Experimental Examination Of Booster Heating Coil In Foodstuff Display Cabinet

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Abstract: Display cabinets are one, which is used to keep the foodstuffs in warm condition. The foodstuffs are kept in warm conditions by the surrounding hot air. The air got heat from the electric heating coils. The heating coils use the electric power to produce the heat. There are some problems with heat distribution between the different foodstuffs. This problem is caused by many parameters. Out of that heating coil, booster heating coil and guide plate are the critical parameters. An experimental investigation is carried out to find the effect of the heating coil and guide plate. From the experimental analysis, the optimum location of the booster heating coil and guide plates are found out. It is identified that the guide plate at bottom and middle with booster coil gives the minimum temperature variation and minimum energy consumption.

Keywords: Display cabinet, Heat transfer, booster heating coil, Guide plate.

1.0 INTRODUCTION:

Currently, most bakeries in India use heating display cabinet to keep the food particles in warm condition. Because of consumer demand, the bakeries have to maintain the quality of the foodstuff inside the heating cabinet. There are many variations of these basic concepts in the commercial bakeries, but each type of commercial cabinet cooks by controlling the temperature and humanity of the cabinet cavity. The display cabinet's versatility makes it useful in many types of foodservice operations. However, there are problems associated with the use of heating cabinet such as unsatisfactory product quality due to non-uniform temperature distribution. Moreover, increased power consumption due to non-uniformity in temperature and surrounding conditions. An experimental study [1] was conducted to study the effect of several essential factors on the performance of a refrigeration display cabinet including ambient air temperature, indoor relative humidity, ambient airflow, airflow velocity, airflow perforated back panels and night covers. Both inside temperature distribution and heat load were investigated. Maintaining food temperature below critical values is the key to maximizing the high-quality display life of chilled foods. Studies were carried out to see if CFD modeling could be used rabidly identify the changes that would be required to an existing multi-deck display so that it would meet a higher test specification [2] and study the average energy consumption. The commercial CFD [3-6] code has been employed to simulate the airflow pattern and the temperature distribution in a frozen food vertical display cabinet. At first solver, the parameter has been investigated in a 2D monetization. 3D simulations have been then performed, and the effect of the cabinet length, of the warm air curtain and longitudinal ambient air movement has been investigated. A numerical procedure [4] for the simulation of fogging and defogging phenomena is presented to the predication of the demisting process on the glass door of a refrigerated closed display cabinet.

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CFD analysis of flow and temperature distribution is attempted using finite element technique. The oven is modeled as a two –dimensional steady-state natural convection heat transfer problem. The effects of heater location and total heat input on temperature uniformity of foodstuffs are studied. The analysis shows [7] that if heaters located at the bottom along with additional flow guidance arrangements Minimum overall [8-9] energy consumption and minimum variation among the foodstuffs are essential requirements. Besides, when new foodstuff is kept inside the oven, it must reach the required temperature at lowest possible time. To check aspect experimental and numerical investigation. CFD is a simulation. [10] tool, which uses powerful computer and applied mathematics to model fluid situations for the prediction of heat, mass and momentum transfer and optimal design in industrial processes. The present paper deals with an experimental analysis of the display cabinet with booster heating coil.

2.0 PROBLEM FORMULATION

The display (EURO-P (Puffs Box)) cabinet is used to keep foodstuff in warm conditions with the heating coils or elements as a heating source. There are many different types of display cabinet available with two or three heating elements and also in different sizes. They are also available in natural convection and forced convection modes. Figure 1 showed the heating display cabinet, which is modeled and analyzed as a two dimensional considering the heat generation convection and density variation. The dimension of the display cabinet is of .06m length, 0.463m Height, and 0.25m depth.

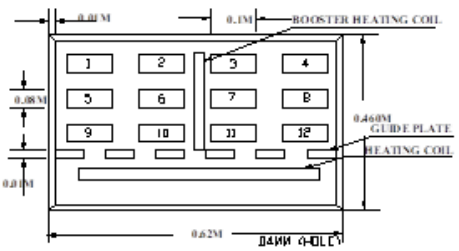

Fig 1.0 *Geometry of the display cabinet*

The input power varies from 1500W to 2000W. The number of heating coils is different for analysis and the booster coil used to analysis to enhance the heat transfer. The foodstuffs are of 100mmlength, and 80mm width and arranged in three-row

and four columns. The vertical spacing between foodstuffs is 10mm, and horizontal spacing between foodstuffs is 11mm. The clearance between the walls and foodstuffs is taken as 10mm. from bottom and 11mm from top

3.0 EXPERIMENTAL SET UP:

In experimental analysis, the temperature was measured by using a resistance temperature detector (RTD) is fixed on the backside of the cabinet whose stem is inserted into the foodstuffs. The output of the RTD is connected to the data logger, which gives the temperature in centigrade. Then the data logger is connected to the computer system to get the excel results every five minutes. The energy measuring unit is connected to the heater input power supply. This output connected to the system to store the energy consumption of the foodstuff display cabinet in the form of numerical value. Figure 2 shows the experimental setup.

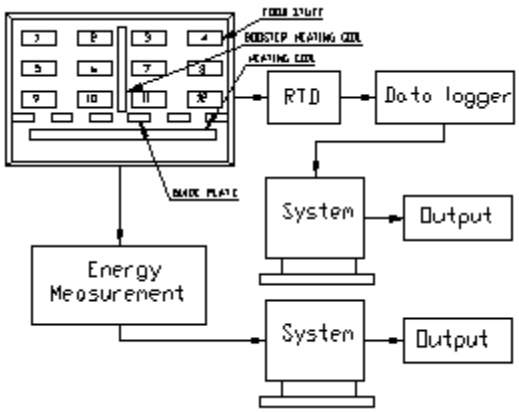

Fig 2 *Experimental setup*

4.0 ASSUMPTION:

The following assumptions are taken for the formulation of the problem.

- The entire system is assumed to be a closed system.
- The radiation effect is neglected.
- The airflow inside the foodstuff display cabinet is assumed to be laminar.
- The viscosity and specific heat are assumed to be constant.
- The air is assumed to be compressible.

5.0 RESULT AND DISCUSSION:

An experimental investigation is carried out with four different conditions with and without booster heating coil. The oven with 12 kinds of stuff with two heating elements is one in the bottom and another in the middle used in the experimental investigation and temperature distribution and power consumption are analyzed.

5.1 Without booster heating coil:

1. Guide plate at the bottom (Fig 3)

The variation of foodstuff temperature with time obtained by (Fig 3) experimental for without booster heating coil and bottom guide plate is plotted in fig 3. The total number of 10 holes is placed in lengthwise, and 6 holes is placed in widthwise then a totally 60 holes are placed in a plate. The graph shows (Fig 4) the temperature distribution of display cabinet with bottom guide plate and without booster coil for the period of 60minutes. It shows temperature with time for 12 locations of the food stuffs1-4 in top row, 5-8 in middle row and 9-12 in bottom row. All foodstuffs are at 30ºC to 33ºC at start and reach the steady-state condition within 60minutes. Out of 12 foodstuff locations, the locations 9, 10 and11 heated quickly and attain the temperature range 77ºC, 76ºC, and 74ºC. The side foodstuffs locations 2, 3, 4 7 and 8 rose to lower Range 58, 59,62ºC, 63ºC and 64ºC respectively. At the same time, the difference between the maximum and minimum temperature is 20ºC

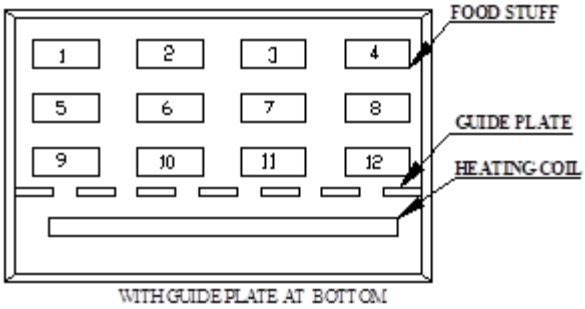

Fig. 3 *Experimental setup without booster heating coil guide plate and with the bottom guide plate*

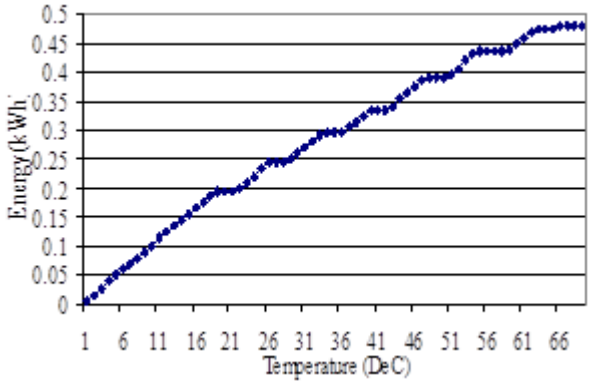

Fig. 4 *Temperature variation of foodstuffs (without booster heating coil)*

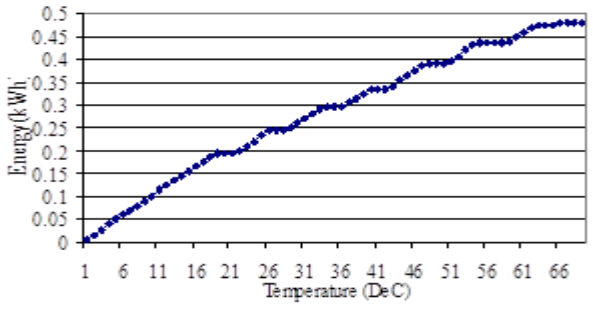

Fig 5 *Cumulative energy consumption*

The following (Fig 5) graph shows that the cumulative energy consumption of the food stuff display cabinet. The energy is consumed gradually up to 0.2kWh in 18minutes (Fig 5), and the temperature is reached at the highest value then the thermostat is used to cut off the power of the coil. After

2minutes there is no power consumption. The Temperature is reached before steady-state conditions. The power is consumed 5.0 minutes of 2minutes cutoff. Then the temperature is reached in the steady-state condition. The energy is consumed 3 minutes of 1 minute's cutoff. In this stage, the power is consumed up to maximum of 0.012kWh (Fig 6). Total power consumption up to steady-state is 0.45kWh

5.2 With booster heating coil

The following conditions are varied in the display cabinet.

- Flow guide
  1. Without Guide Plate. (Fig 6)
  2. Guide plate in the middle. (Fig 10)
  3. Guide plate at the bottom. (Fig 14)
  4. Guide plate at middle and bottom. (Fig 18)

5.2.1 Without guide plate:

The variation of foodstuff temperature with time obtained by experimental (Fig 6) for the bottom and middle coil position and without guide plate is plotted in fig 7. It shows the temperature with time for 12 locations of the food stuffs1-4 in top row, 5-8 in middle row and 9-12 in bottom row. All foodstuffs are at 30ºC to 33ºC at start and reach the steady-state condition within 60minutes. Out of 12 foodstuff locations, the locations 6, 7, 10, 11 heated quickly and attain the temperature range 71ºC, 74ºC, 75ºC, 72ºC. The side foodstuffs locations 1, 5, 4 and 8 rose to lower range 63ºC, 60ºC, 70ºC, 64ºC respectively. At the same time, the difference between the maximum and minimum temperatures is 15ºC.

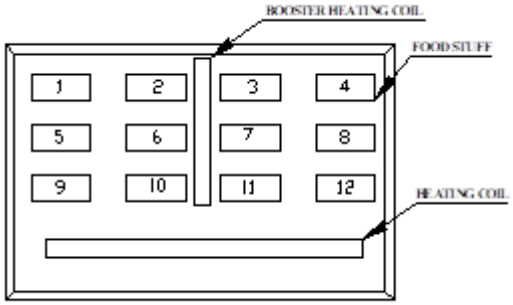

Fig. 6 *Experimental setups without guide plate*

The following (Fig 8) graph shows that the cumulative energy consumption of foodstuff display cabinet. The energy is consumed gradually up to 0.155kWh in 14minutes, and the temperature is reached at highest value then the thermostat is used to cut off the power of the coil. After 4minutes there is no power consumption. The temperature is reached before the steady-state condition. The power is consumed 3.0 minutes of 1.30 minutes cutoff. Then the temperature is reached in steady-state condition. The energy is consumed 3.0 minutes of 2.0 minutes cutoff. In this stage the power is consumed up to maximum of 0.02kWh (Fig 9) in every 9 minutes. Totally total power consumption up to steady state is 0.425kWh.

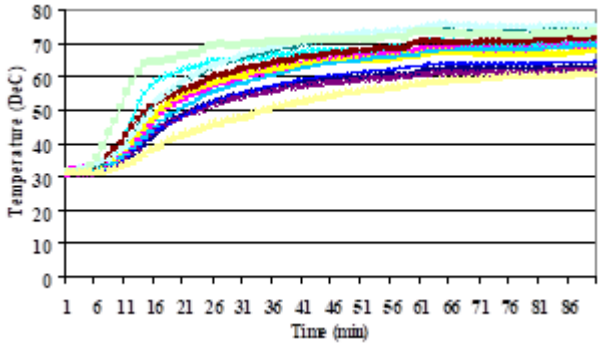

Fig. 7 *Temperature variation of foodstuffs (without guide plate)*

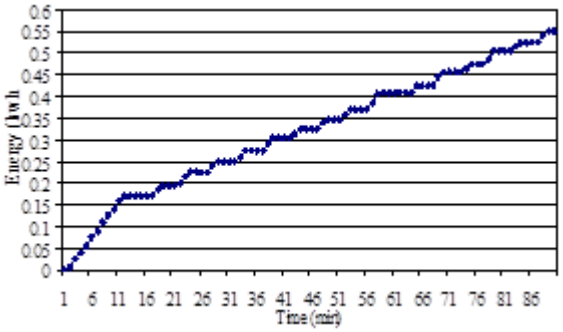

Fig .8 *Cumulative energy consumption*

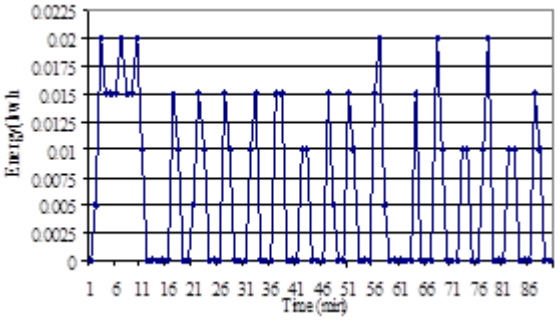

Fig .9 *Energy consumption*

5.2.2 Guide plate at middle:

The figure 10 shows the display cabinet of guide late at middle. The main use of guide plate is to guide the got air which enters in to the cabinet. The guide plate, which act as a protection of hot air which is produced form the coil. Because of this the temperature is not uniform inside the display cabinet and also time taken to attain steady state in also high. The total number of 6 holes placed in height wise and 4 holes is placed in widthwise then totally 48 holes are placed in a plate. The fig 11 shows the temperature distribution of display cabinet with middle guide plate for the time period 90minutes. The graph the temperature at bottom of the food (9, 10,11and 12) the maximum temperature of the foodstuff 10 goes to 76ºC, the maximum temperature of the middle row food stuff 6 goes to 70ºC. But the top row of the food stuff goes a maximum of only 64ºC, the temperature of top and middle row of foodstuff is 6ºC. The time taken to attain the steady state temperature is 50 minutes. The temperature is reached to 55ºC with in 20minutes of food stuff 2, 3, 9,10and11. But the

temperature difference between the food stuff of top row and bottom row is 12ºC.

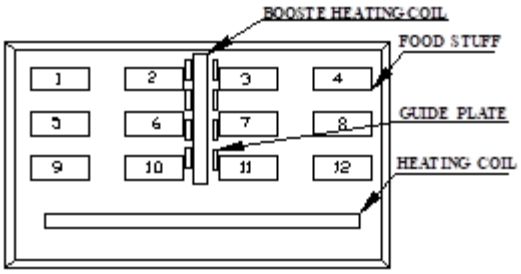

Fig. 10 *Guide plate at middle*

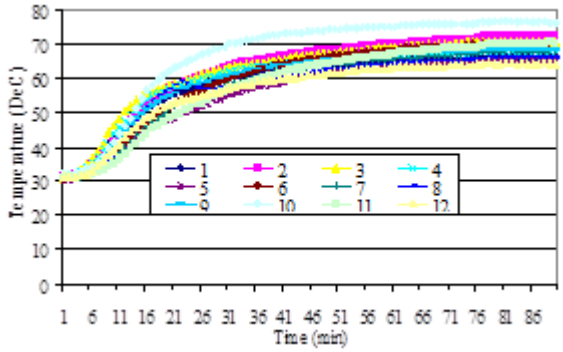

Fig. 11 *Temperature variation of food stuff (guide plate at middle)*

The following graph shows that the cumulative energy consumption of food stuff display cabinet. The energy is consumed gradually up to 0.1525kWh in 13minutes (Fig 12) and the temperature is reached at highest value then the thermostat is used to cutoff the power of the coil. After 5minutes there is no power consumption. The temperature is reached before steady state condition the power is consumed 2.0 minutes of 4.0 minutes cutoff. Then the temperature is reached in steady state condition the energy is consumed 1.0 minutes of 3.0 minutes cutoff. Initially the maximum energy is consumed (Fig 13) 0.02kWh after 31 minutes there is no maximum energy consumption. After 13 minutes the maximum energy consumption is .02kWh in three times. Totally total power consumption up to steady state is 0.375kWh.

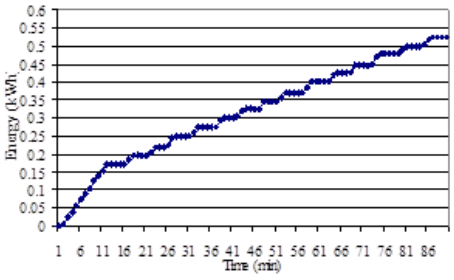

Fig .12 *Cumulative energy consumption of display cabinet (Middle guide plate)*

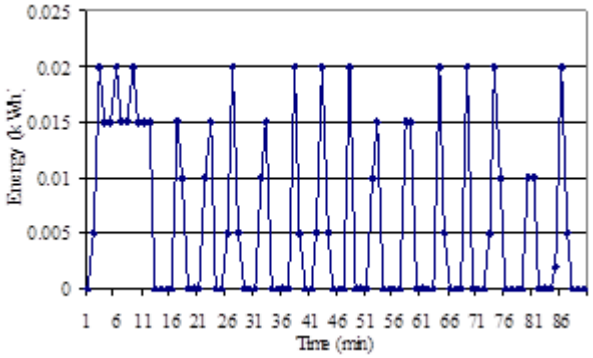

Fig .13 *Energy consumption of display cabinet (Middle guide plate)*

5.2.3 Guide plate at the bottom:

Figure 14 shows the display cabinet of guide late at bottom. The total number of 10 holes placed in lengthwise and 6 holes is placed in widthwise then totally 60 holes are placed in a plate. The graph shows the temperature distribution of display cabinet with bottom guide plate for the period 90minutes. The graph (Fig 15) the temperature at the bottom of the food (9, 10,11and 12). The maximum temperature of the foodstuff 10 and 11 goes to 71ºC, and 68 C, the maximum temperature of the middle row foodstuff 6and 7 goes to 69ºC. However, the top row of the foodstuff 2 and 3 goes a maximum of only 65ºC, the temperature of top and middle row of foodstuff is 4ºC. The foodstuff reading 2 and 3, 6and 7 goes to as same temperature after steady-state temperature distribution. The time taken to attain a steady-state temperature is 55 minutes. The temperature is reached to 50ºC within 20 minutes of foodstuff 1, 4 and 5. Then the temperature is reached to 55ºC within 17 minutes of foodstuff 2, 3, and 6. However, the temperature difference between the foodstuff of top row and bottom row is 11ºC.

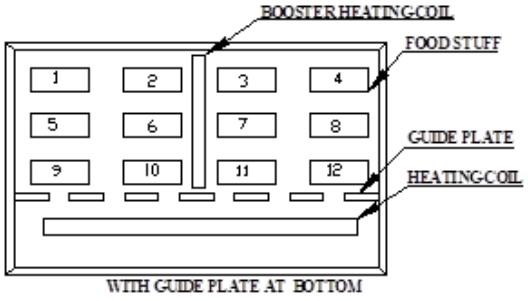

Fig. 14 *Display cabinet with guide plate at the bottom*

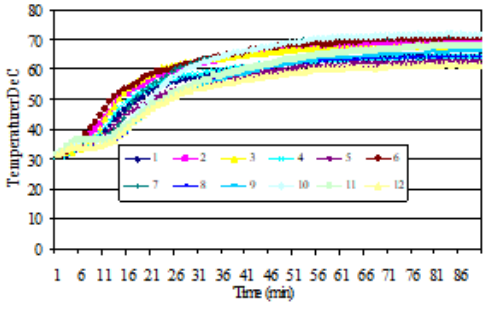

Fig. 15 *Temperature variation of foodstuff (bottom guide plate)*

The following graph shows the cumulative energy consumption of foodstuff display cabinet. The energy is consumed gradually up to 0.15kWh in 11minutes (Fig .16), and the temperature is reached at highest value then the thermostat is used to cut off the power of the coil. After 5minutes there is no power consumption. The temperature is reached before the steady-state condition. The power is consumed 1.0 minutes of 4.0 minutes cutoff. Then the (Fig .17) temperature is reached in

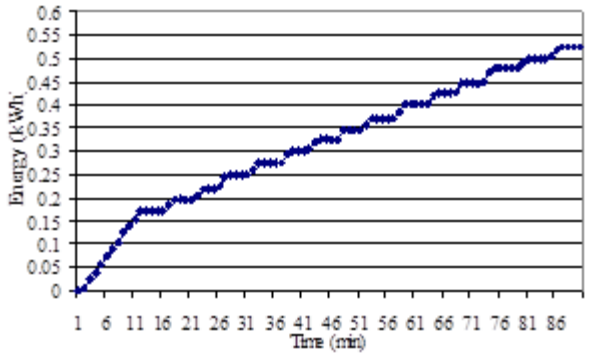

Fig .16 *Cumulative energy consumption of display cabinet (Bottom Guide plate)*

Steady-State condition the energy is consumed 1.0 minutes of 4.0 minutes cutoff. Initially the maximum energy is consumed 0.02kWh up to 11minutes then after 4 minutes there is no maximum energy consumption. Three times the maximum energy is consumed in between 16minutes to 31minutes. After steady-state temperature the maximum energy is consumed every 20 minutes.0.35. The total power consumption up to steady-state is 0.325kWh.

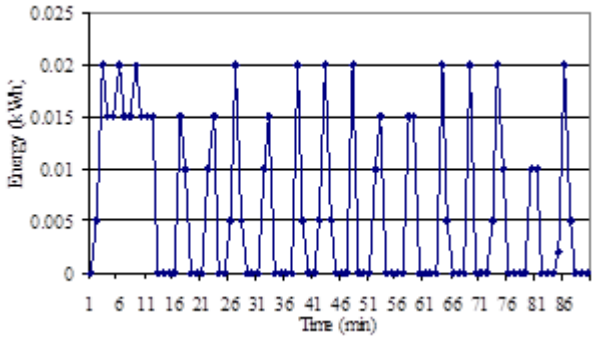

Fig 17 *Energy consumption*

5.2.4 Guide plate at middle and bottom:

Figure 18 shows the display cabinet of guide late at middle and bottom. The total number of holes is placed 108. The graph (Fig 19) shows the temperature distribution of the display cabinet with middle and bottom guide plates for the period 70minutes. The graph shows the temperature at the bottom of the food (9, 10,11and 12). The maximum temperature of the foodstuff 10 and 11 goes to 68 C; the maximum temperature of the middle row foodstuff 6and 7 goes to 64ºC. However, the top row of the foodstuff 2 and 3 goes a maximum of only 66ºC; the temperature of top and middle row of foodstuff is 2ºC. The foodstuff 1, 6, 7 and 9 go to 64 º C temperatures after steady-state temperature distribution. The foodstuff 3,11 and 12 go to 68ºC temperature after steady-state temperature distribution.The time taken to attain a steady-state temperature is 40minutes. The temperature is reached to 40ºC within 12minutes of foodstuff 2, 3 and 8. The top row gets maximum temperature of 61º C, and the bottom row gets maximum temperature of 68º C. Then the temperature difference between the top and bottom row is 7º C.

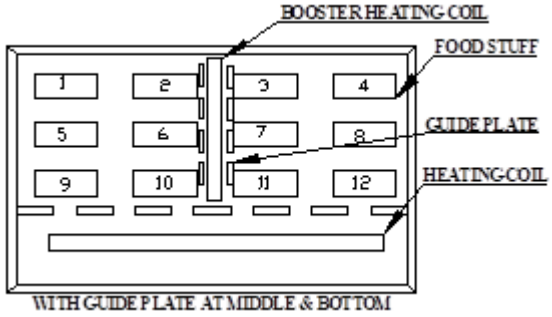

Fig 18 *Display cabinet with guide plate at middle*

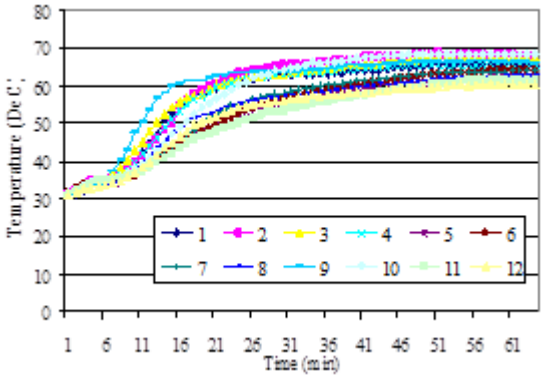

Fig 19 *Temperature variation of foodstuff (Middle and Bottom guide plate)*

The following graph shows the cumulative energy consumption of the foodstuff display cabinet. The energy is consumed gradually up to 0.155kWh in 12minutes (Fig 20), and the temperature is reached at highest value then the thermostat is used to cut off the power of the coil. After 5minutes there is no power consumption. The temperature is reached before the steady-state condition. The power is consumed 1.0 minutes of 5.0 minutes cutoff. Then the temperature is reached in the steady-state condition. The energy is consumed 0.5 to 1.0 minutes of 5.0 minutes cutoff. Initially (Fig 21) the maximum energy is consumed 0.02kWh up to 11minutes then after 17minutes there is no maximum energy consumption. Three times the maximum energy is consumed in between 31minutes to 43minutes. After steady state temperature the maximum energy is consumed every 18 minutes once. Then total power consumption up to steady-state is 0.255kWh

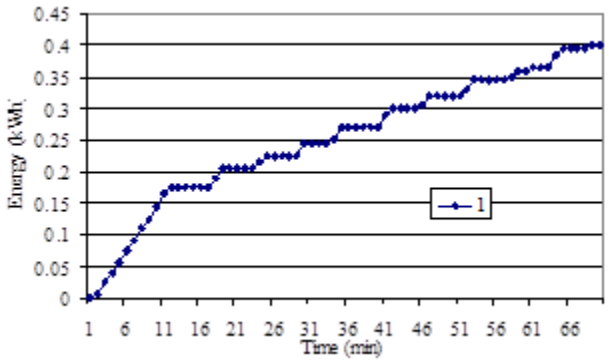

Fig 20 *Cumulative energy consumption of display cabinet (Bottom Guide plate)*

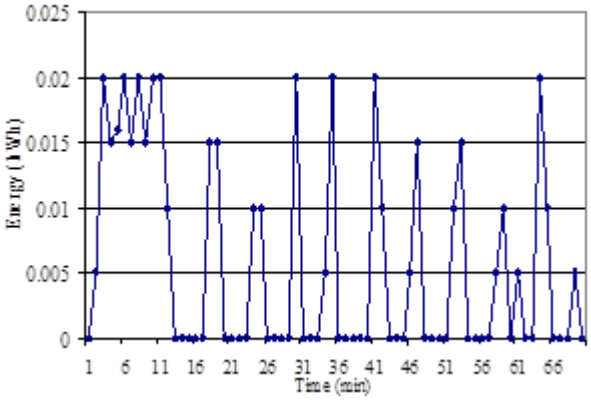

Fig 21 *Energy consumption of display cabinet (Bottom Guide plate)*

5.2.5 Effect of guide plate arrangement.

The following table 1 and 2 show the comparison of the maximum and minimum temperature distribution of with and booster heating coil. The table shows the third row with bottom guide plate the maximum and minimum temperature difference is 20 ºC, display cabinet takes 0.45 kWh for 60minutes, and fifth row shows without bottom and middle guide plate the maximum and minimum temperature difference is 15ºC, display cabinet takes 0.425 kWh for 60minutes, and sixth row shows with middle guide plate the maximum, and minimum temperature difference is 12ºC, display cabinet takes 0.325 kWh for 55minutes, and seventh row shows with bottom guide plate the maximum and minimum temperature difference is 11ºC, display cabinet takes 0.25 kWh for 40minutes. Moreover, eight rows show the minimum temperature difference is 7ºC for with middle and bottom guide plate and minimum power consumption (0.255kWh).

Table 1*. Effect of temperature distribution*

Guide plate arrangement	Max Tem DeC	Min Tem Dec	Tem Differ DeC
Without booster heating coil			
Guide plate at bottom	77	57	20
With booster heating coil			
Without guide plate	76	61	15
Guide plate at middle	76	64	12
Guide plate at bottom	72	61	11

Table 2. *Effect of energy consumption*

Guide plate arrangement	Time taken to attain steady-state temperature(min)	Energy consumption (kWh)
Without booster heating coil		
Guide plate at bottom	60	0.455
With booster heating coil		
Without the guide plate	60	0.425
Guide plate at bottom	55	0.325
Guide plate at middle	55	0.375
Guide plate at middle and bottom	40	0.255

6. 0 CONCLUSION:

The heating display used in these bakeries gives non-uniformity in temperature distribution and also takes more time to attain steady state due to heat losses. In this context the experimental analysis of heating cabinet is done in order to minimize the temperature difference between foodstuffs, the effect of various parameters such as coil location, flow guides, and properties of food particles on the heating are analyzed.

- It is found that the temperature difference is less in the display cabinet where the guide plate is placed in the side and middle of the cabinet, and also time taken to attain steady state is comparatively less, the difference is around 7°C.
- It is found that the power consumption is less when temperature attained to steady-state where the guide plate is placed in middle and bottom.
- The time taken to attain a steady-state temperature is less.

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