Energy Transfer in Commercial Baking Ovens

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READING THERMAL

ASB BakingTech 2017

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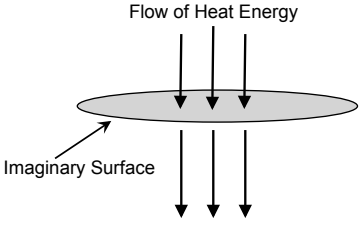
Heat Flux
(a.k.a. Energy / Heat Transfer)

What Is Heat Flux?

- **Heat Flux** is the amount of energy passing through an imaginary surface of specific cross sectional area per unit time.
  - Units: Btu / hr•ft^2 or kW / m^2



What if we collect this energy?

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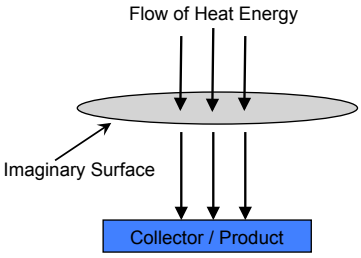

- **Total Heat** is the amount of energy experienced (collected) over a period of time.
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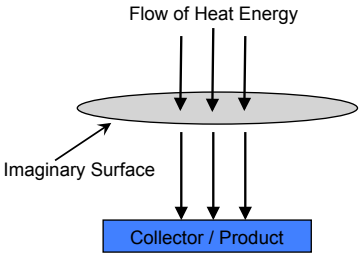

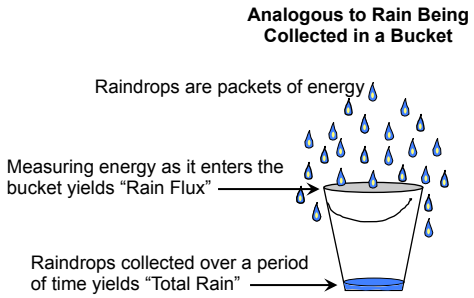

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What Are The Types Of Heat Flux?

- Heat is transferred to a product via three different mechanisms, each of which can be described by a Heat Flux component associated with Conduction, Convection, and Radiation.
- Each of these modes of heat transfer is present in baking and other thermal applications.
- Every product has its own unique mix of heat flux components; there is not one optimal heat flux profile for all products.

What Are The Types Of Heat Flux?

Conduction (Q_b) heat transfer from the band

$Q_b = k \times A \times (T_b - T_c)$

k = thermal conductivity coefficient
A = area of product in contact with the band
T_b = temperature of the band
T_c = temperature of the product in contact with the band

Heat transfer is highly dependent on the contact between the band and the product, and k the thermal conductivity coefficient for the product.

What Are The Types Of Heat Flux?

Convection (Q_c) heat transfer from the air

$Q_c = h_c \times A \times (T_a - T_c)$

h_c = convective heat transfer coefficient
A = area of product in contact with the air
T_a = temperature of air hitting the product
T_c = temperature of product surface

There is no easy way to calculate Q_c because h_c is a complicated value based on air velocity, density and viscosity, all effected by temperature and pressure.

What Are The Types Of Heat Flux?

Radiation (Q_r) heat transfer from hot objects

$Q_r = A \times \sigma \times \varepsilon (T^4_h - T^4_c)$

A = area of radiating surface
σ = Stefan Boltzmann constant for a black body (ideal) radiation
ε = emissivity of the radiating object from 0 to 1
T_h = absolute temperature (K) of hot object
T_c = absolute temperature (K) of cold product

Note the importance of the temperature term: if the ΔT doubles the heat transfer rate multiplies by 16!

Emissivity of dark objects approaches 1 while shiny objects approach 0.
e.g. Carbon Steel = 0.5

Why Measure Heat Flux?

1. Because heat transfer related CONDUCTION, RADIATION, and CONVECTION defines the product bake.
2. Critical to understanding finished product characteristics is knowing the Total Heat experienced by the product, and the component quantities of Radiant and Convective heat fluxes.
3. While temperature is most often measured, and is easy to understand, it does not indicate heat transfer:

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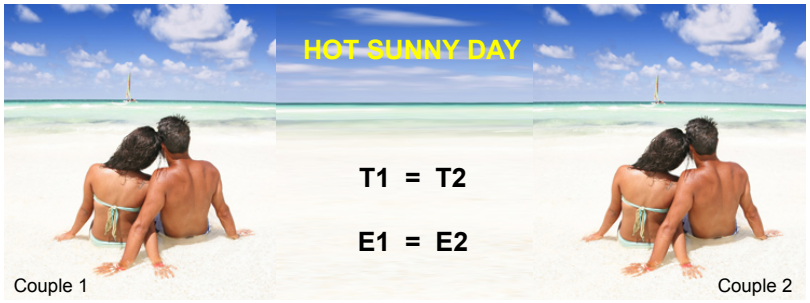

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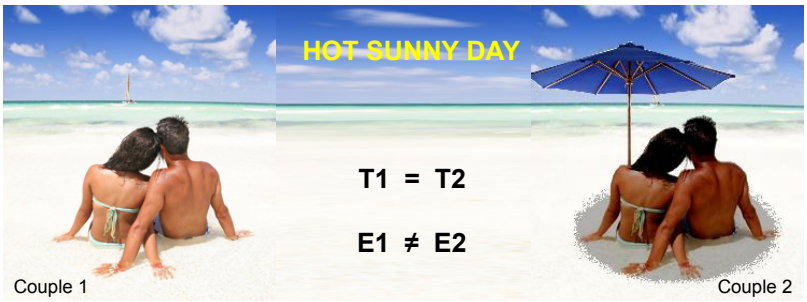
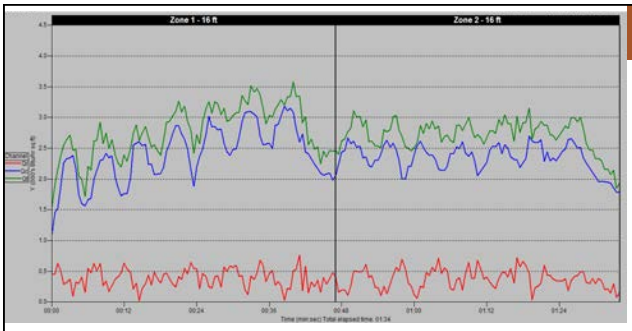


Heat Flux Sensor

Measures convective and radiant heat fluxes at product level

- Displays Heat Flux: $Q_{radiant}$ $Q_{convective}$ Q_{total} (Btu/hr•ft^2 or W/m^2)
- Displays Total Heat: radiant & convective (Btu/ft^2 or Joules/m^2)
- Heat transfer to the product from above the conveyor
- Identify which modes of heat transfer are predominant
- Heat Flux & Total Heat define the product

- Main Application:
  - Over time heat transfer characteristics
  - Total heat experienced by the product
  - Proportion of radiation & convection

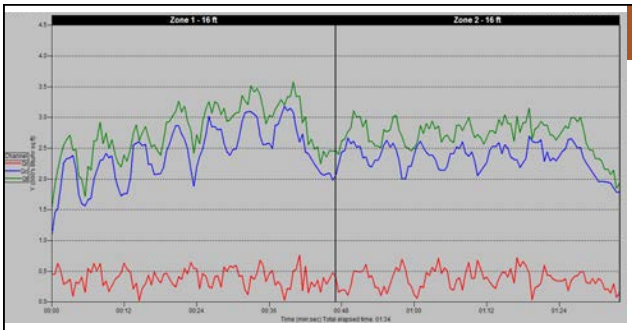


Profile Graphs

Heat Flux Profile

- Heat Flux Components (Btu / hr•ft^2)
  - Qr is radiant heat flux
  - Qc is convective heat flux
  - Qt is total heat flux (Qr+Qc)

We can determine Total Heat experienced by the product via integration and finding the area under Qr and Qc.



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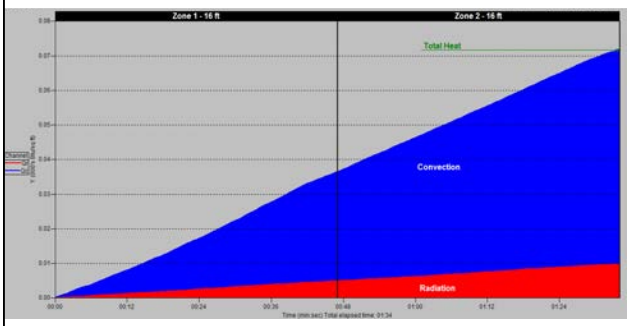
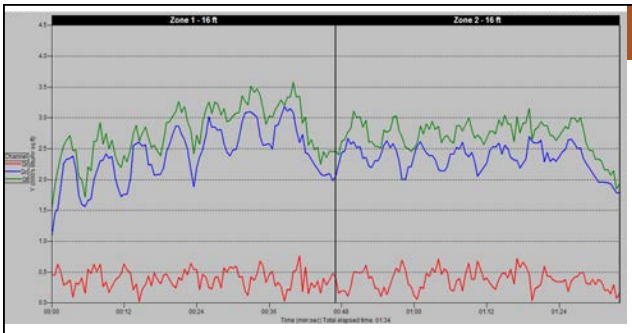


Total Heat Profile

- Total Heat (Btu / ft^2)
  - Red Area is total radiant heat experienced by the product
  - Blue Area is total convective heat experienced by the product
  - Radiation and Convection are stacked to display Total Heat

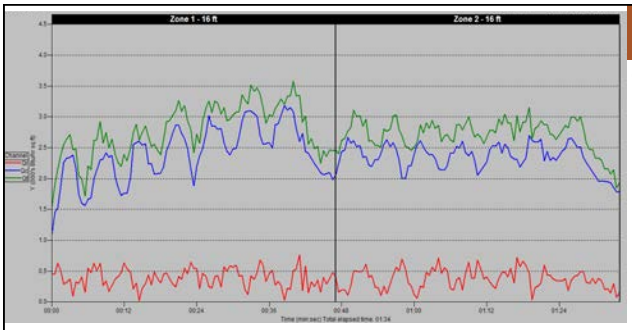


Heat Flux Experiment Multi Grain Cracker

Condition 1

- Convection Heating Only
  - Dwell Time = 1min:34sec
  - All Convection Heat in Zones 1 & 2
  - Very little Radiant heat flux...only from oven ceiling and sidewalls
  - Each Convection spike is related to air distribution ports

Next, let's add 5 Radiant Burners to Zone 1.



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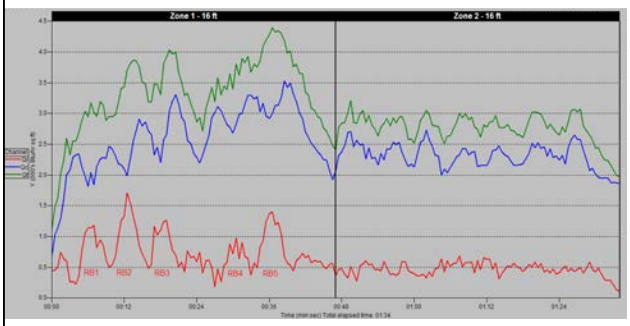
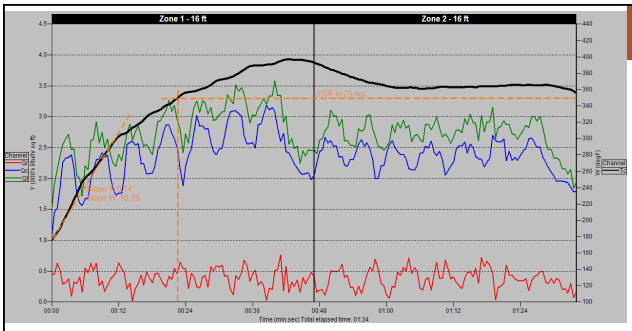


Condition 2

- Convection & Radiant Heating
  - Dwell Time = 1min:34sec
  - 5 Radiant Burners added to Zone 1
  - 18,000 Btu per Burner (#67 orifice plate)
  - Convective heat flux remains the same
  - Radiant heat flux spikes occur at burner locations
  - Total heat flux increases proportionally

Next, let's look at the temperature profiles.

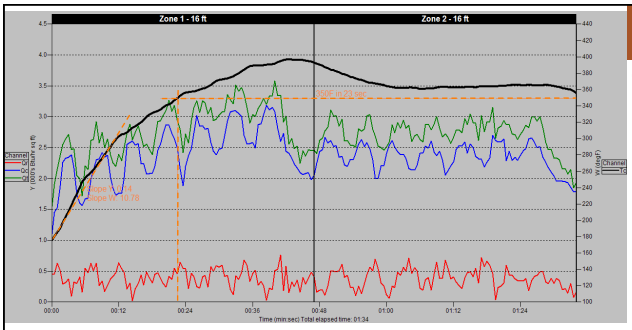


Heat Flux Experiment
Multi Grain Cracker

Condition 1

- Convection Heating Only
  - Tc is temperature profile
  - Tc slope = 10.8
  - Tc reaches 350°F in 23sec

Next, how do the radiant burners affect temperature?



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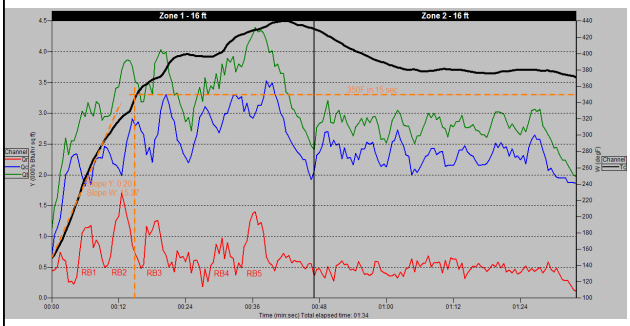
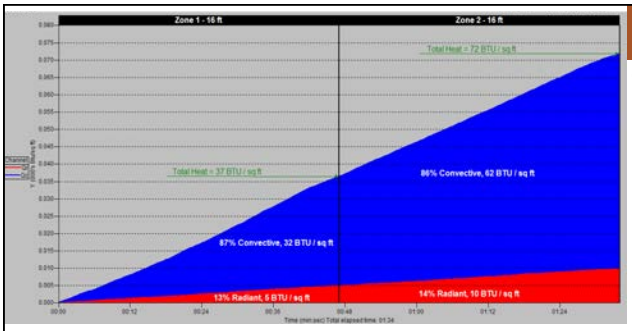


Condition 2

- Convection & Radiant Heating
  - Tc slope = 15.3
  - Tc reaches 350ºF in 15sec
  - Radiant burners increase the slope of the temperature profile

Next, let's look at the Total Heat profiles.

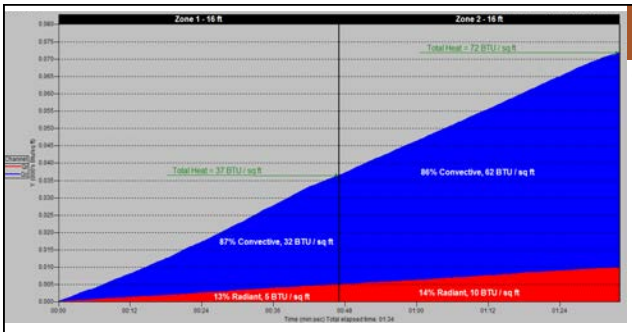


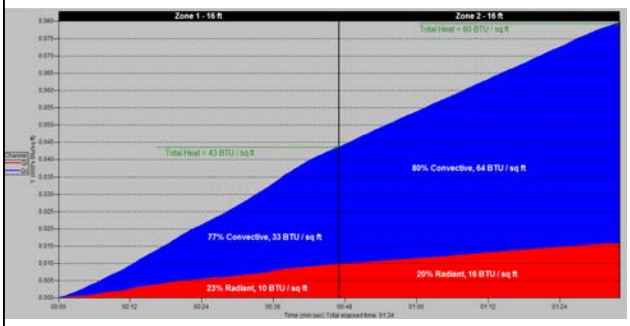
Heat Flux Experiment
Multi Grain Cracker

Condition 1

- Convection Heating Only
  - End of Zone 1
    - o Total Heat = 37 Btu / ft^2
    - o 87% Convective, 32 Btu / ft^2
    - o 13% Radiant, 5 Btu / ft^2

Next, how do the radiant burners affect Total Heat?





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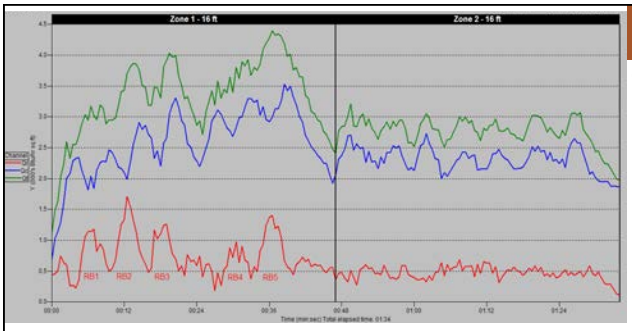
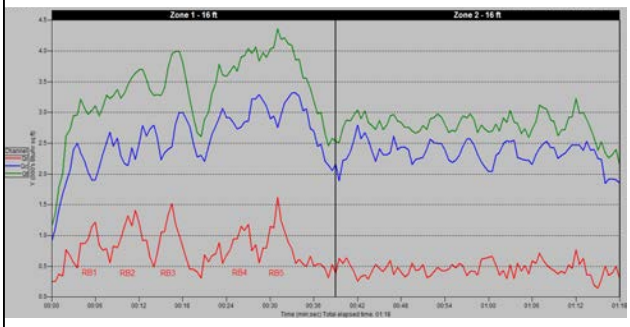
Condition 2

- Convection & Radiant Heating
  - End of Zone 1
    - o Radiant heat has doubled from 5 Btu / ft^2 to 10 Btu / ft^2 and is now 23% of the Total Heat
    - o Convective heat is essentially the same
    - o Total Heat has increased to 43 Btu / ft^2, essentially proportional to the Radiant heat increase

Next, what is the effect of reducing dwell time?





Heat Flux Experiment
Multi Grain Cracker

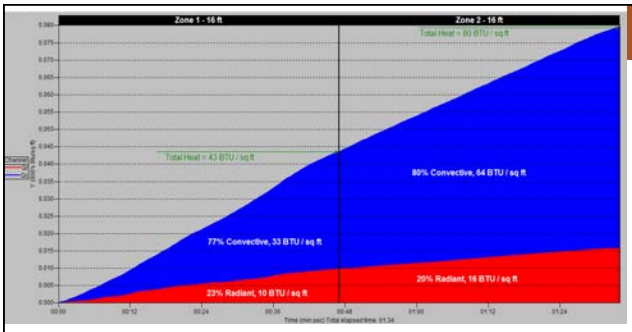
Condition 2

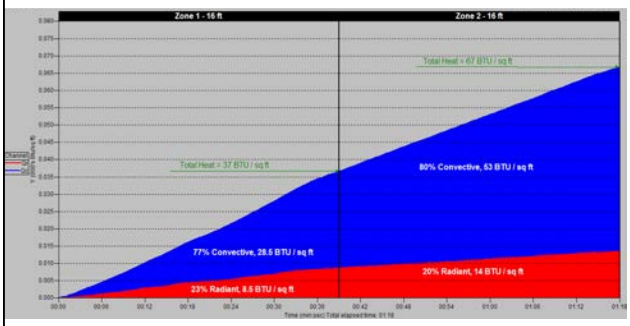
- Convection & Radiant Heating
  - Dwell Time = 1min:34sec

Condition 3

- Convection & Radiant Heating
  - Dwell Time = 1min:18sec, reduced by 16sec
  - The magnitude (Btu / hr•ft^2) of the heat flux profiles remains the same but occurs in a shorter period of time

Lastly, what is the effect on Total Heat experienced by the product?





Heat Flux Experiment
Multi Grain Cracker

Condition 2

- Convection & Radiant Heating
  - Dwell Time = 1min:34sec
  - Total Heat experienced by the product is 80 Btu / ft^2

Condition 3

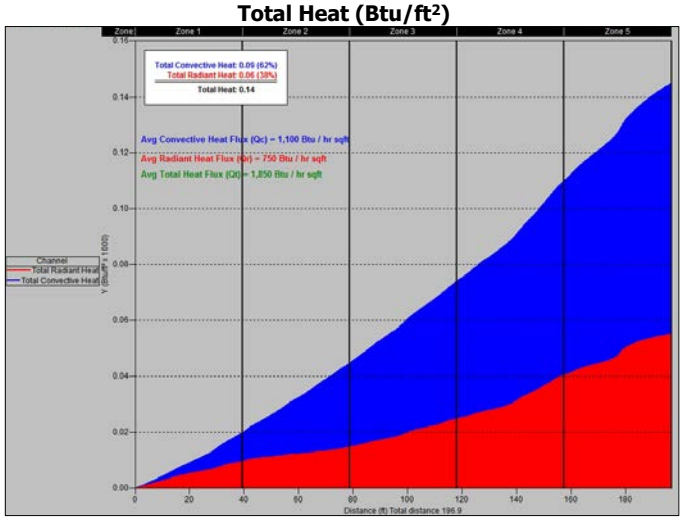
- Convection & Radiant Heating
  - Dwell Time = 1min:18sec, reduced by 16sec
  - Total Heat experienced by the product is 67 Btu / ft^2... 13 Btu / ft^2 less
  - All Radiant and Convective percentages remain the same
  - Less heat transfer (less baking) but same Radiant / Convective % mix

How Can I Use Heat Flux Profiles?

- Often used when trying to produce the same product on two different lines, or when trying to transfer product from one line to another. When the heat flux profiles are matched, the two lines will produce the same product.
- Understand why two lines, supposedly identical, have different throughput, i.e. one consistently produces greater tonnage than the other.
- Used as a tool in speeding up production: Total Heat and %mix of Convection and Radiation must be maintained.
- R&D product development: moving from a test kitchen or pilot line to full scale production.

Radiant Tunnel Oven

Total Heat (Btu/ft²)



Product

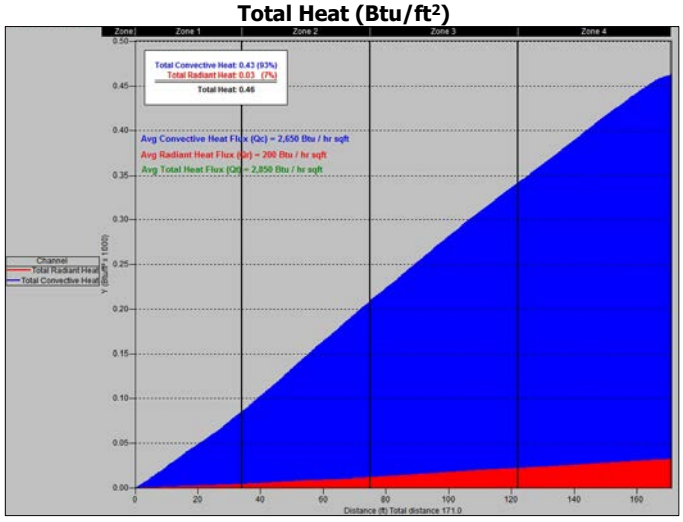
- Thin Chocolate Sandwich Cookie Half

Oven

- DGF Ribbon Burners Above & Below Conveyor
- No Forced Air Distribution
- 5 Zones
- Length = 197ft
- Width = 1.2m
- Heavy Mesh Band (CB5)
- Bake Time = 5min
- Conveyor Speed = 39fpm

Convection / Recirculation Oven

Total Heat (Btu/ft²)



Product

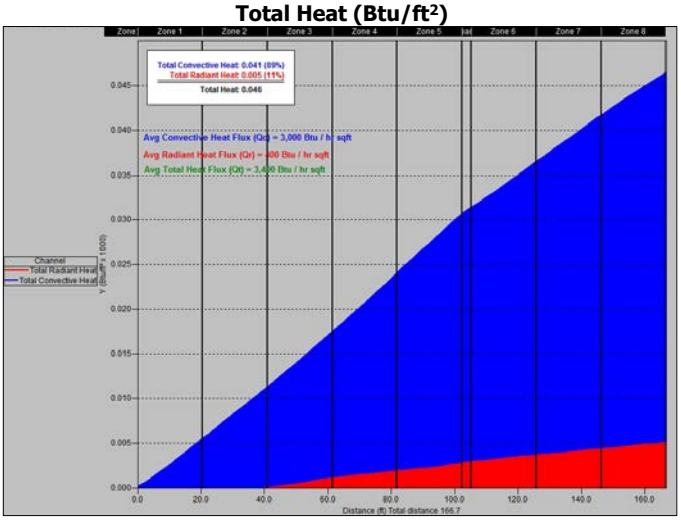
- Large Soft Chocolate Chip Cookie

Oven

- DGF Burner in Zone Penthouses
- Airflow from Plenums Above & Below Band
- 4 Zones
- Length = 171ft
- Width = 1.2m
- Solid Steel Band
- Bake Time = 10min:22sec
- Conveyor Speed = 17fpm

Impingement Oven

Total Heat (Btu/ft²)



Product

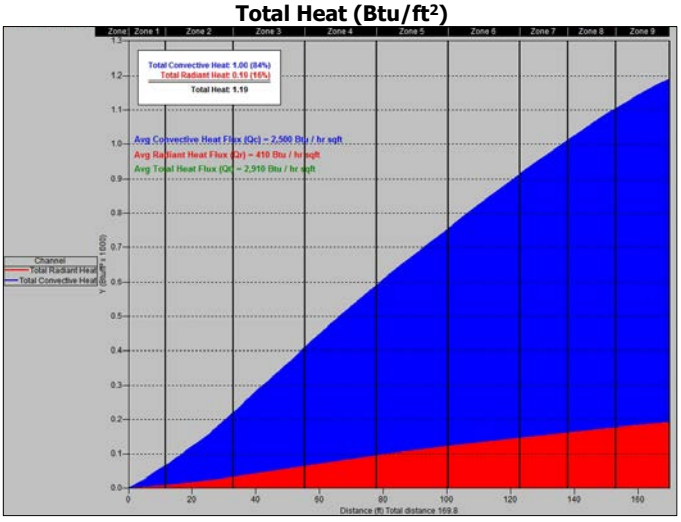
- Baked Potato Chip

Oven

- DGF Burner in Zone Penthouses
- High Speed Airflow from Above & Below Band
- 8 Zones
- Length = 167ft
- Width = 1.5m
- Open Mesh Band
- Bake Time = 50sec
- Conveyor Speed = 200fpm

Tunnel Oven

Total Heat (Btu/ft²)



Product

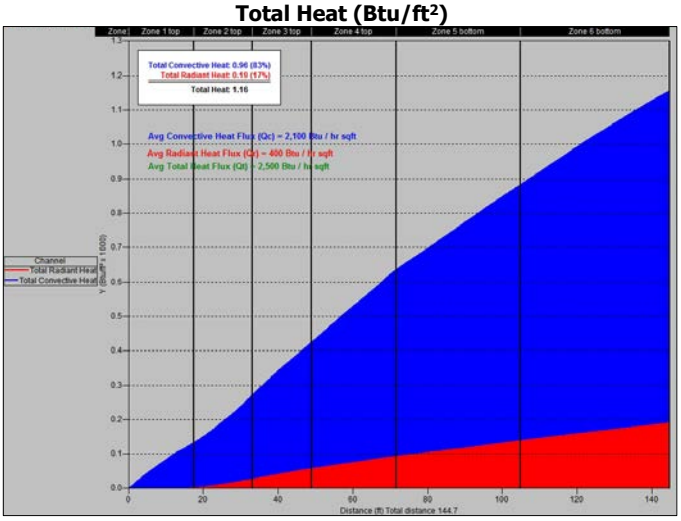
- Whole Wheat Bread

Oven

- DGF Ribbon Burners Below Conveyor
- Air Circulation from Above & Below Conveyor
- 9 Zones
- Length = 169.8ft
- Width = 13ft 4in
- Grid Conveyor
- Bake Time = 27min:39sec
- Conveyor Speed = 6fpm

Lap Oven

Total Heat (Btu/ft²)



Product

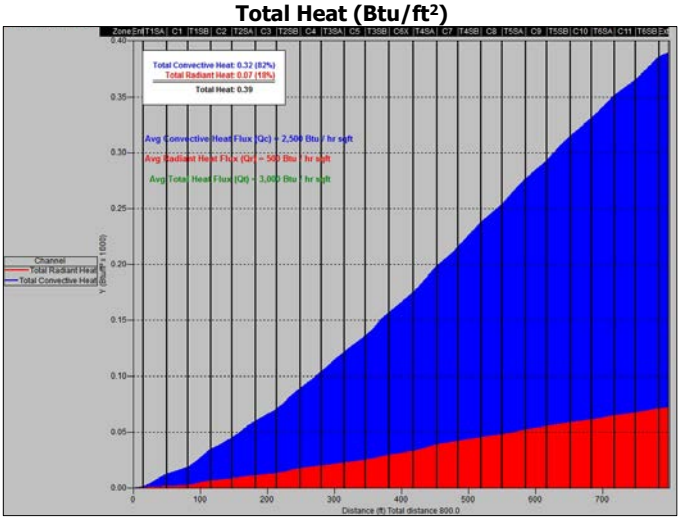
- Multigrain Bread

Oven

- DGF Ribbon Burners Below Tray Conveyor
- Air Circulation from Above & Below Conveyor
- 4 Top + 2 Bottom Zones
- Length = 144.7ft
- Width = 13ft 4in
- Open Tray Conveyor
- Bake Time = 28min:50sec
- Conveyor Speed = 5fpm

Twin Oval Oven

Total Heat (Btu/ft²)



Product

- Hamburger Buns

Oven

- DGF Ribbon Burners Below Chain Conveyor
- Air Circulation from Below Conveyor
- 3 Zones / 6 Tiers
- Length = 800ft
- Width = 39in x 25in Pan
- Open Endless Conveyor
- Bake Time = 7min:55sec
- Conveyor Speed = 101fpm

Energy Transfer Reference Summary

Total Heat (Btu/ft²)

Oven	Product	Bake Time	Convective	Radiant	Total
Radiant Tunnel	Thin Chocolate Sandwich Cookie Half	5min	90 (62%)	60 (38%)	150
Convection / Recirculation	Large Soft Chocolate Chip Cookie	10min:22sec	430 (93%)	30 (7%)	460
Impingement	Baked Potato Chip	50sec	41 (89%)	5 (11%)	46
Tunnel	Whole Wheat Bread	27min:39sec	1000 (84%)	190 (16%)	1190

Avg Heat Flux (Btu/hr·ft²)

Oven	Product	Bake Time	Convective	Radiant	Total
Radiant Tunnel	Thin Chocolate Sandwich Cookie Half	5min	1100 (59%)	750 (41%)	1850
Convection / Recirculation	Large Soft Chocolate Chip Cookie	10min:22sec	2650 (93%)	200 (7%)	2850
Impingement	Baked Potato Chip	50sec	3000 (88%)	400 (12%)	3400
Tunnel	Whole Wheat Bread	27min:39sec	2500 (86%)	410 (14%)	2910
Lap	Multigrain Bread	28min:50sec	2100 (84%)	400 (16%)	2500
Twin Oval	Hamburger Buns	7min:55sec	2500 (83%)	500 (17%)	3000

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ASB

Thank You!

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