CHAM Case Study: HVAC
CFD Modelling of KVI Extraction Unit in a Kitchen

This report describes the CFD modelling of the effect of incorporating a KVI extraction unit in a model kitchen. The KVI capture jet hood™ with side jet technology is a powerful ventilation hood which serves to remove excess heat and contaminated air from industrial kitchen appliances and cooking equipment. This steady-state demonstration case was performed by CHAM on behalf of SimuTek Solutions. The problem defined, whilst simplified, serves as a demonstration of the capabilities of CHAM's general purpose CFD code, PHOENICS, for this type of application.

CFD Model and Set Up

The essential ingredients in the setup of the CFD simulations were the geometry of the kitchen and extraction unit, together with specification of a heat source suitable to model the power output of a kitchen hob. The calculation mesh used had a total of 343,000 grid points.

The dimensions of the kitchen were chosen to be 3.5m wide by 3.5m long by 3m high, and within this kitchen at the front far left corner is a stove unit that measures 1.2m x 1.5m x 1m. Atop the stove is a hob (of smaller area) that we assume to have a power output of 10KW (corresponding roughly, given its area, to a surface temperature of ~500 °C). There is a kitchen door at the back and far right of the room measuring 1m wide by 2m tall that serves as a pressure relief.

The final item is the KVI extractor, the geometry and specifications of which were constructed in PHOENICS using basic object shapes and information obtained from Halton UK[i]. (Note that the hood used in the simulations is a 'broad brush' representation of the structure outlined in this reference. It is sufficient to capture qualitative behaviour relevant to the demonstration; more refined modelling would be required for a detailed quantitative comparison with the aforementioned reference.)

The extraction hood is 1.2m wide x 2.9m long x 0.5m high. Together with its primary extraction unit (represented in PHOENICS as an angled outlet) a notable feature of the KVI hood is that it contains two thin (~0.05m) air jets [inlets] extending the full length of the outer edge of the structure (see Figure 1).

The hood was positioned 0.65m above the stove. Inlets inject air at the ambient temperature with a volume flow rate of 17.5l/s (spread evenly amongst the three) and the extractor removes air at a rate of 648l/s. The case took ~30 minutes to construct and mesh.

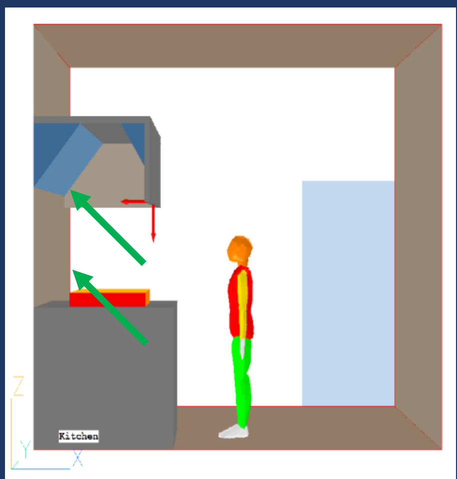

Figure 1: Geometry of the kitchen and KVI unit located above the hob (shown red). The inlet locations are marked by a red arrow showing the direction of air injection. The angled outlet is the blue wedge on the left of the hood and is indicated by a green arrow.

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Results

Each simulation was run for 1000 iterations, taking a total of 40 minutes (343,000 grid points) after which a good level of convergence was obtained. (Note this calculation time was for a serial run on a 2.4GHz PC).

Figure 2 displays the resulting temperature contours and overlays the associated velocity field for a simulation with the KVI extractor operational. The extractor unit pulls hot air from the hob strongly towards its extraction point; recirculation produces a distinctive 'swirl pattern' that prevents excess warm air from escaping into the rest of the kitchen.

(Temperatures greater than 50°C have been suppressed in the figure so as to emphasise the temperature variation in the plume entering the hood extractor).

The average temperature in the room is raised only very slightly despite the surface of the hob reaching a maximum temperature of ~500°C.

Figure 3 shows the temperature profile across the kitchen and it becomes clear that the hot air is unable to escape from beneath the hood and is captured in the region directly above the hob. As evidence, the average temperature in the rest of the kitchen remains only slightly raised above the normal room temperature (~23.8°C).

Although not shown here, the flow pattern is similar with the inlet jets switched off, when using a very strong exhaust flow rate. (Qualitatively, the results are identical to those shown in Figure 2.) The purpose of the inlet jets becomes clearer at lower exhaust rates.

Figure 4 shows different results with the previously strong extraction rate reduced from 648l/s to 520l/s. This corresponds to a power reduction of ~20%. In this scenario, the peripheral air jets are also switched off and hot air is able to escape from the hood, raising the average temperature in the room by ~7.5 °C to 31.3 °C.

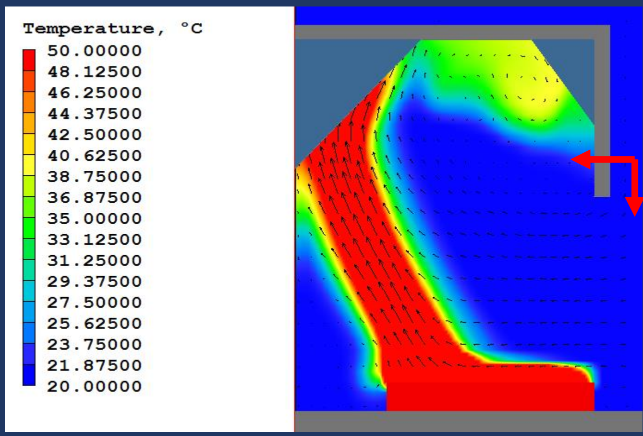

Figure 2: Temperature contours and overlaid velocity field in the case with the KVI extractor switched on.

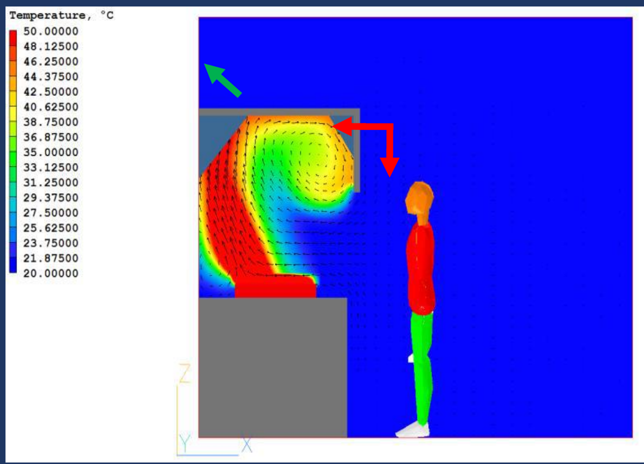

Figure 3: Temperature contours and overlaid velocity field across the whole kitchen in a case where KVI inlet jets are switched on.

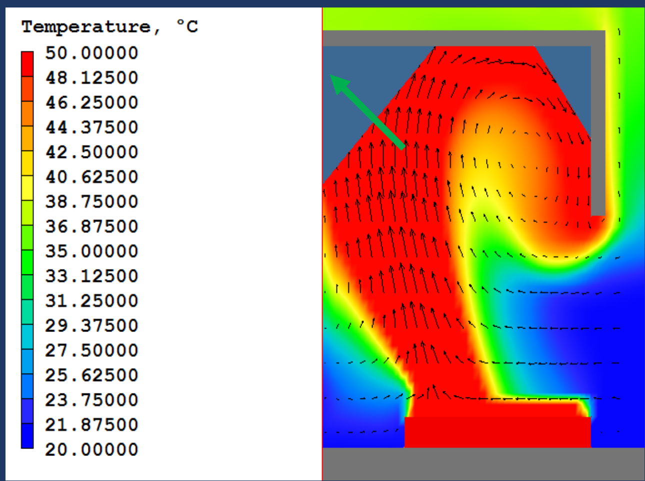

Figure 4: Temperature contours and overlaid velocity field in a case with 20% exhaust reduction and the KVI inlet jets switched off.

Figure 5 confirms that a significant portion of the heat from the hob spills out from the hood area, raising substantially the temperature of the air in the rest of the kitchen.

The effect of reducing the extraction rate by 20%, but this time leaving all the inlet jets switched on, is now explored.

The desired advantage of the KVI family of extractors using inlet jet technology is that they should be capable of removing the same amount of heat as conventional extraction units but with a lower volume flow rate, and consequently, requiring less power.

This result can be observed in Figure 6 which, in contrast to Figure 4, confirms that the heat is once again confined beneath the hood and does not leak into the rest of the kitchen (see also Figure 7).

The average room temperature in this case rises by less than 0.2ºC (to 24ºC). Reducing the power consumption further - this time with a 28% reduction in the exhaust and the inlet jets active - we can see that heat is just beginning to leak out of the hood.

From the relatively low temperature of the leaked air, we can conclude that the critical exhaust value at which leakage occurs in our CFD model is close to a 28-30% reduction.

It is important to emphasise that these qualitative results are based upon a crude representation of the exhaust hood and an arbitrarily-selected choice of setup parameters. Quantitative results might only be expected using CAD representation of the hood coupled with accurate hob and operational conditions from physical testing.

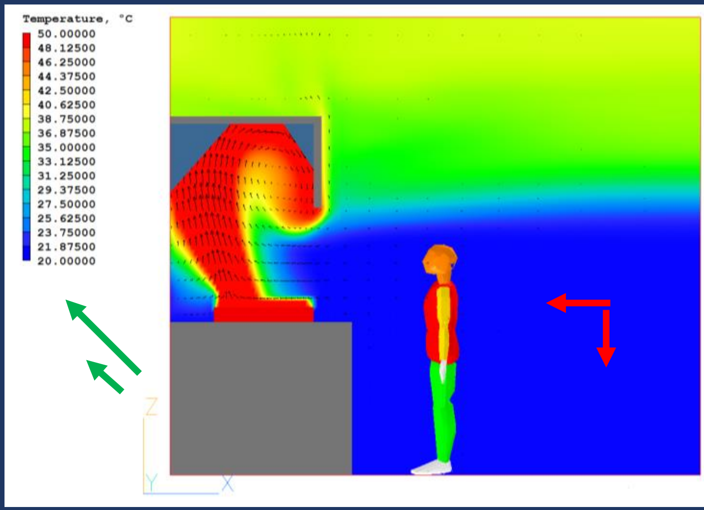

Figure 5: Temperature contours and velocity field across the whole kitchen in the case with 20% exhaust reduction and the KVI inlet jets switched off.

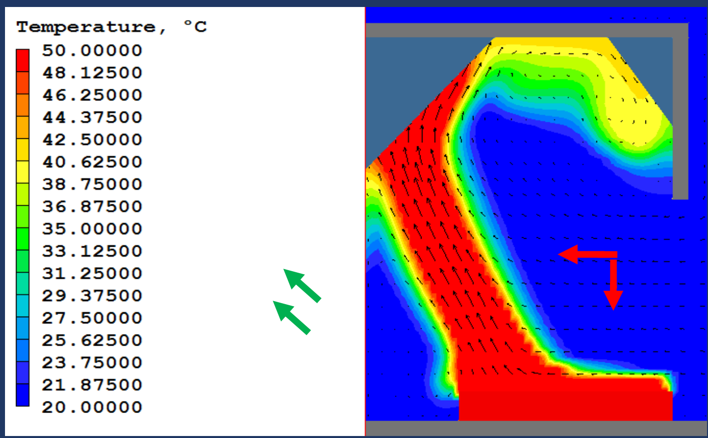

Figure 6: Temperature contours and overlaid velocity field in the case with the exhaust extraction rate reduced by 20% (as in Figure 4) with the inlet jets switched on.

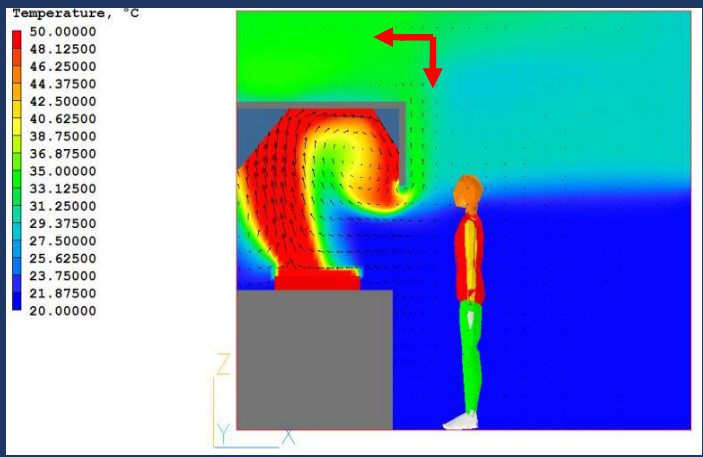

Figure 7: Temperature contours and overlaid velocity field across the kitchen in the case with the exhaust extraction rate reduced by 20% (as in Figure 4) with the inlet jets switched on.

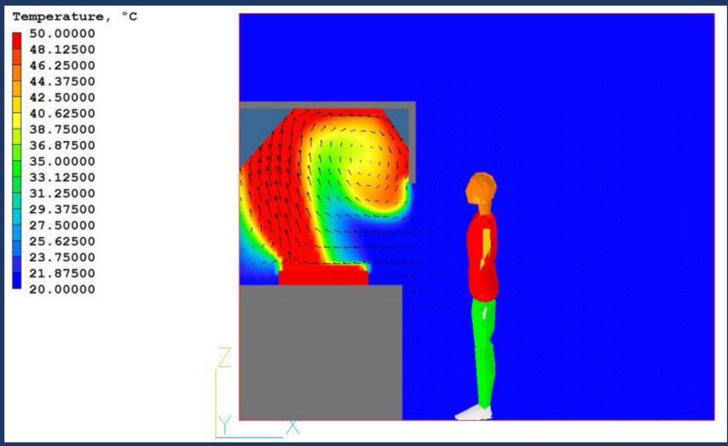

Figure 8: Temperature contours and overlaid velocity field across the whole kitchen in the case with the exhaust extraction rate reduced by 28% with the inlet jets switched on.

Observations

The purpose of the CFD analysis described above was to demonstrate how PHOENICS can be used to investigate by how much one can reduce the exhaust volume and still confine heat to within the hood unit.

Whilst the crude representation of the design used for these demonstration purposes began to falter at just below a 30% reduction, it should be noted that the real KVI hood has been rated to operate with as much as 30-40% less power than conventional extractors.

Nevertheless, the overall behaviour of an extraction unit has been modelled successfully using PHOENICS and serves as a demonstration of the capabilities of this software. It also confirms that the use of ambient air inlet jets permits a lower extraction flow rate and consequential reduction in power consumption compared to

Reference

[i] http://www.halton.com/halton/cms.nsf/files/8EABEBF7F64E39DAC225742C00288561/$file/kvi%20en.pdf