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Evaluation of chimney stack effect in a new brewery using DesignBuilder-EnergyPlus software

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Abstract

The aim of this paper was to use Computational Fluid Dynamics (CFD) to study the effectiveness of natural ventilation through a chimney, forming part of the environmentally-friendly design features of a new brewery. Different simulations were conducted in order to provide an insight on the mode of operation of window openings, to provide the best ventilation conditions and to identify any situations that may require certain remedies.

Selection and peer-review under responsibility of KES International

Keywords: Malta; CFD; chimney; stack-effect

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1. Introduction

In industrial buildings such as the new brewery that is being studied, a number of industrial processes could produce large amounts of heat that need to be extracted out of the building. Passive measures could use natural phenomena such as night time ventilation and buoyancy effects through chimneys to achieve the required scope, while reducing the need for active ventilation or cooling that consumes electricity.

Nomenclature

CFD	computational fluid dynamics

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1.1. Scoping

The main scope of this research was to assess the effectiveness of natural ventilation in the Brew House of the new Farsons Brewery, Mriehel, Malta, especially under the hot and humid summer climatic conditions, when the brewing activity is at its peak.

1.2. Site Description

Figure 1 shows an aerial view of the New Farsons Brewery Complex, which includes storage facilities, offices and laboratories (http://www.farsons.com). The northern front part shows the main brew area comprising of two floors. On the top level (upper brew hall), natural lighting is enhanced by the use of large glazing areas on the northern, eastern and western sides. The lower brew hall which is below ground level has a number of upper east and west windows that can be opened, to introduce fresh air into the brewing area. The rectangular tower behind the brew hall is the natural ventilation chimney, which contains a set of large openings on the top southern and northern sides. The generation of heat within the brew house mainly comes from four kettles situated at the lowest storey, with their top part protruding and terminating in the upper brew hall.

Fig. 1. An aerial view of the new Farsons Brewery at Mriehel, Malta.

2. Development of Simulations

2.1. DesignBuilder CFD Simulation Settings

The EnergyPlus weather data for Malta that was developed in a previous work [1], was imported into DesignBuilder software (http://www.designbuilder.co.uk). This will allow us at a later stage to run the simulation of EnergyPlus in DesignBuilder, in order to get the actual CFD boundary conditions. The thermal load gains have been modified to match the heat flux released by the four kettles during brewing (48 kW in total).

The numerical method employed by DesignBuilder CFD is known as a primitive variable method, which implies the solution of a set of equations that involves the conservation of heat, mass and momentum, known as the Navier-Stokes equations. The equations comprise a set of coupled non-linear second-order partial differential equations.

The computational fluid dynamics (CFD) modeling of DesignBuilder software has the ability of providing CFD calculations both for the internal and external conditions of a building model for every possible situation, and individually applied to a particular hour of the year, including a full visualization of the pressure, air speeds and direction and temperature profiles for every point inside or outside the model. The simulations were carried out for summer and winter Design Conditions at 2 p.m., when top and lower windows were opened or closed respectively or simultaneously.

2.2. CFD Simulations

Summer Design Week during the brewing process (17th July)

Figure 2 shows the pressure distribution results of CFD after convergence when all windows were opened. It is seen that the pressure distribution has a fairly marked difference between the bottom and the top levels of the chimney. The buoyancy is demonstrated because as the air heats up inside the building and moves up the chimney, the pressure increases and expels the hot air out from the open windows on top, with colder air being sucked in from the open windows at the bottom.

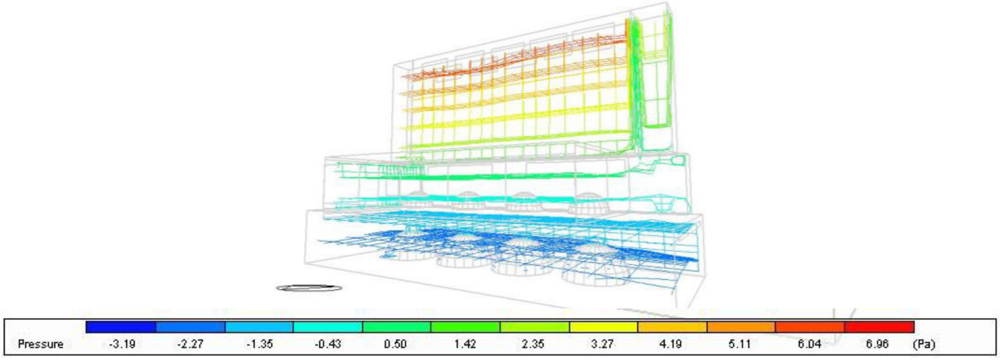

Fig. 2. Pressure distribution at 10 a.m. and 2 p.m. for summer design (17 Jul).

An intense flux rises as the building heats up due to the brewing process. The wind speed increase in the chimney is caused by temperature rise (temperature-driven flow) and the stack effect is enhanced. There is some recirculation on the sides of the building but most of the air has escaped from the top windows, because the temperatures at the sides of the chimney are much cooler than the central part. The magnitude of wind speed due to buoyancy was found to be of the same level as that studied by other research [2].

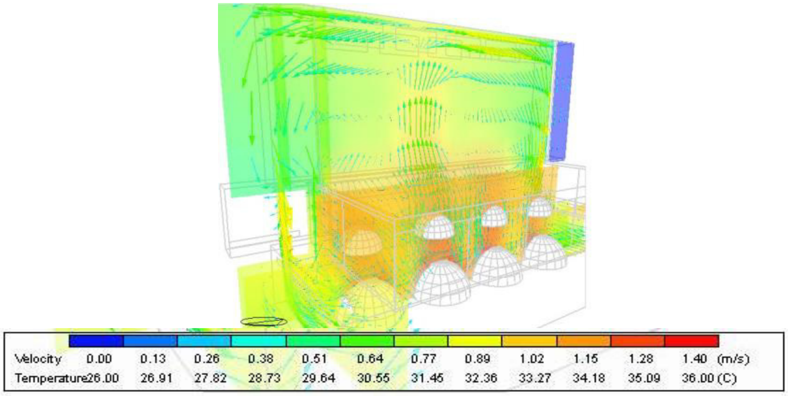

Fig. 3. Temperature and wind speed profiles for summer design at 14:00 (17 Jul).

It is clear that temperatures soar above the 35 °C mark. One of the reasons for this high temperature is the large amount of glazing in the upper brew hall, which allows sunshine to overheat the internal space. In order to appreciate the amount of solar radiation incoming on the glazing, a graph of the solar gains for 17th July is presented in Figure 4.

If one were to compare the behaviour of the flow at 14:00 with the case when the upper brew hall is assumed to be shaded, then it is clear that the temperatures are lower by about 3-5 °C (below 30 ºC in the brew halls) and the convective currents are still strong to ensure the flow of hot air up the chimney, as shown in Figure 5. Hence, one of the recommendations given is to shade the glazing in summer.

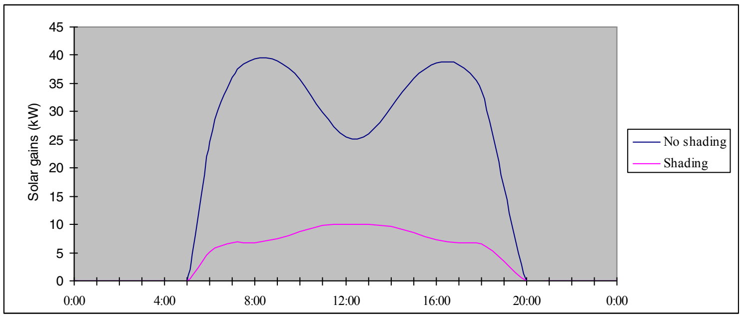

Fig. 4. Solar gains through glazing (kW) for 17th of July with shading and no shading in the upper brew hall.

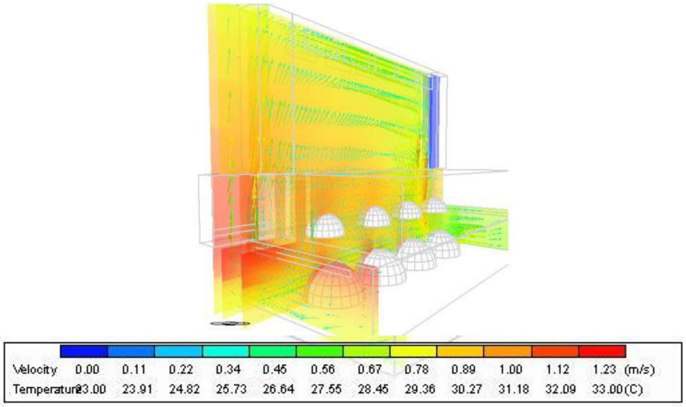

Fig.5. Temperature and air flow 17 July, 14:00 (case of shaded upper brew hall).

Figure 6 shows the temperature distribution when only the top windows are open. Since there is no wind driven ventilation, the flow rate is low and the brew halls heat up fast in the centre. As a result a temperature driven current is created and the flow through the central chimney is reversed. This case may be useful, if the previous night was too cold and no ventilation is needed. In summer, this never occurs. Hence, it is suggested that in summer, all windows must be open to ensure proper ventilation.

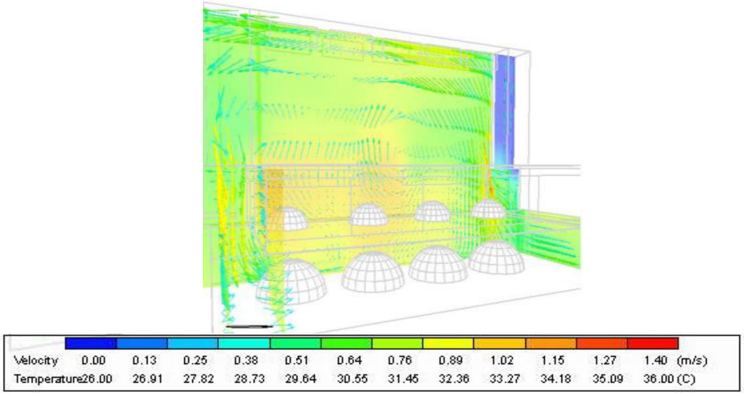

Fig.6. Temperature and air flow with heat flux, open chimney but closed brew hall windows (17 Jul 14:00).

Winter Design Week when brewing process is carried out

In winter, the solar radiation is weaker and the day is shorter. Moreover, the sun path would be more compressed and the sun would not shine through the upper brew hall glazing for long. Hence, shading would not make as much an effect on the internal gains as in summer. In other words, there is no need for cooling of the brew hall in winter, and hence the lower windows may be closed, as otherwise the brew hall shall become uncomfortably cold.

When the top chimney windows only are opened, there is exchange of fresh air and stale air through the chimney openings, while hot air accumulates at the bottom of the chimney. As the warm air goes up, it turns anticlockwise. Cool fresh air mixes with the rising hot air and refreshes the flow along the two sides of the building. This optimal option is useful to renew the stale air without excessive cooling in the brew halls. The maximum temperature reached was around 25 °C.

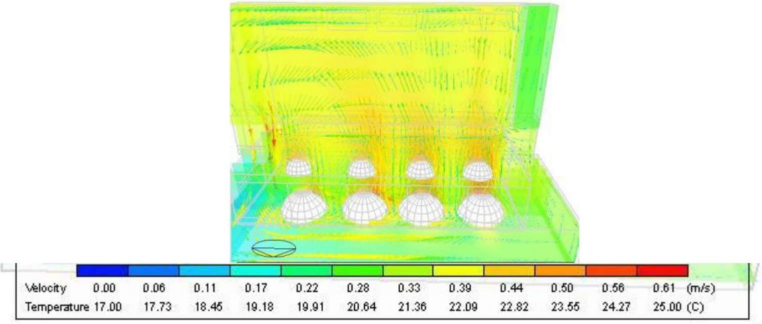

Fig.7. Temperature and air flow distribution at 14:00 for winter design (20 Jan) with heat flux but brew hall windows closed.

Winter Design Week when no brewing process is carried out

If all windows were opened during no brewing activity, a negative pressure gradient develops in winter, as seen in Figure 8. This creates a reverse stack effect and produces a downward cool inflow into the brew halls. As long as a temperature gradient exists, the ventilation persists. Moreover, the lateral pressure gradient in the eastern part of the lower brew hall drives the flow from east to west. This means that now there will be both a vertical downward flow of fresh air, as well as a transverse fresh air flow from east to west. This option may expel stale air from the brew house in winter.

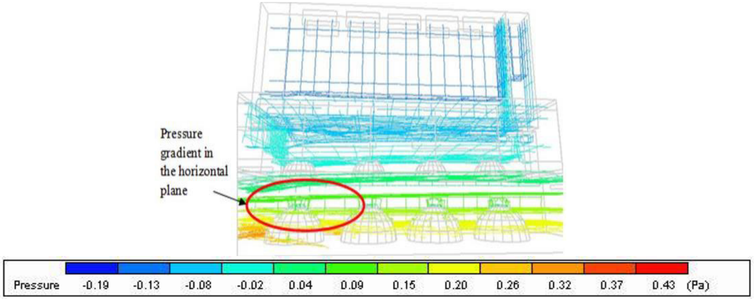

Fig.8. Pressure distribution at 14:00 for winter design (20 Jan) with no heat flux and chimney windows open.

When all windows are closed in winter, a gradual increase of temperature takes place up to a comfortable level of 19 ºC in the afternoon. This situation is presented as the most favourable situation, when brewing is not in operation.

3. Conclusions

The analysis of summer results showed that natural ventilation on its own will not be sufficient to cool the building. It can be argued that the best strategy would be to make use of night time ventilation to cool the building, before brewing starts in the morning. Meanwhile forced ventilation would need to be used around noon time to help the extraction of excessive heat from the facility. Due to the effect of buoyancy, heat accumulates and stays near the top of the chimney when the pressure gradient is positive and the top windows are closed. The results showed that the air temperature increases quickly from top chimney level down to about 10 metres.

It would be interesting to develop a smart programming schedule for the windows to operate them automatically, based on the internal and external temperatures. A shading system should be applied to the eastern and western facades of the upper brew hall to lower solar overheating, especially in summer. It is also recommended that steps are taken to improve the situation and to eliminate some problems that have cropped during the operation of the facility in its first year. Planting green vegetation close to the lower windows may reduce dust ingress into the facility, while allowing wind to flow through the brew halls. Also, it is necessary to reduce heat losses from the brewing machinery at the lower brew hall (insulate steam valves that release un-necessary heat).

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