Experimental Investigation of Natural Ventilation in an Office Building

Michael Jurenka, Peter Voit
TRANSSOLAR Energietechnik GmbH,
Nobelstraße 15, 70569 Stuttgart, Germany
jurenka@transsolar.com, voit@transsolar.com

ABSTRACT

The work presented in this paper was done in 1997 as a final thesis in mechanical engineering, supervised by TRANSSOLAR Energietechnik GmbH in cooperation with the Institute for Thermodynamics and Heat Technology (ITW), University of Stuttgart. The contents of the work is the investigation of natural ventilation through window openings (single sided and cross ventilation) in an existing office space. Both measurements and computer simulation have been conducted.
As a result of the work the original ventilation system was modified by assembling high-level opening lights that are automatically controlled and driven by electric motors. Depending on indoor temperature, outdoor temperature, carbon dioxide concentration and wind speed the control system adjusts the required opening area. In addition the control system provides a timer to ventilate the office space during night time to cool down the thermal mass of the building.

KEYWORDS

natural, ventilation, office, building, automatic, control, TRNSYS, experimental, investigation

INTRODUCTION

Natural ventilation through window openings is the cheapest and most simple way of ventilation. It is usually well accepted by its users due to the transparency of the system and the users possibility to take influence on the ventilation process. Applying manually controlled, natural ventilation to an office building often shows two phenomena. During winter people abstain from sufficient ventilation instead of regularly replacing the stale air with fresh air. During summer the air temperature raises to a high level. A proper ventilation during night time usually helps to reduce the temperature level during day time but is often not performed for different reasons (i.e. break-in, rain). Both phenomena might be improved by a well designed natural ventilation system which mainly is controlled manually but supported by an automatic control. The intention of this design is to keep the acceptance of the system but to improve the disadvantages. The purpose of the automatic control is to take over those actions the user usually forgets or can't do: sufficient ventilation during winter and a proper night time ventilation during summer. A ventilation system like this can only be regarded as energy efficient though if there is a cooling load during the whole year – which often is the case in modern office buildings.

EXPERIMENTAL INVESTIGATION

The purpose of the work was to analyse an existing, natural ventilation system and to find measures to improve the system for the summer case. For this reason the room air temperatures and the air exchange rates were of main interest while analysing the existing system. The movement of the air within the space was not looked at.

Building Description

The building of the Technologiezentrum Stuttgart is subdivided into two two-level wings connected by a glazed atrium. The sustaining structure of the building is made of precast concrete parts. The ripped ceiling and the beams of the structure mainly represent the thermal mass relevant for the office spaces. For each floor the facade is basically divided into three sections vertically. The section above the balustrade is glazed. About one third of this section can be opened. The third section is formed by fixed high-level lights. The office spaces are ventilated naturally through window openings. Depending on the location of the rooms within the building single-sided ventilation towards the atrium, single-sided ventilation towards outside or cross ventilation is applied. The atrium is fitted with large lamella faces at the western and eastern fronts. In addition there are openings in the roof with a considerably small opening area.

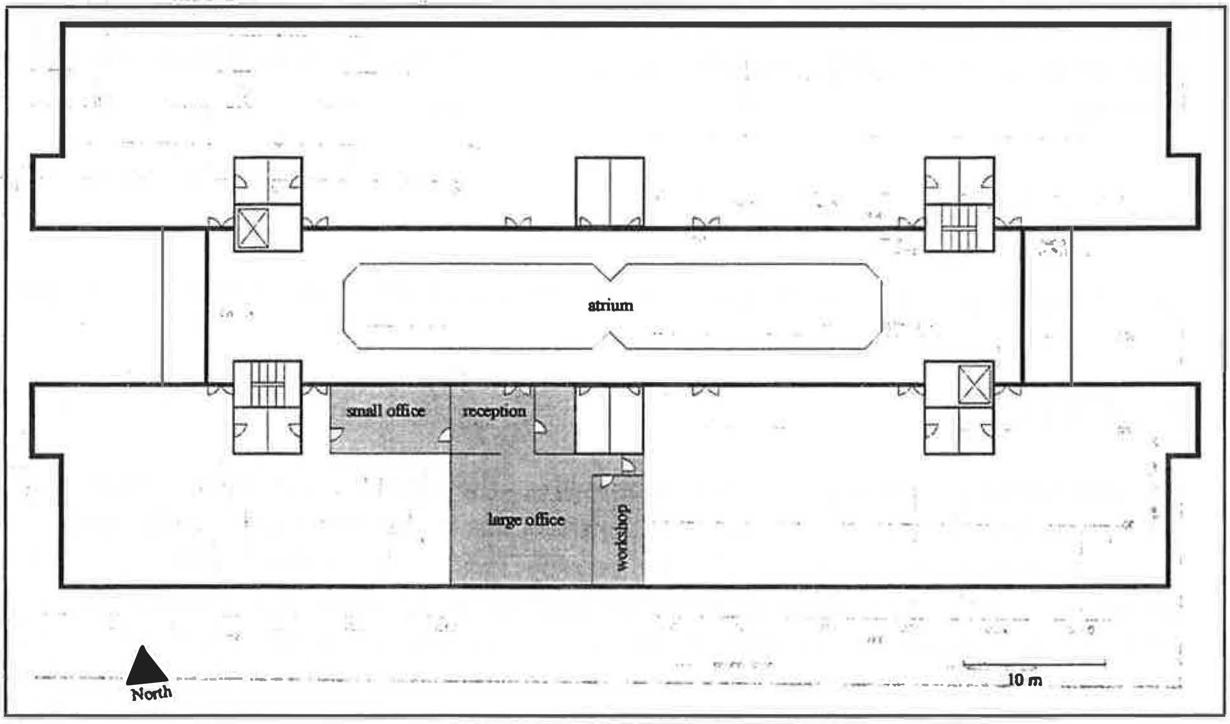

Fig. 1: Floor plan of the office building

In fig. 1 a floor plan of the building is given. The office space investigated is marked grey in fig.1. It consists of several rooms which are connected by large openings. The space is ventilated through outside openings and through openings towards the atrium. The area is occupied by about 20 people working on one computer each.

Experimental Approach

Within the scope of this work different kinds of measurements were carried out with different intentions:

- The courses of the room air temperatures were measured accompanied by measurements of weather data. The results of these measurements were used to verify the built simulation model. They also provided basic information about the dependence of the room air temperature on wind speed, direction of the wind, internal loads, state of the thermal masses and opening situation.
- Tracer gas measurements for different opening situations were carried out intending to compare the opening situations on basis of the measured air exchange rates. The results of these measurements proved to be not suited for comparing different opening situations on basis of measurements due to changing boundary conditions.
- The static flow characteristic of a hopper window was determined by measuring the volume flow rate and the pressure difference between inside and outside. These measurements provided parameters for the simulation model. The results of the measurements showed good agreement with the theoretical approach.

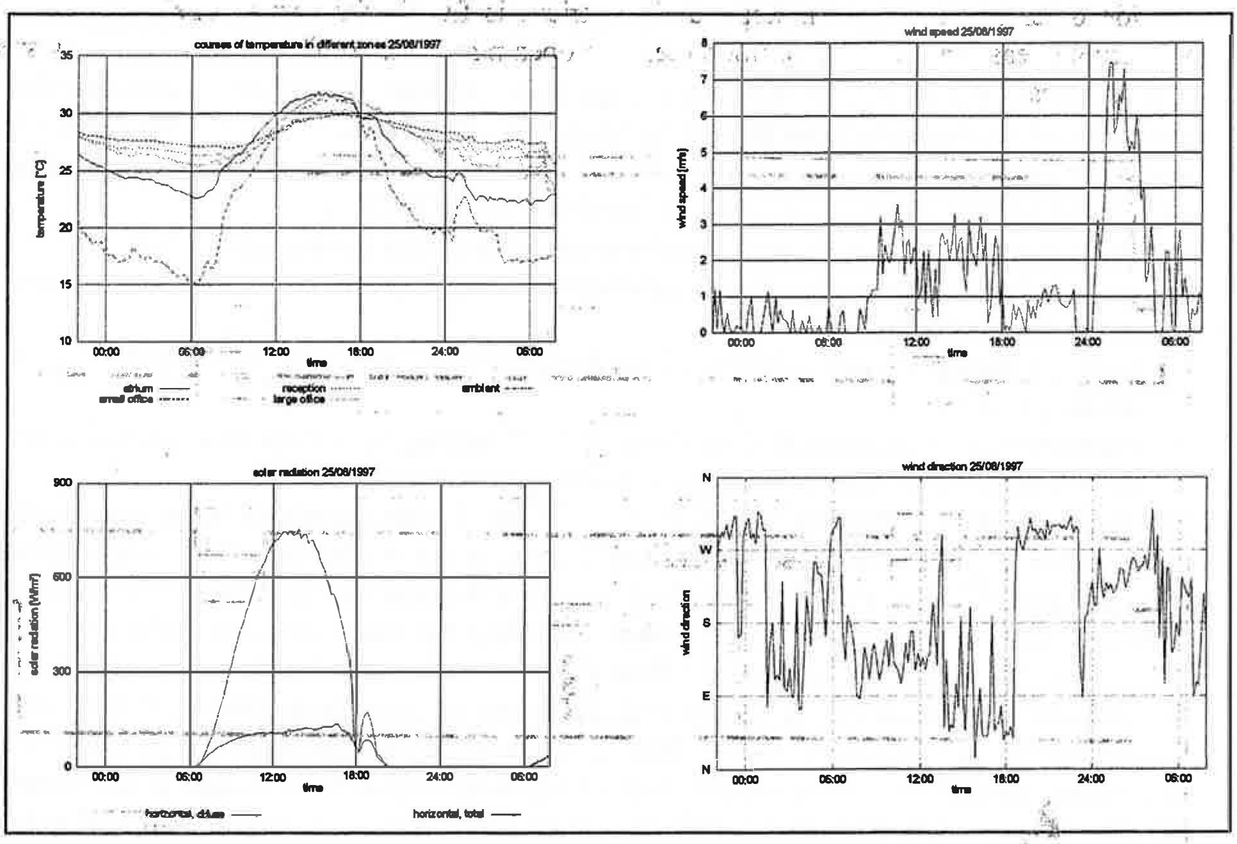

Fig. 2: set of measured data for an ordinary working day

Fig. 2 shows a set of measured data that consists of temperature courses in different zones and of weather data. The data set documents an ordinary working day at low occupancy of the office space at a hot summer day. The lamella faces in the atrium and the windows in the office rooms were fully opened during day time. During the night the windows in the office rooms were tilted. Regarding the temperature courses in the different zones the temperature in the large office reaches ambient temperature while the temperature in the small office reaches a maximum of about 2 °C below ambient temperature. This is mainly due to the higher solar gains in the large office. It also shows that the thermal mass in the small office is able to cool down the air from outside.

Several data sets like the one presented by the way of example were measured on weekends at clearly defined internal gains for different opening situations. These data sets proved to be limited regarding the verification of the simulation model for the following reason. The time period of 34 hours was too short to allow both conditioning the thermal mass of the model and verifying the model. Anyway the verification showed that the model basically worked. Apart from verification the data sets showed that wind direction has a great influence on the air exchange rate and hence the room air temperature even for really small values of wind speed.

TABLE 1
Results of tracer gas measurements

opening situation	mean pressure difference [Pa]	mean wind speed [m/s]	main wind direction	temperature difference [K]	air exchange rate [1/h]
1	0.60	2.6	SWW	9	0.94
2	0.01	4.0	SW	9	2.80
3	-0.31	0.2	SSW	9	3.86
4	0.55	0.1	SW	12	2.96

Tab. 1 summarises the results of four tracer gas measurements carried out to determine the air exchange rate in the air volume formed by large office and reception (fig. 1). The decay of the tracer gas was measured over a time period of 30 minutes for each of the following opening situations with the lamella faces in the atrium fully opened in all cases:

1. single-sided ventilation through tilted windows (0.4 m^2) in the southern facade
2. single-sided ventilation through tilted windows (0.4 m^2) and high-level opening lights (1.2 m^2) in the southern facade
3. cross ventilation through tilted windows in the southern facade (0.4 m^2) and towards the atrium (0.4 m^2)
4. cross ventilation through tilted windows (0.4 m^2) and high-level opening lights (1.2 m^2) in the southern facade and tilted windows towards the atrium (0.4 m^2)

The mean pressure difference which is given in tab. 1 was calculated from measurements taken at the height of the high-level opening lights in the workshop, which was connected with the large office by a considerably large opening. A negative sign means that the pressure outside is greater than the pressure inside. Knowing the mean pressure difference allows conclusions about the direction of the flow. Looking at data set 3 a flow through the office from southern direction can be recognised. This data set once again shows the influence of wind direction. A southern wind with little speed causes an air exchange rate of nearly 4 1/h. The results from the tracer gas measurements mainly provided basic insight in the nature of air flow through buildings which will not be discussed here. Comparing different opening situations on the basis of the measured data sets is very limited though due to changing boundary conditions.

TRNSYS Simulation

A TRNSYS simulation model of the office space and the atrium was built using TYPE 56 (multi-zone building) and TYPE 159 (multi-zone air flow). Verifying the built model with the measured data showed that the model basically worked. It also showed how the model could be optimised. An optimisation of the model was not realised so far because this requires additional measurements. The big advantage of employing computer simulation in the case of ventilation is the possibility of comparing different measures at identical boundary conditions.

Results

The most important results of the analysis of the existing system are resumed in the following:

- On hot summer days the temperature in the office rooms raises up to above 30 °C. As the temperature difference between inside and outside is very little ventilation mainly depends on forces due to wind.
- Single-sided ventilation towards the atrium is the worst case as there is almost no influence of the wind.
- Cross ventilation shows no remarkable advantages compared to single-sided ventilation in case of western winds.
- Cross ventilation causes great air exchange rates even at low wind speeds in case of southern winds.
- The solar gains of the atrium cannot be removed sufficiently by the provided lamella faces even if there is wind.
- The building has a remarkable thermal mass which is often hidden behind a hanging ceiling.
- The existing openings are not burglar-proof regarding night time ventilation.
- Measures for improving the existing natural ventilation system in the summer case should focus on integrating the thermal mass of the rooms to a greater extent, improving the ventilation during night time and reducing the solar gains of the atrium

CONTROL SYSTEM

One suggestion for improvement of the existing ventilation system was adding additional, automatically controlled openings to the system. This measure was realised by replacing some of the fixed high-level lights by opening high-level lights. The additional openings are controlled by a control system prototype that originally was designed to be used for another project. The control system basically controls the required opening area depending on indoor temperature, outdoor temperature, wind speed and carbon dioxide concentration.

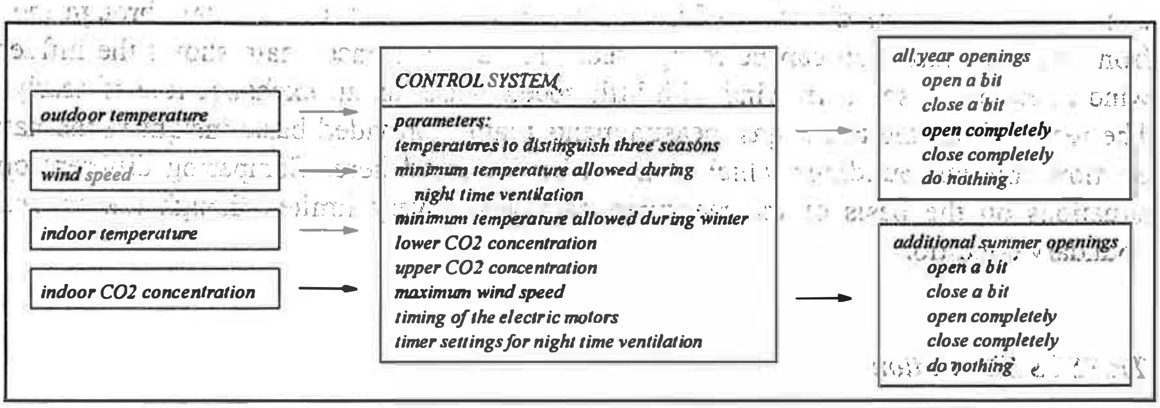

Fig. 3: control system design

The inputs to the system are given on the left hand side in fig. 3. A mean value of the outdoor temperature is used to differentiate between autumn/spring, summer and winter. The system

can be adjusted to special requirements by setting some parameters which are given in fig. 3 as well. According to the states of the inputs and the set parameters the system invokes one of the actions given on the right hand side in fig. 3. Checking the states of the inputs and executing an adequate action is done regularly in a set interval.
Controlling the required opening area helps to reduce the ventilation heat loss to a minimum during winter while guaranteeing a sufficient air exchange rate. Another feature of the control system is the integrated timer which can be used to regularly ventilate the room at night time during summer.
The control system has outputs for all year openings and additional summer openings. This design was chosen according to the requirements the system was designed for. Having outputs for winter openings and spring/summer/autumn openings would be a good solution as well.

CONCLUSIONS

Automatically controlled openings were added to the existing window openings which are manually controlled. Keeping the possibility of user interaction this measure improved the ventilation system for the following reasons:

- In the case of single-sided ventilation, openings on different levels result in better ventilation of the office.
- During summer automatic night time ventilation cools down the thermal mass. This results in a reduced air temperature during day time.
- During winter automatic control of the required opening area reduces the ventilation heat loss to a minimum while guaranteeing sufficient ventilation.

Using the proposed ventilation system design, the selection and positioning of the openings are extremely important to get a reliably working system. For the summer case large openings are required that are positioned in a manner that cross ventilation is supported and great air exchange rates are achieved. For the winter case small openings are needed. There always is a correlation between opening area and motor position which might be linear or anything else depending on the opening mechanism. Comfort aspects need to be taken in account planning the position of the winter openings. In this context openings are advantageous that clearly act as inlet or outlet openings.
Operating the system for one year also brought to light some deficiencies of the installation. The opening lights are hardly adjustable during winter when small gaps are required for sufficient ventilation. In addition setting all the parameters of the control system proved to be more complex than initially expected. After all the system showed good performance but demands carefully planning.