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SIMULATION STUDIES ON A KITCHEN VENTILATION SYSTEM

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Synopsis

The efficiency of a kitchen ventilation system is usually determined by its ability in heat and effluent removal. The main part of a ventilation system is the hood, with its face (or capture) velocity. Heat generation associated with the cooking process is the main factor that affects the thermal comfort. The heat removal capability is studied under different capture velocities so as to determine the minimum requirement for efficient removal of heat and effluent. Four arrangements of make-up air are simulated, with air coming from the front of hood, from the ceiling, from the underneath burner and from the wall. Various angles are also attempted as the direction of the make-up air coming from the wall. Finally, the interaction between the kitchen and the refreshment area will be studied. All simulation works were performed using the CFD package, FLUENT (V4.3).

1.0 Introduction

During the cooking process, the chemical and physical characteristics of food are changed, with impurities such as grease, smoke and small solid and liquid particles being produced and dispersed into the ambient air. The purpose of a well-designed ventilation system is to remove the impurities and part of the heat created by the cooking equipment, so as to provide a comfortable and hygienic environment.

Many types of food centres exist in Singapore; two main groups are those without air conditioning, such as hawker center, and those air-conditioned food centers in shopping centres and hotels. Both groups show the same problems associated with their kitchen ventilating system. The indoor climate of both kitchens and refreshment area of a hawker center is often unsatisfactory which have significant effects on the workers' productivity and customers' comfort.

Ventilating techniques have been provided in the hawkers' centers in Singapore for many years. However, many of them are not functioning properly due to bad design, incorrect usage and lack of maintenance. Many factors affect the effectiveness of ventilation; supply and exhaust airflow are two main ones.

Chinese and Indian food enjoy great popularity in Singapore. The preparation of both kinds of food often involves deep-frying and therefore generates more grease, vapor and heat than that of western preparation. Since there has been a lack of studies on the food centers in Singapore, the present project considers the air motion in the Singapore kitchen, in particular, the contaminant-removing capability of oily cooking processes in the hawker centres.

2.0 Acceptable Thermal Comfort

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment [1]. Though regional climate conditions, living conditions, and cultures differ widely throughout the world, the preferred temperature that people choose for comfort has been found to be similar.

ASHRAE Standard 55 [2] provides the guideline for the environmental parameters for human occupancy, in which acceptable temperature is up to 29°C with humidity at the 60% upper limit. It is also noted that in this standard, air speed may offset increased temperature up to a maximum at 34°C. The health requirements in kitchen are: room temperature of kitchen at 28°C, the upper limit of the air humidity at 16.5g/kg dry air, and a relative humidity (R.H.) of 70% [3].

3.0 The Boundary Conditions for Computational Analysis

As the refreshment area is an "open concept" type, the thermal comfort is affected by the temperature and humidity of the ambient air, the heat and R.H. from kitchen and various activities in this area. One study[4] shows that the average daytime temperature in Singapore is 28°C, but the lowest R.H. of ambient air is well above 60%. So it is possible to keep the temperature to achieve ASHRAE acceptable operative temperature, but it will be difficult to keep its R.H. upper limit at 60%.

The model size of kitchens is based on the typical size of cells of the hawker centres in Singapore. In a 2-D model, the room is 2.8 m × 3 m, the hood is 0.6m×0.6m, and the hood is 1.1 m over the cooking surface. The grid used in the simulation was 30 (horizontal) × 32 (vertical). The cook's position is assumed to be at 0.4m in the front of the support (see Fig. 1).

The contaminants are produced at a high level of concentration over a short period of time. Both solid and liquid particles are generated during cooking. The solid particles are usually a result of the food burning and the generated carbonaceous particles. Large liquid particles will quickly fall back onto the adjacent surfaces due to gravitational forces. Most liquid droplets are very small, and they remain airborne and drift about before settling on a surface. Annis and Annis [6] sampled grease aerosol produced by five natural foods fried in an electric skillet. The median particle diameter of these particles is lower than 1 μm and its average diameter is about 0.5 μm. Average concentration is less than 1.2 mg/m^3. However, their study is rather basic because of the complexity of the particle size distribution existing at various stages of frying for a variety of cooking processes have not been taken into account.

The normal skin temperature of human being is 28°C [1]. Area B represents the burner head. The 400°C is chosen as its typical burner head temperature for common use [3]. Area A simulates the heat source, and the heating value is 4.5 kW. Although the acceptable R.H of standard 60% is lower than the normal condition in Singapore, it is still taken as the humidity of the make-up air. The 0.6mg/m^3 and 0.5 μm are selected as the average size of the particles. The initial conditions in the kitchen are: the temperature of fresh air 28°C, humility 80% and the initial temperature in the kitchen 33°C.

4.0 Simulation Results

4.1 Temperature and capture velocity

The capture velocity of hood is varied from 0~0.5m/s, with step increase of 0.1 m/s. From the temperature contours in Figs. 2 and 3, it is found that the capture velocity affects the temperature greatly. When the capture velocity increases to 0.3m/s and above, the temperature around the cook's working place is acceptable. As the velocity increases continuously, the temperature around the cooking surface could be controlled better, but there is no obvious temperature improvement observed around the cook. The results show that the comfortable thermal environment can be achieved by keeping the hood facing velocity at 0.3m/s or above.

4.2 Radiation temperature and capture velocity

The radiation temperature relates to the type of heat source employed. According to the radiation theory and equations used in FLUENT, the radiant flux is related only to the temperature and the location of the heat-emitting source. If the heat source is treated as the heat flux, specifying the capture velocity should have little effects on the radiation heat transfer. The simulation results support the theory. With the increase of capture velocity, there is no obvious change in radiation heat transfer and no obvious effects on the radiation temperature distribution (see Figs. 4 and 5). On the contrary, if the heat source is temperature specified, with the increase of capture velocity, the thermal condition of the kitchen could be improved. But the suitable capture velocity for the controllable radiation heat depends on the temperature of the heat source. Therefore, it could be concluded that the performance of hood has little effect on radiation temperature due to the heat flux, regardless of whether the make-up air is available or not, but the thermal condition could be improved if the heat source is temperature specified.

4.3 Humidity and capture velocity

The humidity removal ability of a hood is studied by generating a high humidity source from the cooking surface and observing the effect of the capture velocity on the subsequent distribution. The simulation results show that when there is no exhaust or when the exhaust velocity is lower than the escape velocity of vapor, the water vapor will disperse into the room rapidly and affects the comfort of the cook. Once the capture velocity is above the escape velocity of vapor, even at low speed, the vapor can be controlled well and humidity varies little around the cook. (See Figs. 6 and 7). In other words, once the capture velocity is already above the escape velocity of vapor, the increase of capture velocity does not have obvious effect on the vapor removal.

4.4 The particles and capture velocity

The kitchen contaminations are produced at a high level of concentration over a short period of time. The contaminations involved include particulate, moisture, heat, odors, and gases, and these contaminants can be produced in a variety of combinations. Solid particles are usually a result of an error in cooking that causes the food to burn, generating carbonaceous particles. Vegetables in particular are of a cellulosic nature, and they readily form these solid particles when burned.

The large liquid particles are formed through minor explosions within the cooking vessel and they are visible as they move through the air and spatter on the surrounding surfaces. The size of the particles formed this way ensures that most will quickly fall back onto the adjacent surfaces due to gravitational forces. The more common liquid particles are small and they remain airborne and drift about before setting on a surface. When oil are heated to elevated temperatures, there is evaporation. A mixture of warm air and warm evaporated oil molecules is carried upward by the thermal currents. As the mixture enters a cooler region, the oil vapor condenses into a liquid and is converted into very small particles.

Annis and Annis [5] studied five kinds of natural food, and the following are their results of the size distribution and concentration of naturally generated cooking aerosols in the region of a range hood. The average diameter of particles generated from the cooking surface is about 0.5 μm, and the average concentration produced is about 0.6 mg/m^3. As shown in Figs. 8 and 9, only when the capture velocity is equal or higher than the particle escape velocity can they be removed; otherwise, the particles will disperse into the room.

4.5 The location of the make-up air system

Most ventilation systems in a hawker centre are not operated in their full capacity. The performance of the hood when installed in different places is studied. At a capture velocity of 0.2 m/s, the make-up air can come from the front of hood, down of heavy duty, ceiling, and from the wall, as shown in Fig. 10. The simulation results show that when the capture velocity is low, location in front of hood has better performance than others. (The down location is the worst. The air current's effect on the heat removal could be understood if the velocity vector is referred. But the situation will change when the capture velocity increases.)

4.6 The direction of make-up air coming into the room from the wall

When the make-up air system is installed in the wall, by keeping the capture velocity at a constant speed of 0.2 m/s and varying the in-coming direction of fresh air, the performance of the hood is studied. If the angle varies from 30° to 45°, the temperature can be controlled better than other angles. Once the angle for fresh air coming in exceeds 60° or below 30°, the heat can not be removed in time. As a result, the cook will feel uncomfortable. The velocity vector profile display the velocity field which will affect the temperature field and therefore explain how air flow affects the performance of the hood (see Figs. 11 and 12).

4.7 The comfort in the refreshment area and capture velocity

The thermal comfort in the refreshment area is affected by many factors, such as the temperature and R.H. of the ambient air and by the heat and R.H. from the kitchen. But the main effect comes from the various heating activities in the area. When the capture velocity is large enough, both the R.H. and temperature can be controlled in the kitchen. Hence, both temperature and R.H. will not affect the thermal comfort in the refreshment area. However, the temperature contour (see Fig. 13) shows that there is no obvious thermal improvement in this area when the hood capture velocity increases. The main reason is that when the ratio of refreshment area to the kitchen area is too large, it is difficult to improve the thermal condition in the refreshment area, which depends mainly on the hood velocity. Moreover, there are many heating activities and heat sources in the refreshment area. For example, each food dish could have a temperature higher than 50°C. The radiation transfer from the cooking equipment in the kitchen is another heat source, which will affect the temperature in the area.

5. Conclusions

The operational performance of a hood has significant effects on the temperature distribution of the ambient air in the kitchen, and therefore affect the thermal comfort of the cook. But it has little effect on the radiation temperature heat flux specified. Once the capture velocity is equal to or large than the velocity of vapour escape velocity, the vapour could not disperse into the kitchen and the R.H. of the ambient air would not increase. The hoods installed at different places and the direction for make-up air to enter have different performance. The performance of hoods in the kitchens has little contribution to the thermal comfort in the refreshment area. The main factors that affect the thermal condition are the various activities in the refreshment area.

6. Acknowledgements

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7. References

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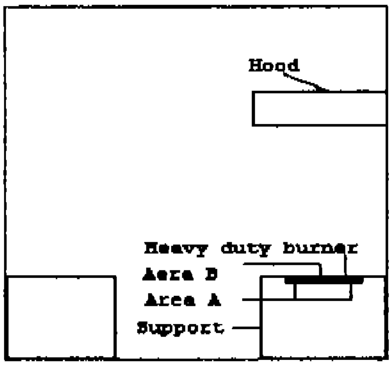


Fig. 1 Kitchen model for simulation

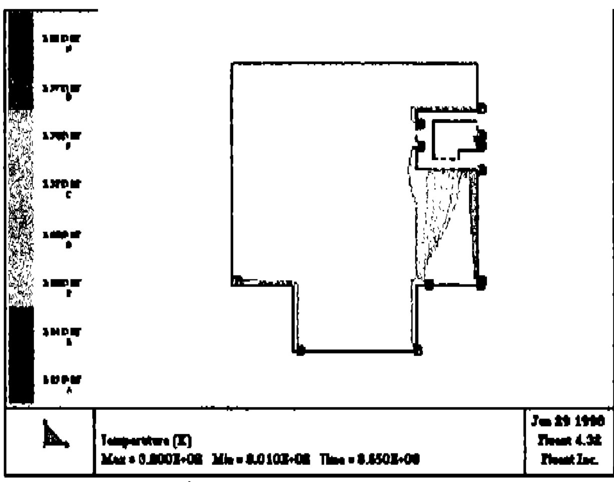


Fig 2. Temperature contour
(capture velocity 0.2 m/s)

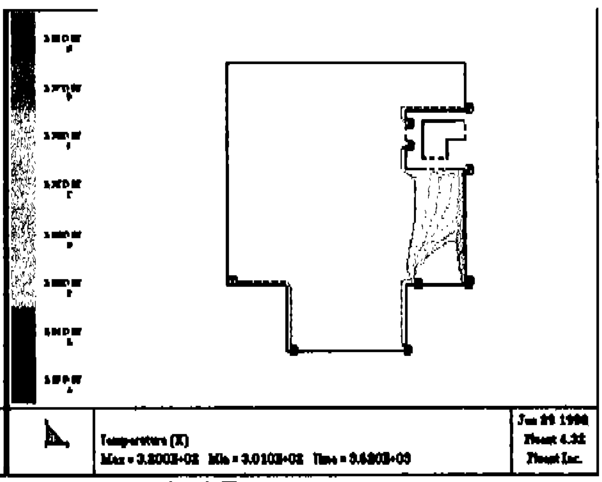
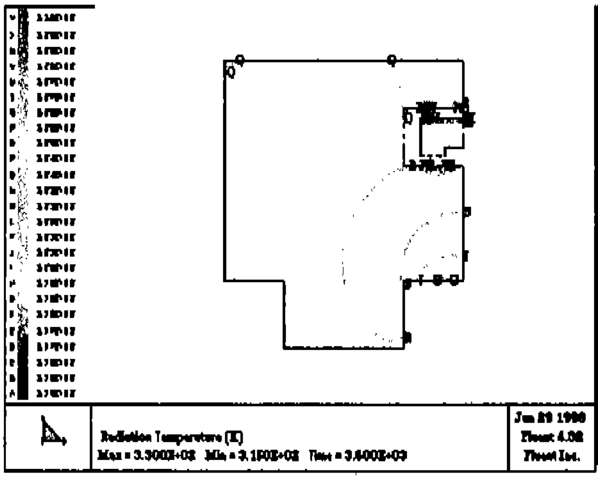


Fig. 3 Temperature contour
(capture velocity 0.4 m/s)



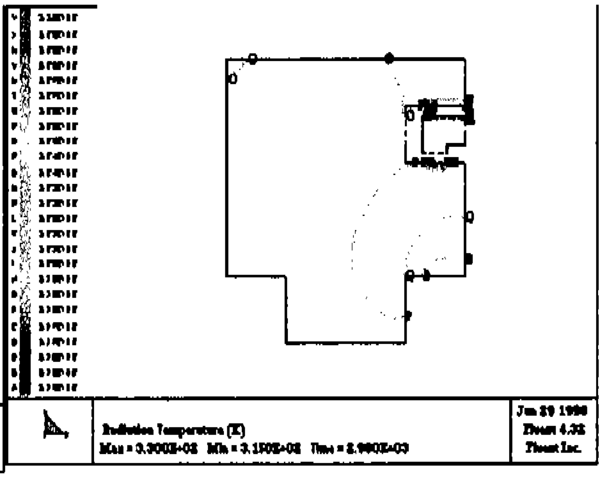


Fig. 4 Radiation temperature contour (capture velocity 0.2 m/s, only heat flux 4.5 kW available)

Fig. 5 Radiation temperature contour (capture velocity 0.5 m/s, only heat flux 4.5 kW available)

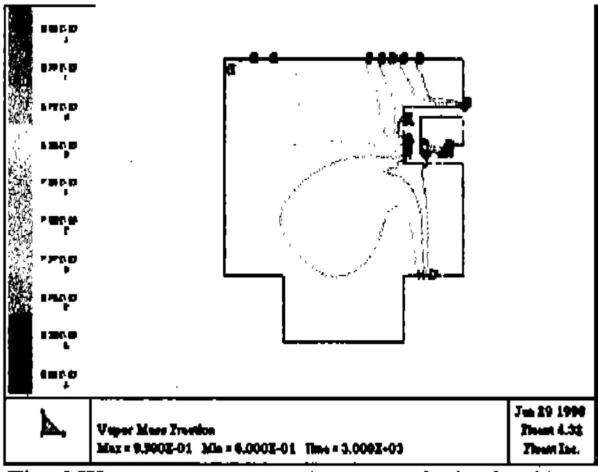


Fig. 6 Water vapor contour (capture velocity 0 m/s)

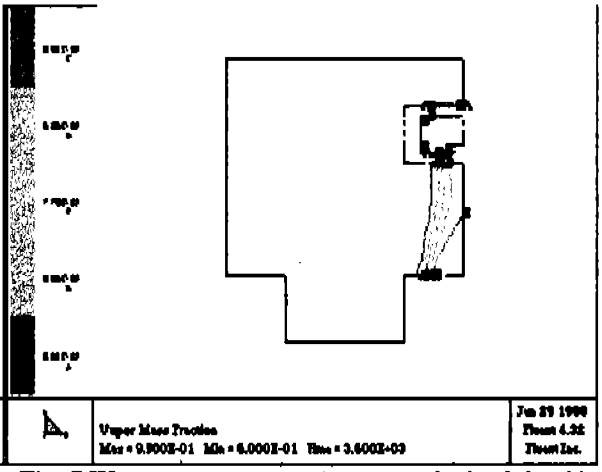


Fig. 7 Water vapor contour (capture velocity 0.1 m/s)

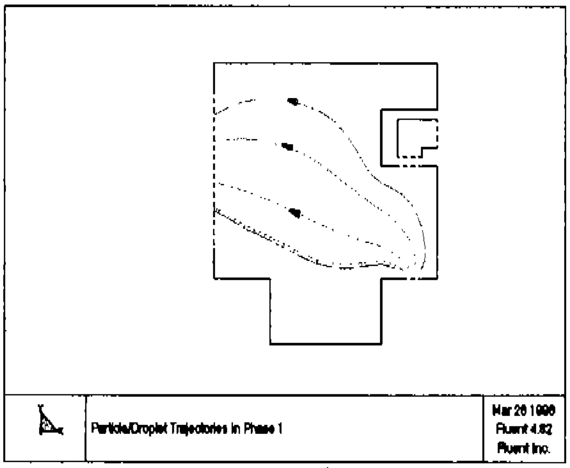


Fig. 8 Effluent trajectory (capture velocity 0 m/s)

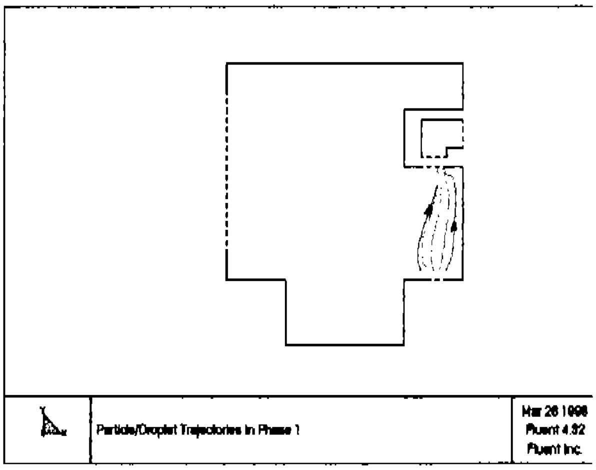


Fig. 9 Effluent trajectory (capture velocity 0.1 m/s)

(The lines in Figs. 8 and 9 are the track of effluent disperse)

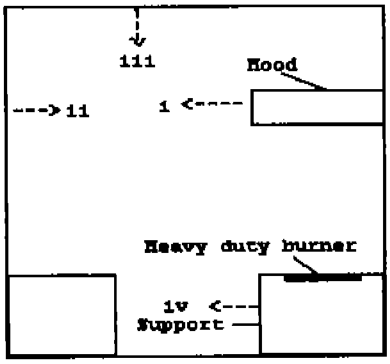


Fig. 10
i-- Make-up air coming from the front of the hood
ii--Make-up air coming from the wall
iii--Make-up air coming from the ceiling
iv--Make-up air coming from below heavy duty burner

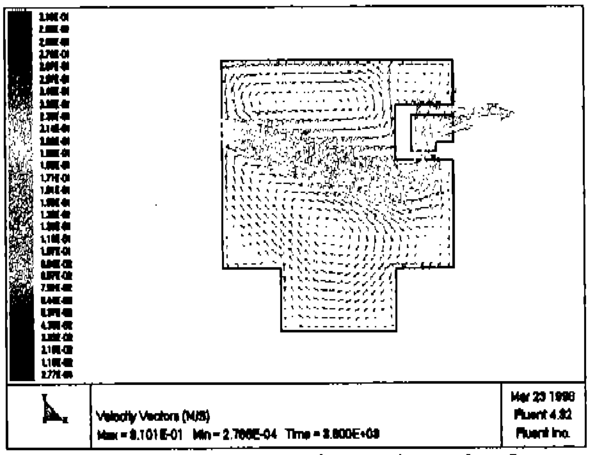


Fig. 11 Velocity vector (make-up air coming from the wall with an angle of 15°)

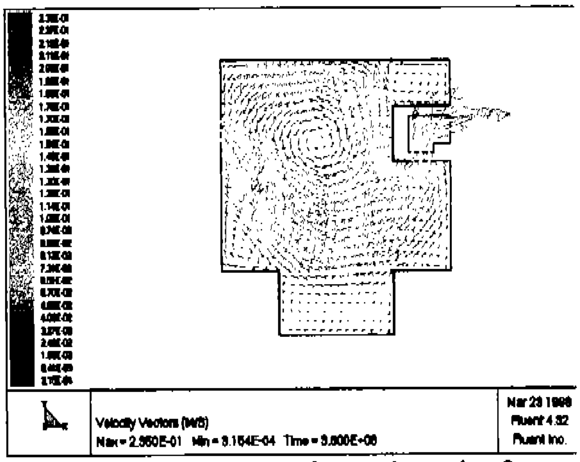


Fig. 12 Velocity vector (make-up air coming from the wall with an angle of 45°)

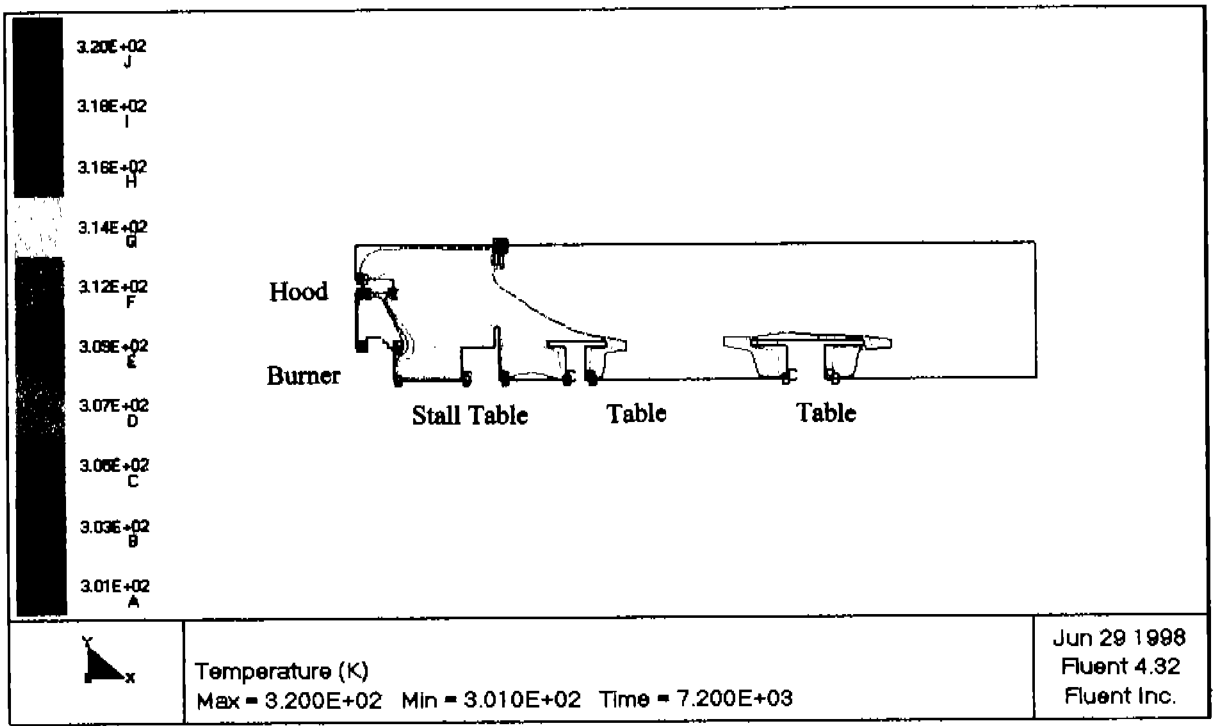


Fig. 13 Temperature contour (kitchen and refreshment area, capture velocity 0.1 m/s)