

AN EVALUATION OF THE ENERGY CONSUMPTION
OF AUTOMOBILE PAINT-DRYING OVENS

by

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LIST OF SYMBOLS

| Symbol | Meaning |
|-----------------------------|--|
| T_A | Oven air temperature ($^{\circ}\text{F}$) |
| T_m | Air temperature leaving the burner ($^{\circ}\text{F}$) |
| T_O | Fresh air temperature entering the burner ($^{\circ}\text{F}$) |
| $T_{W1} \rightarrow T_{W5}$ | Oven wall temperatures ($^{\circ}\text{F}$) |
| $T_{D1} \rightarrow T_{D5}$ | Air duct wall temperatures ($^{\circ}\text{F}$) |
| T_S | Internal oven steel temperature ($^{\circ}\text{F}$) |
| T_T | Body carrying truck temperature ($^{\circ}\text{F}$) |
| T_B | Car body temperature ($^{\circ}\text{F}$) |
| T_p | Ambient plant air temperature ($^{\circ}\text{F}$) |
| \dot{m}_{tt} | Solvent evaporation rate ($\frac{\text{lb}}{\text{Hr}}$) |
| h_{fg} | Heat of solvent vaporization ($\frac{\text{Btu}}{\text{lb.}}$) |
| \dot{m}_O | Mass flow rate fresh air ($\frac{\text{lb}}{\text{Hr}}$) |
| \dot{m}_R | Mass flow rate return air ($\frac{\text{lb}}{\text{Hr}}$) |
| \dot{m}_m | Mass flow rate supply air ($\frac{\text{lb}}{\text{Hr}}$) |
| \dot{m}_E | Mass flow rate exhaust air ($\frac{\text{lb}}{\text{Hr}}$) |
| m_A | Mass of air in the oven (lb) |
| m_B | Mass of car body (lb) |
| $m_{W1} \rightarrow m_{W5}$ | Mass of oven wall layers (lb) |
| $m_{D1} \rightarrow m_{D4}$ | Mass of ductwork segments (lb) |
| m_T | Mass of body carrying trucks (lb) |
| m_S | Mass of internal oven steel (lb) |
| C_p | Specific heat of air (Btu/lb- $^{\circ}\text{F}$) |
| $C_{D1} - C_{D4}$ | Specific heat of ductwork (Btu/lb- $^{\circ}\text{F}$) |
| $C_{W1} - C_{W5}$ | Specific heat of wall layers (Btu/lb- $^{\circ}\text{F}$) |

LIST OF SYMBOLS (Cont'd)

| Symbol | Meaning |
|---|---|
| C_T | Specific heat of body truck (Btu/lb-°F) |
| C_S | Specific heat of oven steel (Btu/lb-°F) |
| C_B | Specific heat of car body (Btu/lb-°F) |
| K | Fiberglass insulation resistance (Btu-in/hr-°F-ft ²) |
| ΔX | Wall layer thickness (inches) |
| A_W | Surface area of oven walls, floor and ceiling (ft ²) |
| A_S | Surface area of internal oven steel (ft ²) |
| A_T | Surface area of body carrying truck (ft ²) |
| A_B | Surface area of car body (ft ²) |
| $A_{D1} \rightarrow A_{D4}$ | Surface area of ductwork (ft ²) |
| | Avg. convective heat transfer coefficients (Btu/ft ² -°F-hr) |
| \bar{h}_1 | Oven wall coefficient (inside oven) |
| \bar{h}_2 | Oven wall coefficient (plant side) |
| $\bar{h}_{D1} \rightarrow \bar{h}_{D4}$ | Ductwork coefficients (inside duct) |
| \bar{h}'_{D2} | Supply duct coefficient (plant side) |
| \bar{h}'_{D4} | Return duct coefficient (plant side) |
| \bar{h}_S | Internal steel coefficient |
| \bar{h}_B | Body coefficient |
| \bar{h}_T | Body carrying truck coefficient |
| U_W | Overall wall heat transfer coefficient (Btu/hr-ft ² -°F) |
| $U_{D2} \text{ \& } U_{D4}$ | Overall ductwork (outside the oven) heat transfer coefficients (Btu/hr-ft ² -°F) |
| \dot{E} | Burner energy rate (Btu/hr) |
| \dot{E}_{SS} | Steady-state burner energy rate (Btu/hr) |
| θ | Time (hours) |
| ΔT | Time interval of integration (hours) |

Chapter I

INTRODUCTION

In the last two years, we have witnessed a tremendous outcry over the United States' current 'energy crisis'. We have not witnessed a corresponding outpour of concrete solutions to the problem, however, and perhaps the time has come to begin work in the direction of some solution."¹

It seems rare for a day to pass without being confronted with some form of news about the "energy crisis" such as that presented above. The disheartening fact is that at present there appears to be little hope for recovery in the immediate future. Society today is organized around energy. Unfortunately, energy management and conservation has been severely lacking in the past. Today, however, society is taking a look back over its shoulder and re-examining some of its past mistakes in energy use and is attempting to correct them for the future.

Without a doubt, industry is the United States largest single user of all forms of energy. Consequently, it is the hardest hit by the energy pinch [1]*. Recognizing the impending energy shortage, large scale re-evaluations of energy uses within industry are being made at the present time.

The evaluation not only examines the future energy needs of industry; but it also re-examines past and present energy consuming processes, with the hope of eliminating or reducing the amount of energy they require.

¹D. Deyoe, "Heat Recovery--How Can the Heat Ripe Help?" ASHRAE Journal, April, 1973, p. 35.

*Numbers in [] refer to references in Selected References.

The Fisher Body Division of General Motors Corporation is very much involved in the re-evaluation process. One plant in particular, Flint Fisher Body No. 1, is deeply concerned with the predicted energy shortage. The plant has three basic manufacturing functions: 1) Metal stamping and assembly, 2) Body-in-white assembly, 3) Body painting and trim. Due to the nature of the plant's operations a great deal of energy is required to maintain its production and to supply the related process equipment. A typical process, which is representative of many energy consuming processes being re-evaluated, is body paint drying. Every body that is painted in the plant requires oven drying to cure and reflow the acrylic paints. The curing and reflow processes require an air (oxygen) supply and a temperature of 315°F for approximately eleven minutes. The ovens used to dry the bodies are heated by gas-fired, forced-air, burners located on the roof of the plant.

In the past, with unlimited, low-cost energy available, there appeared to be little need for controlling the ovens' energy consumption to the fullest extent. Now, however, the situation has drastically changed. The gas suppliers are cutting back on the amounts of process gas sold and in some areas are putting industrial users on standby service. Needless to say, shutdowns are costly and every means available is being employed to prevent them.

The need for reducing the energy consumption in every phase of plant operation is what prompted the writing of this thesis. The paint-drying ovens were chosen as a typical example of an energy consuming operation which deserves the attention of analysis for purposes of detection and possible improvement in energy consumption characteristics.

Unfortunately, most of the design work on the ovens has been done by experiment and experience. Little or no data has been written regarding their operation or thermal response characteristics. Therefore, much of the background information for this thesis has been acquired through observation and personal communications with those directly involved with the ovens' operation and maintenance.

Chapter II

MINIMIZATION OF ENERGY CONSUMPTION

In the last decade great strides have been made in optimization theory and technique. Most of this work has been performed by Chemical and Industrial Engineers and Mathematicians. Only recently has the Mechanical Engineer become involved (mainly in the aerospace industry), which made it necessary to start this evaluation from basic heat transfer relationships for the oven and develop a technique suitable for conserving energy in their operation.

The first part in the evaluation was to determine a relationship between the energy required to maintain the ovens at steady-state and the energy required to cool and then reheat the ovens. This was done to determine if any energy savings would result from shutting the ovens down during periods when the paint lines were not running.

During steady-state operation the losses from the ovens will be at a maximum. This is due to the fact that the energy loss rate is highest when the driving potential (temperature difference) is at its maximum (which occurs at steady-state). This can be shown by the following equation:

$$E_{SS} = \int_0^{\theta} \sum_{i=1}^n U_i A_i (T_A - T_p) d\theta \quad (1)$$

In other words the steady-state energy input into an oven is equal to the summation of all the component losses in the system integrated over the interval being considered. This integral has maximum value when the difference $(T_A - T_p)$ is a maximum, i.e., when T_A is maximum.

cool-down, reheat cycle requires less energy than is needed for the steady

state operation. This is because $\int_0^1 \sum_{i=1}^n U_i A_i (T_A - T_p) d\theta$ is always greater

than $\int_0^1 \sum_{i=1}^n U_i A_i (T_A(\theta) - T_p) d\theta$; since $(T_A(\theta) - T_p)$ is always less than

$(T_A - T_p)$ after cool down has been initiated. Also $\int_{\theta_1}^{\theta} \sum_{i=1}^n U_i A_i (T_A - T_p) d\theta$

is always greater than $\int_{\theta_1}^{\theta} \sum_{i=1}^n U_i A_i (T_A(\theta) - T_p) d\theta$; since $(T_A - T_p)$ is always

greater than $(T_A(\theta) - T_p)$ until steady state is reached when $T_A = T_A(\theta)$.

Therefore the following inequality is obtained:

$$E_{SS} \Big|_0^{\theta} > E_{\text{heat-up}} \Big|_{\theta_1}^{\theta} \quad (4)$$

The inequality states that the energy required to hold the ovens at steady-state, for any time interval, is always greater than the energy required to reheat them after shut down (for the same time interval). This can be seen graphically in Figure 1.

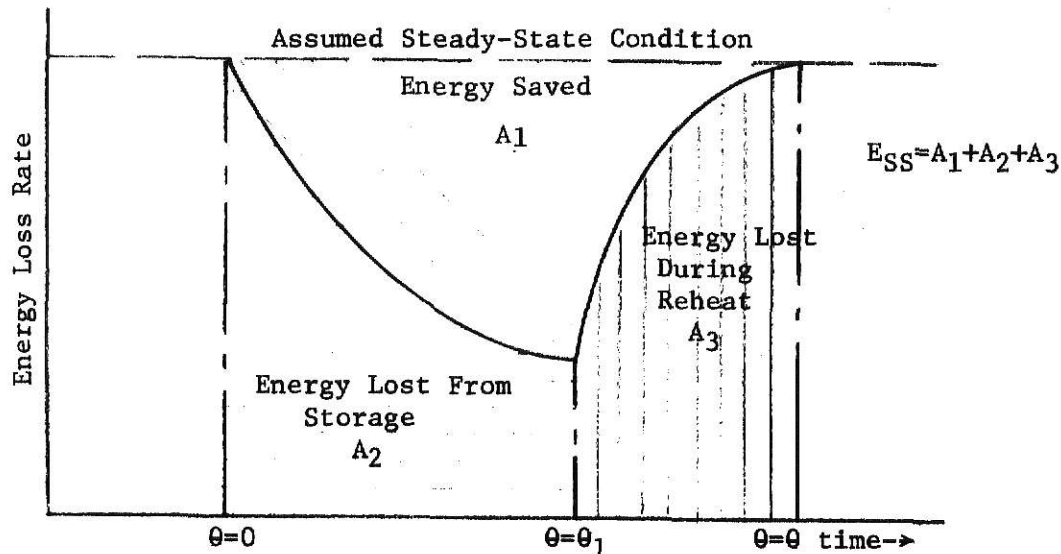


Fig. 1. The Energy Inequality

It can be deduced from the above figure that the savings will be greatest by keeping the interval from θ_1 to θ at its minimum possible value. In other words to minimize the ovens' energy consumption, turn the burner on at the last possible moment, for the interval being considered, to its maximum allowable rate. The above scheme is often referred to as bang-bang control and is commonly employed to minimize fuel consumption for rockets and missiles [2], [3], [4].

Another possible area of energy savings to be considered is the use of the waste heat from the oven exhausts. Volatile solvents are released during the paint drying process and if proper exhaust rates are not maintained an explosive condition in the ovens can result. At present approximately twenty-four percent of the total flow is continually exhausted from the ovens. However, due to the nature of the exhaust system, this flow drops by approximately one-half when the recirculating air system is shut off during cool down periods. When the ovens are in operation the exhaust air quantity results in a load of 2,082,024 Btu/hour per zone on the burner, a factor which cannot be overlooked.

It is important to note that the exhaust air must be made up by an equal amount of fresh air to prevent infiltration from the plant and to supply the necessary oxygen for drying. At present the air is taken from outside the plant and must be heated before entering the oven. Thus another avenue opens up for conserving energy: waste heat utilization for preheating the supply air. This technique is becoming very common in industry today and will be investigated in this thesis as a means of using the available energy from the exhaust air.

The next sections of this thesis cover the methods used in determining the proper bang-bang control sequence, the feasibility of waste heat utilization from the exhaust gases, and recommendations based on the findings.

Chapter III

DATA COLLECTION TECHNIQUE

There are two techniques which can be used to obtain the type of data necessary to evaluate the energy savings resulting from bang-bang control and waste heat utilization. One method of course is simply to run many physical tests on the ovens and record the thermal response curves and energy requirements for varying outdoor conditions. This method is very costly, time consuming, and would be of little value in evaluating future ovens or similar processes. The second method and the one preferred here is to develop a mathematical model of the ovens' thermal response and use a computer to compress the time factor so that the necessary information can rapidly be obtained. The model will also be useful in evaluating future processes with only minor modifications.

Chapter IV

MODEL FORMULATION

The first step in the development of any model is to get an understanding of the physical system the model is to represent. To accomplish this the blueprints of a typical oven were carefully analyzed. Figure 3 is a schematic of a typical oven zone, i.e., a segment of the total, continuous oven which is heated by an individual burner. The number of zones an oven contains may vary from two to four depending on the period of heating required.

The first zone in the ovens is a heat-up zone. It is within this zone that the bodies are elevated from their entering temperature to the operating temperature of the oven, which in this case is 315°F. Due to the transient nature of the body temperatures in this zone, it will not be considered in this analysis.

The bodies upon leaving zone one are held at 315°F for approximately eleven minutes. If the line were run continually, 24 hours per day, seven days a week, the burners would, of course, have to be left on full time. However, due to frequent production and line stoppages this is not the case. The shut down periods provide the avenue for energy reduction using the bang-bang control scheme. Due to the non-steady-state conditions developed by this type control scheme, a transient, thermal model is required for the evaluation.

The ovens can be modeled by writing a set of linear differential equations for the temperature changes occurring in the components within them (see Figure 2 for the total flow circuit schematic). The oven and

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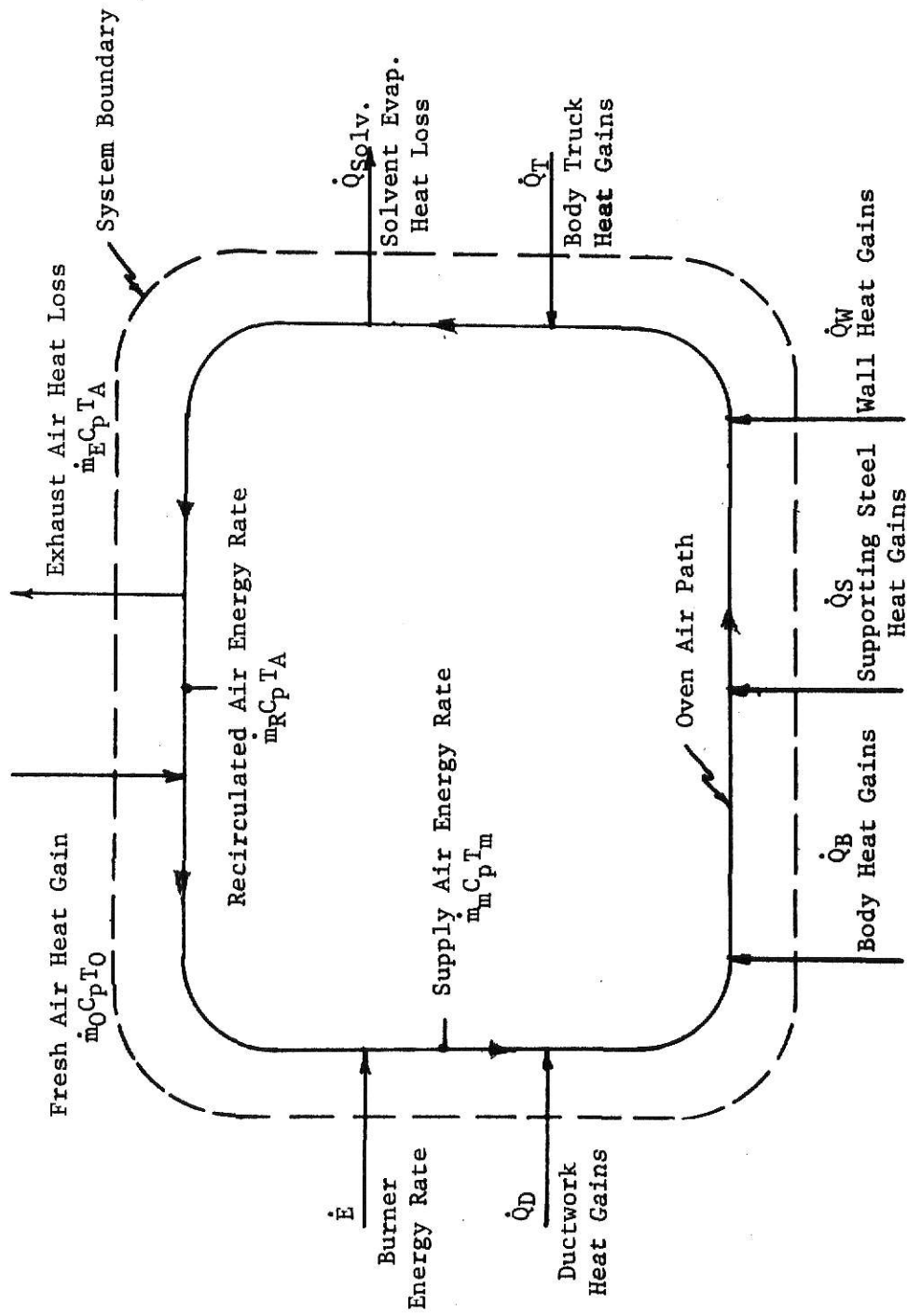


Figure 2. Total Air Flow Schematic

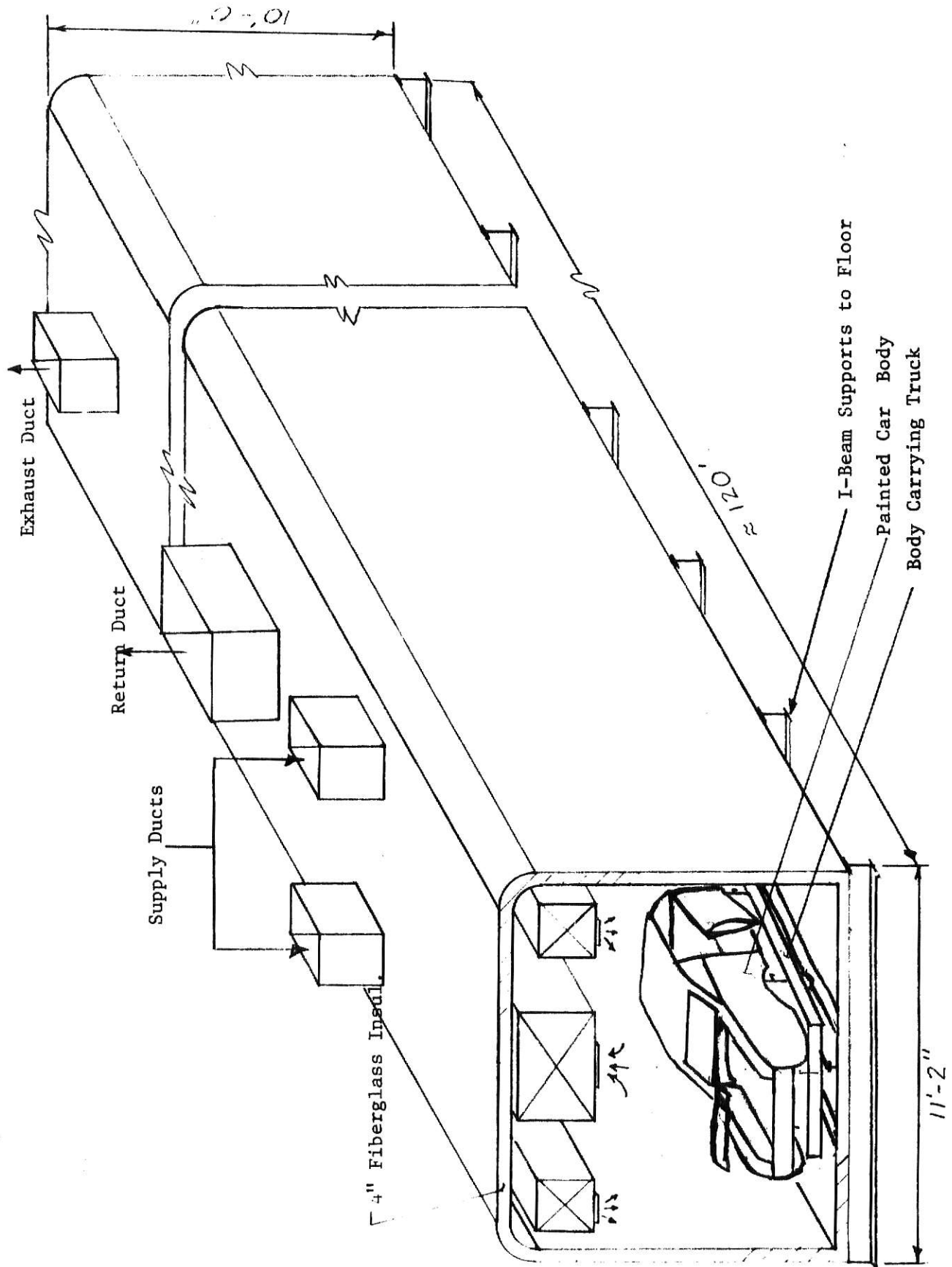


Figure 3. Typical Oven Zone Layout

its contents were separated into thirteen characteristic temperatures each with an equation to represent each time rate of change. The equations for each component are of the form:

$$\frac{m_x C_x \frac{dT_x}{d\theta}}{\text{Energy storage rate}} = \frac{\bar{h}_x A_x (\Delta T)}{\text{Convective heat transfer rate}} + \frac{\frac{K}{\Delta x} A_x (\Delta T)}{\text{Conductive heat transfer rate}} \quad (5)$$

For the supporting steel track and track plates within the ovens (see Figure 3),

$$m_S C_S \frac{dT_S}{d\theta} = \bar{h}_S A_S (T_A - T_S) \quad (6)$$

For the bodies in the oven (Figure 3),

$$m_B C_B \frac{dT_B}{d\theta} = \bar{h}_B A_B (T_A - T_B) \quad (7)$$

For the body trucks which carry the bodies through the oven. (Fig. 3),

$$m_T C_T \frac{dT_T}{d\theta} = \bar{h}_T A_T (T_A - T_T) \quad (8)$$

The ductwork connecting air distribution systems to the heater houses on the roof was divided into four segments. Segment 1 represents the supply ductwork inside the oven; segment 2 represents the supply duct from the heater house to the oven; segment 3 represents the return air ductwork inside the oven; and segment 4 represents the return ductwork from the oven to the heater house.

The following equations represent the energy transfer for the four segments:

$$\text{Segment 1: } m_{D1} C_{D1} \frac{dT_{D1}}{d\theta} = \bar{h}_{D1} A_{D1} (T_m - T_{D1}) + \bar{h}'_{D1} A_{D1} (T_A - T_{D1}) \quad (9)$$

$$\text{Segment 2: } m_{D2} C_{D2} \frac{dT_{D2}}{d\theta} = \bar{h}_{D2} A_{D2} (T_m - T_{D2}) + \bar{h}'_{D2} A_{D2} (T_P - T_{D2}) \quad (10)$$

$$\text{Segment 3. } m_{D3} C_{D3} \frac{dT_{D3}}{d\theta} = \bar{h}_{D3} A_{D3} (T_A - T_{D3}) \quad (11)$$

$$\text{Segment 4. } m_{D4} C_{D4} \frac{dT_{D4}}{d\theta} = \bar{h}_{D4} A_{D4} (T_A - T_{D4}) + \bar{h}'_{D4} A_{D4} (T_p - T_{D4}) \quad (12)$$

The equations for the walls, floor, and ceiling of the oven required inclusion of internal conduction terms because of spatial temp-variation through their thickness. The conduction of energy through the wall was determined by using a finite difference technique. The wall was divided into five segments as shown in Figure 4.

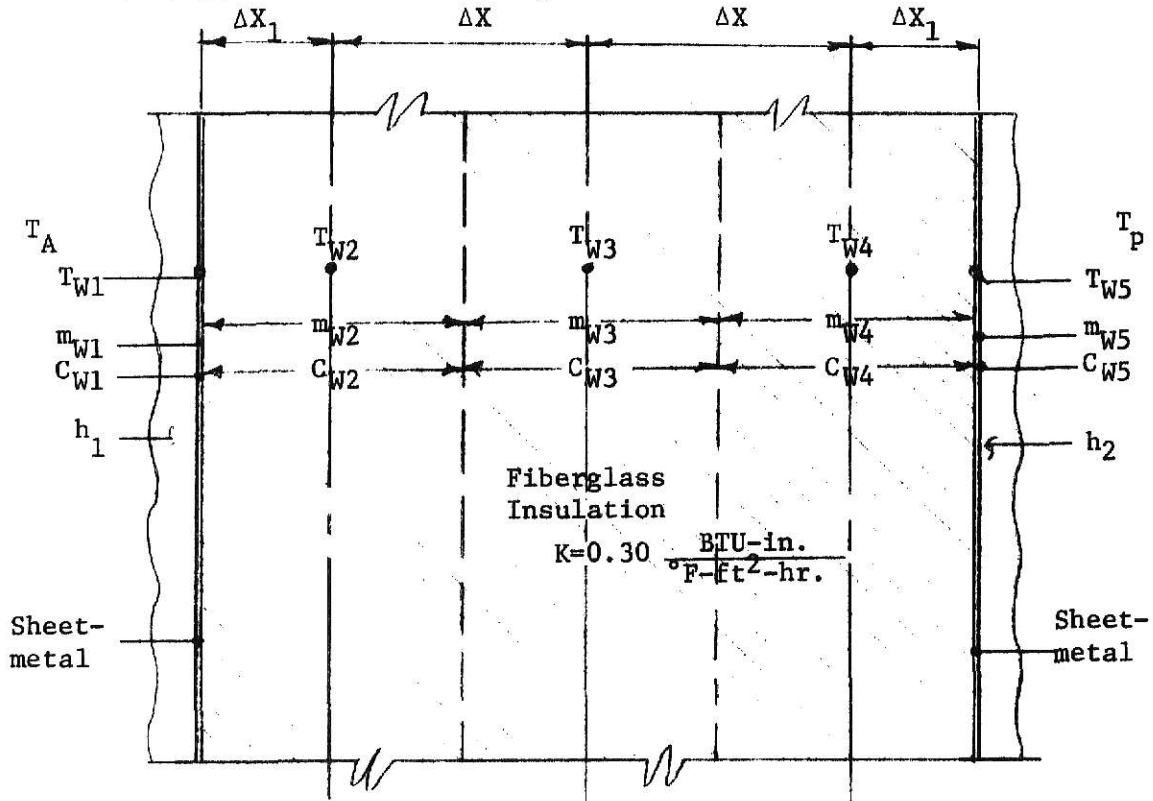


Fig. 4. Oven Wall Section

Five temperature nodes in the wall were chosen, one at the center of each segment. The two sheet metal layers were treated as though they had mass, and thermal capacity, but no resistance (due to their high conductivity and thin gage).

The electrical analogy shown in Figure 5 illustrates the thermal characteristics of the above walls more clearly. It can be utilized in obtaining the flux and storage equations for the walls.

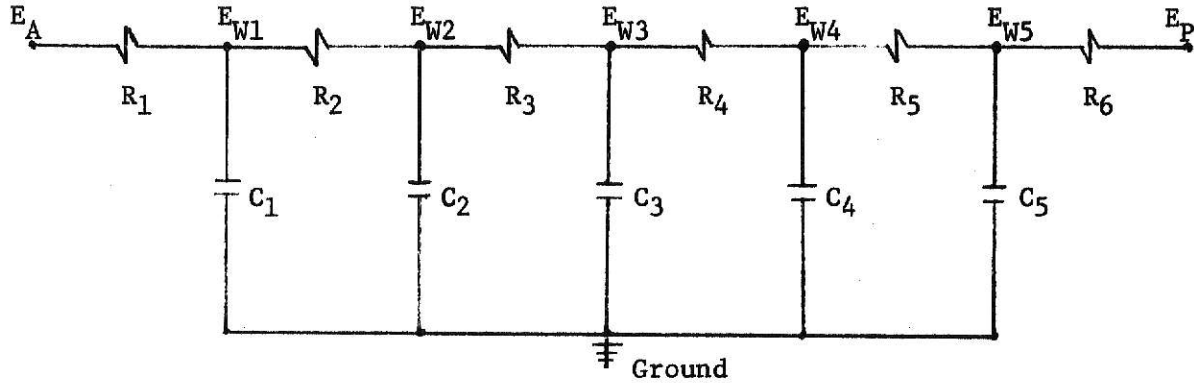


Fig. 5. Oven Wall Electrical Analogy

Using the notation of Figure 5, the analog circuit equations are the following:

$$C_1 \frac{dE_{W1}}{d\theta} = \frac{1}{R_1} (E_A - E_{W1}) + \frac{1}{R_2} (E_{W2} - E_{W1}) \quad (13)$$

$$C_2 \frac{dE_{W2}}{d\theta} = \frac{1}{R_2} (E_{W1} - E_{W2}) + \frac{1}{R_3} (E_{W3} - E_{W2}) \quad (14)$$

$$C_3 \frac{dE_{W3}}{d\theta} = \frac{1}{R_3} (E_{W2} - E_{W3}) + \frac{1}{R_4} (E_{W4} - E_{W3}) \quad (15)$$

$$C_4 \frac{dE_{W4}}{d\theta} = \frac{1}{R_4} (E_{W3} - E_{W4}) + \frac{1}{R_5} (E_{W5} - E_{W4}) \quad (16)$$

$$C_5 \frac{dE_{W5}}{d\theta} = \frac{1}{R_5} (E_{W4} - E_{W5}) + \frac{1}{R_6} (E_P - E_{W5}) \quad (17)$$

By letting the electrical values for E, C and R be replaced by their thermal equivalents, the equations become:

$$\dot{m}_{W1} C_{W1} \frac{dT_{W1}}{d\theta} = \bar{h}_1 A_W (T_A - T_{W1}) + \left(\frac{K}{\Delta X_1} \right) A_W (T_{W2} - T_{W1}) \quad (18)$$

$$\dot{m}_{W2} C_{W2} \frac{dT_{W2}}{d\theta} = \left(\frac{K}{\Delta X_1} \right) A_W (T_{W1} - T_{W2}) + \left(\frac{K}{\Delta X} \right) A_W (T_{W3} - T_{W2}) \quad (19)$$

$$\dot{m}_{W3} C_{W3} \frac{dT_{W3}}{d\theta} = \left(\frac{K}{\Delta X} \right) A_W (T_{W2} - T_{W3}) + \left(\frac{K}{\Delta X} \right) A_W (T_{W4} - T_{W3}) \quad (20)$$

$$\dot{m}_{W4} C_{W4} \frac{dT_{W4}}{d\theta} = \left(\frac{K}{\Delta X} \right) A_W (T_{W3} - T_{W4}) + \left(\frac{K}{\Delta X_1} \right) A_W (T_{W5} - T_{W4}) \quad (21)$$

$$\dot{m}_{W5} C_{W5} \frac{dT_{W5}}{d\theta} = \left(\frac{K}{\Delta X_1} \right) A_W (T_{W4} - T_{W5}) + \bar{h}_2 A_W (T_p - T_{W5}) \quad (22)$$

To determine the burner exit air temperature, T_m , an energy and mass balance was written for the system as drawn in Figure 6.

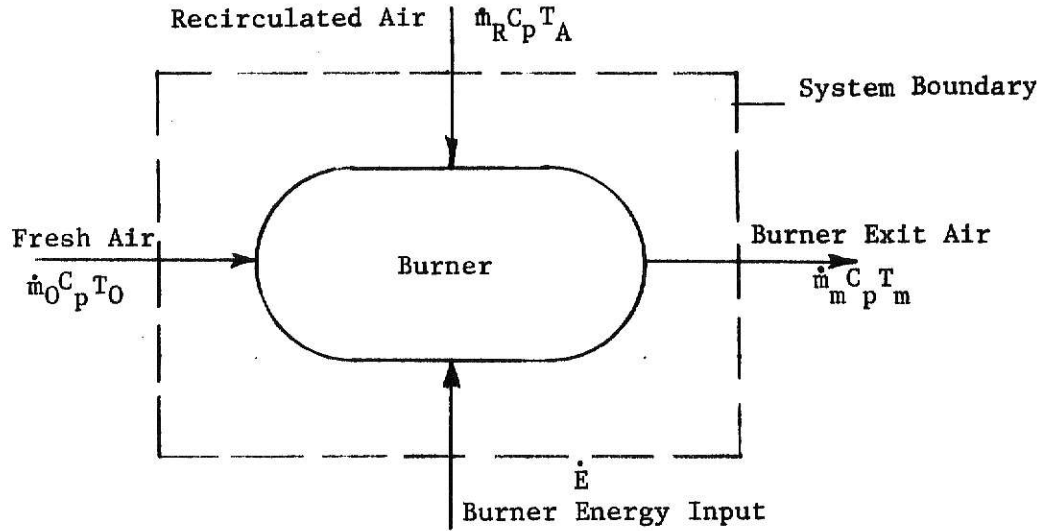


Fig. 6. Burner System

The mass balance is expressed by the following equation:

$$\dot{m}_O + \dot{m}_R = \dot{m}_m \quad (23)$$

The energy balance is written (assuming $C_p \approx \text{const}$),

$$\dot{m}_O C_p T_O + \dot{m}_R C_p T_A + \dot{E} = \dot{m}_m C_p T_m \quad (24)$$

Solving for T_m yields:

$$T_m = \frac{\dot{m}_O C_P T_O + \dot{m}_R C_P T_A + \dot{E}}{\dot{m}_m C_P}$$

The fresh air fraction in the ovens is maintained at 24% \dot{m}_m (when the burners are on) and the recirculated air percent is 76% of \dot{m}_m ; with these substitutions, the expression for T_m becomes

$$T_m = 0.24 T_O + 0.76 T_A + \frac{\dot{E}}{\dot{m}_m C_P} \quad (26)$$

For the time rate of change of the air temperature in the oven an energy balance was written for the system shown in Figure 7 (assuming complete mixing and no property gradients in the oven).

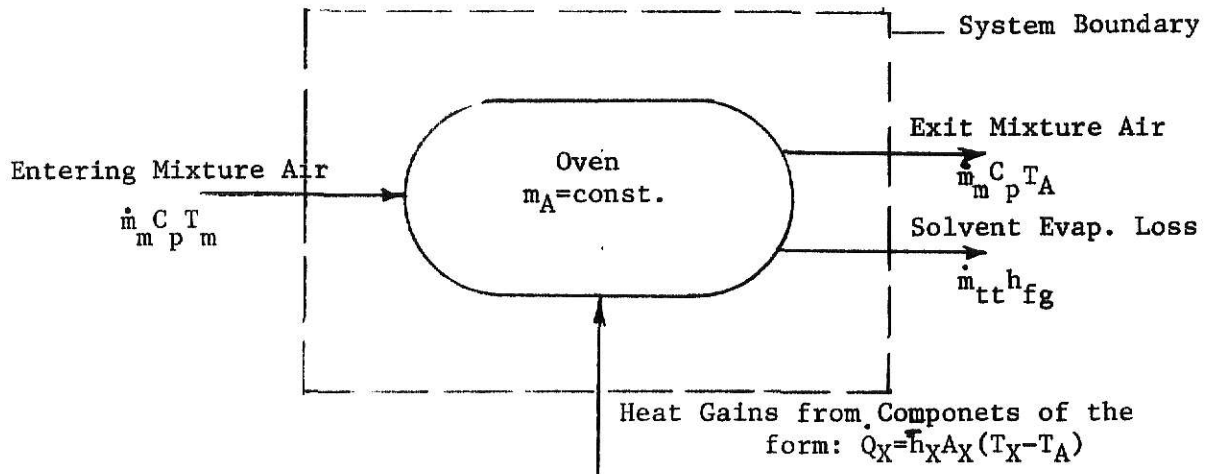


Fig. 7. Transient Oven System

The transient energy balance is the following:

$$\begin{aligned} \dot{m}_A C_P T_A &= \dot{m}_m C_P T_m - \dot{m}_m C_P T_A + \bar{h}_B A_B (T_B - T_A) + \bar{h}_S A_S (T_S - T_A) \\ &+ \bar{h}_{D1} A_{D1} (T_{D1} - T_m) + \bar{h}_{D2} A_{D2} (T_{D2} - T_m) + \bar{h}_{D3} A_{D3} (T_{D3} - T_A) \\ &+ \bar{h}_{D4} A_{D4} (T_{D4} - T_A) + \bar{h}_1 A_W (T_{W1} - T_A) + \bar{h}_T A_T (T_T - T_A) \\ &- \dot{m}_{tt} h_{fg} \end{aligned} \quad (27)$$

The above equations represent the energy transfers occurring in the ovens during any time period. In addition to this it is necessary to have an equation from which the steady-state energy rate can be computed for specific values of plant and outside air temperatures. The form of the equation was chosen to make dual calculations of \dot{E}_{SS} , the steady-state energy requirements, for comparison to actual operating data.

Figure 8 depicts the steady-state operation of the ovens.

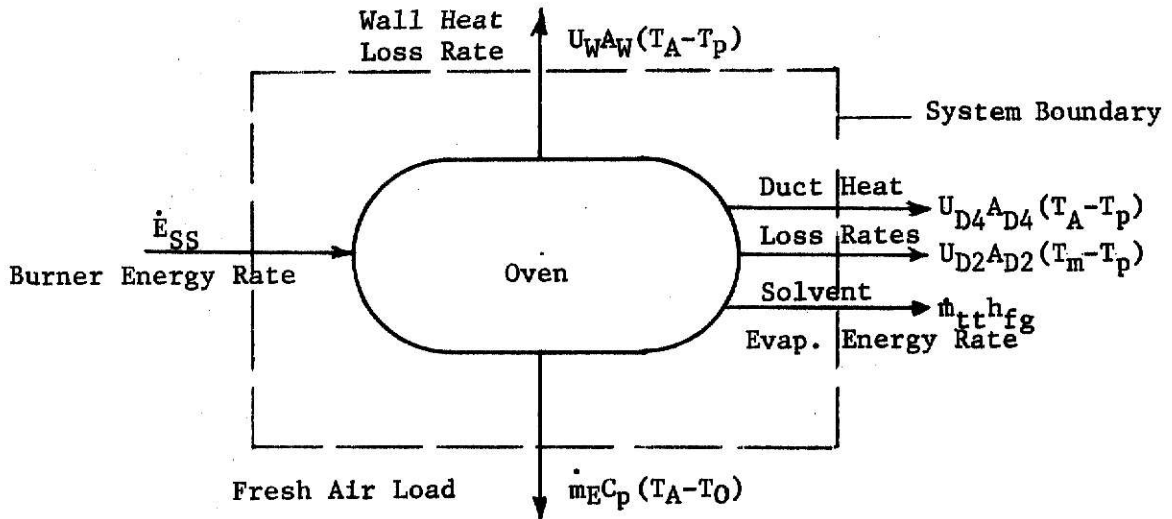


Fig. 8. Steady-State Oven System

The steady-state energy balance is

$$\begin{aligned} \dot{E}_{SS} = & U_W A_W (T_A - T_p) + U_{D2} A_{D2} (T_m - T_p) + U_{D4} A_{D4} (T_A - T_p) \\ & + \dot{m}_{tt} h_{fg} + \dot{m}_E C_p (T_A - T_0) \end{aligned} \quad (28)$$

The values for the masses and areas in the model are given in Appendix A. The values for the average convective heat transfer coefficients, thermal capacities, mass flow rates, and resistances are given in Appendix A.

Finite difference equations of the form $\frac{dT}{d\theta} = \frac{T^+ - T}{\Delta\theta}$ were substituted into the model equations and a simple, total-step, iteration, procedure for

calculation was used in the computer program presented in Appendix B. The results were checked for stability and accuracy by a trial run comparison to IBM's Subroutine HPCL. The comparisons revealed only a maximum difference of 3°F.

The next step in the model development was to verify the model results by comparison to actual measured data. This is done in the next chapter.

Chapter V

VERIFICATION OF THE MODEL

After the basic modeling equations were completed, it was necessary to check the accuracy of its results with real data. To do this a test was set up at Fisher Body Flint Plant No. 1. The center zone of a typical reflow oven was selected as the test location to eliminate any end effects in the oven from the plant. The fresh air temperature was recorded and then the burner was shut down simultaneously with the paint line. (Note the exhaust fans are left on to prevent explosive conditions from accumulation of evaporated solvent in the oven). The oven air temperature then was recorded against time, on a Honeywell recorder.

After the oven cooled down for approximately four hours it was reheated. The reheat procedure was to turn the recirculating fans and burners on to their maximum rates simultaneously. The outdoor air temperature entering the burner was recorded and the oven air temperature was again recorded against time.

With the same conditions for T_0 and T_p input into the equations representing the cool down operation, results from the modeling routine were obtained. The measured results and the computed results are presented in Figure 9. The computed results showed reasonable agreement with the experimental data. The greatest deviation being about 9.0°F at 2.3 hours.

The model was also tested for the heat-up conditions used in the plant's test run. The measured and computed results are compared in Figure 10. Again the comparison of results show reasonable agreement. The greatest difference between experimental and model data was 15°F .

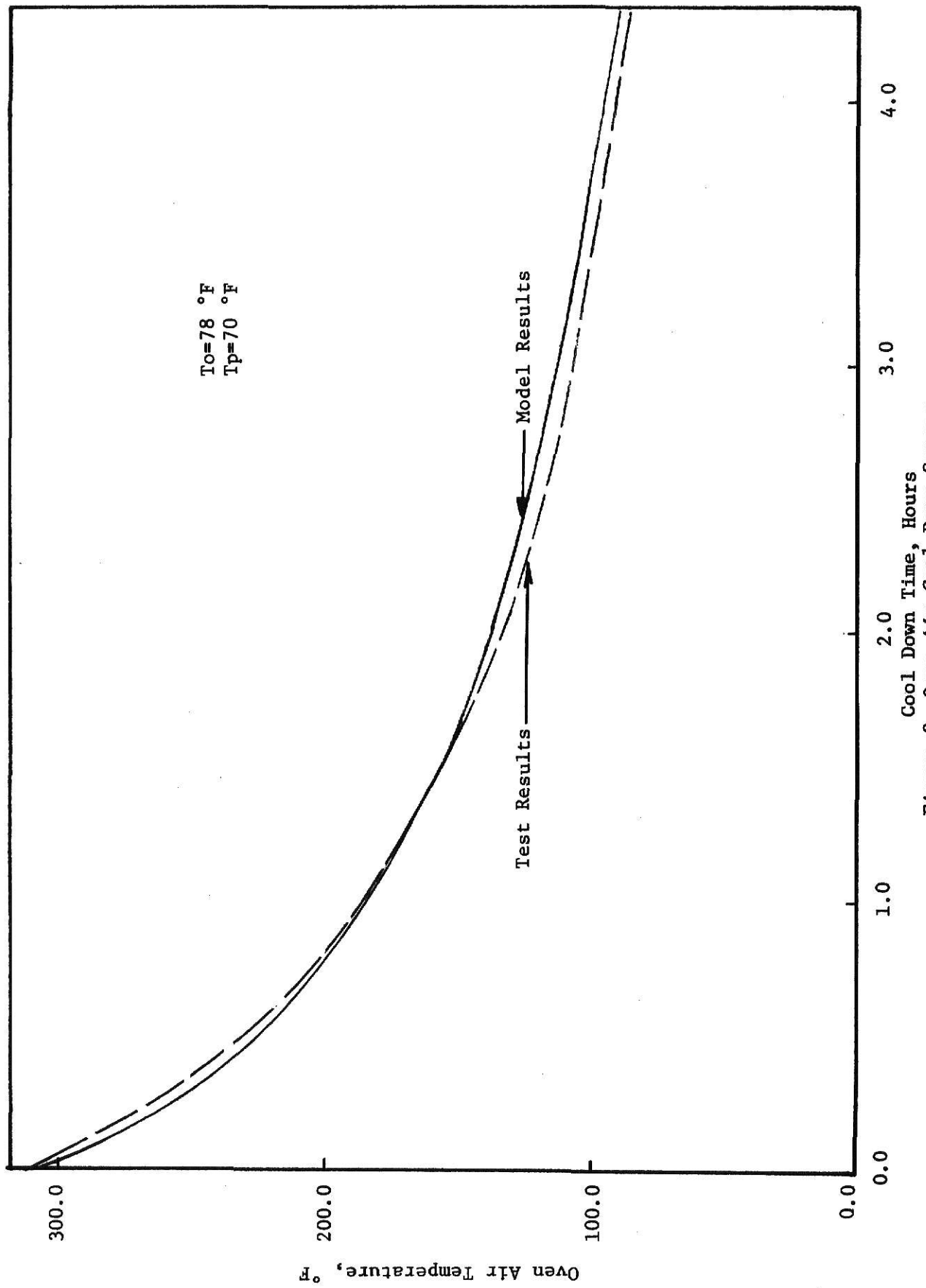


Figure 9. Oven Air Cool-Down Curves

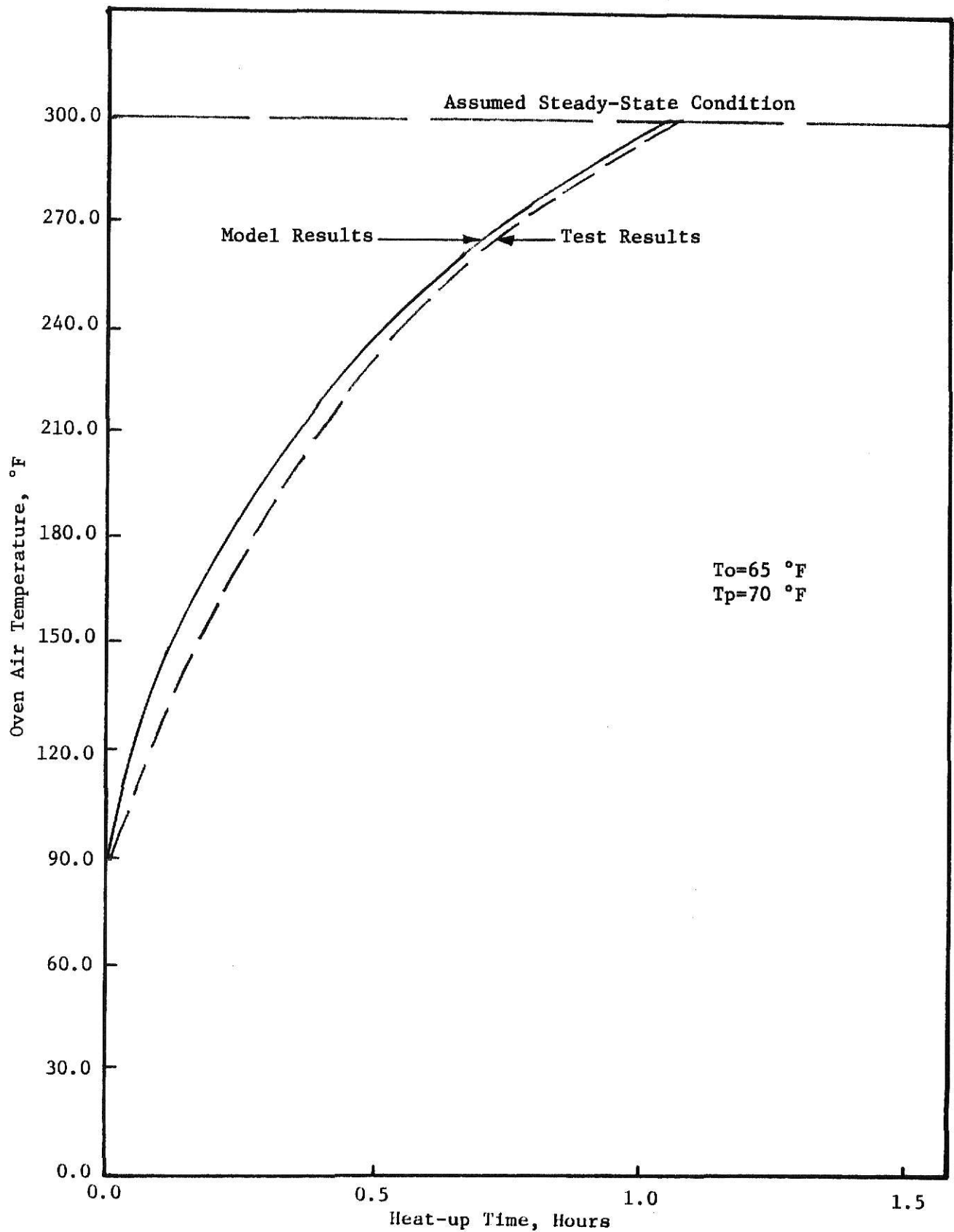


Figure 10. Oven Air Heat-Up Curves

Because of the close comparison of the model results to the measured results, the model and program can now be used with some confidence. The computer model was used to determine the proper time intervals for burner firing and shut off to achieve the minimum energy use during paint line shut down periods. The next chapter of this thesis contains a presentation of the proper control sequence for various outdoor conditions.

Chapter VI

BANG - BANG CONTROL SAVINGS

The model was used for the determination of the proper oven firing rates under a bang-bang control scheme. The first step in the procedure was to determine the appropriate outdoor temperature ranges to be applied. Reasonable time intervals to leave the ovens shut down were also specified.

In Flint, Michigan, the plant location, the outdoor design dry-bulb conditions are -1°F winter and 89°F summer [5]. To effectively cover this entire range, six values of outdoor temperatures were selected: 0°F , 20°F , 40°F , 60°F , 80°F , 100°F .

The burners, at the present time, are manually shut down and fired, even though the operating temperature level is controlled by a proportional, burner, control system. Because of this, the minimum time allowable for a complete shut down was selected as one-half hour. This allows time for the operator to reach the burners from the maintenance shop and have the necessary time to fire an entire oven.

The program was run for two classes of shut downs. In the first class the time duration of shut down is less than one shift (8 hrs); in the second class the shut down period is of sufficient duration for the oven to come to steady-state equilibrium with plant temperature.

The first class of shut downs are short enough to require that the exhaust fans remain on during the entire cool down period. The computer model is applicable exactly as it was written for this type of shut down. For the second class of shut down a modification was made in the program to reduce computer time required for solution. Instead of running the cool

down routine to equilibrium (plant conditions) and then reheating, the plant equilibrium temperatures were input as initial conditions into the heat-up routine and it was run separately to the assumed line start-up temperature of 300°F where the proportional controller takes over.

Class I Shut Downs

For the first class of shut downs, time intervals for burner shutdown were selected as 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 hours. The model was run for the six outdoor temperatures selected and the results are presented in Figures 11 and 12.

Figure 11 shows the proper burner down times for maximum energy savings for specified fresh air temperatures. It contains burner shut down time specifications for production line down-periods of up to five hours.

Figure 12 represents the dollar savings gained under the same burner down condition as used in Figure 11. These savings were computed on a basis of 65.8 cents per million BTU of natural gas [6]. Total savings also include the savings in electrical power resulting from shutting down the recirculating fan during periods of burner shut down. This figure can be utilized by the oven maintenance operator to determine if the predicted savings are great enough to justify the manpower required to kill and re-fire the burners.

Class II Shut Downs

The savings from shutting down the burners are plotted in Figure 13 as a function of outside air temperature and the total time the line is shut off. The resulting savings are also based on a energy cost of 65.8

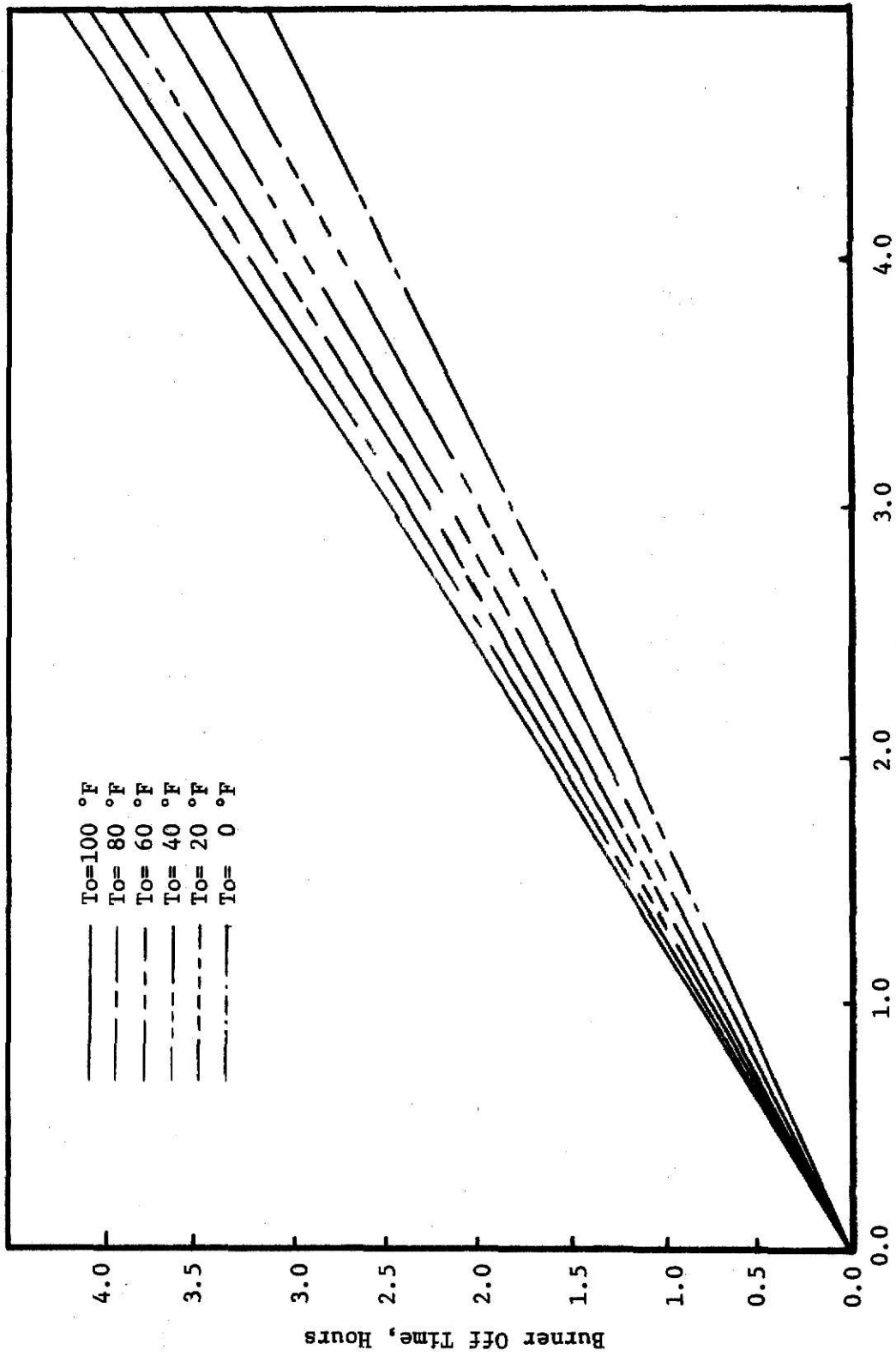


Figure 11. Class I Shut-Down Times

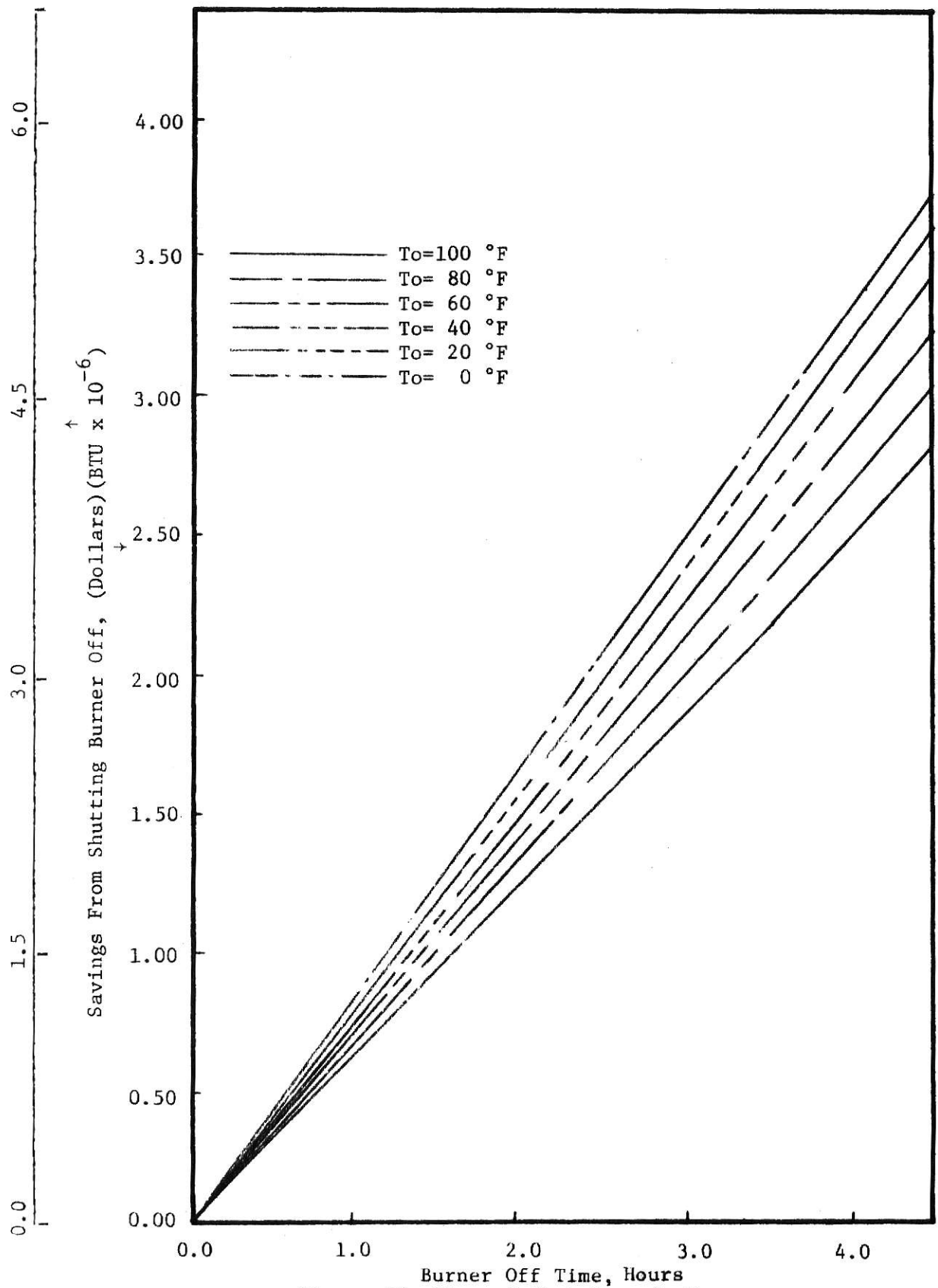


Figure 12. Class I Shut-Down Savings

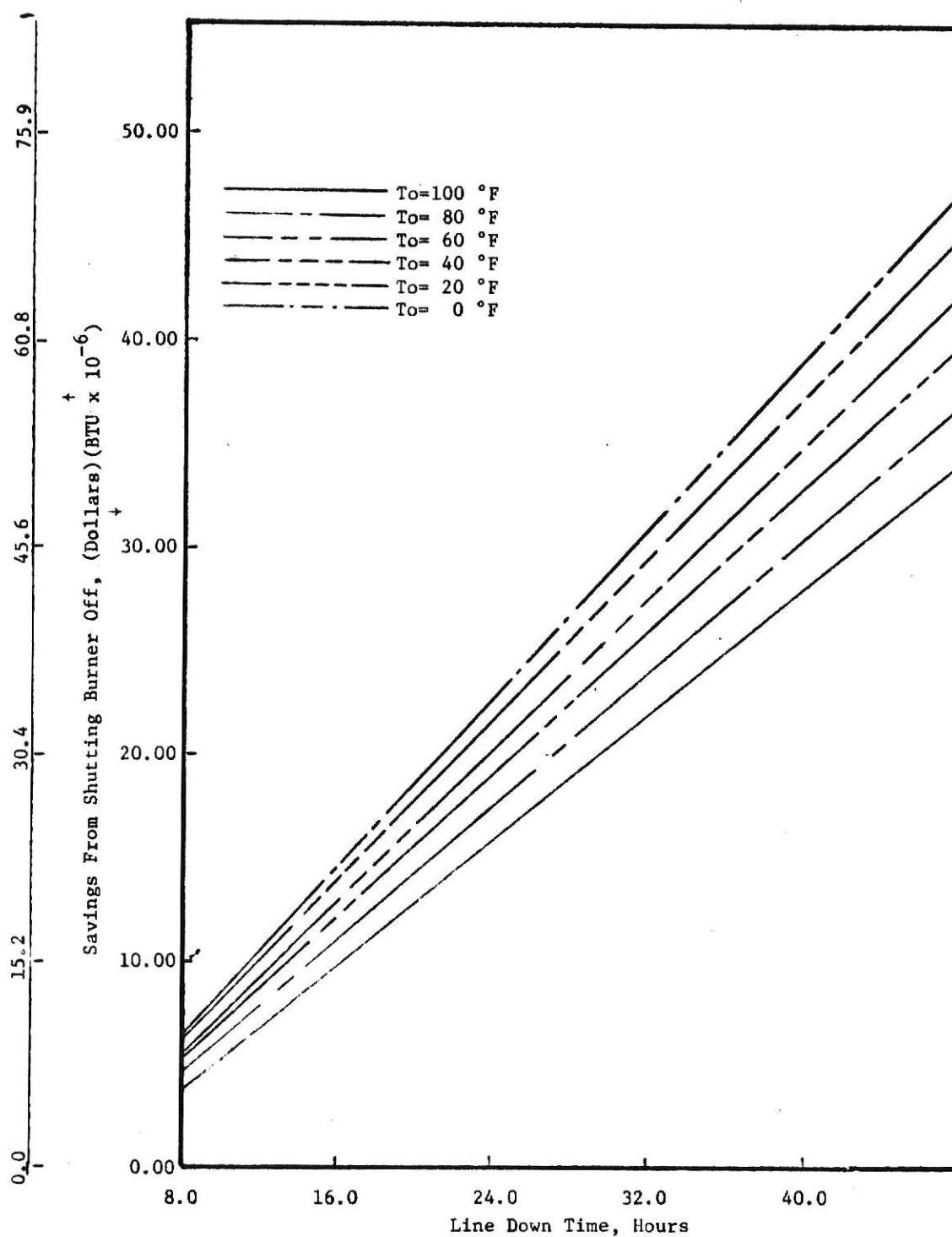
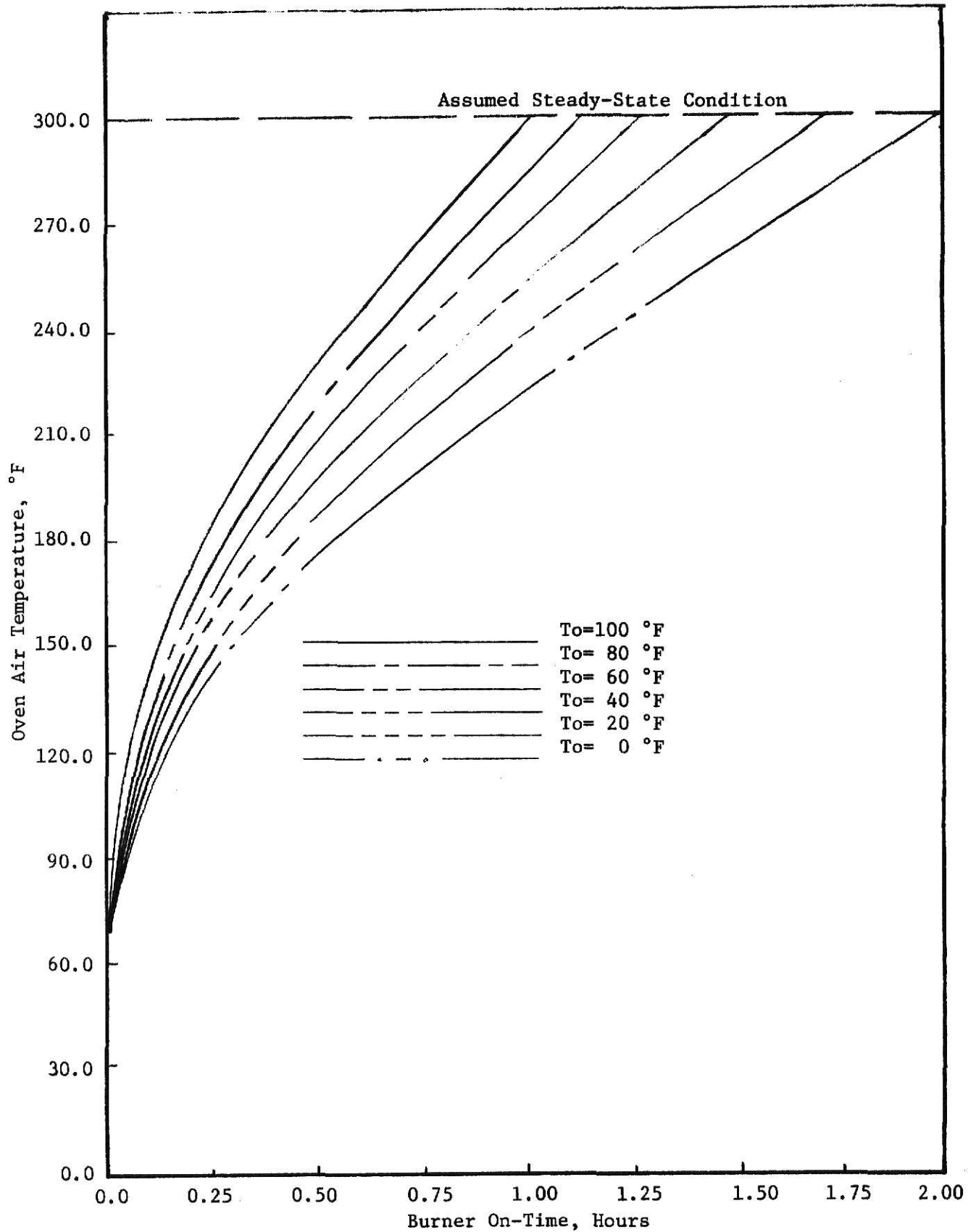


Figure 13. Class II Shut-Down Savings

cents per million BTU's and are expressed as dollar savings over leaving the ovens running at steady-state. The large savings are due to the long time periods of shut down and short periods of heat-up as shown in Figure 14.

To get some idea of the magnitude of the savings involved, the case of one eight hour shutdown per day was considered. Using a base of 234 working days per year and a savings of five dollars per day per burner, the yearly savings amounts to \$1,170. This represents an energy savings of 1,778 million BTU of fuel.



Chapter VII

WASTE HEAT RECOVERY

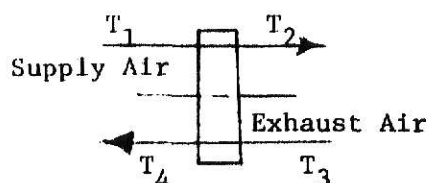
The feasibility of saving energy by using waste heat recovery is determined primarily by three factors. First, the cost of buying the heat exchangers, revising the existing ductwork, and increasing fan static pressure must be evaluated. Secondly, the chemical nature of the exhaust gases and their condensation properties must be examined to determine if any scrubbing is necessary. Finally, the yearly energy savings due to recovery must be computed and compared to the cost of the first two factors to make certain that an economic benefit results.

Rotary regenerative equipment was chosen for evaluation of the heat reclaim process. The rotary equipment generally has a lower initial cost than a heat pipe system [7] and its operational characteristics are suitable for the service contemplated here.

Each zone in the oven, when operating at steady-state, has an exhaust air rate of approximately 5000 cfm at 315°F. No latent heat transfer was considered due to the low moisture content of the air at this temperature. Typically a nonhygroscopic, metallic regenerator for this quantity of air will be approximately five feet square by two feet deep, and weighs around 2500 pounds [7].

To operate at maximum efficiency, the units are set-up for counter flow heat transfer. In the counter flow arrangement, efficiencies usually fall in the range of 65 to 85% [7]. Regenerator efficiency is defined in the following manner:

$$N = \frac{(T_1 - T_2)}{(T_1 - T_3)} ; \quad \text{where}$$



(30)

The pressure drop across the exchanger was also included in the evaluation. For air velocities of 500 fpm the pressure drop across the units will generally range from 0.5 to 0.8 inches of water [7].

It was necessary to find average monthly temperature values for use in computing an average monthly savings gained by using the regenerators. The data in Table 1 represents the average degree days for the area, per month, which were used in the calculations [8].

Table 1. Average monthly degree day values.

| Jan. | Feb. | March | April | May | June |
|------|------|-------|-------|-----|------|
| 1218 | 1080 | 861 | 531 | 259 | 73 |

| July | Aug. | Sept. | Oct. | Nov. | Dec. |
|------|------|-------|------|------|------|
| 73 | 95 | 95 | 337 | 712 | 1116 |

With the information above, the average monthly temperature values were computed by the following formula and are presented in Table 2.

$$t_{avg} = 65. - \frac{DD}{DM} \quad (31)$$

where DD = degree days
 DM = days in the month
 t avg = average temperature for the month

Using the average outdoor temperature values in equation 28, which gives the steady-state energy requirements without regeneration, the average monthly burner energy costs were calculated. The results are presented in Table 2.

Table 2. Average Monthly Energy Savings Per Zone with Waste Heat Utilization

| Month | Avg. T_0 No Preheat °F | $\dot{E}_{SS} \times$ 10^{-6} Btu/hr | Btu/mo. \times 10^{-6} | Dollar Cost | Avg. T_0 Preheat °F | $\dot{E}_{SS} \times$ 10^{-6} Btu/hr | Btu/mo. \times 10^{-6} | Dollar Cost | Monthly Savings \$ |
|---------------|--------------------------------|---|-------------------------------|----------------|--------------------------|---|-------------------------------|----------------|-----------------------|
| January | 25.7 | 1.42 | 545.3 | \$ 358 | 242.6 | .68 | 261.1 | \$ 172 | \$ 186 |
| February | 26.4 | 1.42 | 447.6 | 314 | 242.8 | .68 | 228.5 | 150 | 164 |
| March | 37.2 | 1.37 | 526.1 | 346 | 245.5 | .66 | 253.4 | 167 | 179 |
| April | 41.3 | 1.32 | 485.8 | 320 | 248.1 | .65 | 239.2 | 157 | 163 |
| May | 56.5 | 1.28 | 491.5 | 323 | 250.4 | .63 | 241.9 | 159 | 164 |
| June | 62.5 | 1.26 | 463.7 | 305 | 251.8 | .62 | 228.2 | 150 | 155 |
| July | 62.6 | 1.26 | 483.8 | 318 | 251.9 | .62 | 238.1 | 157 | 161 |
| August | 61.9 | 1.26 | 483.8 | 318 | 251.7 | .62 | 238.1 | 157 | 161 |
| September | 61.8 | 1.26 | 463.7 | 305 | 251.6 | .62 | 228.2 | 150 | 155 |
| October | 54.1 | 1.29 | 495.4 | 326 | 249.7 | .63 | 241.9 | 159 | 167 |
| November | 41.2 | 1.35 | 496.8 | 327 | 246.5 | .66 | 242.8 | 159 | 168 |
| December | 29.0 | 1.41 | 541.4 | 356 | 243.5 | .66 | 253.4 | 167 | 189 |
| <u>\$3916</u> | | | | | | | | | <u>\$1904</u> |

Total Avg.
Year Savings = \$2012

Base 384 Hrs/31 day mo.
368 hrs/30 day mo.
336 hrs/28 day mo.

Assume 16 hour/day operation

Using a regenerator efficiency of 75% and equation 30, the preheated outdoor air temperatures were calculated for the design temperatures from Table 2. These are presented in Table 2.

The steady state energy requirements were determined by using the preheated outdoor air temperatures in equation 28. These are also presented in Table 2. The difference between the two steady-state energy requirements represents the savings by using regeneration for each zone in the oven. Using a value of 65.8 cents per million BTU's the dollar savings were computed and are presented in Table 2. The total annual savings amounted to \$2,012 (3057 million BTU's per year).

Extensive ductwork revision must be undertaken for inclusion of regenerators in the existing ovens. These revisions are impossible to estimate without being able to obtain local conditions and local costs. However, for complete economic justification, these capital costs must be less than the anticipated fuel savings.

It is important to remember that inclusion of the heat recovery system will modify the response times calculated earlier for the various outside air temperatures. Because of regenerator use, the fresh air temperature would increase at a rate proportional to the increase in oven air temperature. With the increased fresh air temperature faster rise in oven air temperature would occur. This would reduce the length of heat-up interval, which according to equation 4, would cause the system to move to a higher level of energy savings. Determination of these savings and of the modified oven response were not treated numerically in this study.

Chapter VIII

RECOMMENDATIONS AND CONCLUSION

It has been shown that substantial energy savings will result from the proper use of oven on-off sequences and from waste heat utilization. The dollar savings based on a single zone, obtained by shutting down the burner during line shut downs, were found to be rather low, ranging up to \$3.50 for 4 hour burner off times. The shut off procedures do, however, provide a means of reducing the amount of fuel required. This is becoming a critical factor for an industry faced with fuel rationing.

Application of the waste heat recovery system was shown to result in significant dollar savings. Again there is a need to emphasize the fact that the fuel savings by the regenerators may be offset to some extent by the capital investment to buy and install the equipment, plus a small expenditure to operate its control and power system. These two factors do not, however, rule out its future potential. As in the case of oven on-off control the increasing cost of fuel is not the only factor to be considered. The availability of heating fuel is decreasing rapidly, and all possible measures should be used to reduce its consumption.

The "energy crisis" is very real and its presence is being felt more and more everyday. A strong effort needs to be put forth to reduce energy consumption by all segments of society.

This thesis represents an example of the type of analysis of past practice which will be required of all energy consuming processes. The total energy savings are shown to be relatively small because total energy use is small for this system. The techniques of analysis and modeling, however, are appropriate to similar systems, regardless of size for future analysis purposes.

**THIS BOOK
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NUMEROUS PAGES
WITH THE ORIGINAL
PRINTING BEING
SKEWED
DIFFERENTLY FROM
THE TOP OF THE
PAGE TO THE
BOTTOM.**

**THIS IS AS RECEIVED
FROM THE
CUSTOMER.**

SELECTED REFERENCES

1. Fleming, William S., "Energy Conservation - Outlook and State-of-the-Art," ASHRAE Journal, March, 1973, 15: 45-52.
2. Leitmann, George, An Introduction to Optimal Control, New York: McGraw-Hill Book Company, 1966.
3. Citron, Stephen J., Elements of Optimal Control, New York: Holt, Rinehart, and Winston, Inc., 1969.
4. Thigge-Lotz, I. and Marbach, H., "The Optimal Control of Some Attitude Control Systems for Different Performance Criteria," ASME Paper No. 62-JACC-6, 1962.
5. "Weather Data and Design Conditions, ASHRAE Handbook of Fundamentals, 1972 Edition, 667-688.
6. Personnel Communication, Glen Patrick, Sr., Mechanical Engineer, Fisher Body Flint Plant No. 1, April 19, 1973.
7. "Air-to-Air Heat Recovery Equipment," ASHRAE Guide and Data Book - Equipment, 1969, 447-454.
8. Jennings, Burgess H., Environmental Engineering Analysis and Practice, Scranton, Pa.: International Textbook Company, 1970.
9. Steel Construction, Second Edition, 1936.
10. "Physical Properties of Materials," ASHRAE Handbook of Fundamentals, 1972 Edition, 569-574.
11. "Heat Transfer," ASHRAE Handbook of Fundamentals, 1973 Edition, 31-62.

APPENDICES

Appendix A

NUMERICAL PARAMETER VALUES

VALUES OF MODEL PARAMETERS PER 120 FEET OVEN ZONE

The following values for the masses of the oven and its components were calculated from specifications on the construction prints of the ovens. All values used in the program are based on a typical zone 120 feet long. All masses were calculated with the following equation:

$$m = \rho V ; \text{ where } \rho = \text{density of component (lb/ft}^3\text{)} \\ V = \text{volume of component (ft}^3\text{)}$$

For the steel components $\rho = 489. \text{ lb/ft}^3$ [9]. For air the density was calculated as a function of air temperature with a base temperature of 315°F $\rho_A = .075 \text{ lb/ft}^3 \left(\frac{775.}{T_A + 460.} \right)$. For the fiberglass in the walls the density was given by the manufacturer, $\rho_f = 9.0 \text{ lb/ft}^3$.

$$m_A = \left(\frac{467,261.25}{T_A + 460.} \right) \text{ lb}$$

$$m_{W1} = m_{W5} = 7768. \text{ lb}$$

$$m_{W2} = m_{W3} = m_{W4} = 4750. \text{ lb}$$

$$m_{D1} = 2136. \text{ lb}$$

$$m_{D2} = 396. \text{ lb}$$

$$m_{D3} = 1962. \text{ lb}$$

$$m_{D4} = 234. \text{ lb}$$

$$m_T = 10,702. \text{ lb}$$

$$m_S = 10,469. \text{ lb}$$

$$m_B = 5189. \text{ lb}$$

The mass flow rate of the outdoor air which is equal to the mass flow rate of the exhaust air from the oven has a different value for heat-up and cool-down conditions. This is due to the change in system resistance the exhaust fan experiences when the recirculating fan is on.

The following figure shows the system resistance curves for the two cases mentioned above.

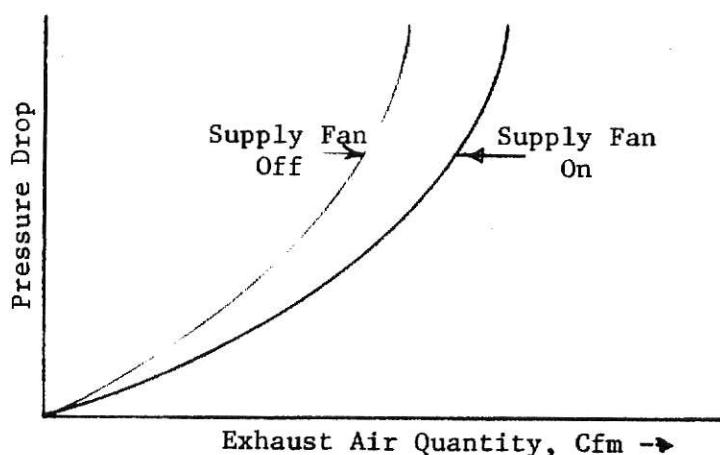


Fig. 15. Exhaust System Resistance Curves

Both curves show the same characteristic parabolic shape. The value for the exhaust air flow rates are determined by superimposing the proper fan characteristic curve over the two resistance curves. The ratio of mass flow rate for outside air can vary from $\approx 1:1$ to $3:1$ (supply fan on \dot{m}_o :supply fan off \dot{m}_o) depending the exact system operating point on the fan curve. The value selected for this thesis was $2:1$. The results obtained agree reasonably well with experimental data thereby providing some justification for its use.

The surface areas for the various oven components were taken off the construction prints from a typical oven and are listed below:

- | | |
|---------------------------------|--------------------------------|
| 1) $A_w = 4902. \text{ft}^2$ | 5) $A_{D4} = 156. \text{ft}^2$ |
| 2) $A_{D1} = 1428. \text{ft}^2$ | 6) $A_B = 4790. \text{ft}^2$ |
| 3) $A_{D2} = 264. \text{ft}^2$ | 7) $A_S = 1098. \text{ft}^2$ |
| 4) $A_{D3} = 1308. \text{ft}^2$ | 8) $A_T = 909. \text{ft}^2$ |

The values for the specific heats of the oven components were obtained from reference [10]. The specific heat of the air at constant pressure $C_p = 0.24 \text{ Btu/lb-}^\circ\text{F}$. The values of specific heat for the metallic oven components were found to be $C = 0.12 \text{ Btu/lb-}^\circ\text{F}$. The value of the specific heat for the fiberglass layers in the walls of the oven was given by the manufacturer $C_f = 0.24 \text{ Btu/lb-}^\circ\text{F}$. Also included from the manufacturer was the thermal resistance value for the fiberglass rated from 200°F to 400°F which was $K_f = 0.30 \text{ Btu-in/hr-}^\circ\text{F-ft}^2$.

The average heat transfer coefficients were determined for the components exposed to the oven air with recirculating fans on and again with the recirculating fans turned off. With the fans turned off the values for the components in the oven were selected at $1.1 \text{ Btu/hr-}^\circ\text{F-ft}^2$. This is a value typical for combined forced and free convection from flat plates for very low velocities [11].

The value selected for the condition when the recirculating fans were on was $3.3 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$. Again in this case an actual value would be practically impossible to determine because of the complex component shapes and air flow patterns. This value is however, reasonable when compared to the value at the lower flow rate and typical values listed in reference [11]. Some justification of the choice is provided by the fact that the chosen values caused the model to fit the actual data very closely.

The average heat transfer coefficients for the surfaces exposed to plant air were chosen at the still air value of $1.65 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ as given in reference [11].

Appendix B

COMPUTER PROGRAM AND SAMPLE OUTPUT

ILLEGIBLE DOCUMENT

**THE FOLLOWING
DOCUMENT(S) IS OF
POOR LEGIBILITY IN
THE ORIGINAL**

**THIS IS THE BEST
COPY AVAILABLE**


```

34 M03=1.1
35 AR=4700.2
36 W9=5189.1
37 CR=.12
38 R2=.30
39 AY=4902.
40 C41=.12
41 T1=1.33/2.
42 W01=7764.5
43 CW2=.24
44 W42=4750.
45 T=1.33
46 H2=1.65
47 AS=1008.
48 W5=10469.
49 AD1=1428.
50 W01=2136.
51 AD2=264.
52 M02=346.
53 M020=1.65
54 A03=1304.
55 M03=1962.
56 AT=009.1
57 WT=10702.
58 CP=.24
59 AD4=156.
60 2 A1=((HR*AY)/(WR*CH))*DT
61 A3=((R2*AY)/(CW1*T1*W01))*DT
62 A4=((T1*AY)/(W01*CW1))*DT
63 A5=((R2*AY)/(T1*CW2*W02))*DT
64 A7=((R2*AY)/(T1*CW2*W42))*DT
65 A9=((H2*AY)/(W01*CW1))*DT
66 A10=((H5*AS)/(WWS*CW1))*DT
67 A11=((W01*AD1)/(W01*CW1))*DT
68 A13=((M02*AD2)/(M02*CW1))*DT
69 A14=((M02*AD2)/(M02*CW1))*DT
70 A15=((M03*AD3)/(M03*CW1))*DT
71 A16=((M1*AT)/(WT*CW1))*DT
72 A12=A13+A14
73 AR=A0+A3
74 A6=A5+A7
75 A2=A3+A4
76 THE FOLLOWING THIRTEEN EQUATIONS ARE THE MODEL FOR THE OVEN.
WRITE(6,150)TA,T01,TW2,TW3,TW4,TW5,TS,TD1,TD2,TD3,TD4,T1,TA,TM,
1 TIME
150 FORKAT(15F8.3)
20 T01=A1*TA-(A1-1.)*TA
T2=TA+460.
W4=467241.25/T2
A17=W4*CP
W00=14596200./T2
W00=W00/2.
TM=T0
T01N=- (A2-1.)*TM1+A3*TM2+A4*TA
TM2=A5*TM1-(A6-1.)*TM2+A7*TM3
TM3=A7*TM2-(A5-1.)*TM3+A7*TM4
TM4=A7*TM3-(A6-1.)*TM4+A5*TM5
TM5=A3*TM4-(A8-1.)*TM5+A9*TP
TSM=-(A10-1.)*TS+A10*TA
TD1N=- (A11*2.-1.)*TD1+A11*TM+A11*TA

```

```

02 1023=- (A12-1.)*T02+A13*TA+A14*TP
03 1033=- (A15-1.)*T03+A15*TA
04 1043=- (A12-1.)*T04+A13*TA+A14*TP
05 1053=- (A16-1.)*T1+A16*TA
06 1063= (W1/A17)*(H4*H3*TA+H1*H4*TW1+H5*AS*TS+H01*AD1*TD1)+
107 1073= (W02*H03*AD3*TD3+H02*AD4*TD4+H1*TA*AT)
108 1083= ((W00/4A)*TD-3.05*126.)
109 1093= ((W00*CP+H1*H4*H5*H4*H5*AS+
110 1103= (A11/A17)*ED*DT- (A11+A13)*TW- (((W00*CP+H1*H4*H5*H4*H5*AS+
111 1113= Y0
112 1123= R1.*R
113 1133= X1.*X
114 1143= TT*DT*X
115 1153= THE NEXT IF STATEMENT SETS THE NUMBER OF HEAT-UP RUNS IN THE
116 1163= 44. THESE ARE TO BE SET BY THE OPERATOR.
117 1173= 11.19,10,10
118 1183= 11.19,10,10
119 1193= 11.19,10,10
120 1203= 11.19,10,10
121 1213= 11.19,10,10
122 1223= 11.19,10,10
123 1233= 11.19,10,10
124 1243= 11.19,10,10
125 1253= 11.19,10,10
126 1263= 11.19,10,10
127 1273= 11.19,10,10
128 1283= 11.19,10,10
129 1293= 11.19,10,10
130 1303= 11.19,10,10
131 1313= 11.19,10,10
132 1323= 11.19,10,10
133 1333= 11.19,10,10
134 1343= 11.19,10,10
135 1353= 11.19,10,10
136 1363= 11.19,10,10
137 1373= 11.19,10,10
138 1383= 11.19,10,10
139 1393= 11.19,10,10
140 1403= 11.19,10,10
141 1413= 11.19,10,10

```

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142 A3=((I2=AN)/C4)=I1*(N1))#DT
143 A4=((M1=AN)/(I1=AN)*I1)#DT
144 A5=((I2=AN)/(I1=AN)*I2))#DT
145 A7=((I2=AN)/(I1=AN)*I2))#DT
146 A9=((I2=AN)/(I1=AN)*I2))#DT
147 A10=((M1=AN)/(I1=AN)*I1)#DT
148 A11=((M1=AN)/(I1=AN)*I1)#DT
149 A13=((M2=AN)/(I1=AN)*I1)#DT
150 A14=((M2=AN)/(I1=AN)*I1)#DT
151 A15=((M3=AN)/(I1=AN)*I1)#DT
152 A16=((M4=AN)/(I1=AN)*I1)#DT
153 A17=A13+A14
154 A8=A9+A3
155 A6=A5+A7
156 A2=A3+A4
157 R=0.
158
159 4. T4=T4N
160 T41=T4N
161 T42=T4N
162 T43=T4N
163 T44=T4N
164 T45=T4N
165 T46=T4N
166 T47=T4N
167 T48=T4N
168 T49=T4N
169 T50=T4N
170 T51=T4N
171 T52=T4N
172 T53=T4N
173 T54=T4N
174 T55=T4N
175 T56=T4N
176 T57=T4N
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180 T61=T4N
181 T62=T4N
182 T63=T4N
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184 T65=T4N
185 T66=T4N
186 T67=T4N
187 T68=T4N
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225 T106=T4N
226 T107=T4N
227 T108=T4N
228 T109=T4N
229 T110=T4N
230 T111=T4N
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508 T389=T4N
509 T
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106 R=0.
107 GO TO 4
C COMPUTE THE COST TO HEAT THE OVEN UP AND ALSO THE COST TO
C HOLD THE OVEN AT THE STEADY-STATE CONDITION.
108 A WRITE(6,400)TAN,TWIN,TW2N,TW3N,TW4N,TW5N,TSN,TD1N,TD2N,TD3N,TD4N,
109 TTN,TNA,TN,TIME
110 ATIME=ED*(TIME-Y1)
111 ATUREEDSS=ATIME*50002.*TIME
112 SAVE=ATUR-ATUH
113 SAVE=(SAVE/ATUH)*100.
114 WRITE(6,220)SAVE
200 FOR AT(10,T4,THE PERCENT STEADY-STATE ENERGY SAVED=F7.2)
115 WRITE(6,210)RTUH,RTUR,SAVE
210 FOR AT(10,T4,RTUS TO HEAT-UP=F16.8,T45,RTUS TO HOLD=F1,
116 T16,T10,RTUS SAVES=F14.8)
C COMPUTE THE PERCENT SAVINGS TO SHUT DOWN THE OVEN.
117 DOLS=.65*(SAVE/1000000.)
WRITE(6,290)DOLS
200 FOR AT(10,T4,THE SAVINGS BY COOLING DOWN THE OVEN=F10.2)
C RESET THE INITIAL CONDITIONS IN THE PROBLEM TO THE VALUE THEY
C WERE WHEN HEAT-UP WAS STARTED.
118 ED=0.
119 TT=F5.Y1
120 TS=Y2
121 T1=Y3
122 T2=Y4
123 T3=Y5
124 T4=Y6
125 T5=Y7
126 TS=Y8
127 T1=Y9
128 T2=Y10
129 T3=Y11
130 T4=Y12
131 TT=Y13
132 T6=Y14
133 X=Y15
134 T2=Y16
135 T3=Y17
136 T4=Y18
137 R=Y19
138 H1=Y30
139 H4=Y31
140 MS=Y32
141 H01=Y35
142 H03=Y36
143 HT=Y37
144 H02=Y38
145 S=Y41.
WRITE(6,140)S
140 FOR AT(10,T4,RETURN TO COOLING,T45,S=F5.2)
WRITE(6,400)
400 FOR AT(10,T4,T1,T2,TW1,TW2,TW3,TW4,TW5,TW6,TW7,TW8,
141 TW9,TW10,TW11,TW12,TW13,TW14,TW15,TW16,TW17,TW18,TW19,
142 TW20,TW21,TW22,TW23,TW24,TW25,TW26,TW27,TW28,TW29,TW30,
143 TW31,TW32,TW33,TW34,TW35,TW36,TW37,TW38,TW39,TW40,TW41,
144 TW42,TW43,TW44,TW45,TW46,TW47,TW48,TW49,TW50,TW51,TW52,
145 TS,T6,T10,T16,T20,T24,T28,T32,T36,T40,T44,T48,T52,
146 T56,T60,T64,T68,T72,T76,T80,T84,T88,T92,T96,T100,
147 T104,T108,T112,T116,T120,T124,T128,T132,T136,T140,T144,
145 T148,T152,T156,T160,T164,T168,T172,T176,T180,T184,T188,
146 T192,T196,T200,T204,T208,T212,T216,T220,T224,T228,
147 T232,T236,T240,T244,T248,T252,T256,T260,T264,T268,T272,
148 T276,T280,T284,T288,T292,T296,T300,T304,T308,T312,T316,
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370 T8400,T8404,T8408,T8412,T8416,T8420,T8424,T8428,T8432,
371 T84
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245      ITM,TMA,TM,TIME
246      100 FORMAT(15F8.3)
247      R=0.
248      40 TM=TMN
249      TM1=TM1N
250      TM2=TM2N
251      TM3=TM3N
252      TM4=TM4N
253      TM5=TM5N
254      TS=TSN
255      T01=T01N
256      T02=T02N
257      T03=T03N
258      T04=T04N
259      TT=TTN
260      TA=TAN
261      C TEST IF THE OVEN HAS COOLED PAST THE DESIRED STOPPING POINT.
262      IF(TA-70.)10,10,20
263      10 CONTINUE
264      STOP
265      END
266
267      SENTRY

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SAMPLE OUTPUT

| IB | IM1 | IM2 | IM3 | IM4 | IM5 | IS | IM1 | IM2 | IM3 | IM4 | IT | IT2 | ITM |
|---------|---------|---------|---------|---------|--------|---------|---------|---------|---------|---------|---------|---------|-------|
| 315.000 | 300.517 | 268.908 | 193.306 | 118.104 | 80.495 | 315.000 | 322.528 | 186.236 | 315.000 | 315.000 | 315.000 | 315.000 | 0.000 |
| 300.648 | 293.648 | 267.825 | 193.472 | 115.106 | 80.383 | 312.820 | 217.546 | 91.786 | 305.622 | 191.081 | 313.217 | 276.631 | 0.100 |
| 282.360 | 279.148 | 264.594 | 193.243 | 118.046 | 80.344 | 308.822 | 179.529 | 71.529 | 287.602 | 158.000 | 309.918 | 261.029 | 0.200 |
| 265.644 | 265.924 | 259.803 | 192.701 | 118.034 | 80.326 | 303.748 | 163.009 | 67.165 | 271.784 | 146.093 | 305.685 | 246.958 | 0.300 |
| 251.187 | 254.175 | 254.076 | 191.774 | 117.931 | 80.309 | 297.958 | 153.703 | 66.253 | 257.357 | 139.573 | 300.805 | 235.109 | 0.400 |
| 238.727 | 243.691 | 247.655 | 190.468 | 117.754 | 80.282 | 291.686 | 147.132 | 66.253 | 244.531 | 134.762 | 295.462 | 224.791 | 0.500 |

HEAT-UP BEGINS HERE

| | | | | | | | | | | | | | |
|---------|---------|---------|---------|---------|--------|---------|---------|---------|---------|---------|---------|---------|---------|
| 274.969 | 266.868 | 244.126 | 188.968 | 117.693 | 80.241 | 286.465 | 303.753 | 234.021 | 271.262 | 204.596 | 290.287 | 269.281 | 341.762 |
| 287.870 | 279.853 | 244.507 | 188.297 | 117.370 | 80.220 | 287.343 | 317.778 | 248.065 | 283.629 | 215.094 | 290.666 | 300.091 | 351.593 |

THE PERCENT STEADY-STATE ENERGY SAVED= 65.41

BTUS TO HEAT-UP= 0.2918990E 06 BTUS TO HOLD= 0.84397030E 06 BTUS SAVED= 0.55207040E 06

THE SAVINGS BY LOADING DOWN THE UOEN=3 0.36

RETURN TO COOLING S= 2.00

| T0 | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 | T16 | T17 | T18 | T19 | T20 | T21 | T22 | T23 | T24 | T25 | T26 | T27 | T28 | T29 | T30 | T31 | T32 | T33 | T34 | T35 | T36 | T37 | T38 | T39 | T40 | T41 | T42 | T43 | T44 | T45 | T46 | T47 | T48 | T49 | T50 | T51 | T52 | T53 | T54 | T55 | T56 | T57 | T58 | T59 | T60 | T61 | T62 | T63 | T64 | T65 | T66 | T67 | T68 | T69 | T70 | T71 | T72 | T73 | T74 | T75 | T76 | T77 | T78 | T79 | T80 | T81 | T82 | T83 | T84 | T85 | T86 | T87 | T88 | T89 | T90 | T91 | T92 | T93 | T94 | T95 | T96 | T97 | T98 | T99 | T100 | T101 | T102 | T103 | T104 | T105 | T106 | T107 | T108 | T109 | T110 | T111 | T112 | T113 | T114 | T115 | T116 | T117 | T118 | T119 | T120 | T121 | T122 | T123 | T124 | T125 | T126 | T127 | T128 | T129 | T130 | T131 | T132 | T133 | T134 | T135 | T136 | T137 | T138 | T139 | T140 | T141 | T142 | T143 | T144 | T145 | T146 | T147 | T148 | T149 | T150 | T151 | T152 | T153 | T154 | T155 | T156 | T157 | T158 | T159 | T160 | T161 | T162 | T163 | T164 | T165 | T166 | T167 | T168 | T169 | T170 | T171 | T172 | T173 | T174 | T175 | T176 | T177 | T178 | T179 | T180 | T181 | T182 | T183 | T184 | T185 | T186 | T187 | T188 | T189 | T190 | T191 | T192 | T193 | T194 | T195 | T196 | T197 | T198 | T199 | T200 | T201 | T202 | T203 | T204 | T205 | T206 | T207 | T208 | T209 | T210 | T211 | T212 | T213 | T214 | T215 | T216 | T217 | T218 | T219 | T220 | T221 | T222 | T223 | T224 | T225 | T226 | T227 | T228 | T229 | T230 | T231 | T232 | T233 | T234 | T235 | T236 | T237 | T238 | T239 | T240 | T241 | T242 | T243 | T244 | T245 | T246 | T247 | T248 | T249 | T250 | T251 | T252 | T253 | T254 | T255 | T256 | T257 | T258 | T259 | T260 | T261 | T262 | T263 | T264 | T265 | T266 | T267 | T268 | T269 | T270 | T271 | T272 | T273 | T274 | T275 | T276 | T277 | T278 | T279 | T280 | T281 | T282 | T283 | T284 | T285 | T286 | T287 | T288 | T289 | T290 | T291 | T292 | T293 | T294 | T295 | T296 | T297 | T298 | T299 | T300 | T301 | T302 | T303 | T304 | T305 | T306 | T307 | T308 | T309 | T310 | T311 | T312 | T313 | T314 | T315 | T316 | T317 | T318 | T319 | T320 | T321 | T322 | T323 | T324 | T325 | T326 | T327 | T328 | T329 | T330 | T331 | T332 | T333 | T334 | T335 | T336 | T337 | T338 | T339 | T340 | T341 | T342 | T343 | T344 | T345 | T346 | T347 | T348 | T349 | T350 | T351 | T352 | T353 | T354 | T355 | T356 | T357 | T358 | T359 | T360 | T361 | T362 | T363 | T364 | T365 | T366 | T367 | T368 | T369 | T370 | T371 | T372 | T373 | T374 | T375 | T376 | T377 | T378 | T379 | T380 | T381 | T382 | T383 | T384 | T385 | T386 | T387 | T388 | T389 | T390 | T391 | T392 | T393 | T394 | T395 | T396 | T397 | T398 | T399 | T400 | T401 | T402 | T403 | T404 | T405 | T406 | T407 | T408 | T409 | T410 | T411 | T412 | T413 | T414 | T415 | T416 | T417 | T418 | T419 | T420 | T421 | T422 | T423 | T424 | T425 | T426 | T427 | T428 | T429 | T430 | T431 | T432 | T433 | T434 | T435 | T436 | T437 | T438 | T439 | T440 | T441 | T442 | T443 | T444 | T445 | T446 | T447 | T448 | T449 | T450 | T451 | T452 | T453 | T454 | T455 | T456 | T457 | T458 | T459 | T460 | T461 | T462 | T463 | T464 | T465 | T466 | T467 | T468 | T469 | T470 | T471 | T472 | T473 | T474 | T475 | T476 | T477 | T478 | T479 | T480 | T481 | T482 | T483 | T484 | T485 | T486 | T487 | T488 | T489 | T490 | T491 | T492 | T493 | T494 | T495 | T496 | T497 | T498 | T499 | T500 | T501 | T502 | T503 | T504 | T505 | T506 | T507 | T508 | T509 | T510 | T511 | T512 | T513 | T514 | T515 | T516 | T517 | T518 | T519 | T520 | T521 | T522 | T523 | T524 | T525 | T526 | T527 | T528 | T529 | T530 | T531 | T532 | T533 | T534 | T535 | T536 | T537 | T538 | T539 | T540 | T541 | T542 | T543 | T544 | T545 | T546 | T547 | T548 | T549 | T550 | T551 | T552 | T553 | T554 | T555 | T556 | T557 | T558 | T559 | T560 | T561 | T562 | T563 | T564 | T565 | T566 | T567 | T568 | T569 | T570 | T571 | T572 | T573 | T574 | T575 | T576 | T577 | T578 | T579 | T580 | T581 | T582 | T583 | T584 | T585 | T586 | 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T730 | T731 | T732 | T733 | T734 | T735 | T736 | T737 | T738 | T739 | T740 | T741 | T742 | T743 | T744 | T745 | T746 | T747 | T748 | T749 | T750 | T751 | T752 | T753 | T754 | T755 | T756 | T757 | T758 | T759 | T760 | T761 | T762 | T763 | T764 | T765 | T766 | T767 | T768 | T769 | T770 | T771 | T772 | T773 | T774 | T775 | T776 | T777 | T778 | T779 | T780 | T781 | T782 | T783 | T784 | T785 | T786 | T787 | T788 | T789 | T790 | T791 | T792 | T793 | T794 | T795 | T796 | T797 | T798 | T799 | T800 | T801 | T802 | T803 | T804 | T805 | T806 | T807 | T808 | T809 | T810 | T811 | T812 | T813 | T814 | T815 | T816 | T817 | T818 | T819 | T820 | T821 | T822 | T823 | T824 | T825 | T826 | T827 | T828 | T829 | T830 | T831 | T832 | T833 | T834 | T835 | T836 | T837 | T838 | T839 | T840 | T841 | T842 | T843 | T844 | T845 | T846 | T847 | T848 | T849 | T850 | T851 | T852 | T853 | T854 | T855 | T856 | T857 | T858 | T859 | T860 | T861 | T862 | T863 | T864 | T865 | T866 | T867 | T868 | T869 | T870 | T871 | T872 | T873 | T874 | T875 | T876 | T877 | T878 | T879 | T880 | T881 | T882 | T883 | T884 | T885 | T886 | T887 | T888 | T889 | T890 | T891 | T892 | T893 | T894 | T895 | T896 | T897 | T898 | T899 | T900 | T901 | T902 | T903 | T904 | T905 | T906 | T907 | T908 | T909 | T910 | T911 | T912 | T913 | T914 | T915 | T916 | T917 | T918 | T919 | T920 | T921 | T922 | T923 | T924 | T925 | T926 | T927 | T928 | T929 | T930 | T931 | T932 | T933 | T934 | T935 | T936 | T937 | T938 | T939 | T940 | T941 | T942 | T943 | T944 | T945 | T946 | T947 | T948 | T949 | T950 | T951 | T952 | T953 | T954 | T955 | T956 | T957 | T958 | T959 | T960 | T961 | T962 | T963 | T964 | T965 | T966 | T967 | T968 | T969 | T970 | T971 | T972 | T973 | T974 | T975 | T976 | T977 | T978 | T979 | T980 | T981 | T982 | T983 | T984 | T985 | T986 | T987 | T988 | T989 | T990 | T991 | T992 | T993 | T994 | T995 | T996 | T997 | T998 | T999 | T1000 | T1001 | T1002 | T1003 | T1004 | T1005 | T1006 | T1007 | T1008 | T1009 | T1010 | T1011 | T1012 | T1013 | T1014 | T1015 | T1016 | T1017 | T1018 | T1019 | T1020 | T1021 | T1022 | T1023 | T1024 | T1025 | T1026 | T1027 | T1028 | T1029 | T1030 | T1031 | T1032 | T1033 | T1034 | T1035 | T1036 | T1037 | T1038 | T1039 | T1040 | T1041 | T1042 | T1043 | T1044 | T1045 | T1046 | T1047 | T1048 | T1049 | T1050 | T1051 | T1052 | T1053 | T1054 | T1055 | T1056 | T1057 | T1058 | T1059 | T1060 | T1061 | T1062 | T1063 | T1064 | T1065 | T1066 | T1067 | T1068 | T1069 | T1070 | T1071 | T1072 | T1073 | T1074 | T1075 | T1076 | T1077 | T1078 | T1079 | T1080 | T1081 | T1082 | T1083 | T1084 | T1085 | T1086 | T1087 | T1088 | T1089 | T1090 | T1091 | T1092 | T1093 | T1094 | T1095 | T1096 | T1097 | T1098 | T1099 | T1100 | T1101 | T1102 | T1103 | T1104 | T1105 | T1106 | T1107 | T1108 | T1109 | T1110 | T1111 | T1112 | T1113 | T1114 | T1115 | T1116 | T1117 | T1118 | T1119 | T1120 | T1121 | T1122 | T1123 | T1124 | T1125 | T1126 | T1127 | T1128 | T1129 | T1130 | T1131 | T1132 | T1133 | T1134 | T1135 | T1136 | T1137 | T1138 | T1139 | T1140 | T1141 | T1142 | T1143 | T1144 | T1145 | T1146 | T1147 | T1148 | T1149 | T1150 | T1151 | T1152 | T1153 | T1154 | T1155 | T1156 | T1157 | T1158 | T1159 | T1160 | T1161 | T1162 | T1163 | T1164 | T1165 | T1166 | T1167 | T1168 | T1169 | T1170 | T1171 | T1172 | T1173 | T1174 | T1175 | T1176 | T1177 | T1178 | T1179 | T1180 | T1181 | T1182 | T1183 | T1184 | T1185 | T1186 | T1187 | T1188 | T1189 | T1190 | T1191 | T1192 | T1193 | T1194 | T1195 | T1196 | T1197 | T1198 | T1199 | T1200 | T1201 | T1202 | T1203 | T1204 | T1205 | T1206 | T1207 | T1208 | T1209 | T1210 | T1211 | T1212 | T1213 | T1214 | T1215 | T1216 | T1217 | T1218 | T1219 | T1220 | T1221 | T1222 | T1223 | T1224 | T1225 | T1226 | T1227 | T1228 | T1229 | T1230 | T1231 | T1232 | T1233 | T1234 | T1235 | T1236 | T1237 | T1238 | T1239 | T1240 | T1241 | T1242 | T1243 | T1244 | T1245 | T1246 | T1247 | T1248 | T1249 | T1250 | T1251 | T1252 | T1253 | T1254 | T1255 | T1256 | T1257 | T1258 | T1259 | T1260 | T1261 | T1262 | T1263 | T1264 | T1265 | T1266 | T1267 | T1268 | T1269 | T1270 | T1271 | T1272 | T1273 | T1274 | T1275 | T1276 | T1277 | T1278 | T1279 | T1280 | T1281 | T1282 | T1283 | T1284 | T1285 | T1286 | T1287 | T1288 | T1289 | T1290 | T1291 | T1292 | T1293 | T1294 | T1295 | T1296 | T1297 | T1298 | T1299 | T1300 | T1301 | T1302 | T1303 | T1304 | T1305 | T1306 | T1307 | T1308 | T1309 | T1310 | T1311 | T1312 | T1313 | T1314 | T1315 | T1316 | T1317 | T1318 | T1319 | T1320 | T1321 | T1322 | T1323 | T1324 | T1325 | T1326 | T1327 | T1328 | T1329 | T1330 | T1331 | T1332 | T1333 | T1334 | T1335 | T1336 | T1337 | T1338 | T1339 | T1340 | T1341 | T1342 | T1343 | T1344 | T1345 | T1346 | T1347 | T1348 | T1349 | T1350 | T1351 | T1352 | T1353 | T1354 | T1355 | T1356 | T1357 | T1358 | T1359 | T1360 | T1361 | T1362 | T1363 | T1364 | T1365 | T1366 | T1367 | T1368 | T1369 | T1370 | T1371 | T1372 | T1373 | T1374 | T1375 | T1376 | T1377 | T1378 | T1379 | T1380 | T1381 | T1382 | T1383 | T1384 | T1385 | T1386 | T1387 | T1388 | T1389 | T1390 | T1391 | T1392 | T1393 | T1394 | T1395 | T1396 | T1397 | T1398 | T1399 | T1400 | T1401 | T1402 | T1403 | T1404 | T1405 | T1406 | T1407 | T1408 | T1409 | T1410 | T1411 | T1412 | T1413 | T1414 | T1415 | T1416 | T1417 | T1418 | T1419 | T1420 | T1421 | T1422 | T1423 | T1424 | T1425 | T1426 | T1427 | T1428 | T1429 | T1430 | T1431 | T1432 | T1433 | T1434 | T1435 | T1436 | T1437 | T1438 | T1439 | T1440 | T1441 | T1442 | T1443 | T1444 | T1445 | T1446 | T1447 | T1448 | T1449 | T1450 | T1451 | T1452 | T1453 | T1454 | T1455 | T1456 | T1457 | T1458 | T1459 | T1460 | T1461 | T1462 | T1463 | T1464 | T1465 | T1466 | T1467 | T1468 | T1469 | T1470 | T1471 | T1472 | T1473 | T1474 | T1475 | T1476 | T1477 | T1478 | T1479 | T1480 | T1481 | T1482 | T1483 | T1484 | T1485 | T1486 | T1487 | T1488 | T1489 | T |
|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------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|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------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--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---|

RETURN TO COOLING S= 3.00

| TS | TM1 | TM2 | TM3 | TM4 | TM5 | TS | TA | TD2 | TD3 | TD4 | TT | TA | TM | TM |
|---------|---------|---------|---------|---------|--------|---------|---------|--------|---------|---------|---------|---------|--------|------|
| 194.365 | 202.984 | 216.003 | 179.574 | 115.477 | 79.831 | 257.546 | 125.710 | 65.999 | 197.895 | 118.108 | 265.468 | 185.677 | 60.000 | 1.00 |
| 194.754 | 202.916 | 215.943 | 179.547 | 115.471 | 79.880 | 257.477 | 125.676 | 65.999 | 197.811 | 118.081 | 265.405 | 185.613 | 60.000 | 1.00 |
| 187.463 | 196.300 | 209.576 | 176.800 | 114.739 | 79.740 | 256.610 | 122.335 | 65.999 | 190.737 | 115.479 | 259.180 | 179.571 | 60.000 | 1.00 |
| 181.092 | 191.021 | 204.597 | 173.951 | 113.921 | 79.582 | 245.640 | 119.287 | 65.999 | 184.130 | 113.226 | 252.977 | 173.662 | 60.000 | 1.00 |
| 175.079 | 184.069 | 198.627 | 171.029 | 113.056 | 79.406 | 237.125 | 116.354 | 65.999 | 177.918 | 110.701 | 246.819 | 168.042 | 60.000 | 1.00 |
| 169.375 | 176.480 | 193.201 | 168.058 | 112.123 | 79.219 | 230.540 | 113.565 | 65.999 | 172.045 | 108.489 | 240.712 | 162.691 | 60.000 | 1.00 |
| 163.995 | 171.991 | 193.024 | 165.098 | 111.151 | 79.021 | 224.144 | 110.930 | 65.999 | 166.522 | 106.398 | 234.730 | 157.617 | 60.000 | 1.00 |

HEAT-UP BEGINS HERE

| | | | | | | | | | | | | | | |
|---------|---------|---------|---------|---------|--------|---------|---------|---------|---------|---------|---------|---------|---------|-------|
| 210.365 | 204.625 | 185.553 | 162.161 | 110.131 | 78.810 | 219.766 | 243.664 | 198.005 | 205.177 | 163.009 | 248.837 | 220.459 | 284.975 | 1.631 |
| 242.914 | 235.436 | 189.638 | 159.756 | 109.106 | 78.593 | 225.770 | 275.089 | 233.696 | 236.367 | 185.932 | 231.411 | 253.494 | 309.532 | 1.771 |
| 265.551 | 254.708 | 196.367 | 158.166 | 108.156 | 78.377 | 234.972 | 295.676 | 237.541 | 262.202 | 200.911 | 238.238 | 273.413 | 327.554 | 1.871 |
| 283.188 | 271.557 | 204.461 | 157.440 | 107.279 | 78.176 | 246.760 | 311.933 | 248.087 | 280.571 | 212.557 | 247.357 | 289.613 | 342.219 | 1.971 |
| 294.282 | 282.243 | 210.733 | 157.421 | 106.753 | 78.044 | 255.953 | 322.269 | 254.729 | 291.990 | 219.904 | 254.834 | 300.093 | 351.702 | 1.974 |

THE PERCENT STEADY-STATE ENERGY SAVED= 61.84

BTUS TO HEAT-UP= C.99329900E 06 BTUS TO HOLD= 0.26931190E 07 BTUS SAVED= 0.16098190E 07

THE SAVINGS BY COOLING DURN THE OVEN= \$ 1.06

RETURN TO COOLING S= 5.00

| TS | TW1 | TW2 | TW3 | TW4 | TW5 | TL | TU1 | TU2 | TU3 | TU4 | FT | TA | TM |
|--------------------|---------|---------|---------|---------|--------|---------|---------|---------|---------|---------|---------|---------|---------|
| 140.047 | 148.799 | 164.291 | 150.140 | 105.785 | 77.898 | 193.947 | 99.159 | 65.999 | 142.060 | 97.045 | 295.825 | 134.837 | 60.000 |
| 140.003 | 148.755 | 164.247 | 150.111 | 105.783 | 77.896 | 193.860 | 99.137 | 65.999 | 142.016 | 97.028 | 295.770 | 134.795 | 59.000 |
| 135.747 | 144.430 | 159.936 | 147.199 | 104.559 | 77.658 | 184.054 | 97.041 | 65.999 | 137.635 | 95.361 | 200.296 | 130.726 | 60.000 |
| 131.643 | 140.252 | 155.755 | 144.328 | 103.552 | 77.419 | 182.794 | 95.618 | 65.999 | 133.596 | 93.752 | 194.932 | 126.799 | 60.000 |
| 127.861 | 136.215 | 151.699 | 141.502 | 102.438 | 77.180 | 177.484 | 93.668 | 65.999 | 129.478 | 92.200 | 189.652 | 123.006 | 59.000 |
| 123.857 | 132.311 | 147.764 | 138.725 | 101.323 | 76.961 | 172.517 | 91.180 | 65.999 | 125.590 | 90.700 | 184.525 | 119.541 | 58.000 |
| 120.149 | 128.573 | 143.982 | 136.025 | 100.239 | 76.706 | 167.345 | 89.377 | 65.999 | 121.872 | 89.265 | 173.573 | 115.836 | 57.000 |
| HEAT-UP ENERGY PER | | | | | | | | | | | | | |
| 169.032 | 162.870 | 143.427 | 133.442 | 94.151 | 75.470 | 166.904 | 205.158 | 174.764 | 163.521 | 136.243 | 176.611 | 185.392 | 247.854 |
| 200.008 | 192.560 | 148.485 | 131.446 | 98.103 | 76.239 | 175.503 | 236.213 | 199.156 | 197.361 | 158.717 | 161.543 | 212.719 | 272.643 |
| 244.712 | 214.085 | 159.568 | 120.304 | 97.151 | 76.019 | 187.425 | 257.082 | 213.094 | 221.559 | 173.859 | 190.299 | 231.746 | 295.973 |
| 242.915 | 231.350 | 165.436 | 130.943 | 96.367 | 75.821 | 201.050 | 273.625 | 223.821 | 240.252 | 185.710 | 201.009 | 249.453 | 305.917 |
| 250.154 | 246.130 | 174.698 | 130.587 | 95.729 | 75.656 | 215.105 | 287.843 | 232.949 | 255.912 | 195.807 | 212.687 | 263.398 | 318.988 |
| 271.858 | 259.478 | 184.401 | 131.928 | 95.320 | 75.530 | 229.089 | 300.731 | 241.179 | 269.853 | 204.913 | 224.803 | 277.148 | 330.972 |
| 284.662 | 271.954 | 194.794 | 133.659 | 95.128 | 75.447 | 242.787 | 312.821 | 248.876 | 282.795 | 213.428 | 237.071 | 289.673 | 342.298 |
| 295.222 | 282.255 | 201.765 | 135.620 | 95.135 | 75.413 | 254.282 | 322.820 | 255.229 | 293.431 | 220.457 | 247.627 | 300.080 | 351.708 |

THE PERCENT STEADY-STATE ENERGY SAVED= 61.92

RTUS TO HEAT-UP= 0.10506000E 07 RTUS TO HOLD= 0.4334578CE 07 RTUS SAVED= 0.26839780E 07

THE SAVINGS BY COOLING DOWN THE LVEN= 3

1.77

RETURN TO COOLING S= 6.00

| T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 | T16 | T17 | T18 | T19 | T20 | T21 | T22 | T23 | T24 | T25 | T26 | T27 | T28 | T29 | T30 | T31 | T32 | T33 | T34 | T35 | T36 | T37 | T38 | T39 | T40 | T41 | T42 | T43 | T44 | T45 | T46 | T47 | T48 | T49 | T50 | T51 | T52 | T53 | T54 | T55 | T56 | T57 | T58 | T59 | T60 | T61 | T62 | T63 | T64 | T65 | T66 | T67 | T68 | T69 | T70 | T71 | T72 | T73 | T74 | T75 | T76 | T77 | T78 | T79 | T80 | T81 | T82 | T83 | T84 | T85 | T86 | T87 | T88 | T89 | T90 | T91 | T92 | T93 | T94 | T95 | T96 | T97 | T98 | T99 | T100 | T101 | T102 | T103 | T104 | T105 | T106 | T107 | T108 | T109 | T110 | T111 | T112 | T113 | T114 | T115 | T116 | T117 | T118 | T119 | T120 | T121 | T122 | T123 | T124 | T125 | T126 | T127 | T128 | T129 | T130 | T131 | T132 | T133 | T134 | T135 | T136 | T137 | T138 | T139 | T140 | T141 | T142 | T143 | T144 | T145 | T146 | T147 | T148 | T149 | T150 | T151 | T152 | T153 | T154 | T155 | T156 | T157 | T158 | T159 | T160 | T161 | T162 | T163 | T164 | T165 | T166 | T167 | T168 | T169 | T170 | T171 | T172 | T173 | T174 | T175 | T176 | T177 | T178 | T179 | T180 | T181 | T182 | T183 | T184 | T185 | T186 | T187 | T188 | T189 | T190 | T191 | T192 | T193 | T194 | T195 | T196 | T197 | T198 | T199 | T200 | T201 | T202 | T203 | T204 | T205 | T206 | T207 | T208 | T209 | T210 | T211 | T212 | T213 | T214 | T215 | T216 | T217 | T218 | T219 | T220 | T221 | T222 | T223 | T224 | T225 | T226 | T227 | T228 | T229 | T230 | T231 | T232 | T233 | T234 | T235 | T236 | T237 | T238 | T239 | T240 | T241 | T242 | T243 | T244 | T245 | T246 | T247 | T248 | T249 | T250 | T251 | T252 | T253 | T254 | T255 | T256 | T257 | T258 | T259 | T260 | T261 | T262 | T263 | T264 | T265 | T266 | T267 | T268 | T269 | T270 | T271 | T272 | T273 | T274 | T275 | T276 | T277 | T278 | T279 | T280 | T281 | T282 | T283 | T284 | T285 | T286 | T287 | T288 | T289 | T290 | T291 | T292 | T293 | T294 | T295 | T296 | T297 | T298 | T299 | T300 | T301 | T302 | T303 | T304 | T305 | T306 | T307 | T308 | T309 | T310 | T311 | T312 | T313 | T314 | T315 | T316 | T317 | T318 | T319 | T320 | T321 | T322 | T323 | T324 | T325 | T326 | T327 | T328 | T329 | T330 | T331 | T332 | T333 | T334 | T335 | T336 | T337 | T338 | T339 | T340 | T341 | T342 | T343 | T344 | T345 | T346 | T347 | T348 | T349 | T350 | T351 | T352 | T353 | T354 | T355 | T356 | T357 | T358 | T359 | T360 | T361 | T362 | T363 | T364 | T365 | T366 | T367 | T368 | T369 | T370 | T371 | T372 | T373 | T374 | T375 | T376 | T377 | T378 | T379 | T380 | T381 | T382 | T383 | T384 | T385 | T386 | T387 | T388 | T389 | T390 | T391 | T392 | T393 | T394 | T395 | T396 | T397 | T398 | T399 | T400 | T401 | T402 | T403 | T404 | T405 | T406 | T407 | T408 | T409 | T410 | T411 | T412 | T413 | T414 | T415 | T416 | T417 | T418 | T419 | T420 | T421 | T422 | T423 | T424 | T425 | T426 | T427 | T428 | T429 | T430 | T431 | T432 | T433 | T434 | T435 | T436 | T437 | T438 | T439 | T440 | T441 | T442 | T443 | T444 | T445 | T446 | T447 | T448 | T449 | T450 | T451 | T452 | T453 | T454 | T455 | T456 | T457 | T458 | T459 | T460 | T461 | T462 | T463 | T464 | T465 | T466 | T467 | T468 | T469 | T470 | T471 | T472 | T473 | T474 | T475 | T476 | T477 | T478 | T479 | T480 | T481 | T482 | T483 | T484 | T485 | T486 | T487 | T488 | T489 | T490 | T491 | T492 | T493 | T494 | T495 | T496 | T497 | T498 | T499 | T500 | T501 | T502 | T503 | T504 | T505 | T506 | T507 | T508 | T509 | T510 | T511 | T512 | T513 | T514 | T515 | T516 | T517 | T518 | T519 | T520 | T521 | T522 | T523 | T524 | T525 | T526 | T527 | T528 | T529 | T530 | T531 | T532 | T533 | T534 | T535 | T536 | T537 | T538 | T539 | T540 | T541 | T542 | T543 | T544 | T545 | T546 | T547 | T548 | T549 | T550 | T551 | T552 | T553 | T554 | T555 | T556 | T557 | T558 | T559 | T560 | T561 | T562 | T563 | T564 | T565 | T566 | T567 | T568 | T569 | T570 | T571 | T572 | T573 | T574 | T575 | T576 | T577 | T578 | T579 | T580 | T581 | T582 | T583 | T584 | T585 | T586 | T587 | T588 | T589 | T590 | T591 | T592 | T593 | T594 | T595 | T596 | T597 | T598 | T599 | T600 | T601 | T602 | T603 | T604 | T605 | T606 | T607 | T608 | T609 | T610 | T611 | T612 | T613 | T614 | T615 | T616 | T617 | T618 | T619 | T620 | T621 | T622 | T623 | T624 | T625 | T626 | T627 | T628 | T629 | T630 | T631 | T632 | T633 | T634 | T635 | T636 | T637 | T638 | T639 | T640 | T641 | T642 | T643 | T644 | T645 | T646 | T647 | T648 | T649 | T650 | T651 | T652 | T653 | T654 | T655 | T656 | T657 | T658 | T659 | T660 | T661 | T662 | T663 | T664 | T665 | T666 | T667 | T668 | T669 | T670 | T671 | T672 | T673 | T674 | T675 | T676 | T677 | T678 | T679 | T680 | T681 | T682 | T683 | T684 | T685 | T686 | T687 | T688 | T689 | T690 | T691 | T692 | T693 | T694 | T695 | T696 | T697 | T698 | T699 | T700 | T701 | T702 | T703 | T704 | T705 | T706 | T707 | T708 | T709 | T710 | T711 | T712 | T713 | T714 | T715 | T716 | T717 | T718 | T719 | T720 | T721 | T722 | T723 | T724 | T725 | T726 | T727 | T728 | T729 | T730 | T731 | T732 | T733 | T734 | T735 | T736 | T737 | T738 | T739 | T740 | T741 | T742 | T743 | T744 | T745 | T746 | T747 | T748 | T749 | T750 | T751 | T752 | T753 | T754 | T755 | T756 | T757 | T758 | T759 | T760 | T761 | T762 | T763 | T764 | T765 | T766 | T767 | T768 | T769 | T770 | T771 | T772 | T773 | T774 | T775 | T776 | T777 | T778 | T779 | T780 | T781 | T782 | T783 | T784 | T785 | T786 | T787 | T788 | T789 | T790 | T791 | T792 | T793 | T794 | T795 | T796 | T797 | T798 | T799 | T800 | T801 | T802 | T803 | T804 | T805 | T806 | T807 | T808 | T809 | T810 | T811 | T812 | T813 | T814 | T815 | T816 | T817 | T818 | T819 | T820 | T821 | T822 | T823 | T824 | T825 | T826 | T827 | T828 | T829 | T830 | T831 | T832 | T833 | T834 | T835 | T836 | T837 | T838 | T839 | T840 | T841 | T842 | T843 | T844 | T845 | T846 | T847 | T848 | T849 | T850 | T851 | T852 | T853 | T854 | T855 | T856 | T857 | T858 | T859 | T860 | T861 | T862 | T863 | T864 | T865 | T866 | T867 | T868 | T869 | T870 | T871 | T872 | T873 | T874 | T875 | T876 | T877 | T878 | T879 | T880 | T881 | T882 | T883 | T884 | T885 | T886 | T887 | T888 | T889 | T890 | T891 | T892 | T893 | T894 | T895 | T896 | T897 | T898 | T899 | T900 | T901 | T902 | T903 | T904 | T905 | T906 | T907 | T908 | T909 | T910 | T911 | T912 | T913 | T914 | T915 | T916 | T917 | T918 | T919 | T920 | T921 | T922 | T923 | T924 | T925 | T926 | T927 | T928 | T929 | T930 | T931 | T932 | T933 | T934 | T935 | T936 | T937 | T938 | T939 | T940 | T941 | T942 | T943 | T944 | T945 | T946 | T947 | T948 | T949 | T950 | T951 | T952 | T953 | T954 | T955 | T956 | T957 | T958 | T959 | T960 | T961 | T962 | T963 | T964 | T965 | T966 | T967 | T968 | T969 | T970 | T971 | T972 | T973 | T974 | T975 | T976 | T977 | T978 | T979 | T980 | T981 | T982 | T983 | T984 | T985 | T986 | T987 | T988 | T989 | T990 | T991 | T992 | T993 | T994 | T995 | T996 | T997 | T998 | T999 | T1000 | T1001 | T1002 | T1003 | T1004 | T1005 | T1006 | T1007 | T1008 | T1009 | T1010 | T1011 | T1012 | T1013 | T1014 | T1015 | T1016 | T1017 | T1018 | T1019 | T1020 | T1021 | T1022 | T1023 | T1024 | T1025 | T1026 | T1027 | T1028 | T1029 | T1030 | T1031 | T1032 | T1033 | T1034 | T1035 | T1036 | T1037 | T1038 | T1039 | T1040 | T1041 | T1042 | T1043 | T1044 | T1045 | T1046 | T1047 | T1048 | T1049 | T1050 | T1051 | T1052 | T1053 | T1054 | T1055 | T1056 | T1057 | T1058 | T1059 | T1060 | T1061 | T1062 | T1063 | T1064 | T1065 | T1066 | T1067 | T1068 | T1069 | T1070 | T1071 | T1072 | T1073 | T1074 | T1075 | T1076 | T1077 | T1078 | T1079 | T1080 | T1081 | T1082 | T1083 | T1084 | T1085 | T1086 | T1087 | T1088 | T1089 | T1090 | T1091 | T1092 | T1093 | T1094 | T1095 | T1096 | T1097 | T1098 | T1099 | T1100 | T1101 | T1102 | T1103 | T1104 | T1105 | T1106 | T1107 | T1108 | T1109 | T1110 | T1111 | T1112 | T1113 | T1114 | T1115 | T1116 | T1117 | T1118 | T1119 | T1120 | T1121 | T1122 | T1123 | T1124 | T1125 | T1126 | T1127 | T1128 | T1129 | T1130 | T1131 | T1132 | T1133 | T1134 | T1135 | T1136 | T1137 | T1138 | T1139 | T1140 | T1141 | T1142 | T1143 | T1144 | T1145 | T1146 | T1147 | T1148 | T1149 | T1150 | T1151 | T1152 | T1153 | T1154 | T1155 | T1156 | T1157 | T1158 | T1159 | T1160 | T1161 | T1162 | T1163 | T1164 | T1165 | T1166 | T1167 | T1168 | T1169 | T1170 | T1171 | T1172 | T1173 | T1174 | T1175 | T1176 | T1177 | T1178 | T1179 | T1180 | T1181 | T1182 | T1183 | T1184 | T1185 | T1186 | T1187 | T1188 | T1189 | T1190 | T1191 | T1192 | T1193 | T1194 | T1195 | T1196 | T1197 | T1198 | T1199 | T1200 | T1201 | T1202 | T1203 | T1204 | T1205 | T1206 | T1207 | T1208 | T1209 | T1210 | T1211 | T1212 | T1213 | T1214 | T1215 | T1216 | T1217 | T1218 | T1219 | T1220 | T1221 | T1222 | T1223 | T1224 | T1225 | T1226 | T1227 | T1228 | T1229 | T1230 | T1231 | T1232 | T1233 | T1234 | T1235 | T1236 | T1237 | T1238 | T1239 | T1240 | T1241 | T1242 | T1243 | T1244 | T1245 | T1246 | T1247 | T1248 | T1249 | T1250 | T1251 | T1252 | T1253 | T1254 | T1255 | T1256 | T1257 | T1258 | T1259 | T1260 | T1261 | T1262 | T1263 | T1264 | T1265 | T1266 | T1267 | T1268 | T1269 | T1270 | T1271 | T1272 | T1273 | T1274 | T1275 | T1276 | T1277 | T1278 | T1279 | T1280 | T1281 | T1282 | T1283 | T1284 | T1285 | T1286 | T1287 | T1288 | T1289 | T1290 | T1291 | T1292 | T1293 | T1294 | T1295 | T1296 | T1297 | T1298 | T1299 | T1300 | T1301 | T1302 | T1303 | T1304 | T1305 | T1306 | T1307 | T1308 | T1309 | T1310 | T1311 | T1312 | T1313 | T1314 | T1315 | T1316 | T1317 | T1318 | T1319 | T1320 | T1321 | T1322 | T1323 | T1324 | T1325 | T1326 | T1327 | T1328 | T1329 | T1330 | T1331 | T1332 | T1333 | T1334 | T1335 | T1336 | T1337 | T1338 | T1339 | T1340 | T1341 | T1342 | T1343 | T1344 | T1345 | T1346 | T1347 | T1348 | T1349 | T1350 | T1351 | T1352 | T1353 | T1354 | T1355 | T1356 | T1357 | T1358 | T1359 | T1360 | T1361 | T1362 | T1363 | T1364 | T1365 | T1366 | T1367 | T1368 | T1369 | T1370 | T1371 | T1372 | T1373 | T1374 | T1375 | T1376 | T1377 | T1378 | T1379 | T1380 | T1381 | T1382 | T1383 | T1384 | T1385 | T1386 | T1387 | T1388 | T1389 | T1390 | T1391 | T1392 | T1393 | T1394 | T1395 | T1396 | T1397 | T1398 | T1399 | T1400 | T1401 | T1402 | T1403 | T1404 | T1405 | T1406 | T1407 | T1408 | T1409 | T1410 | T1411 | T1412 | T1413 | T1414 | T1415 | T1416 | T1417 | T1418 | T1419 | T1420 | T1421 | T1422 | T1423 | T1424 | T1425 | T1426 | T1427 | T1428 | T1429 | T1430 | T1431 | T1432 | T1433 | T1434 | T1435 | T1436 | T1437 | T1438 | T1439 | T1440 | T1441 | T1442 | T1443 | T1444 | T1445 | T1446 | T1447 | T1448 | T1449 | T1450 | T1451 | T1452 | T1453 | T1454 | T1455 | T1456 | T1457 | T1458 | T1459 | T1460 | T1461 | T1462 | T1463 | T1464 | T1465 | T1466 | T1467 | T1468 | T1469 | T1470 | T1471 | T1472 | T1473 | T1474 | T1475 | T1476 | T1477 | T1478 | T1479 | T1480 | T1481 | T1482 | T1483 | T1484 | T1485 | T1486 | T1 |
|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----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RETURN TO COOLING S= 7.00

| IB | IA1 | IA2 | IA3 | IA4 | IA5 | IA | IB1 | IB2 | IB3 | IB4 | IT | TA | TM | IM |
|---------|---------|---------|---------|--------|--------|---------|--------|--------|---------|--------|---------|--------|--------|-------|
| 103.917 | 111.447 | 126.501 | 123.302 | 94.924 | 75.554 | 144.294 | 81.144 | 65.999 | 104.912 | 82.716 | 156.188 | 99.525 | 60.070 | 2.0.1 |
| 103.474 | 111.415 | 126.469 | 123.178 | 94.924 | 75.551 | 144.252 | 81.128 | 65.999 | 104.882 | 82.704 | 156.145 | 99.796 | 50.060 | 2.0.2 |
| 100.464 | 101.314 | 123.275 | 120.783 | 93.914 | 75.331 | 140.040 | 79.643 | 65.999 | 101.824 | 81.522 | 151.811 | 96.908 | 60.060 | 2.1.2 |
| 97.553 | 105.313 | 120.176 | 118.445 | 92.923 | 75.115 | 135.040 | 78.205 | 65.999 | 98.868 | 80.385 | 147.590 | 94.116 | 60.050 | 2.2.2 |
| 94.739 | 101.407 | 117.164 | 116.163 | 91.952 | 74.902 | 131.591 | 76.420 | 65.999 | 96.011 | 79.276 | 143.479 | 92.417 | 60.050 | 2.3.2 |
| 92.020 | 98.596 | 114.249 | 113.438 | 91.001 | 74.694 | 128.148 | 75.478 | 65.999 | 93.249 | 78.209 | 139.477 | 88.802 | 60.050 | 2.4.2 |
| 89.416 | 96.901 | 111.446 | 111.191 | 90.080 | 74.493 | 124.459 | 74.194 | 65.999 | 90.605 | 77.187 | 135.622 | 86.311 | 60.050 | 2.5.1 |

HEAT-UP BEGINS HERE

| | | | | | | | | | | | | | | |
|---------|---------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|-------|
| 139.917 | 135.216 | 111.585 | 109.774 | 89.173 | 74.293 | 127.502 | 177.855 | 158.569 | 124.170 | 117.361 | 135.777 | 156.432 | 201.676 | 2.6.1 |
| 173.202 | 161.250 | 118.076 | 109.356 | 88.313 | 74.101 | 134.535 | 208.639 | 181.977 | 168.443 | 139.554 | 143.213 | 184.032 | 246.713 | 2.7.1 |
| 196.490 | 185.561 | 126.855 | 107.792 | 87.560 | 73.922 | 152.742 | 234.749 | 195.937 | 193.016 | 154.874 | 154.015 | 204.584 | 265.334 | 2.8.0 |
| 214.757 | 203.043 | 136.710 | 108.099 | 86.958 | 73.766 | 167.998 | 246.870 | 206.861 | 212.045 | 166.946 | 166.413 | 221.431 | 280.566 | 2.9.0 |
| 230.333 | 216.209 | 146.872 | 109.194 | 86.546 | 73.644 | 183.356 | 261.405 | 216.191 | 228.042 | 177.267 | 179.498 | 236.208 | 293.956 | 4.0.1 |
| 244.362 | 231.920 | 157.007 | 110.765 | 86.344 | 73.563 | 196.399 | 274.563 | 224.612 | 242.311 | 186.584 | 192.794 | 249.765 | 306.219 | 4.1.1 |
| 257.454 | 244.739 | 166.961 | 113.334 | 86.358 | 73.525 | 212.794 | 286.947 | 234.482 | 255.549 | 195.291 | 206.057 | 262.565 | 317.793 | 4.2.1 |
| 269.934 | 256.972 | 175.753 | 116.112 | 85.584 | 73.552 | 227.015 | 298.771 | 239.997 | 268.123 | 203.605 | 219.166 | 274.860 | 328.910 | 4.3.1 |
| 282.016 | 268.790 | 189.341 | 119.317 | 87.012 | 73.584 | 240.576 | 310.224 | 247.267 | 280.263 | 211.668 | 232.056 | 286.802 | 339.718 | 4.4.1 |
| 295.809 | 280.328 | 195.751 | 122.823 | 87.629 | 73.679 | 253.700 | 321.415 | 254.366 | 292.096 | 219.502 | 244.738 | 298.496 | 350.279 | 4.5.1 |
| 295.325 | 281.813 | 196.563 | 123.301 | 87.722 | 73.695 | 255.377 | 322.855 | 255.279 | 293.617 | 220.512 | 246.368 | 300.002 | 351.651 | 4.5.4 |

THE PERCENT STEADY-STATE ENERGY SAVED= 64.26

BTUS TO HEAT-UP= 0.21272990E 07 BTUS TO HOLD= 0.59526270E 07 BTUS SAVED= 0.3E253280E 07

THE SAVINGS BY COOLING DOWN THE JVEN=3 2.52

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AN EVALUATION OF THE ENERGY CONSUMPTION
OF AUTOMOBILE PAINT-DRYING OVENS

by

Rodney Alan Walsh

B.S., General Motors Institute, 1973

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1973

ABSTRACT

The energy shortage presently facing this nation has caused a great deal of alarm and concern to all portions of society. The automobile industry, a major energy consumer, is attempting to reduce the amount of energy it consumes in an effort to lessen the energy shortage. Large scale energy evaluations of past and present processes are being conducted to see if any reduction in energy consumption can be obtained. One such process, automobile paint drying, was evaluated in this thesis.

The evaluation was conducted in three segments. The first segment was concerned with developing various schemes to reduce the energy consumption in the ovens. Two methods were determined to lower their energy requirements. The first method involves the shutting down of the ovens during periods when the paint lines are not running. It was found that the use of bang-bang control would minimize the energy consumed during the down time intervals. The second method proposed was the use of the waste heat from the ovens' exhaust gases. The use of rotary regenerative equipment was selected to obtain the heat recovery.

The second segment of the evaluation was to develop a transient, thermal model of the ovens. The model was used to obtain the information necessary for selecting the proper bang-bang control sequences which minimized the ovens' energy consumption. The model developed represents the thermal characteristics of the ovens' components with a set of linear first-order differential equations. A computer program was written which uses a finite difference technique to obtain the solutions to the model equations.

The final segment of the evaluation was concerned with the resultant savings from the two proposed methods for energy reduction. It was found that the bang-bang control scheme and the regenerative equipment both substantially reduced the energy-consumption of the ovens. The magnitude of the monetary savings from the reduction schemes was small because of the relatively small size of the burners being evaluated. However, with the availability of fuel decreasing rapidly, the fuel consumption savings are sure to increase in their significance.

VITA

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Thesis: AN EVALUATION OF THE ENERGY CONSUMPTION OF AUTOMOBILE PAINT
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