A METHODOLOGY FOR THE PRACTICAL ASSESSMENT OF NATURAL VENTILATION DESIGNS IN INDUSTRIAL BUILDINGS WITH REFERENCE TO THE INDOOR THERMAL COMFORT

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ABSTRACT

The design of natural ventilation devices in industrial buildings is complicated by the nonlinear interaction between the air flow rate and the indoor air temperature. Designs are therefore usually based on relatively simple calculations of the areas of ventilation openings to provide a specified flow rate at a given indoor/outdoor air temperature difference. However, the practical performance testing required for acceptance of the ventilator design still remains a difficult and dubious task.

Although detailed integrated simulation tools for naturally ventilated buildings have recently been unveiled, these tools are not yet accessible to practising building services engineers. In this paper a simplified methodology for the practical assessment of natural ventilation designs with reference to the thermal environment in industrial buildings is proposed and successfully applied.

The methodology is based on continuous temperature measurements over a period of time combined with simplified predictions of indoor thermal parameters for extreme environmental conditions. In the development of the methodology there is a strong emphasis on its comprehensibility and ease of use by practising building services engineering consultants. Graphical representation of the results ensures easy interpretation of the data.

A complete case study with measurements and simulations is presented to illustrate the methodology as it is applied to a casthouse building at a large aluminium smelter.

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1. INTRODUCTION

The design of natural ventilation devices in industrial buildings is complicated by the nonlinear interaction between the air flow rate and the indoor air temperature. Designs are therefore usually based on relatively simple calculations of the areas of ventilation openings to provide a specified flow rate at a given indoor/outdoor air temperature difference. However, the practical performance testing required for acceptance of the ventilator design still remains a difficult and dubious task.

Although detailed integrated simulation tools for naturally ventilated buildings have recently been unveiled [1], these tools are not yet accessible to practising building services engineers. In this paper a simplified methodology for the practical assessment of natural ventilation designs with reference to the thermal environment in industrial buildings is proposed.

In order to illustrate the methodology and its application a complete case study with measurements and calculations is presented.

2. PROBLEM DEFINITION

The object of the case study is a casthouse building at the ALUSAF Hillside aluminium smelter situated at Richardsbay on the east coast of South Africa. The casthouse is a large single zone building with a floor area of 9900 m^2 and an average roof height of just over 10 m. The building envelope consists of a 2.1 m high wall of 150 mm thick concrete panels around the perimeter. The rest of the walls and roof is constructed of 2 mm thick corrugated mild steel plates. There is no insulation on the envelope.

The roof is fitted at its highest point with eight simple ventilator openings with a total effective outlet area of 312 m^2. The eastern wall is fitted with intake louvres at ground level with a total area of 133 m^2. There are doors in both the eastern and western walls with a total inlet area of 218 m^2 which always remain open. The total internal load, including eight furnaces and vehicles is approximately 6600 kW throughout the day.

According to the original specification the ventilator design should be such that the temperature differential between the ambient high temperature and the temperature of the gas at the ventilator outlet, i.e. the well-mixed resultant indoor air temperature, must be less or equal to 15 °C. The purpose of the method proposed here is therefore to evaluate the performance of the ventilator design in this regard.

At this stage it is important to note the difference between natural ventilation designed to provide an acceptable thermal environment and task specific ventilation facilities such as hoods and its associated extraction fans. The purpose of the ventilators as originally specified in this case is to ensure an acceptable overall thermal environment within the building. For this reason, the differential temperature limits contained in the original specification was used as the basic criterion for this evaluation. Task specific extraction facilities are therefore provided wherever excess smoke and gasses are produced such as on the ingot casting lines itself where the evaporation or burning of oil may have a negative impact on the indoor air quality.

3. METHODOLOGY

The evaluation methodology proposed here consists of the following:

- Continuous measurements of ambient and maximum indoor air temperatures are made over a period of more than 48 hours. As a first step in the evaluation, the measured temperatures are compared with the original specification.
- Since extreme climatic conditions may not necessarily be experienced during the measuring period, the measurements are used as the basis for predictions of the indoor thermal environment under extreme climatic conditions with the aid of load calculation software and simplified relations for natural ventilation flow rates.
- In order to further qualitatively evaluate the performance of the ventilators a number of single point air velocities are also made at the intake louvres, doors and openings in the casthouse.

4. EXPERIMENTAL APPARATUS AND PROCEDURES

The temperature measurements were conducted with the aid of several Thies mechanical recording thermohygrographs models 1.0620.00.49 and 1.0620.00.11. The instruments were calibrated prior to the experiment by a qualified technician. The absolute value of the errors produced by these instruments are typically less or equal to 0.5 °C.

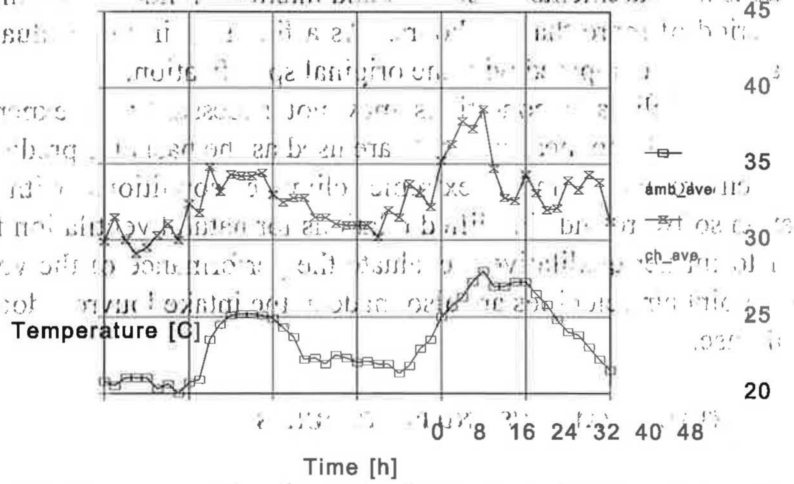
The instantaneous air velocities were measured with the aid of a single TA 3000T direction sensitive hot wire anemometer with a range of 0.1 to 15 m/s supplied and calibrated by Giles Scientific (Pty) Ltd.

The temperatures were monitored continuously for a 48 hour period. The indoor air temperatures were measured at six stations along the length of the casthouse roof approximately 2 m under the roof ventilators. Care was taken not to position the instrument close to any equipment which may locally radiate extra heat. The ambient temperatures were measured at three stations approximately 1.2 m above floor level just outside the casthouse. All the stations were shaded at all times.

Instantanious air velocities were measured at several points inside each door on the western side of the casthouse, each opening on the eastern side of the casthouse and the louvres on the western side of the casthouse. From this the averaged values of air velocities were deduced. Velocities were also measured at several critical points inside the casthouse building.

5. RESULTS OF THE TEMPERATURE MEASUREMENTS

As explained earlier ambient air temperatures were measured at three different stations and the casthouse indoor air temperatures at six stations. In order to evaluate the results the instantaneous average of all the stations as well as maximum ambient and indoor air temperatures were extracted from the measured data. Figure 1 shows the average temperatures calculated for the 48 hour period while Figure 2 shows the maximum temperatures.



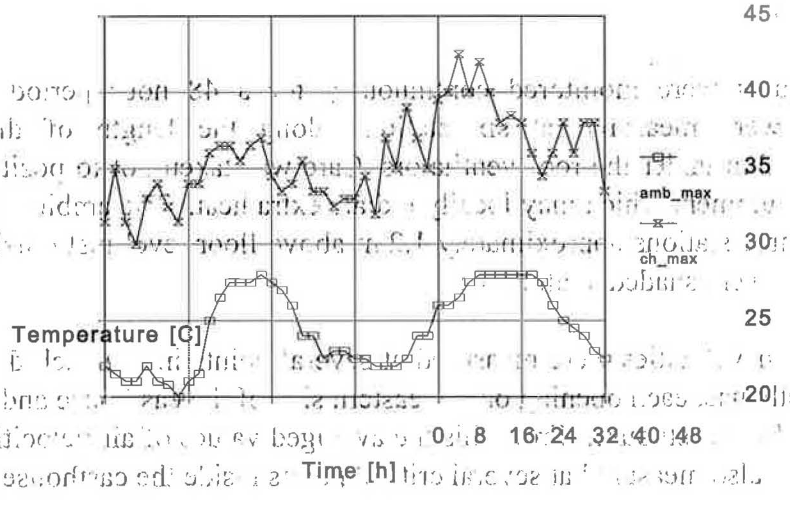
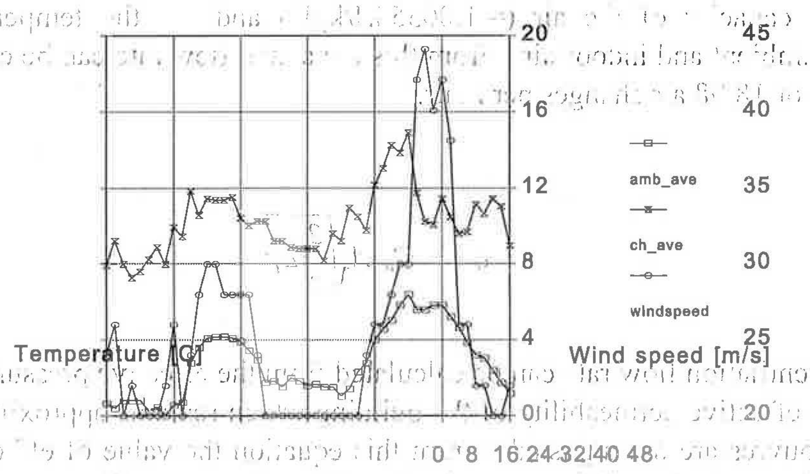


Figure 2 shows that the ambient high temperature during the measuring period was 28 °C while the maximum casthouse temperature was 42.5 °C. This means that the maximum temperature differential between the ambient high and the indoor air temperature was 14.5 °C. Since 15 °C was never exceeded during the test period it is clear that the ventilator performance was within specification for the particular measuring period.

6. PREDICTIONS FOR EXTREME CONDITIONS

Although the results presented above gives an indication that the ventilators perform satisfactorily, the question still remains whether the specified maximum differential will not perhaps be exceeded under more extreme conditions. This would obviously be when the ambient air temperature reaches an absolute maximum thereby reducing the conduction heat transfer to the outside. The other factor that plays an important role is the local atmospheric wind speed and direction. It is a well known fact that the temperature or 'stack' effect and the wind effect that influences natural ventilation is not additive and that the presence of wind may inhibit ventilation [1]. However, in most practical cases the least amount of ventilation is experienced when there is no wind. The most extreme condition would therefore be when the ambient air temperature reaches an absolute high while there is no wind to aid ventilation. In order to evaluate this case it is necessary to predict what the indoor air temperature will be under these conditions.

The average ambient and indoor air temperatures that were measured in the casthouse during the first day were used as the basis for the calculations. It was found that between 20:00 on the first day and 01:00 on the second day there was no wind while both the average ambient and casthouse indoor air temperature remained reasonably constant. These results may therefore be used to predict the natural ventilation characteristics of the building when there is no wind provided that we can correctly account for the effect of different indoor and outdoor temperatures. The measured wind speeds and temperatures are shown in Figure 3.



The ambient temperature during the period under investigation remained at approximately 22 °C while the casthouse temperature remained at approximately 31 °C i.e. a temperature differential of 9 °C. This period of no wind and constant ambient and indoor air temperatures may be used to determine the so-called 'effective permeability' of the building which gives an indication of the leakage characteristics.

With no wind blowing the effective pressure difference between ground level and the roof ventilators due to the 'stack effect' which acts as the driving force for ventilation can be calculated as [1]:

$$\Delta p = 0.0342 \frac{p_{barom} \Delta h}{T_i T_o} (T_o - T_i)$$

with p_{barom} the local barometric pressure (= 101325 kPa), Δh the difference in height between the inlet areas and the roof ventilators (≈ 12.6 m), T_i the indoor air temperature in Kelvin (= 295.15 K) and T_o the ambient temperature in Kelvin (= 304.15 K). From this the effective pressure difference for the present case can be calculated as 4.80 Pa.

Using any standard load calculation procedure, in this case the QUICK building thermal analysis program [2], the cooling load required to maintain the indoor air temperature at 31.0 °C under the given ambient and internal load conditions can be calculated. This was found to be 6150 kW. The cooling load provided by the ventilation air flow rate can be found from:

$$Q = q \rho c_p \Delta T$$

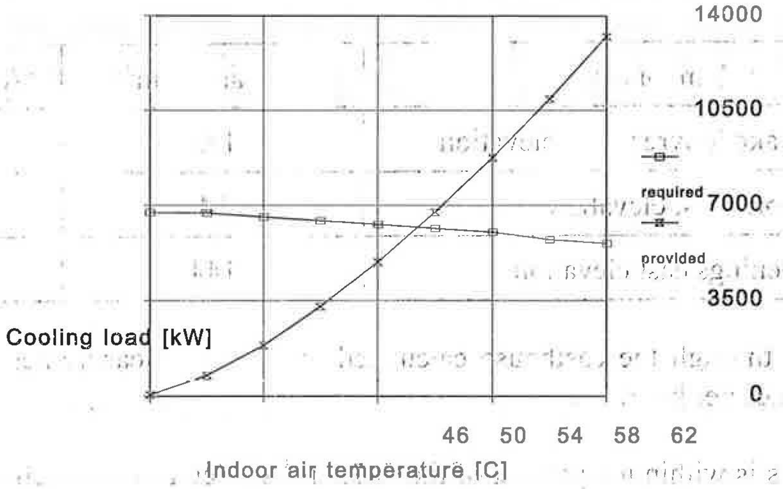
with Q the cooling load, q the air flow rate in m^3/s, ρ the air density (= 1.2 kg/m^3), c_p the specific heat capacity of the air (= 1.0035 kJ/kgK) and ΔT the temperature differential between the ambient and indoor air. From this the actual flow rate can be calculated as equal to 567.5 m^3/s or 18.98 air changes per hour.

The natural ventilation flow rate can be calculated from the effective pressure difference as:

$$q = C_d A \sqrt{\frac{2}{\rho} \Delta p}$$

with C_dA the effective permeability of the building which remains approximately constant as long as the louvres are not adjusted. From this equation the value of effective permeability can be found as 200.64. This value for the effective permeability may now be used to determine flow rates at other conditions.

The extreme maximum ambient air temperature for the climatic region is indicated as 45.6 °C. If one now uses the same load calculation procedure to determine the cooling loads required to maintain the indoor air at different temperatures under these extreme conditions, the 'required' graph shown in Figure 4 is obtained. These loads take into account all the important effects such as conduction through the walls, solar radiation, internal loads etc. The graph may therefore be used to size the required air-conditioning system needed to maintain the indoor air temperature at a specified value.



By calculating the effective pressure difference, its corresponding natural ventilation flow rate and the associated cooling load provided by the outdoor air fed into the building via natural ventilation, the 'provided' graph shown in Figure 4 is obtained. The intersection of these two graphs show where the required and provided cooling loads will be in balance and therefore also the indoor air temperature that will prevail. From the figure it is clear that an indoor air temperature in the region of 55.3 °C will be obtained.

From the calculations above it is predicted that the maximum temperature differential in the casthouse under extreme conditions will be less than 10 °C. Since it is less than the required 15 °C it can be concluded that the ventilation design should be adequate even under extreme conditions.

From this temperature difference an air flow rate can also be calculated using Equations 1 and 3. The effective pressure difference will be 4.04 Pa and the air flow rate will be 520.9 m^3/s or 17.4 air changes per hour.

7. SINGLE POINT AIR VELOCITY MEASUREMENTS

The qualitatively averaged air velocities measured between 15:00 and 15:30 on the first day in the inlet areas of the casthouse are shown in the table below. The indoor/outdoor temperature differential during this time was 9.3 °C.

Table 1: Measured air flow velocities.

Component	Inlet areas [m²]	Air velocity [m/s]
Casthouse intake louvres west elevation	133	0.50
Casthouse doors west elevation	74	1.25
Casthouse openings east elevation	144	2.50

The flow rate through the casthouse calculated from these measurements is 519.0 m^3/s or 17.46 air changes per hour.

This 519.0 m^3/s is within ten percent of the 567.5 m^3/s calculated in Section 6 for which case the temperature differential was approximately the same. This gives greater confindence in the calculated value for the permeability and therefore also in the flow rate and temperatures calculated for the extreme conditions.

8. A NOTE ON INDOOR AIR QUALITY

Despite the satisfactory results obtained above, it was clear from a visual inspection that the accumulation of smoke inside the casthouse presents a problem when large amounts of oil was burned on the ingot casting lines. The cause of this problem was twofold namely (i) inadequate task specific ventilation hoods and extraction fans and (ii) the fact that cross-draughts under the hoods caused by the natural ventilation through the building blows the smoke from underneath the hoods into the building. Cross-draught air velocities of between 1 and 2.5 m/s were measured next to the hoods. This shows that despite the large air change rates obtained, and maybe even because of it, the indoor air quality was inadequate. The installation of larger hoods and fans as well as vertical screens at suitable locations close to the sides of the hoods were therefore undertaken to ensure better indoor air quality. Adequate natural ventilation on a macro scale can therefore never simply be assumed to be sufficient to maintain good indoor air quality.

9. CONCLUSIONS

A simple methodology for the evaluation of the thermal performance of ventilation devices in industrial buildings was presented. The methodology is based on continuous temperature measurements over a period of time combined with simplified predictions of indoor thermal parameters for extreme environmental conditions. The simplicity of the proposed methodology ensures its comprehensibility and ease of use by practising building services engineering consultants. Graphical representation of the results ensures easy interpretation of the data.

A complete case study with measurements and simulations was presented to illustrate the methodology as it was applied to a casthouse building at a large aluminium smelter. From the results obtained for the case study it can be concluded that the ventilator design for this case is adequate and that the ventilators perform within specification. Problems did however arise with the task specific ventilation hoods and extraction fans at the ingot casting lines and have subsequently been addressed.

10. Acknowledgements

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11. References

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