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Ventilation for Comfort and Efficiency in a Theatre

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Abstract
This paper focuses on two subjects: comfort levels and efficient ventilation in Arcola theatre in London, which strives to become the first zero carbon theatre. Being a leader in promoting sustainability in arts, Arcola is looking for a sustainable solution for its performance space.
Air quality and thermal comfort were examined. To investigate air quality measurements of carbon dioxide levels were undertaken in the studio space during performances. To assess thermal comfort temperature monitoring was carried out for three seasons. The results showed that air quality in the studios does not meet the requirements. The air infiltration rate is not adequate for its high occupancy load. Insufficient ventilation in the space results in elevated levels of carbon dioxide. Temperature monitoring revealed that generally the space can provide comfortable conditions for most of the year. However, there were problems during hot days and during winter time. In hot whether the temperature in the studio rises to uncomfortable levels and it is not possible to effectively reduce it by ventilation. During winter, temperatures were quite low due to lack of space heating. Summarising a ventilation system is necessary to provide optimal comfort levels in the theatre. The strategies proposed have been based on the monitoring data as well as other research into natural ventilation in a theatre.

Introduction

This work investigated comfort levels of a theatre studio as well as looked into suitable energy efficient ventilation systems for a theatre. The performance space in Arcola Theatre was monitored, results discussed and potential solutions evaluated.

Arcola is located in an old industrial building where ex-production spaces have been converted to theatre studios. While ventilation in the building was sufficient for production purposes in the factory, it has not been designed to cope with high levels of occupancy during performances. There is no mechanical ventilation or especially designed natural ventilation in the building and air infiltration essentially relies on openings in the building envelope. The main performance space has an extract and supply fans installed, however, these cannot be used during performances due to excessive noise. Acoustics was also a reason to block all the existing openings, which led to greater reductions of air infiltration. The studio, therefore, has low air change rate that is not adequate for its high occupancy load.

Results

An investigation was carried out to assess thermal comfort and air quality in the studio during performances. It was found that thermal comfort, even though fairly acceptable for most of the year, was not adequate in extreme conditions. During performances, the temperature rises due to high internal gains from lights and occupants. Air stratification forms where throughout the space temperature rises gradually with height. Due to poor ventilation, the warm air layer has nowhere to escape, affecting the thermal comfort of the audience in particular the spectators sitting at the balcony. As mechanical ventilation cannot be used during performances due to noise, it is not possible to effectively bring the temperature down by increasing the air chance rate in the space. This is particularly problematic during hot weather, where temperatures easily reached 30 ˚C in the space. At the time of performances on the balcony, which is the highest occupied area, temperatures were around 27-28°C. Average temperatures at the chest level of a person standing on a floor were over 22°C while at the chest level of a person seated in the lowest row were over 21°C. These findings indicate that while stage area in hot weather might be still in comfortable zone higher areas of the studio could already suffer from overheating, especially a balcony.

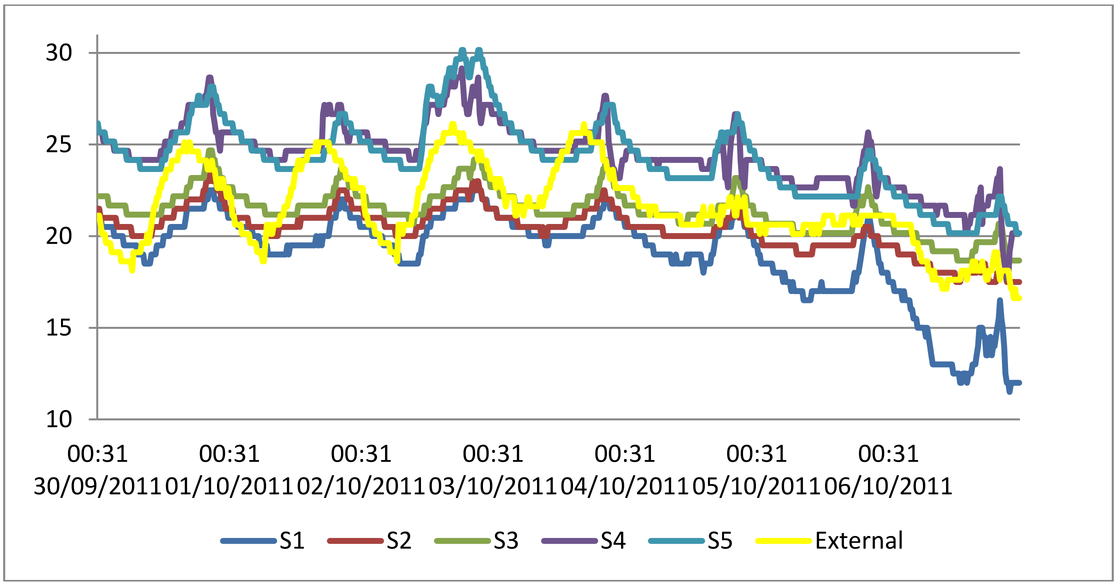

Figure 1: Graph representing temperature readings in Studio 1 and the external temperature during Phaedra's Love production between 30th September and 6th October.

Conversely, throughout the winter temperatures are quite low due to lack of space heating. To make the space occupiable an industrial gas heater is used just before performances to keep the space at reasonable temperature during the shows. However, in very cold evenings, this method does not seem to provide adequate comfort levels for the occupants. Apparently many spectators keep their winter jackets on and some bring blankets for shows. During performances temperatures were around 15°C in the lowest occupied areas. Constant heating, with sufficient capacity is needed to provide comfortable conditions. To reduce CO_2 emissions a highly efficient solution that also does not affect the air quality of the spaces (as gas heaters do) is strongly required.

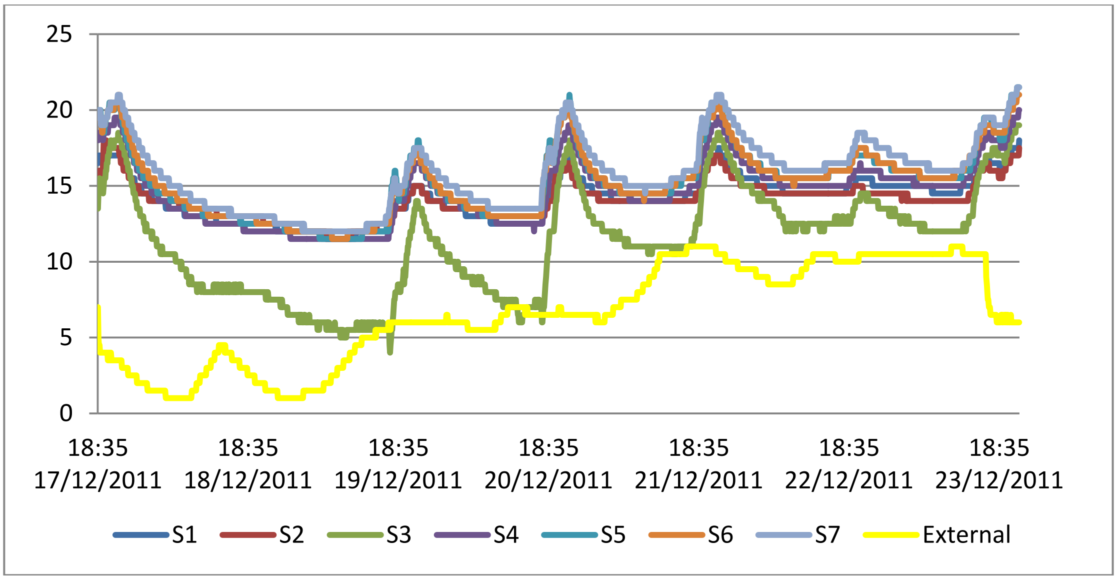

Figure 2: Graph representing temperature readings in Studio 1 and the external temperature monitored during Goodbye Barcelona production between 17th and 23rd December.

The charts below show air temperature distribution through the section of the studio during performance times. The greyed area is a breading zone, defined between the floor and the head height of a person seating on a balcony. It clearly shows that temperatures have increased gradually. Measurements in hot weather show that every 30 minutes the temperature increased about half degree. The temperature in the occupied area reached 27°C.

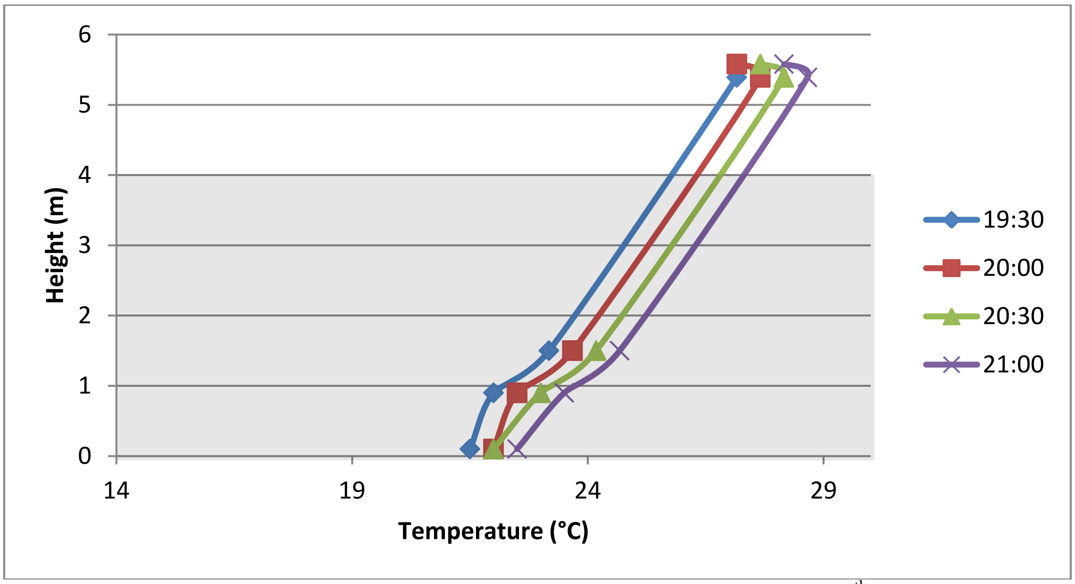

Figure 3: Temperature stratification during a performance Phaedra's Love on 30th September.

Figure 4 represents the temperature stratification during a performance in winter time. Temperatures range from 14.5 to 20.5°C during that time (a difference of 6°C). In first 30 minutes there was a rise of about 1.5°C. Even though the space was preheated before the show the temperature rise is much higher than in warm weather. Conversely, the temperature stratification is more uniform in comparison to the one in the hot period monitored and a rise occurs up to a balcony level remaining constant on higher levels. That observation suggests that a mix mode ventilation could be successfully applied in winter time strategy to save heating energy.

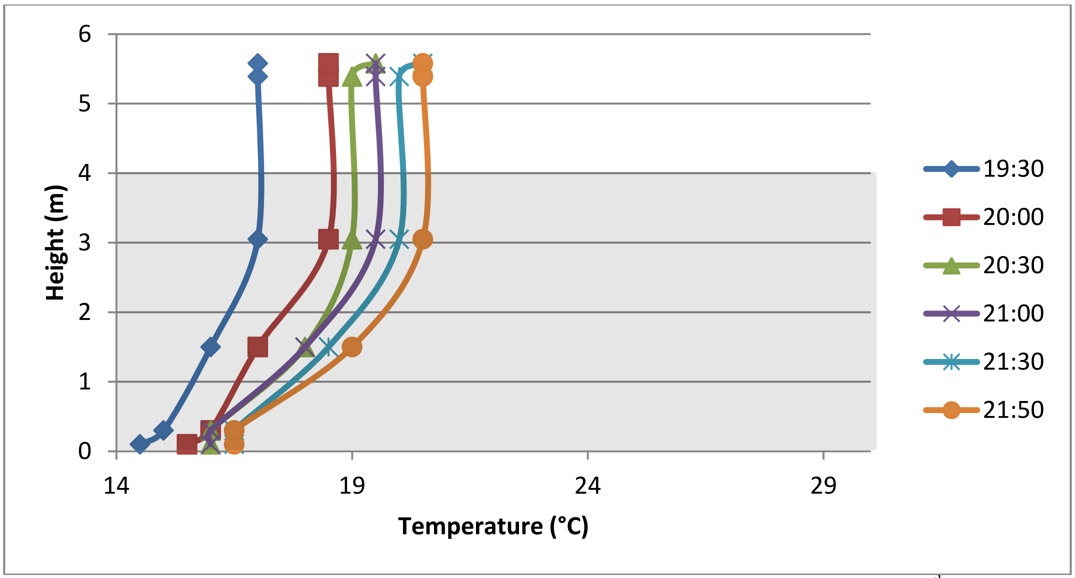

Figure 4: Temperature stratification during a performance Goodbye Barcelona of on 20th December.

The results of air quality monitoring revealed that air quality in the studios do not meet the basic requirements. Carbon dioxide levels are high due to insufficient ventilation. As figure 5 shows CO_2 levels (red line) increased during performance to 3453 ppm. While these high concentrations may not affect the health of the occupants, they clearly indicate that the supply of fresh air and the extract of polluted air are not sufficient for provision of comfort. Stuffiness and unpleasant smells may prevail indoors having an impact on the overall perception and well-being of the audience in the space.

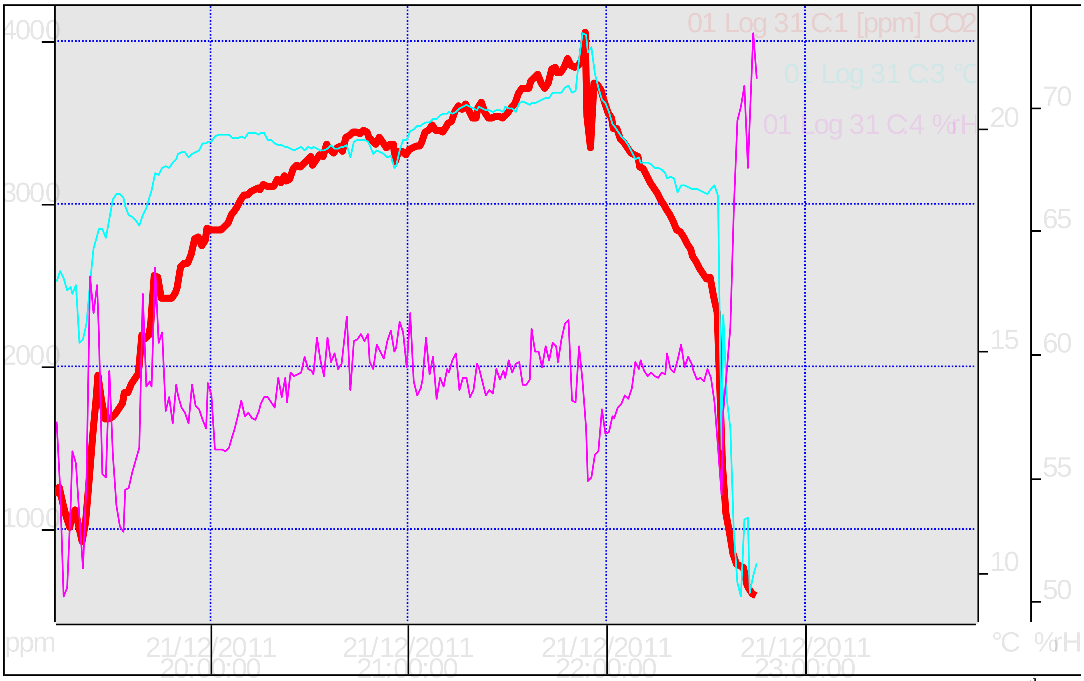

Figure 5: Continuous monitoring of air quality during performance of Goodbye Barcelona on 20th December.

Additionally to the air and temperature monitoring a thermal imaging survey was carried out in winter time to evaluate the state of the external envelope of the building. Infra red images have revealed many areas that need special attention. They also highlight the poor thermal insulation of the envelope which is responsible for the low temperatures recorded in winter and may also be aggravated in the hot periods.

Recommendations

The above findings clearly manifest a necessity to deliver optimal comfort levels in the studio what could be achieved by implementing an appropriate ventilation system in the space. Arcola's commitment to sustainability imposes a sustainable solution.

Air change rates are not adequate, therefore, ventilation needs to be increased and better distributed. To prevent excessive heating energy loss in winter mechanical ventilation with heat recovery may be introduced. That would provide appropriate comfort levels by constantly maintaining controlled air changes while saving energy by recovering heating energy from exhaust air. Although this is a proven and universal solution that could be successfully applied to variety of spaces it still needs constant use of electricity for the operation of fans. The electricity usage, though, is relatively low in comparison to energy recovered by the heat exchanger.

Natural ventilation systems use natural forces for air movement and do not require energy to operate. In traditional systems, excessive energy loss is unavoidable due to lack of control of air change rate as well as heat recovery. However, modern natural ventilation systems can overcome these obstacles with the addition of sophisticated control systems and heat recovery. These systems need to be designed on case to case basis, as many factors are to be taken into account for the correct application and use of such systems. In many cases heat recovery is not optimal or even a possible solution as air driving forces achieved in naturally ventilated systems may be not adequate.

Fortunately, the Arcola's home – Colourworks building has quite an asset in a form of a building feature that can enhance natural forces for ventilation. An old unused chimney runs from the basement, adjoined to Studio 1, to the very top of the four storey building. Simple air flow calculations (Ropiak, 2012), confirmed that the stack effect inside of the structure of this height could deliver enough air driving force to provide sufficient ventilation with an installed heat exchanger. There are many factors that need to be taken into account at design stage, notably location of air supply inlet that would need particular attention as it is critical for the correct implementation of the system. Further monitoring and testing would need to be carried out in order to provide detailed data for design of such system.

Examples of designs have been presented as an inspiration for a possible concept of low energy neutral ventilation for the space. Displacement ventilation strategy is recommended for warm weather period and mixing mode strategy for heating period.

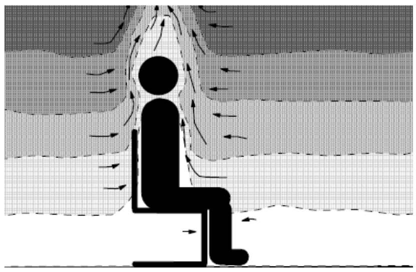

Figure 6: Concept of displacement strategy in operation (Skistad, 2003).

Among many researched solutions most suitable for operation in Colourworks building was considered to be an air to air heat exchanger that is believed to deliver the best efficiency ratio even though implementation and maintenance of such system might be challenging.

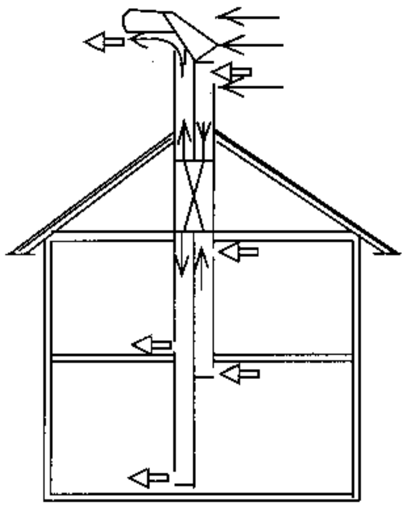

Figure 7: A simple concept for natural ventilation with heat recovery using an air to air heat exchanger (Blom, 1994).

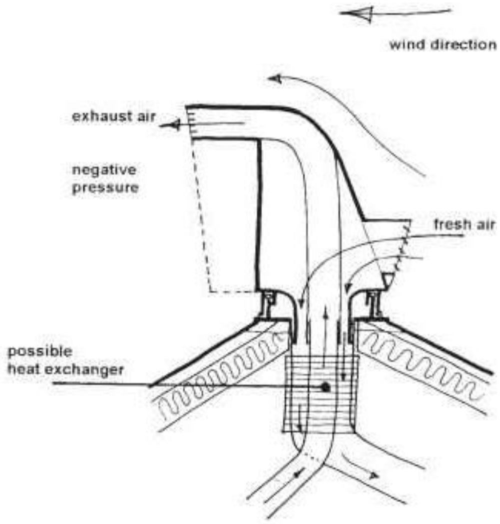

Figure 8: Combined wind tower and wind scoop (Williams, 2011)

Conclusions

A well designed and executed modern naturally ventilated system can provide high comfort levels and air quality in the studio. While it may be more difficult to plan and implement, it may be economically attractive, not only in terms of capital cost (compared to AVAC) but also greatly reduced running costs would be highly appealing. Moreover the outcome will be a fully sustainable solution that is in complete harmony with the environment.

This study has shown that Arcola is in very advantageous position to implement an energy efficient ventilation system. It showed that natural ventilation is a feasible solution in Arcola's performance space and a heat recovery could be successfully employed. This would significantly reduce or even prevent the use of active system for heating. This system would also be adopted to prevent overheating in hot periods. Natural ventilation with heat recovery can be the most efficient of all available options. Adopting clean resources and forces of nature is a way forward into a sustainable future.

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