the outlet of the opening was in the external flow. Reversing the flow, so that the inlet was in the external flow, led to an effect of wind that varied from small to large, depending on the geometry of the inlet. On this basis, if one wishes to minimise the effect of wind, the pressurisation test should be positive i.e. the induced flow should be outward. This is not completely

representative of natural ventilation, but it does minimise a source of uncertainty.

Direct effect of wind on the measurement of adventitious leakage The conventional method of measuring adventitious leakage is the steady pressurisation technique. This is a well-established technique where measurements are made at high pressures (typically 50 Pa) to minimise errors due to wind effects and/or buoyancy. The problem with this approach is that one is really interested in the leakage at pressures below 10 Pa, at which natural ventilation usually occurs. Thus, the ability to measure the leakage at 50 Pa, Q_{50} , with relatively small errors due to wind is offset by the errors introduced when evaluating the leakage at 5 Pa, Q_5 , say.

Ideally one would wish to measure Q_5 directly, but this is generally taken to mean that the effects of wind and buoyancy will be much too large for an accurate measurement. In fact, as noted in [3] this is not strictly correct. If the imposed pressures are steady, their effect can (in principle) largely be taken out by correcting the zero of the pressure measurement. This is a manifestation of the fact that the change in internal pressure due to the imposed fan flow is much less affected by the pressures imposed by wind and/or buoyancy. The main problem with wind is that wind pressures fluctuate with time, thereby making it difficult to record the change in pressure due to the steady imposed flow.

Our research indicates that this problem can be significantly reduced by using an unsteady pressurisation over a short period of time i.e. pulse pressurisation. We have concentrated on demonstrating this by both theoretical and experimental means. Figure 2 shows the pulse pressurisation device, which comprises a cylinder and piston driven by compressed air.



Figure 2. Pulse pressurisation equipment

Figure 3 shows the basic data for five repeated measurements in a test building, in the form of plots of $\Delta p\{t\}$ against time, where $\Delta p\{t\}$ is the difference between the

internal pressure and a reference pressure. The effect of wind is apparent as a variation of $\Delta p\{t\}$ before (and after) the imposed pressure pulse.

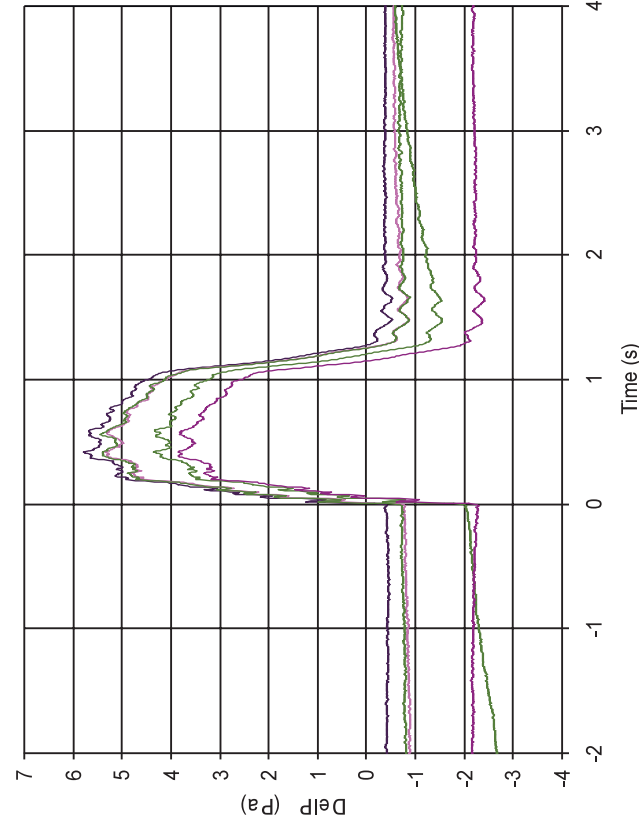


Figure 3. Five recorded pressure pulses in the presence of wind

Theoretical calculations indicate that the measured pressure pulse can be closely approximated by simply adding the still-air pulse to the internal pressure change due to the wind. There is some effect of wind on the shape of the pulse, but it is small for wind speeds below about 5 m/s. The still-air pulse can thus be obtained experimentally by subtracting the internal pressure change due to wind from the measured pressure response. When the experimental data are analysed in this way it can be seen in Figure 4 that the individual pressure pulses collapse closely on to a single curve i.e. the still-air curve. To evaluate the still-air pulse from the measurements it is necessary to interpolate the wind pressure curve between the start and end points of the pulse. This is a source of uncertainty, but the evidence obtained so far indicates clearly that the uncertainty is small.

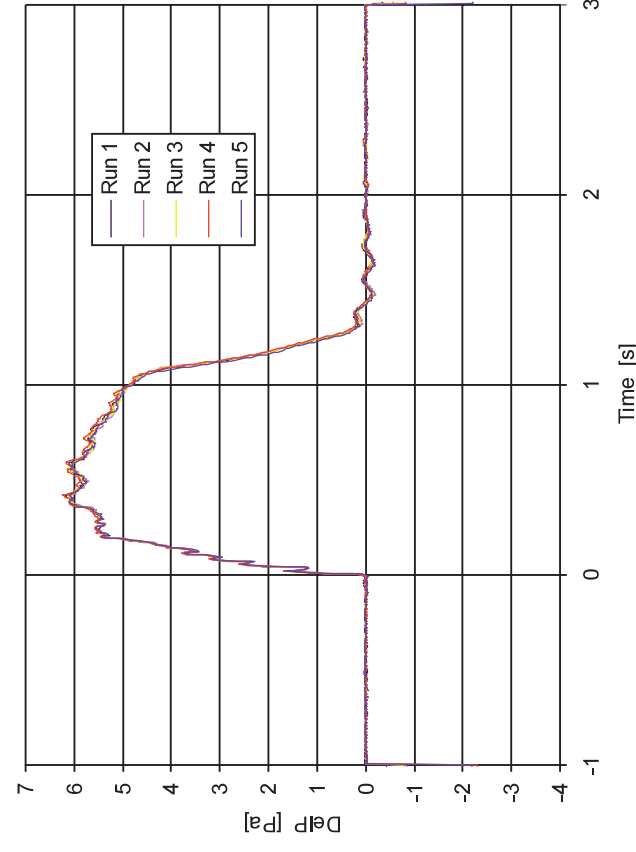


Figure 4. Recorded pressure pulses after adjustment for wind pressures

Concluding remarks Wind effects introduce uncertain-

ties in the measurement of adventitious leakage. Our tests indicate that the effect of wind on the discharge coefficients of the openings is likely to be negligible or small with positive pressurisation. The direct effect of wind on the internal pressure poses greater problems, particularly when the interest lies in the low-pressure leakage. However, with the pulse pressurisation technique that we have developed, the direct effect of wind can be largely eliminated from the results, provided the wind speed is not too high. For this and other reasons, we believe that the pulse technique is a feasible means for determining the low-pressure leakage of a building.

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Report of "International Symposium on Current and Future Status of Productivity Research in Office Space"

Kazuhide Ito
Associate Professor, TPU



The "International Symposium on Current and Future Status of Productivity Research in Office Space" was held in the AIJ (Architectural Institute of Japan) hall on April 12, 2005. This symposium is co-sponsored by three organizations: the Society of Heating, Air-conditioning and Sanitary Engineers (SHASE) of Japan "Committee of Work Place Productivity"; The 21st Century COE program at Keio University "Paradigm Shift from Intelligence to Life "; and The 21st Century COE program at Tokyo Polytechnic University "Wind effects on buildings and urban Environment".

The purpose of the symposium is to share the latest information and future trends in productivity research in office space.

The symposium was introduced and outlined by Prof. Shuzo Murakami (Keio University) at the beginning of

the symposium. The keynote lectures were entitled "Productivity research in theory and in practice: Current status and future challenges" by Prof. David P. Wyon (Technical University of Denmark; DTU), and "Air quality effects on the performance of office work: A paradigm for studies of indoor environmental effects on productivity" by Prof. P. Wargocki (DTU). Another keynote lecture, "The current status of productivity research in Japan", mainly topics on the Committee of Work Place Productivity, SHASE Japan was introduced by Prof. Takaharu Kawase (Chiba University).

In finishing off the symposium, the panel comprising Prof. Shin-ichi Tanabe (Waseda University, Coordinator), Prof. Shuzo Murakami (Keio Univ.), Prof. David P. Wyon (DTU), Prof. Pawel Wargocki (DTU), Dr. Yoshinori Yokoyama (IGREC Co. Ltd.) and Dr. Akira Okamoto (KAJIMA Corporation) discussed the problem of the future status of Productivity research.

137 people participated in the symposium and it was very successful.



Report on "Workshop between University of Nottingham & Tokyo Polytechnic University"



Hideyuki Tanaka
COE Researcher, TPU

The University of Nottingham (School of the Built Environment, School of Civil Engineering) and Tokyo Polytechnic University (The department of architecture) held a "Workshop between University of Nottingham & Tokyo Polytechnic University" at the University of Nottingham in

Britain on April 25 to 26, 2005. The University of Nottingham is evaluated very highly in Britain. The university campus had a lot of green, and it harmonized with the brick buildings, making a very relaxed atmosphere.

There were two objects of this workshop: (1) to exchange information on current research activities, and (2) to develop plans for collaborative research. For object (1), current research activities by the members of each university were presented, and for object (2), possibilities for future collaborative research were discussed. There were 30 attendees for the object (1) session, and this opened with presentations by Professor S.B.Riffat

(University of Nottingham) and President Nobuyuki Kobayashi (Tokyo Polytechnic University). Presentations were then made on 1) Natural Ventilation Design, 2) Hybrid ventilation, air-conditioning, cooling/heating, 3) Air pollution, and 4) Wind environment. Although there were 7 presenters from each university, Professor Ryuchiyo Yoshie (Tokyo Polytechnic University) made 3 high-quality presentations by himself. A lot of information on the research topics was exchanged between the two universities at the ends of the presentations and during intermissions. Thus, object (1) was fully achieved. We were invited to a dinner by the members of the University of Nottingham after the end of the workshop on the 1st, and we had a very pleasant time.

We had a very enjoyable meeting on the 2nd, and exchanged views about future collaborative research themes. As a result, it was decided that 7 collaborative researches would be advanced by each person in charge. Finally, memorandums were exchanged between the two universities, and the workshop was successfully concluded.



Campus of University of Nottingham



Presentation on 1st day



Exchange of memorandums

Research works on effective use of natural ventilation



Tomonobu Goto
COE Researcher, TPU

In order to establish a sustainable society with a lower environmental load, our research group has been studying ways to effectively use natural ventilation. To this end, it is necessary to investigate from the aspect of building performance, e.g. precise prediction of ventilation flow rate and of the resulting indoor environment, and from the aspect of building occupants, e.g. the thermal load on occupants

and their thermal comfort. Two research works now in progress on these aspects are introduced.

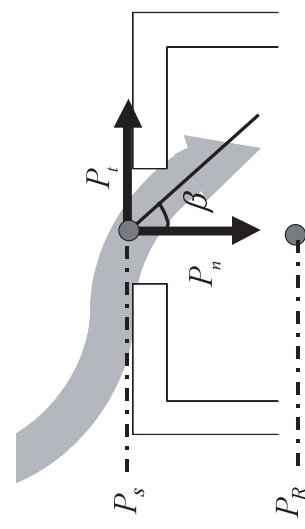
High-precision method for predicting ventilation flow rates

From the aspect of building performance, we are developing a method for predicting ventilation flow rates. At present, the orifice flow model, described by Equation (1) in Figure 1, is widely used and the discharge coefficient (α) is considered to be a constant. However, previous researches have demonstrated that the discharge

coefficient varies with wind direction and opening position.

In order to solve this problem, a local dynamic similarity model for cross-ventilation was developed by Kurabuchi and Ohba et al. [1,2]. The dynamic pressure of airflow at the opening can be divided into two pressures, i.e. dynamic pressure normal to the opening (P_n) and dynamic pressure tangential to the opening (P_t) as shown in Figure 1, and the discharge coefficients are considered to be the same when the ratios of P_n to P_t are consistent with each other. This ratio corresponds to the inflow angles (β). P_n cannot, however, be determined unless ventilation flow rate is determined. Thus, the dimensionless room pressure (P_R^*) is defined by Equation (2), where the driving pressure of ventilation flow ($P_W - P_R$) takes the place of P_n . This concept is called local dynamic similarity, meaning that dynamic similarity exists only in the vicinity of the opening, not in the total flow. If P_R^* is constant, the discharge coefficient can be uniquely determined regardless of building shape, opening position and wind direction.

In the past year, wind tunnel experiments were conducted under various conditions of building location, opening position and wind direction, and the model's validity was confirmed at inflow openings. Furthermore, a simplified method using Irwin's surface wind sensor



P_s : static pressure
 P_t : dynamic pressure tangential to opening
 P_n : dynamic pressure normal to opening
 P_w : wind pressure ($\cong P_n + P_t$)
 P_R : room pressure

$$Q = \alpha A \sqrt{\frac{2}{\rho} (P_w - P_R)} \quad \dots (1)$$

$$P_R^* = \frac{P_R - P_w}{P_t} \quad \dots (2)$$

Q : ventilation flow rate
 α : discharge coefficient
 β : inflow angle
 P_t : dynamic pressure tangential to opening
 P_n : dynamic pressure normal to opening
 P_s : static pressure at opening
 P_w : wind pressure ($\cong P_n + P_t$)
 P_R : room pressure

Figure 1. Local dynamic similarity model



Photo 1. Irwin's surface wind sensors placed on wall surface

(Photo 1) was investigated for estimating P_t , which was adopted as a new parameter for determining the discharge coefficients.

Thermal adaptation of occupants

PMV and SET* are indices normally used to evaluate the thermal comfort of occupants, and are based on the body's thermal balance and corresponding subjective response which observed in climate chamber. In those indices, the occupants are considered to be passive recipients of thermal conditions, but they also adapt themselves to modify the conditions in real situations. For example, occupants usually adjust their clothing to control their own heat balance. In addition, it has been reported that the occupants of naturally ventilated buildings can feel comfortable in a wide range of temperature, which cannot be explained by only behavioral adaptation [3]. This means that the occupants vary their thermal preference and satisfaction according to their experience and context.

Thus, we are now carrying out field surveys on different types of buildings, and investigating the behavioral and psychological adaptation of occupants from indoor climate measurements and questionnaire surveys. Outputs from this study are important in reconsidering the evaluation of thermal comfort in buildings using natural ventilation.



Photo 2. Scene of indoor climate measurement

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4th International Symposium on Computational Wind Engineering (CWE2006)

Date: July 16-19, 2006

Venue: PACIFICO YOKOHAMA, Yokohama, Japan

Co-Convened by: Japan Association for Wind Engineering,

The 21st Century COE Program (Tokyo Polytechnic University)

This symposium seeks to facilitate the exchange of the latest scientific and technical information in the field of Computational Fluid Dynamics, particularly in its application to Wind Engineering. CWE does not necessarily mean CFD, but can include various techniques using computers. The major topics for the next symposium are:

- Methodology of numerical simulation
- Turbulence model
- Simulation of atmospheric boundary layer wind
- Simulation of meteorological phenomena (typhoon, tornado, downburst, etc.)
- Monte Carlo simulation
- Meso-scale meteorological model
- Flow over complex terrains
- Wind environmental problems around buildings
- Flow around bluff bodies
- Building aerodynamics
- Bridge aerodynamics
- Fluid-structure interaction
- Flow-induced vibration
- Pedestrian wind environment
- Indoor/Outdoor air pollution
- Air-contamination problems
- Full-scale data for validation of CFD
- Wind tunnel data for validation of CFD
- Other wind problems with computational aid

Key Dates:

Abstracts (200 Words) September 30, 2005
 Notification of Acceptance December 31, 2005
 4-page Extended Abstracts due March 31, 2006
 Early Registration May 31, 2006
 Symposium July 16-19, 2006
 Notification of Selected Papers September 30, 2006
 Full papers due (selected papers) December 31, 2006

Contact Information:

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2nd Workshop on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies (2nd APEC-WW)

Date: December 5-6, 2005

Venue: Hong Kong University of Science and Technology, Hong Kong, China

Co-hosted by: Tokyo Polytechnic University and Hong Kong University of Science and Technology

The series of Workshops on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies provides a stimulating and constructive forum for researchers and engineers specializing in problems of wind loading and wind environment. The 2nd APEC-WW will follow the spirit set in the 1st APEC-WW, which was held in Atsugi, Japan in 2004. The purposes of APEC-WW are:

- to harmonize structural loading standards/codes in the APEC area; and
- to harmonize bylaws/specifications on wind environmental problems in the APEC area.

Please contact the following persons for details:

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2nd International Workshop on Natural Ventilation

Date: December 1-2, 2005

Venue: AIJ Building, Tokyo, Japan

Organizer: Prof. Ohba (Tokyo Polytechnic University), Prof. Kurabuchi (Tokyo University of Science), Dr. Sawachi (National Institute for Land and Infrastructure Management), Dr. Nishizawa (Building Research Institute)

To mitigate global warm and to develop a sustainable society, it is important to reduce the air-conditioning and ventilation load and to use natural energy effectively. The purposes of this workshop are to debate current research trends on natural ventilation and spread enthusiasm for this research work to young researchers. Main topics are Natural Ventilation Design, Prediction Model of Ventilation Rate, and Airflow Patterns Inside and Outside Buildings. Buildings with natural ventilation systems will also be discussed in the panel discussion.

For more information, please contact the following: regist-nv@arch.t-kougei.ac.jp

Invitation to COE Short Term Fellowship program

Every year we invite some aspiring engineers to the APEC Wind Hazard Mitigation Center at Tokyo Polytechnic University. To encourage their research work with us, we pay their roundtrip airfare and an adequate stipend for living in Japan. The invitation period for this fiscal year will be from mid-January to the mid-March, 2006. If you are interested in joining this program, please send your CE and a statement of purpose via E-mail to our secretary, Ms.Sachi Koizumi, by September 30.

E-mail address: koizumi@arch.t-kougei.ac.jp

For more details, please check: <http://www.arch.t-kougei.ac.jp/COE/collection-1.html>



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