ENERGY COMPARISON OF HOT AND COLD BEEF PROCESSING

by

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INTRODUCTION

A prevalent practice in beef packing plants is to slaughter the animal and chill the carcass for approximately 24-72 hours. Frequently, following the cooling period, the excess fat and bone are removed as the carcass is fabricated into muscles and muscle systems before packaging and shipment. Recent studies on product quality indicate that a procedure usually termed hot boning or hot processing can be applied to produce beef steak, roast, and ground products. Hot processing entails the removal of excess fat and bone from the beef carcass soon after slaughter. The traditional cooling period after slaughter is either shortened or eliminated, thus, the carcass is warm when cut and the resultant cuts are subsequently chilled.

This study compares two hot-processing procedures to conventional centralized beef processing to determine what method is the most energy efficient. This comparison determines the difference in the average energy requirements of the various options and is not applicable to equipment sizing.

The energy comparisons are based upon model facilities that slaughter sixty head of cattle an hour for eight hours a day. However, conclusions found for this size hot-processing facility should not be unreservedly ascribed to other sized plants.

OBJECTIVES

1) To determine the rate of product cooling and the internal product temperature of the proposed hot-processing schemes through transient heat analysis.
2) To develop a computer program that calculates the energy requirements of conventional and hot-processing techniques.
3) To compare the energy requirements of two different hot-processing schemes against conventional cold processing.

REVIEW OF LITERATURE

Conventional and Hot Processing

Typically, in a packing plant fabricating boxed beef products, immediately after slaughter the carcass is placed in a chill or drip cooler maintained near 30°F for 18-24 hours. At the expiration of this period the carcass is moved to a holding cooler operating near 32°F where it may remain up to 72 hours after slaughter. The carcass is then moved to the boning line where excess fat and bone are removed and the carcass is fabricated into the desired cuts. The boning line temperature is approximately 50°F and the time the carcass spends on the line is somewhat variable. The fabricated product is then vacuum-packed. It is placed in boxes and stored in a 28-32°F cooler awaiting shipment to retail markets. Throughout this study this conventional method of processing will be termed cold processing.

Henrickson (1975) stated that the refrigerated space required for chilling a 600 pound beef carcass is 86,400 cu in. He added 34,000 cu in of space above and below the carcass making a total of 120,000 cu in. He asserted that the edible portion of the carcass could be cooled in 26,000 cu in of space resulting in a 78 percent savings in space. A 30 percent reduction in the energy requirement to cool each carcass was also claimed by Henrickson on the basis that 22,380 Btu will reduce the edible portion of the carcass from 102°F to 32°F, while 31,500 Btu would be required to achieve the same temperature reduction in the total carcass.

These estimated energy savings coupled with a recent and growing conservation necessity had led to intensified interest in hot processing.

The intent of hot processing is to remove excess fat and bone as soon as possible following slaughter without adversely affecting product quality. This would eliminate the use of energy to chill carcass portions which will be rendered.

A variety of hot-processing schemes have been proposed and the primary thrust of the research deals with the quality aspect of these proposals. Two basic approaches appear feasible. One approacn is to condition the carcass at 60°F for selected periods of up to 10 hours post-mortem and to then hot process the sides. Research has shown that sides held intact from 3-8 hours post-mortem, then fabricated, give cuts equal to the conventional treatment considering yield, tenderness, color and flavor (Kastner et al, 1973; Kastner and Russell, 1975; Kastner, 1976; Will and Henrickson, 1976).

The second basic approach is to cut the carcass soon after slaughter and to subsequently condition the carcass components. This technique normally results in acceptable organoleptic, yield and bacterial characteristics (Schmidt and Gilbert, 1970 and Schmidt and Keman, 1974). A variation of this technique which is being widely considered is electrical stimulation of the carcass to hasten rigor mortis and, thus, allow faster chilling and excision (McCollum and Henrickson, 1977; Gilbert and Davy, 1976).

One of the still largely unanswered questions of hot processing is the potential bacterial problem. Because hot processing involves vacuum packaging hot cuts and immediately boxing and chilling them the effect of this increased product temperature on the microbial count must be investigated. Schmidt and Gilbert (1970) concluded that pre-rigor excision (1-2 hours post-mortem) with subsequent aging in vacuum packages at 59°F for 24 hours could produce both organoleptically and microbiologically acceptable beef. Fung et al (1979) found that meat that was hot processed and stored for 14 days was considered bacteriologically acceptable.

Cooling Load Analysis

Determination of the total amount of energy required to chill the product and air condition the necessary physical plant requires consideration of seven major areas of heat gain. Two are inherent to the structures, heat conduction through exterior walls and roof, and heat conduction through interior partitions. Ventilation and infiltration constitute another area of heat gain. Heat will also be acquired within the structure due to people, lights and other electrical equipment. Finally, the refrigeration energy required to cool the product must be added to these sources of heat gain.

Traditional techniques (ASHRAE Fundamentals, 1977) of evaluating cooling loads were generated for the purpose of equipment sizing. These were based on so-called "design conditions." This is the worst possible situation which could ever be placed on the system. Since these conditions would only exist for a short time, if at all, it exaggerates the amount of refrigeration energy actually required by the system.

Through the use of digital computers it is possible to rigorously calculate energy requirements by solving heat balance equations at all interior surfaces of a given space (Mitalas and Stephenson, 1967). This procedure provides the best method of determining the energy requirements of each unique system but involves a time consuming and laborious technique.

Kusuda (1976) presents one of the few computer programs that rigorously determines instantaneous cooling load.

The transfer function concept of determining cooling requirements was introduced by Mitalas and Stephenson (1967) as a simplification of their rigorous method described above. This procedure was generated by calculating the cooling load by the rigorous method for typical constructions. The components such as solar heat, conduction heat gain, lighting, equipment and personnel load are simulated by pulses of unit strength. Transfer functions are then calculated as numerical constants which represent the cooling load corresponding to the input exaltation pulse. Transfer functions are generated for a number of typical constructions and then are assumed to be independent of the input pulses. The transfer function can now be multiplied by a time series representation of heat gain to obtain the cooling load (ASHRAE Fundamentals, 1977). The transfer function technique provides an answer of reasonable accuracy and embodies a simpler approach than the rigorous method.

ASHRAE Fundamentals (1977) specifies the accepted standard for calculating the heat gain due to personnel, product, lighting, equipment, ventilation and infiltration. These methods will be used and discussed in the thermal analysis section.

THERMAL ANALYSIS

Hot-Processing Option Overview

Two hot-processing approaches were selected for analysis. These schemes reflect the two basic hot-processing procedures described previously. Figure 1 shows the first option where the carcass is conditoned for 8 hours and then fabricated. The second hot processing option is shown in Figure 2. This option involves cutting the carcass soon after slaughter with a subsequent conditioning and chill period. Appendices A and B show the calculation of the cooling rates of the product for each option. Under hot-processing option I the internal temperature would reach 28.3°F in 104 hours and under option II it would be 28.3 °F in 96 hours.

Figure 3 depicts the conventional cold-processing method. An analysis of its cooling rate is evaluated in Appendix C. It requires approximately 72 hours for the internal product temperature to reach 28.3°F under this procedure.

A comparison of the energy requirements of these three different schemes of meat packing entails evaluating the components that constitute a source of heat gain for the system. This analysis does not attempt to evaluate the total amount of energy used for each packing method. The total quantity of energy used is dependent upon each unique building design and does not lend itself to the generalized approach attempted here. Rather, the objective of this research is to compare areas of dissimilarity within each system and evaluate the difference in the energy requirements of each system. The slaughtering operation, boning line, and packaging and boxing phase will not be considered as these are assumed identical for each oper-

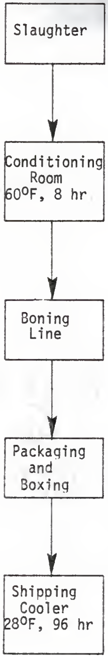


Figure 1. Hot-Processing Option I

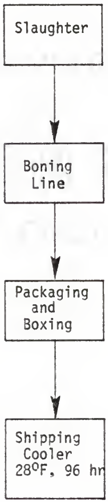


Figure 2. Hot-Processing Option II

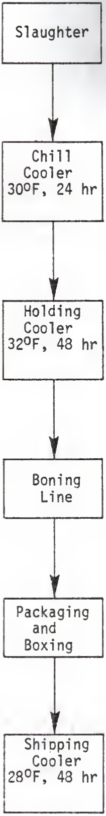


Figure 3. Cold Processing

tion. Carcass fabrication and meat packaging occur so rapidly that heat transfer during these operations is virtually nonexistent.

Appendix D contains a sample calculation of each component of the refrigeration energy load.

Product Load

The refrigeration load imposed by the product results from the energy necessitated to reduce the product temperature from receiving to leaving temperature. This load can be evaluated using equation 1,

$$q = mc(t_1 - t_2) \qquad (1)$$

where q is the quantity of heat removed, m is the mass of the product, c is the specific heat of the product above freezing, and t_1 and t_2, respectively, are the temperatures of the product as it enters and leaves the cooler. This equation is valid as long as the meat doesn't reach the freezing temperature of 28°F (ASHRAE Fundamentals, 1977d).

ASHRAE Applications (1974a) gives typical temperature cooling curves for the carcass in the chilling and holding coolers of the cold-processing method. However, no similar curves are available for the carcass as it is held in the higher temperature conditioning room characteristic of hot-processing option I. Therefore, a transient heat analysis of the carcass under all conditions is necessary to arrive at the average product temperature under the same methods. Appendices A, B and C show this calculation for hot-processing option I, hot-processing option II and cold-processing, respectively.

The mass of the carcass will decrease once it reaches the boning line due to removal of the excess fat and bone. A typical choice beef carcass consists, on a weight basis, of 51 percent lean, 15 percent bone and 34 percent fat (Watt and Merrill, 1963). For this study it was assumed that excess fat (12 percent) and all bone would be eliminated once the carcass completed the boning line process. Under all schemes (hot and cold) it is proposed that the deboned carcass be cut into the desired subprimals and packaged in vacuum bags. The packaged cuts are then placed in cardboard boxes and stored in the shipping cooler.

The specific heat of the meat varies due to the change in the carcass percentages of lean, fat and bone. It was calculated that after boning, the boxed cuts from the carcass averaged 70 percent lean and 30 percent fat. The new specific heat using a value of 0.50 Btu per (lb) (F deg) for fat and 0.80 Btu per (lb) (F deg) for lean is 0.71 Btu per (lb) (F deg) compared to the original carcass specific heat of 0.75 Btu per (lb) (F deg) (ASHRAE Applications, 1974a).

Shrouding

A carcass that is conventionally cold processed is usually shrouded to enhance appearance by smoothing and bleaching the surface fat. A shroud is a cloth saturated in 120-130°F weak brine. It remains on the carcass throughout the initial chilling period but is removed before the carcass is transferred to the holding room. Shrouds lose about six pounds of water per carcass to the chill cooler, largely due to evaporation. To determine the heat gain in the chill room it is necessary to consider both the sensible and latent loads imposed by the warm, wet shroud.

The sensible load can be determined by equation 2,

$$q_{sensible} = m_w c_w \, (t_s - t_r) \qquad (2)$$

where q is the amount of heat removed, m_w is the amount of water loss, c_w

is the specific heat of water, t_s is the temperature of the shroud water and t_r is the temperature of the chill cooler.

The latent load imparted by the shroud is calculated by equation 3,

$$q_{latent} = h_{fg} (m_w) \tag{3}$$

where q is the amount of heat to be removed, h_{fg} is the heat of vaporization of the water and m_w is the amount of water lost by the shroud. An average value of h_{fg} between the 125^{O}F temperature the shroud enters the chill cooler and the 30°F temperature the shroud leaves the cooler is 1049.5 Btu per (lb) water.

Building Transmission

The conduction losses through the roof and exterior walls will be determined by the previously described transfer function concept. The heat gain to the space from the exterior walls and roof is determined by equation 4, (ASHRAE Fundamentals, 1977),

$$q_{e,r} = A \left\{ \sum_{n=o} b_n \left(t_{e,r-n\Delta}\right) - \sum_{n=1} d_n \frac{\left(q_{e,r-n\Delta}\right)}{A} - t_{rc} \sum_{n=o} c_n \right\} \tag{4}$$

where $q_{e,r}$ is the hourly heat gain to the conditioned space; A is the exposed area of the roof or wall; r is the time the calculation is being done; Δ is the time interval between calculations; n is the summation index; t_{rc} is the constant indoor air temperature; b_n, c_n and d_n are the transfer function coefficients; and $t_{e,r-n\Delta}$ is the sol-air temperature at time r-nΔ.

The building transmission calculation will be done the twenty-first day of each month at one hour intervals beginning at 1:00 A.M. Thus the r value will proceed from 1:00 A.M. to 2:00 A.M., etc. with a Δ value of one hour. The number of summation indices (n) in this calculation is a function of the building construction. ASHRAE Fundamentals (1977) gives this information based upon many common industrial constructions. The values of the b_n, d_n and c_n terms can be read from the same source once the desired type of building construction is selected.

The $(q_{e,r-n\Delta})$ term is the value of the heat gained from the calculation performed for the previous hour. Initially this value is set at zero and the calculation is then iterated sufficiently to negate the effect of this procedure.

The value of $(t_{e,r-n\Delta})$ or the sol-air temperature one hour previous to when the calculation is performed is calculated by equation 5, (ASHRAE Applications, 1974b),

$$t_e = t_o + \frac{\alpha I_t}{h_o} - \frac{E\Delta R}{h_o} \qquad (5)$$

where the sol-air temperature is t_e, t_o is the outdoor air temperature, α is the absorptance of the surface for solar radiation, I_t is the total solar radiation incident upon the surface, h_o is the coefficient of heat transfer by long wave radiation and convection at the outer service, E is the hemispherical emittance of the surface and ΔR is the difference between the longwave radiation incident on the surface from the sky and surroundings, and the radiation emitted by a blackbody at outdoor air temperature.

The value of t_o should be gathered from historical weather data for an area near the plant location. These should be the 1:00 A.M., 2:00 A.M., etc. temperature readings to correspond to the previously selected values of r. The values of $\frac{\alpha}{h_o}$ given in ASHRAE Fundamentals (1977) are 0.15 for a light-colored surface and 0.30 for a dark-colored surface. Any intermediate colored surface should be interpolated between these values. I_t is given in ASHRAE Fundamentals (1977) as equal to 1.15 multiplied by the solar heat gain factor (SHGF). The values of the SHGF are given in ASHRAE Fundamentals (1977b) as a function of latitude, date, solar time and building wall orientation. Solar time may run either faster or slower than civil time and this difference can be significant. Its calculation is described in Appendix E. Table 1 in Appendix E lists the "equation of time" variable necessary to calculate solar time while Table 2 shows the solar time throughout the year for Manhattan, Kansas.

The hemispherical emittance, E, is given in ASHRAE Fundamentals (1977a) based upon the building surface. Values of ΔR for horizontal surfaces that receive longwave radiation from the sky only are given as 20 Btu per (hr) (sq ft) and for a vertical surface ΔR is considered to be zero (ASHRAE Fundamentals, 1977).

The heat load which will be imposed due to transmission from interior partitions, ceiling and floors is given by equation 6,

$$q_{p,r} = UA\ (t_b - t_{rc}) \tag{6}$$

where $q_{p,r}$ is the hourly heat gain through the interior partitions, U is the coefficient of overall heat transfer between the adjacent space and the cooler space, A is the exposed area, t_b is the temperature of the adjacent space and t_{rc} is the temperature of the cooler space.

The U value is dependent upon the construction type. It may be read directly in ASHRAE Fundamentals (1977) based upon a construction description or it may be determined by summing the U values of the individual construction components as described in ASHRAE Fundamentals (1977a).

The heat transfer from floors in direct contact with the ground, or over an underground basement that is neither ventilated nor warmed, may be neglected for cooling load estimates (ASHRAE Fundamentals, 1977).

Infiltration

Infiltration is air leakage through building cracks, around windows and doors, and through building floors and walls. The amount of infiltration depends upon the type of building construction, workmanship, and condition of the building. Air leakage, in refrigerated rooms, is primarily due to opening doors. Each time a door is opened outside air enters the cooled space. The temperature and moisture content of this infiltrating air must be brought to the refrigerated space condition, which constitutes a sensible and latent load to the system. The volume of air entering a walk-in refrigerator due to door openings is estimated by ASHRAE Fundamentals (1977c) based upon practical field experience.

The total load component resulting from air infiltration may be calculated by equation 7,

$$q = 4.5\ (\text{cfm})\ (\Delta h) \qquad (7)$$

where q is the hourly heat load, Δh is the difference in enthalphy between inside and outside air, and cfm is the volume of air entering the space, ft^3/min. The 4.5 factor is strictly valid only for air with a density of 0.075 lb dry air per cubic foot. However, accuracy is not noticably affected by its use throughout.

Enthalphy values for the air within the refrigerated space are shown in Table 3 for the coolers considered in this study. The enthalphy of the adjoining office space is 23.7 Btu per pound of dry air, assuming room conditions of 70°F and 40% relative humidity. Enthalphy values are a function of temperature and relative humidity. Outside enthalphy values are calculated by the computer code described later by inputting the dry bulb air temperature and relative humidity values at the time desired.

Table 3. Enthalphy Values Used in Infiltration Calculations - Coolers

Cooler Temp. (F)	Cooler Relative Humidity (%)	Cooler Enthalphy (Btu per lb dry air)
28	85	9.6
30	85	10.3
32	85	11.1
60	80	24.0

Personnel Load

Humans give off moisture and heat that subsequently constitutes a load to the system. The rate that heat and moisture is given off depends upon space temperature, type of work or activity, clothing, size, etc. ASHRAE Fundamentals (1977c) gives the average hourly system load due to occupancy as a function of cooler temperature. The heat equivalency, as given by this source, for a person in a $60^{O}F$ cooler is 600 Btu per hour (by extrapolation) and within a $30^{O}F$ cooler the heat equivalency per person is 950 Btu per hour. These values should be increased for a heavy traffic load where many people may enter the refrigerated space for a short time and carry with them heat above that indicated.

Electrical Load

The two major contributors to electrical load considered here are lights and motors. The electrical energy dissipated within the cooled space due to motors will depend upon the size (horsepower rating) of the motor and the placement of the motor. ASHRAE Fundamentals (1977c) gives the heat equivalent of electrical motors where both the useful output and motor losses are dissipated within the refrigerated space; or where the motor losses are dissipated outside refrigerated space and useful work is expended within refrigerated space; or where motor losses are dissipated within the refrigerated space and useful work is expended outside of the refrigerated space. It will be assumed, for this case, that motor losses are within the refrigerated space and useful work is expended within the refrigerated space. The assumed fan horsepower for this example will be 36 for the chill and shipping cooler. The holding cooler and conditioning room will be assumed to have a 24 horsepower rating. The hourly heat load due to the electrical motor is the product of the fan horsepower rating and the conversion factor to the desired energy units, in this case 2545 Btu per (hp) (hr).

The energy load to the refrigerated space as a result of electrical lighting can be determined by equation 8.

$$q = \text{total wattage} \times \text{use factor} \times \text{special allowance factor} \times 3.41 \qquad (8)$$

The use factor is the ratio of the wattage in use to the total installed wattage. The special allowance factor is used for fixtures that actually require more energy than their rated wattage, such as fluorescent or rapid start fixtures. The 3.41 figure is the conversion factor from watts to Btu per hour.

DESCRIPTION OF PROGRAM

A computer program called HEATLD was written to calculate the energy requirements of each processing option. It contains a main program, three subroutines which determine the energy consumption of each of the three processing options, and a fourth subroutine (TRANEX) which calculates the external transmission using the transfer function coefficient technique (Mitalas and Stephenson, 1967). The fourth subroutine is used repeatedly by the first three. The procedure for inputting data into the program is given in Appendix F and a complete program listing is found in Appendix

This program allows the user to choose the time increment (Δt) at which he desires to run the program. The only restriction is that the selected increment must divide evenly into 24. The smallest time increment, and the most accurate, would be a one hour interval. The accuracy of any interval greater than four is suspect.

The program user also has the option of selecting the hour of the day at which to initiate load calculations. This feature is useful when using time increments greater than one hour. The optimal starting time can be chosen to produce cooling loads which will mostly closely approximate those obtained by hourly calculations.

The main program, a flow chart of which is shown in Figure 4, serves to input the majority of the data and also calls the three option-specific subroutines. An additional function of the main program is to calculate the enthalphy (H) of the outside air using a mathematical model of the psychometric chart (Brooker, 1967). The formulation is divided into two temperature regions. For temperatures greater than 32^{o}F, H is calculated as described in equation 9. And for temperatures less than or equal to 32^{o}F,

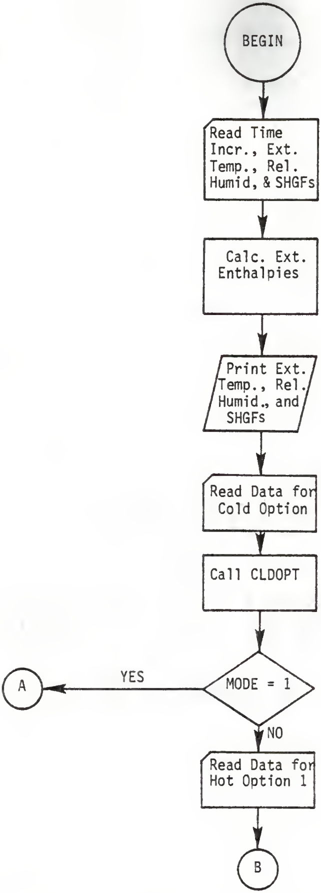


Figure 4. Main Program

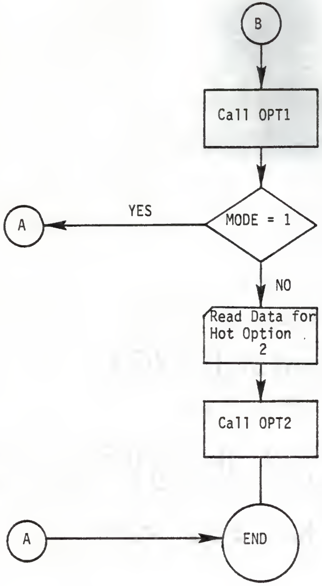


Figure 4. (continued)

H is calculated by equation 10,

$$H = 0.2405\ (T-459.69) + X\ \{0.448\ T - 0.1783\ T + 864.7168\} \qquad (9)$$

$$H = 0.2405\ (T-459.69) + X\ \{0.448\ T - 0.01377T + 862.3629\} \qquad (10)$$

where T is equal to the dry bulb temperature in degrees Rankine. The quantity χ is determined by equation 11,

$$X = 0.6219 \quad \frac{P_v}{14.696-Pv} \qquad (11)$$

where P_v is the actual vapor pressure of the air at a given temperature and relative humidity. Then, P_v is calculated by equation 12.

$$P_v = P_s \cdot RH \qquad (12)$$

In this equation RH is the relative humidity in decimal units of the outside air and P_s is the saturation vapor pressure of air for a given temperature (T). P_s may be calculated by equation 13 or 14, as appropriate.

$$P_s = \exp\ (54.6329 - \frac{12301.688}{T} - 5.16923\ \ln T) \quad T \geq 32^oF \qquad (13)$$

$$P_s = \exp\ (23.3924 - \frac{11286.6489}{T} - 0.46057\ \ln T) \quad T < 32^oF \qquad (14)$$

The main program also prints a large portion of the inputted climatic data so that its accuracy can be confirmed.

A flow chart describing the subroutine CLDOPT is shown in Figure 5. After reading the necessary data, CLDOPT repeatedly calls TRANEX until the exterior transmission load has been calculated for each outside wall. CLDOPT then performs the same calculations for the roofs after reading the appropriate new data. The remaining calculations are done in a very straightforward

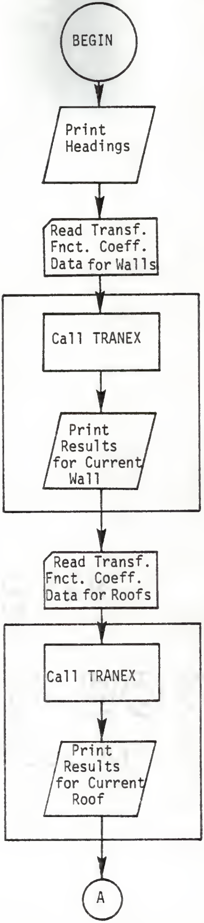


Figure 5. Subroutine CLDOPT

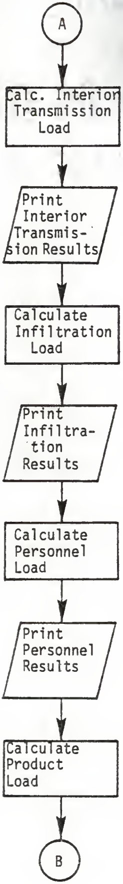


Figure 5. (continued)

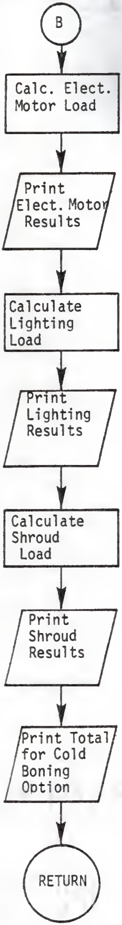


Figure 5. (continued)

manner. The units in all intermediate calculations are BTU/day, choosing the twenty-first day of each month as representative. The final results are given in terms of Btu per pound of finished product.

Flow charts of the subroutines for hot-processing options I and II, OPT1 and OPT2 respectively, have not been made because of their inherent similarity to CLDOPT. Disregarding the obvious changes in plant configuration, the only difference between CLDOPT and the other option subroutines is the inclusion of the shroud in the cold boning calculations.

The subroutine TRANEX is by far the most complex and its flow chart is shown in Figure 6. As formulated, the transfer function coefficient technique calculates the external transmission, $q_e(t_i)$, as function of q_e at times prior to t_i which are initially unknown. The method used was to set all $q_e(t)$ values equal to zero at the beginning of the calculation. An iterative procedure was employed which caused the effect of this assumption to become negligible as the calculation proceeded. As programmed, TRANEX calculates an exterior transmission load value for each time increment. These values are then used to calculate a daily total. The subroutine iterates on the daily total values until two adjacent iterations agree to within some specified convergence criterion which in this case was one percent. An upper limit of 20 was used on the number of iterations. If this limit is reached, an appropriate message is printed and execution halted.

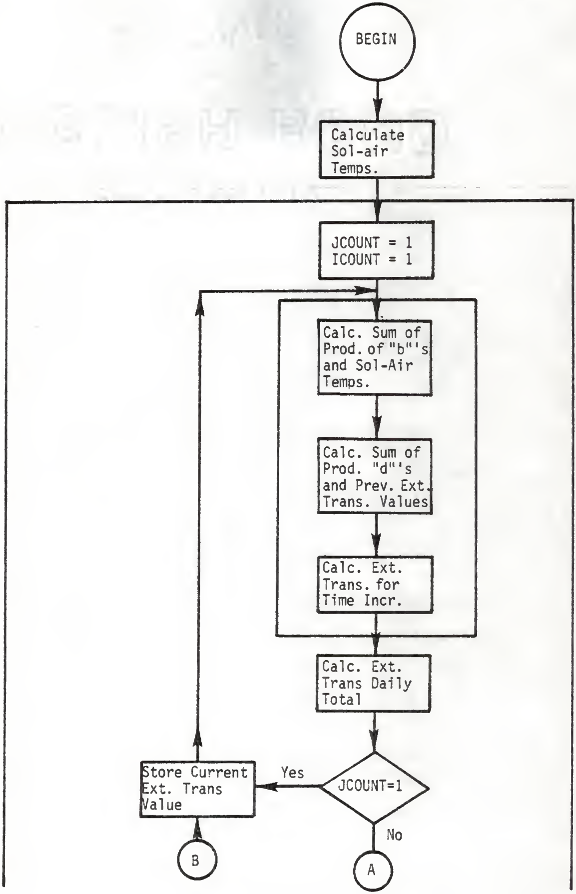


Figure 6. Subroutine TRANEX

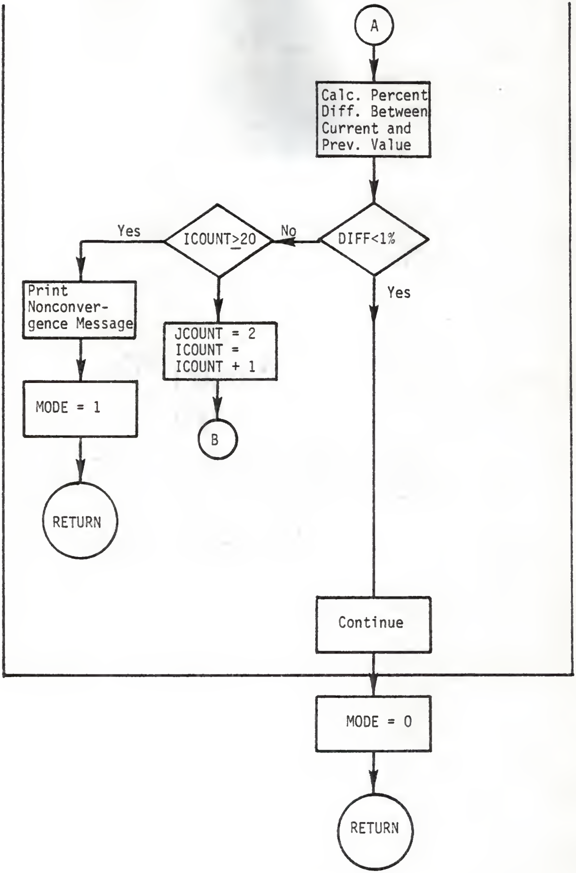


Figure 6. (continued)

PLANT CONFIGURATIONS AND SYSTEM VARIABLES

The flow sequences of the two hot-processing options considered in this study are shown in Figures 7 and 8. These figures also show the associated mass, specific heat and entering and exiting temperatures of the product contained in each of the refrigerated coolers. Figure 9 displays this same information for the conventional cold-processing facility considered in this analysis.

The cooler dimensions and capacities considered in this study for hot processing I, hot processing II and cold processing are shown in Figures 10, 11 and 12, respectively.

A listing of all data requirements and the corresponding values selected in this study is given in Table 4.

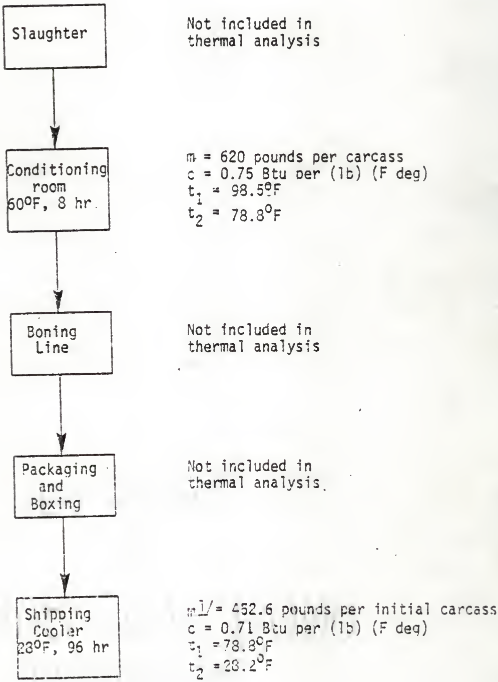


Figure 7. Hot-Processing Option I

1/ In boxed form.

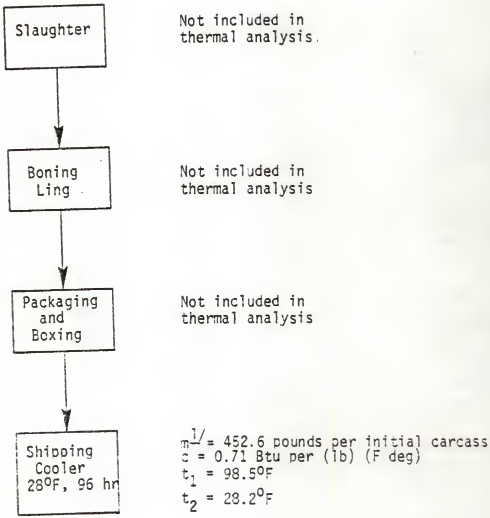
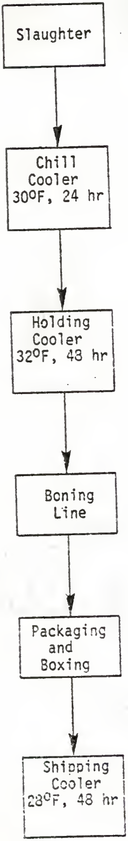


Figure 8. Hot-Processing Option II

1/ In boxed form.



Slaughter: Not included in thermal analysis

Chill Cooler:
m = 620 pounds per carcass
c = 0.75 Btu per (lb) (F deg)
t_1 = 98.5°F
t_2 = 40.7°F

Holding Cooler:
m = 620 pounds per carcass
c = 0.75 Btu per (lb) (F deg)
t_1 = 40.7°F
t_2 = 32.8°F

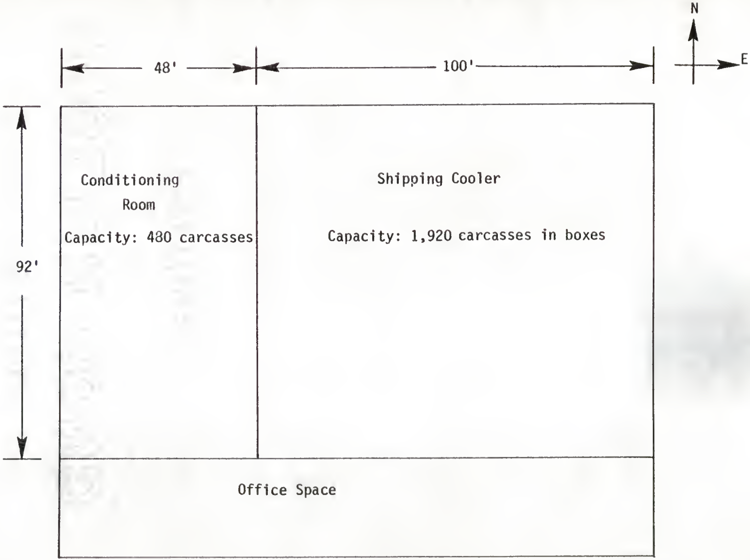
Boning Line: Not included in thermal analysis

Packaging and Boxing: Not included in thermal analysis

Shipping Cooler:
m 1/ = 452.6 pounds per initial carcass
c = 0.71 Btu per (lb) (F deg)
t_1 = 32.8°F
t_2 = 28.5°F

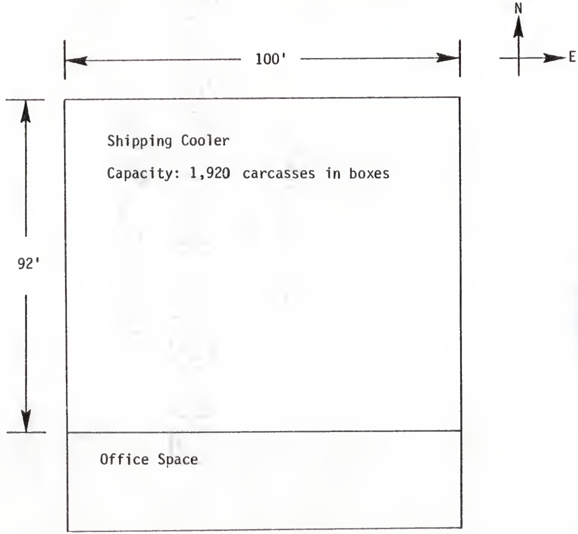
Figure 9. Cold Processing

1/ In boxed form.



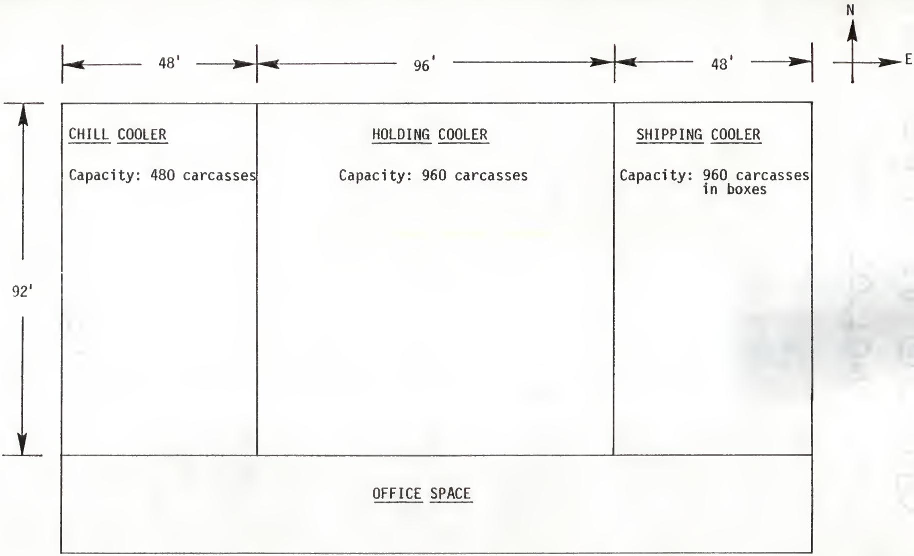
Ceiling height: 28.5'

Figure 10. Hot-Processing I Plant (Regier, 1978)



Ceiling height: 28.5'

Figure 11. Hot-Processing II Plant (Regier, 1978)



Ceiling height 28.5'

Figure 12. Cold-Processing Plant (Regier, 1978).

TABLE 4. TABULATION OF DATA

Description of Data Requirements	Thesis Symbol	Computer Symbol	Values Selected
Outside Ambient Temperature	t_o	TEMPDB	Hourly temperature for Manhattan, Ks, 1977 base.
Outside Relative Humidity	RH	RHDB	Hourly relative humidity for Manhattan, Ks.,1977 base.
Solar Heat Gain Factor	SHGF	SHGFDB	Interpolated hourly from ASHRAE Guide (1977)
Product Weight per carcass			
. before fabrication	m	PROD1	620 pounds per carcass
. after fabrication	m	PROD2	453 pounds per carcass
Number of Carcass		NCARC	480 head
Specific Heat of Product			
. before fabrication	c	SPHT1	0.75 Btu per (lb) (deg F)
. after fabrication	c	SPHT2	0.71 Btu per (lb) (deg F)
Number Persons per Room		NPEOPL	4 per room
Heat Equivalency per Person	Q	QPEOPL	600 Btu per hr conditioning room, 950 But per hr, all other rooms
Area of Exposed Surfaces	A	SRFA	See Appendix E
Thermal Transmittance			
. outside walls	U	U	0.099 Btu per (h) (ft^2) (deg F)
. roof	U	U	0.09 Btu per (h) (ft^2) (deg F)
. wall between coolers	U	U	0.454 Btu per (h) (ft^2) (deg F)
. wall between coolers and office	U	U	0.499 Btu per (h) (ft^2) (deg F)
Temperature of Coolers	t_{rc}	TEMP(I)	See Appendix E
Temperature of Office Space	t_b	TEMP(4)	70^oF
Product Temp. at Entrance	t_1	98.5	See Appendix E
Product Temp. at Exit	t_2	T1EXIT	See Appendix E
Enthalphy of Coolers	h_{cooler}	ENTHIN	See Table 1
Enthalphy of Office Space	h_{office}	ENTHIN	23.7 Btu per (lb) dry air
Infiltration Volume of Coolers	cfm	CFM	14 ft^3 per minute
Wattage per Room	W	WATT	3 watts per sq ft
Special Allowance Factor	SAF	SAF	1.0
Use Factor	UF	USE	1.0

Table 4 (continued)

Description of Data Requirements	Thesis Symbol	Computer Symbol	Values Selected
Water Mass in Shroud	m_w	WTRMS	6 pounds per carcass
Specific Heat of Water	c_w	SPHWTR	1.0 Btu per (lb) deg F)
Temperature of Shroud			
. entering cooler	t_s	TSHRD	125^0F
. leaving cooler	t_r	T1EXIT	30^0F
Fan Horsepower per Room	HP	HP	36 HP, shipping and chill cooler, 24 HP holding cooler and conditioning room
Transfer Function Coefficient			
. Roof	b_n	B	0.0, 0.0007, 0.0016, 0.0005 Btu per hr (ft^2) (deg F)
	c_n	C	0.0028 Btu per hr (ft^2) (deg F)
	d_n	D	1.0, -1.2437, 0.2877, -0.0128
. Outside Walls	b_n	B	0.00001, 0.00081, 0.00339, 0.00196, 0.00018 Btu per hr (ft^2) (deg F)
	c_n	C	0.00635 Btu per hr (ft^2) (deg F)
	d_n	D	1.0, -1.52490, 0.69509, -0.11032, 0.00399, -0.00001
Coefficient of Heat Transfer	h_o	HO	3.0 Btu per hr (ft^2) (deg F)
Absorbance of the surface over h_o	α/h_o	A	0.30
Hemispherical emittance	E	EPSLN	0.90
Difference between longwave radiation from sky and surroundings and that emitted by a blackbody	ΔR	DELTAR	Horizontal: 20 Btu per (hr) (ft^2) Vertical: 0 Btu per (hr) (ft^2)
Time of interval	Δt	IDLT	1 and 4 hours
Starting time		ISTRT	1:00 A.M., 2:00 A.M., 3:00 A.M., 4:00 A.M.

RESULTS AND DISCUSSION

A transient heat analysis was performed to determine the rate of product cooling under hot-processing options I and II and cold processing. This analysis showed that 104 hours was required for the internal product temperature to reach 28.3°F with hot-processing option I. It required 96 hours for the internal product temperature to reach 28.3°F under hot-processing option II and 72 hours with conventional cold-processing techniques.

The results from the transient heat analysis were used in the previously described computer program to compute refrigeration energy loads. The computer program calculated the average energy required for product and space refrigeration for hot-processing options I and II and cold processing.

A monthly comparison of the refrigeration energy expended for hot-processing options I and II and cold processing is shown in Figure 13. A comparison shows that in December, the coldest month, 133.5 Btu were required to process one pound (3.1×10^5 Joules per kg) of beef by the conventional cold-processing technique. In the same month 93.2 But/lb (2.2×10^5 J/kg) were required using hot-processing option I and 76.9 Btu/lb (1.8×10^5 J/kg) using hot-processing option II. This constitutes a 30 percent savings for hot processing I, and a 42 percent savings for hot processing II when compared to cold processing.

July was the warmest month and results obtained for this period show that the cold-processing energy requirements were 153.8 Btu/lb (3.6×10^5 J/kg); the hot-processing I requirements were 103.8 Btu/lb (2.4×10^5 J/kg); and the hot-processing II requirements were 89.6 Btu/lb (2.1×10^5 J/kg). The associated percentage energy savings in July for hot processing I was 33 percent, and 42 percent for hot processing II.

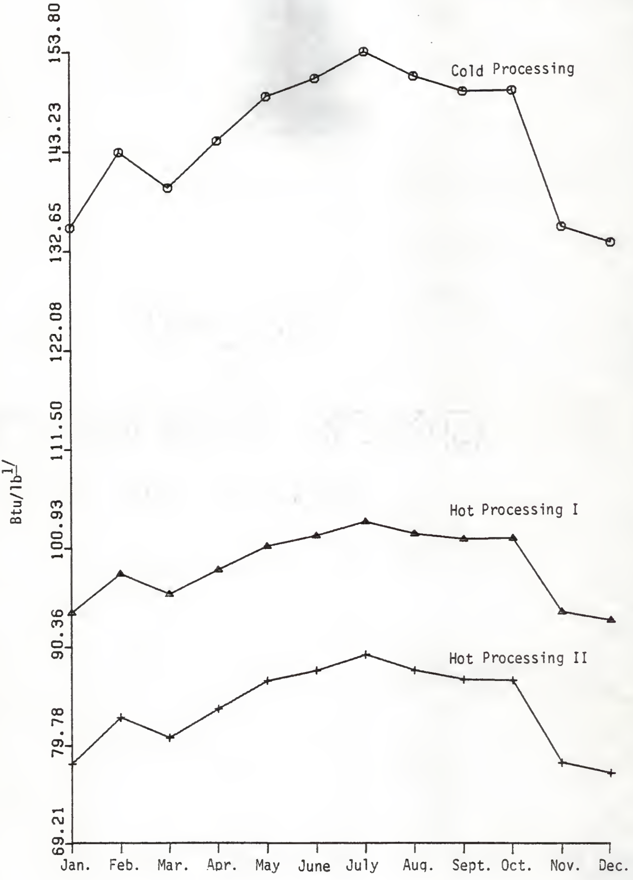


Figure 13. Refrigeration Energy Utilized on the Twenty-First Day of Each Month.

1/ To obtain Joules/kg multiply by 2324.01

Figure 14 shows the proportional amount of each of the individual system loads to the total load for each processing scheme. A comparison on this basis emphasizes the major areas of energy savings between the hot-processing options and cold processing. A major contributor to the hot-processing savings was the absence of the shroud load, inherent only in cold processing. The elimination of the shroud alone generated 30 percent of the energy savings in hot processing I and 24 percent of the savings of hot-processing option II. A second principal source of energy reduction was the reduced product loads of the hot options caused by not cooling portions of the carcasses that will be rendered. The reduced product load constituted 29 percent of the energy reduction between hot processing I and cold processing and 32 percent of the reduction between hot processing II and cold processing. External transmission was another significant area of energy savings. It was responsible for 21 percent of the energy savings associated with hot processing I and 9 percent of the hot-processing II reduction. The reduced electrical and lighting loads of hot processing II were significant sources of energy savings for this option. These savings are the result of the greatly reduced cooler volume associated with hot processing II.

Several sample calculations were performed to determine the effect of changing the time interval between calculations from one to four hours. The effect of starting time, when using four hour intervals, was also investigated. The change in the external transmission load, using any of these procedures, was less than 2 percent, thus, not practically significant.

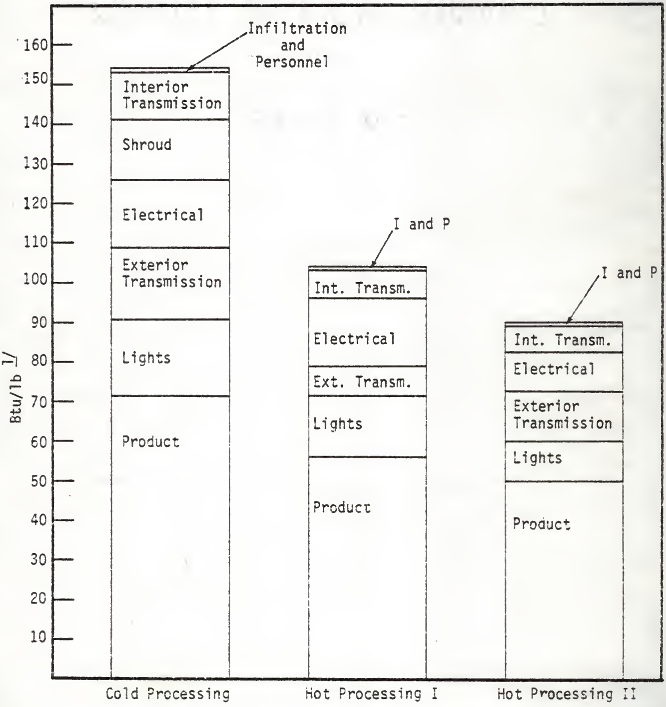


Figure 14. Refrigeration Load Distribution

1/ To obtain Joules/kg multiply by 2324.01

SUMMARY AND CONCLUSIONS

A transient heat analysis indicated that 104 hours was required for the internal product temperature to reach 28.3°F (-2.1°C) when the carcass was conditioned for 8 hours at 60°F (15.6°C) and subsequently hot processed into subprimals, vacuum packaged and boxed. The analysis also showed that 96 hours was required for the internal product temperature to reach 28.3°F (-2.1°C) when the carcass was fabricated into subprimals and vacuum packaged and boxed immediately following slaughter. Conventionally processed beef required 72 hours to reach an internal temperature of 28.3°F (-2.1°C).

A computer program was developed to calculate the average refrigeration energy requirements of both hot-processing schemes and cold processing. A listing is shown in Appendix G.

An energy comparison among the two hot-processing option and cold processing indicated that a significant energy savings may be achieved by utilizing hot processing in the beef industry. This requires adjusting existing plants' refrigeration and holding facilities or constructing new facilities to accomodate hot processing.

Beef carcasses conditioned at 60°F (15.6°C) for eight hours, and immediately fabricated into subprimals, vacuum packaged and boxed required approximately 50 Btu per lb of finished product (1.2×10^5 Joules per kg) less energy than carcasses that were conventional processed into subprimals after chilling for 72 hours. This is a 32 percent reduction in the total refrigeration energy expended during product fabrication.

Carcasses which were fabricated into subprimals, and vacuum packaged and boxed immediately following slaughter required approximately 64 Btu per lb of finished product (1.5 x 10 Joules per kg) less energy than cold-processing carcasses. This is a 42 percent reduction in the refrigeration energy required under the cold-processing technique.

These energy comparisons were based upon model facilities that slaughter sixty head of cattle an hour for eight hours a day. However, conclusions found for this size hot-processing facility should not be unreservedly ascribed to other sized plants.

DIRECTIONS FOR FUTURE RESEARCH

Hot processing is an effort to minimize the product load component of the total refrigeration energy requirement. Further research could extend load reduction and optimization to other components of the refrigeration load. A prime consideration for future efforts would be to determine the minimum amount of cooler space required to efficiency process a beef.

The energy savings due to hot processing is only one of the potential economic advantages. An overall economic analysis to include labor, capital investment, etc. is required to evaluate the full potential of hot processing. A cost-benefit analysis could weigh the economic benefits of hot processing against any detriments. These analyses could further aid the industry in making the decision to implement hot processing.

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APPENDIX A

TRANSIENT HEAT ANALYSIS OF HOT-PROCESSING OPTION I

Problem: To evaluate the internal carcass temperature and the average carcass temperature after 8 hours in the 60°F conditioning room.

Assumptions: Consider the beef round to be represented by the shape of a rectangle. It's dimensions are 20" x 14.5" x 8.5"

Solution: Perform a transient heat analysis on the beef round using Heisler's (1947) equation 15 and chart (Figure 15).

$$\left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{\text{Total}\\\text{Round}}} = \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{20''\\\text{slab}}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{14.5''\\\text{slab}}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{8.5''\\\text{slab}}} \quad (15)$$

T = final internal temperature, F

T_o = uniform initial temperature, F

T_∞ = surrounding fluid temperature, F

To use Heisler's chart must know $\frac{a\theta}{L^2}$ and K/hL where

L = 1/2 slab thickness, ft

θ = time elasped, hours

a = thermal diffusivity, sq ft per hour

K = thermal conductivity, Btu per (hr) (ft) (deg F)

h = surface heat transfer coefficient, Btu per (hr) (sq ft) (deg F)

a = 0.0048 sq ft per hour (ASHRAE Fundamentals, 1977d)

h = 2.05 Btu per (hr) (sq ft) (deg F) (ASHRAE Fundamentals, 1977d)

K_{meat} = 0.28 Btu per (hr) (ft) (deg F) (ASHRAE Fundamentals, 1977d, Lentz, 1961)

From Fig. 15, for Θ = 8 hrs.

slab	$a\theta/L^2$	K/hL	$\frac{T-T_\infty}{T_o-T_\infty}$
20"	0.055	0.164	1.0
14.5"	0.105	0.226	0.99
8.5	0.306	0.386	0.80

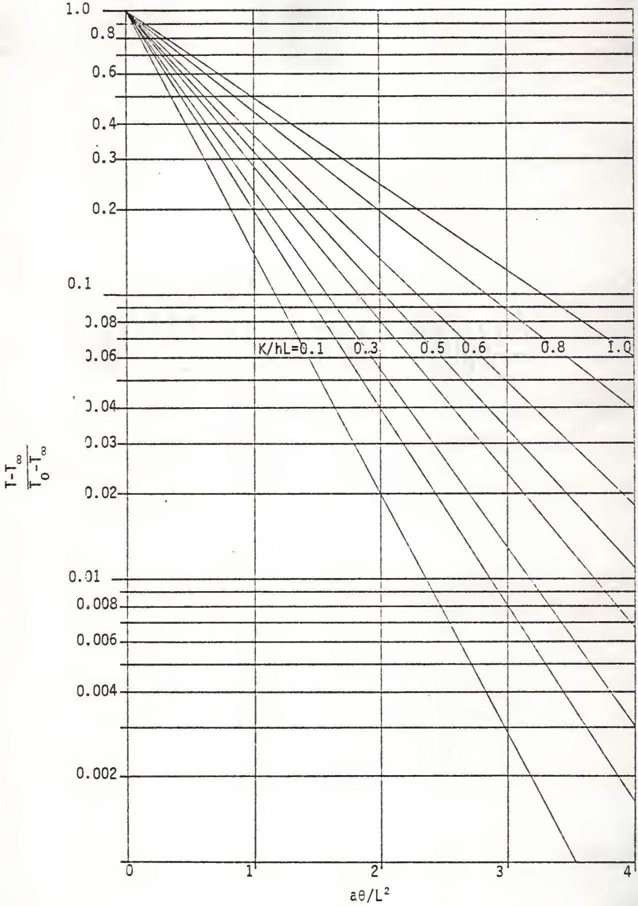


Figure 15. Midplane temperature for an infinite plate of thickness 2L, from Heisler (1947).

After 8 hours at 60^oF, with an initial temperature of 105^oF (ASHRAE Applications, 1974a).

$$\frac{T-60}{105-60} = (1)\ (0.99)\ (0.80)$$

$$T = 95.6^oF$$

To determine the average temperature of the beef round after 8 hours in 60^oF room use Heisler's chart, Figure 16 which relates temperature at any position as a function of center temperature.

slab	K /hL	X/L	$\frac{T_{(x,o)}-T_\infty}{T_{(o,\theta)}-T_\infty}$
20"	0.164	0.5	0.78
14.5"	0.226	0.5	0.80
8.5"	0.386	0.5	0.85

Now using equation 16 (Heisler, 1947)

$$\left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\text{Total}} = \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\text{20" slab}} \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\text{14.5" slab}} \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\text{8.5" slab}} \quad (16)$$

$T_{x,o}$ = average temperature of slab for X/L = 0.5, ^oF

T_∞ = surrounding air temperature, ^oF

$T_{o,\theta}$ = center temperature, ^oF (previously determined)

After 8 hours in 60^oF room

$$\frac{T_{x,o}-60}{95.6-60} = (0.78)\ (0.80)\ (0.85)$$

$$T_{x,o} = 78.8^oF$$

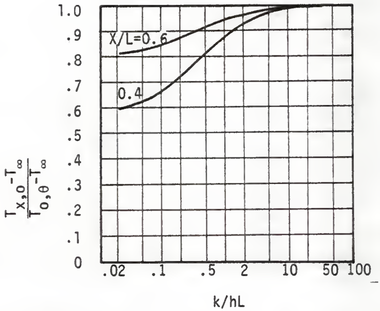


Figure 16. Temperature as a Function of Center Temperature in an Infinite Plate of Thickness 2L, from Heisler (1947).

Problem: To evaluate the time required for an essentially solid box (9.5" x 22" x 17") of meat product to reach an internal temperature of 28.84 °F in the 28°F shipping cooler.

Solution: Perform a transient heat analysis using Heisler's (1947) equation 15 and chart (Figure 15). Must reiterate, varying time (θ) until desired temperature is reached.

$$\left\{\frac{T-T_\infty}{T_0-T_\infty}\right\}_{\text{Total box}} = \left\{\frac{T-T_\infty}{T_0-T_\infty}\right\}_{22''\text{ slab}} \left\{\frac{T-T_\infty}{T_0-T_\infty}\right\}_{17''\text{ slab}} \left\{\frac{T-T_\infty}{T_0-T_\infty}\right\}_{9.5''\text{ slab}} \qquad (15)$$

T = final internal temperature, deg F

T_0 = initial uniform temperature, deg F

T_∞ = surrounding fluid temperature, deg F

To use Heisler's chart must know $a\theta/L^2$ and K/hL where

L = 1/2 slab thickness, ft

θ = time elasped in cooler, hours

a = thermal diffusivity, sq ft per hour

K = thermal conductivity, Btu per (hr) (ft) (deg F)

h = surface heat transfer coefficient, Btu per (hr) (sq ft) (deg F)

a = 0.0048 sq ft per hour(ASHRAE Fundamentals, 1977d)

h = 2.05 Btu per (hr) (sq ft) (deg F) (ASHRAE Fundamentals, 1977d)

K_{meat} = 0.28 Btu per (hr) (ft) (deg F) (ASHRAE Fundamentals, 1977d and Lentz, 1961)

K_{box} = 1.74 Btu per (hr) (ft) (deg F)

weight box = 3.5 pounds, weight meat = 90 pounds

$$K_{composite} = \left\{\frac{90\text{ lb}}{93.5\text{ lb}}\right\}\left\{0.28\,\frac{\text{Btu}}{(\text{hr})(\text{ft})(\text{F})}\right\} + \left\{\frac{3.5\text{ lb}}{93.5\text{ lb}}\right\}\left\{\frac{1.74\text{ Btu}}{(\text{hr})(\text{ft})(\text{F})}\right\} = \frac{0.33\text{ Btu}}{(\text{hr})(\text{ft})(\text{F})}$$

From Figure 15; for θ = 96 hours

slab	$a\theta/L^2$	K/hL	$\frac{T-T_\infty}{T_0-T_\infty}$
22"	0.548	0.176	0.55
17"	0.920	0.227	0.30
9.5"	2.940	0.407	0.027

After 96 hours in a $28^{o}F$ room, with an initial temperature of $95.6^{o}F$

$$\frac{T-28}{95.6-28} = (0.55)\ (0.30)\ (0.027)$$

$$T = 28.30 \simeq 28.84^{o}F$$

To determine the average temperature of the box after 96 hours in the $28^{o}F$ room use Heisler's (1947) chart, Figure 16, which relates the temperature at any position as a function of center temperature.

slab	K /hL	X/L	$\frac{T_{(x,o)}-T_\infty}{T_{(o,\theta)}-T_\infty}$
22"	0.176	0.5	0.75
17"	0.227	0.5	0.83
9.5"	0.407	0.5	0.85

Now using equation 16 (Heisler, 1947)

$$\left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{total} = \left\{\frac{T_{x,o}-T}{T_{o,\theta}-T_\infty}\right\}_{22"\ slab} \left\{\frac{T_{x,o}-T}{T_{o,\theta}-T_\infty}\right\}_{17"\ slab} \left\{\frac{T_{x,o}-T}{T_{o,\theta}-T_\infty}\right\}_{9.5"\ slab} \qquad (16)$$

where:

$T_{x,o}$ = average temperature of slab for X/L = 0.5, deg F

T_∞ = surrounding air temperature, deg F

$T_{o,\theta}$ = center temperature, deg F (previously determined)

$$\frac{T_{x,o}-28}{28.30-28} = (0.75)\ (0.83)\ (0.85)$$

$$T_{x,o} = 28.16^{o}F$$

APPENDIX B

TRANSIENT HEAT ANALYSIS OF HOT-PROCESSING OPTION II

Problem: To evaluate the time required for an essentially solid box (9.5" x 22" x 17") of packaged meat product to reach an internal temperature of 28.84 °F in the 28°F shipping cooler.

Solution: Perform a transient heat analysis using Heisler's (1947) equation 15 and chart (Figure 15).

$$\left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{Total box}} = \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{22" slab}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{17" slab}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{9.5" slab}} \qquad (15)$$

T = final internal temperature, deg F

T_o = initial uniform temperature, deg F

T_∞ = surrounding fluid temperature, deg F

To use Heisler's chart must know $\frac{a\theta}{L^2}$ and $\frac{K}{hL}$ where:

L = 1/2 slab thickness, ft

θ = time elasped in cooler, hours

a = thermal diffusivity, sq ft per hour

K = thermal conductivity, Btu per (hr) (ft) (deg F)

h = surface heat transfer coefficient, Btu per (hr) (sq ft) (deg F)

a = 0.0048 sq ft per hour (ASHRAE Fundamentals, 1977d)

h = 2.05 Btu per (hr) (sq ft) (deg F) (ASHRAE Fundamentals, 1977d)

K_{meat} = 0.28 Btu per (hr) (ft) (deg F) (ASHRAE Fundamentals, 1977d and Lentz, 1961)

K_{box} = 1.74 Btu per (hr) (ft) (deg F)

Weight box = 3.5 pounds, weight meat = 90 pounds

$$K_{composite} = \left\{\frac{90\ lb}{93.5\ lb}\right\} \left\{0.28\ \frac{Btu}{(hr)(ft)(F)}\right\} + \left\{\frac{3.5\ lb}{93.5\ lb}\right\} \left\{\frac{1.74\ Btu}{(hr)(ft)(F)}\right\} = \frac{0.33\ Btu}{(hr)(ft)(F)}$$

From Figure 15; for θ = 96 hours

slab	$a\theta/L$	K/hL	$\frac{T-T_\infty}{T_o-T_\infty}$
22"	0.548	0.176	0.55
17"	0.920	0.227	0.30
9.5"	2.940	0.407	0.027

After 96 hours in a 28^oF room, with an initial temperature of 105^oF

$$\frac{T-28}{105-28} = (0.55)\ (0.30)\ (0.027)$$

$$T = 28.343 \simeq 28.84^oF$$

To determine the average temperature of the box after 96 hours in the 28^oF room use Heisler's (1947) chart, Figure 16, which relates the temperature at any position as a function of center temperature.

slab	K /h L	X/L	$\frac{T_{(x,o)}-T_\infty}{T_{(o,\theta)}-T_\infty}$
22"	0.176	0.5	0.75
17"	0.227	0.5	0.83
9.5"	0.407	0.5	0.85

Now using equation 16 (Heisler, 1947)

$$\left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{total} = \left\{\frac{T_{x,o}-T}{T_{o,\theta}-T_\infty}\right\}_{22"\ slab} \left\{\frac{T_{x,o}-T}{T_{o,\theta}-T_\infty}\right\}_{17"\ slab} \left\{\frac{T_{x,o}-T}{T_{o,\theta}-T_\infty}\right\}_{9.5"\ slab} \quad (16)$$

where:

$T_{x,o}$ = average temperature of slab for X/L = .5, °F

T_∞ = surrounding air temperature, °F

$T_{o,\theta}$ = center temperature, °F (previously determined)

After 96 hours in 28°F room

$$\frac{T_{x,o}-28}{28.34-28} = (0.75)\ (0.83)\ (0.85)$$

$$T_{x,o} = 28.18^{\circ}F$$

APPENDIX C

TRANSIENT HEAT ANALYSIS OF COLD PROCESSING

Problem: To evaluate the internal carcass temperature and the average carcass temperature after 24 hours in the 30 F chill cooler.

Assumptions: Consider the beef round to be represented by the shape of a rectangle. Its dimensions are 20" x 14.5" x 8.5"

Solution: Perform a transient heat analysis on the beef round using Heisler's (1947) equation (15) and chart (Figure 15).

$$\left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{\text{Total}\\\text{Round}}} = \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{20"\\\text{slab}}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{14.5"\\\text{slab}}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{8.5"\\\text{slab}}} \qquad (15)$$

T = final internal temperature, F

T_o = uniform initial temperature, F

T_∞ = surrounding fluid temperature, F

To use Heisler's chart must know $\frac{a\theta}{L^2}$ and K/hL where

L = 1/2 slab thickness, ft

θ = time elasped, hours

a = thermal diffusivity, sq ft per hour

K = thermal conductivity, Btu per (hr) (ft) (deg F)

h = surface heat transfer coefficient, Btu per (hr) (sq ft) (deg F)

a = 0.0048 sq ft per hour (ASHRAE Fundamentals, 1977d)

h = 2.05 Btu per (hr) (sq ft) (deg F) (ASHRAE Fundamentals, 1977d)

K_{meat} = 0.28 Btu per (hr) (ft) (deg F) (ASHRAE Fundamentals, 1977d and Lentz, 1961)

From Fig. 15, for θ = 24 hours

slab	$a\theta/L^2$	K/hL	$\frac{T-T_\infty}{T_o-T_\infty}$
20"	0.166	0.164	0.97
14.5"	0.316	0.226	0.75
8.5"	0.918	0.386	0.38

After 24 hours in 30^{o}F room, with an initial temperature of 105^{o}F

$$\frac{T-30}{105-30} = (0.97)\ (0.75)\ (0.38)$$

$$T = 50.73^oF$$

To determine the average temperature of the round after 24 hours in the 30^{o}F chill cooler use Heisler's (1947) Chart, Figure 16, which relates temperature at any position as function of center temperature.

slab	K/hL	X/L	$\frac{T_{(x,0)}-T_\infty}{T_{(o,\theta)}-T_\infty}$
20"	0.164	0.5	0.76
14.5"	0.226	0.5	0.80
8.5"	0.386	0.5	0.85

Now using equation 16 (Heisler, 1947)

$$\left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\text{Total}} = \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\substack{20"\\ \text{slab}}} \cdot \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\substack{14.5"\\ \text{slab}}} \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{\substack{8.5"\\ \text{slab}}} \quad (16)$$

$T_{x,o}$ = average temperature of slab for X/L = 0.5, ^{o}F

T_∞ = surrounding air temperature, ^{o}F

$T_{o,\theta}$ = center temperature, ^{o}F (previously determined)

After 24 hours in 30^{o}F room

$$\frac{T_{x,o}-30}{50.73-30} = (0.76)\ (0.80)\ (0.85)$$

$$T_{x,o} = 40.71^oF$$

Problem: To evaluate the internal carcass temperature and average carcass temperature after 24 and 48 hours in the 32°F holding cooler.

Assumptions: Consider the beef round to be represented by the shape of a rectangle. Its dimensions are 20" x 14.5" x 8.5".

Solution: Perform a transient heat analysis on the internal round using Heisler's (1947) equation 15 and chart (Figure 15).

$$\left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{\text{Total}\\\text{Round}}} = \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{20"\\\text{slab}}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{14.5"\\\text{slab}}} \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\substack{8.5"\\\text{slab}}} \quad (15)$$

T = final internal temperature, °F

T_o = uniform initial temperature, °F

T_∞ = surrounding fluid temperature, °F

To use Heisler's chart must know $\frac{a\theta}{L^2}$ and K/hL where

L = 1/2 slab thickness, ft

θ = time elasped, hours

a = thermal diffusivity, sq ft per hour

K = thermal conductivity, Btu per (hr) (ft) (deg F)

h = surface heat transfer coefficient, Btu per (hr) (sq ft) (deg F)

a = 0.0048 sq ft per hour (ASHRAE Fundamentals, 1977d)

h = 2.05 Btu per (hr) (sq ft) (deg F) (ASHRAE Fundamentals, 1977d)

K_{meat} = 0.28 Btu per (hr) (ft) (deg F) (ASHRAE Fundamentals, 1977d and Lentz, 1961)

From Fig. 15, for θ = 24 hours.

slab	$a\theta/L^2$	K/hL	$\frac{T-T_\infty}{T_o-T_\infty}$
20"	0.166	0.164	0.97
14.5"	0.316	0.226	0.75
8.5"	0.918	0.386	0.38

After 24 hours in 32°F holding cooler, with an initial temperature of 50.73°F.

$$\frac{T-32}{50.73-32} = (0.97)\ (0.75)\ (0.38)$$

$$T = 37.17^{\circ}F$$

After 48 hours in 32^oF holding cooler, with an initial temperature of 50.7^oF

$$\frac{T-32}{37.17-32} = (0.97)\ (0.75)\ (0.38)$$

$$T = 33.43^oF$$

To determine the average temperature of the round after 24 and 48 hours in the 32^oF holding cooler use Heisler's (1947) chart, Figure 16, which relates temperature at any position as a function of center temperature.

slab	K/hL	X/L	$\frac{T_{(x,o)}-T_\infty}{T_{(o,\theta)}-T_\infty}$
20"	0.164	0.5	0.76
14.5"	0.226	0.5	0.80
8.5"	0.386	0.5	0.85

Now using equation 16 (Heisler, 1947)

$$\left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{Total} = \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{20"\ slab} \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{14.5"\ slab} \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{8.5"\ slab} \quad (16)$$

$T_{x,o}$ = average temperature of slab for X/L = 0.5, ^oF

T_∞ = surrounding air temperature, ^oF

$T_{o,\theta}$ = center temperature, ^oF (previously determined)

After 24 hours in 32^oF holding cooler

$$\frac{T_{x,o}-32}{37.17-32} = (0.76)\ (0.80)\ (0.85)$$

$$T_{x,o} = 34.67^oF$$

After 48 hours in 32^oF holding cooler

$$\frac{T_{x,o}-32}{33.43-32} = (0.76)\ (0.80)\ (0.85)$$

$$T_{x,} = 32.74^oF$$

Problem: To evaluate the internal and average temperature of an essentially solid box (9.5" x 22" x 17") of packaged meat product after 24 and 48 hours in the $28^{o}F$ shipping cooler.

Solution: Perform a transient heat analysis using Heisler's (1947) equation 15 and chart (Figure 15).

$$\left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{total box}} \quad \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{22" slab}} \quad \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{17" slab}} \quad \left\{\frac{T-T_\infty}{T_o-T_\infty}\right\}_{\text{9.5" slab}} \qquad (15)$$

T = final internal temperature, deg F

T_o = initial uniform temperature, deg F

T_∞ = surrounding fluid temperature, deg F

To use Heisler's chart must know $a\theta/L^2$ and K/hL where

L = 1/2 slab thickness, ft

θ = time elasped in cooler, hours

a = thermal diffusivity, sq ft per hour

K = thermal conductivity, Btu per (hr) (ft) (deg F)

h = surface heat transfer coefficient, Btu per (hr) (sq ft) (deg F)

a = 0.0048 sq ft perhour (ASHRAE Fundamentals, 1977d)

h = 2.05 Btu per (hr) (sq ft) (deg F) (ASHRAE Fundamentals, 1977d)

K_{meat} = 0.28 Btu per (hr) (ft) (deg F) (ASHRAE Fundamentals, 1977d and Lentz, 1961)

K_{box} = 1.74 Btu per (hr) (ft) (deg F)

weight box = 3.5 pounds, weight meat = 90 pounds

$$K_{composite} = \left\{\frac{90 \text{ lb}}{93.5 \text{ lb}}\right\} \left\{0.28 \frac{\text{Btu}}{(\text{hr})(\text{ft})(\text{F})}\right\} + \left\{\frac{3.5 \text{ lb}}{93.5 \text{ lb}}\right\} \left\{\frac{1.74 \text{ Btu}}{(\text{hr})(\text{ft})(\text{F})}\right\} = \frac{0.33 \text{ Btu}}{(\text{hr})(\text{ft})(\text{F})}$$

From Figure 15

slab	a /L	K/hL	$\frac{T-T_\infty}{T_o-T_\infty}$
22"	0.137	0.176	0.99
17"	0.230	0.227	0.88
9.5"	0.735	0.407	0.45

After 24 hours in a 28°F room, with an initial temperature of 33.43°F

$$\frac{T-28}{33.43-28} = (0.99)\ (0.88)\ (0.45)$$

$$T = 30.13^{o}F$$

After 48 hours in 28°F room

$$\frac{T-28}{30.13-28} = (0.99)\ (0.88)\ (0.45)$$

$$T = 28.84^{o}F$$

To determine the average temperature of the box after 24 and 48 hours in the 28°F room use Heisler's (1947) chart, Figure 16, which relates the temperature at any position as a function of center temperature.

slab	K/hL	X/L	$\frac{T_{(x,o)}-T_\infty}{T_{(o,\theta)}-T_\infty}$
22"	0.176	0.5	0.75
17"	0.227	0.5"	0.83
9.5"	0.407	0.5	0.85

Now using equation 16 (Heisler, 1947)

$$\left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{Total} = \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{20''\ slab} \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{14.5''\ slab} \left\{\frac{T_{x,o}-T_\infty}{T_{o,\theta}-T_\infty}\right\}_{8.5''\ slab} \qquad (16)$$

$T_{x,o}$ = average temperature of slab for X/L = 0.5, °F

T_∞ = surrounding air temperature, °F

$T_{o,\theta}$ = center temperature, °F (previously determined)

After 24 hours in 28°F room

$$\frac{T_{x,o}-28}{30.13-28} = (0.75)\ (0.83)\ (0.85)$$

$$T_{x,o} = 29.18^{o}F$$

After 48 hours in $28^{o}F$ room

$$\frac{T_{x,o}-28}{28.84-28} = (0.75)\,(0.83)\,(0.85)$$

$$T_{x,o} = 28.46^{o}F$$

APPENDIX D

SAMPLE CALCULATION

External Transmission East wall on July 21, 1976

$$q_{e,r} = A \left\{ \sum_{n=o} b_n \, (t_{e,r-n\Delta}) - \sum_{n=1} d_n \frac{(q_{e,r-n\Delta})}{A} - t_{rc} \sum_{n=o} c_n \right\} \qquad (4)$$

where: $q_{e,r}$ = heat gained by the space in Btu per hour

A = exposed area, sq ft

Δ = time interval in hours

$t_{e,r}$ = sol-air temperature, deg F

t_{rc} = constant indoor air temperature, deg F

b_n, c_n, d_n = transfer function coefficient characteristic of wall construction

For this example:

A = 92 ft x 28.5 ft = 2,622 ft

t_{rc} = 30^oF

b_n, c_n, d_n = transfer functions for 2 in. insulation on 8 in. l.w. concrete block from ASHRAE Fundamentals (1977)

	n=o	n=1	n=2	n=3	n=4	n=5
b	0.0001	0.00081	0.00339	0.00196	0.00018	
d	1.0000	-1.52490	0.69509	-0.11032	0.00399	-0.00001

Σc_n = 0.00635

$$t_{e,r} = t_o + \frac{\alpha I_t}{h_o} - \frac{E\Delta R}{h_o} \qquad (5)$$

where: t_o = outdoor air temperature, deg F

α = absorbance of surface

I_t = total solar radiation incident upon surface, Btu per (hour) (sq ft)

h_o = coefficient of heat transfer, Btu per (hour) (sq ft) (deg F)

E = hemispherical emittance of surface

ΔR = difference between longwave radiation incident upon the surface from the sky and surroundings and the radiation emitted by blackbody at outdoor air temperature, Btu per (hour) (sq ft)

For this example:

α/h_o = 0.30 for dark-colored surface from ASHRAE Fundamentals (1977)
ΔR = 0 for vertical surface from ASHRAE Fundamentals (1977)
E = 0.82 for masonry materials from ASHRAE Fundamentals (1977a)
h_o = 4.0 for 7.5 mph wind from ASHRAE Fundamentals (1977a)
I_t = 1.15 (SHGF)

SHGF is a function of latitude, date, and solar time

For July 21 at 40 deg, North Latitude, East Exposure

CST-DST	Solar Time	SHGF[1/] (Btuh per ft²)	I_t	$t_o(^oF)$	$t_{e,r}(^oF)$
8:00 A.M.	6:30 A.M.	170.5	196.06	76	134.8
12:00 A.M.	10:30 A.M.	113.5	130.53	85	124.2
4:00 P.M.	2:30 P.M.	169.5	194.93	87	145.5
8:00 P.M.	6:30 P.M.	69.5	79.93	75	99.0
12:00 P.M.	10:30 P.M.	0	0	72	72
4:00 A.M.	2:30 A.M.	0	0	78	78

Therefore:

$$q_{e,r} = 2622 \left\{ \begin{bmatrix} 0.0001(134.8) \\ +0.00081(78) \\ +0.00339(72) \\ +0.00196(99) \\ +0.00018(145.5) \end{bmatrix} - \begin{bmatrix} 1.0000(0) \\ -1.52490(0) \\ +0.69509(0) \\ -0.11032(0) \\ +0.0039\ (0) \\ -0.00001(0) \end{bmatrix} - 30(0.00635) \right\}$$

$q_{e,r}$ = 918.9 Btu per hr

Repeat this calculation in successive cycles to nullify effect of initially setting $q_{e,r-n\Delta}$ equal to zero

1/ From ASHRAE Fundamentals (1977b)

Interior Transmission

$$q = U A (t_b - t_{rc}) \quad (6)$$

where: q = heat gained by the space in Btu per hour

U = overall coefficient of heat transfer, Btu per hr (sq ft) (deg F)

A = exposed area, sq ft

t_b = temperature of the adjacent space, deg F

t_{rc} = temperature of the cooler space

For this example:

$A = 48 \text{ ft} \times 28.5 \text{ ft} = 1{,}368 \text{ ft}^2$

$t_b = 70^{o}F$

$t_{rc} = 30^{o}F$

U = 0.0919 Btu per hr (sq ft) (deg F) for wall constructed with 4 in l.w. concrete block with 0.75 in plaster

Therefore:
$$q = 0.0919 \frac{Btu}{hr(ft\ )(F)} (1{,}368 \text{ ft}^2) (70^{o}F - 30^{o}F)$$

$$q = 5028.8 \frac{Btu}{hr}$$

Infiltration

$$q = 4.5 (cfm) (\Delta h) \quad (7)$$

where: q = quantity of heat load, Btu per hour

cfm = volume of air entering the space, cubic feet per minute

Δh = difference in enthalphy between inside and outside air, Btu per pound dry air

For this example using July mean temperatures and relative humidity:

$h_{outside\ air}$ = 38.0 Midnight CST

h_{cooler} = 9.6 For $28^{o}F$ at 85% R.H.

cfm = 14 cu ft per min from ASHRAE Fundamentals (1977c)

Therefore:

$$q_{infiltration} = 4.5(14)\ (38-9.6) = 1{,}789.2 \frac{Btu}{hr}$$

Personnel

$$q = N(Q)$$

where: q = heat gained by the space in Btu per hour
N = number of persons entering refrigerated space
Q = heat equivalency per person, Btu per hour

For this example:
N = 7 persons
Q = 950 Btu per hr (in $32^{o}F$ cooler)

Therefore:

$$q = 7 \text{ person } (950 \frac{Btu}{hr})$$

$$q = 6{,}650 \frac{Btu}{hr}$$

Product Load 480 carcasses

$$q = mc(t_1 - t_2) \qquad (7)$$

where: q = quantity of heat to be removed, Btu
m = weight of product, lbs
c = specific heat of carcass, Btu per (lb) (deg F)
t_1 = temperature carcass as it enters cooler
t_2 = temperature carcass as it exits cooler

For this example:
m = 480 carcass (620 lb per carcass) = 297,600 lb
c = 0.75 Btu per (lb) (deg F)
t_1 = $98.5^{o}F$
t_2 = $40.7^{o}F$

Therefore:

$$q = 197{,}600 \text{ lb } (0.75 \frac{Btu}{lb\ F}) (98.5 - 48.7^{o}F)$$

$$q = 3.556 \times 10^{7} \text{ Btu}$$

Shroud Load

$$q_{total} = q_{sensible} + q_{latent}$$

$$q_{sensible} = m_n \, c_w \, (t_s - t_r) \qquad (2)$$

$$q_{latent} = h_{fg} \, (m_w) \qquad (3)$$

where: q_{total} = total heat gained by sensible and latent factions, Btu

m_w = total weight of water loss, lb

c_w = specific heat of water, Btu per (lb) (deg F)

t_s = temperature of shroud water, F

t_r = temperature of chill cooler, F

h_{fg} = heat of vaporization of water, Btu per lb water

For this example:

m_w = 6 pounds water per carcass (480 carcasses) = 2,880 lb

c_w = 1.0 Btu per (lb) deg F)

t_s = 125^{o}F

t_r = 30^{o}F

t_r = 1049.5 Btu perlb water

Therefore:

$q_{sensible}$ = 273,600 Btu

q_{latent} = 3,022,560 Btu

q_{total} = 3,296,160 Btu

Electrical - Motors

For 24 horsepower motor with motor losses outside the refrigerated space.

$$q = 24 \text{ hp } (2{,}545 \frac{\text{Btu}}{\text{hp-hr}}) = 61{,}080 \frac{\text{Btu}}{\text{hr}}$$

2,545 conversion given in ASHRAE Fundamentals (1977c)

Electrical - Lighting

q = total wattage factor x use factor x special allowance factor x 3.41 (8)

For this example:

total wattage = 3 $watt/ft^2$ (8,832 ft^2) = 26,496 watt

use factor = 1

special allowance factor = 1

$$q = 26{,}496 \text{ watt } (1)\ (1)\ \frac{3.41 \text{ Btu/hr}}{\text{watt}} = 90351.4 \text{ Btu/hr}$$

APPENDIX E

SOLAR TIME

Actual solar time may be calculated using equation 15 from ASHRAE Applications, 1974b.

AST = Local Standard Time + Equation of Time + 4 x (number of minutes east) or - 4 x (number of minutes west) of the Local Standard Time Meridian (15)

The longitudes of the six Standard Time Meridians which affect the U.S. are: Eastern ST, 75 deg; Central ST, 90 deg; Mountain ST, 105 deg; Pacific ST, 120 deg; Yukon ST, 135 deg; Alaska-Hawaii ST, 150 deg. The equation of time can be read from Table 2 based upon the month of the year.

Example: Calculate Actual Solar time at 1:30 P.M., on July 21 for Manhattan, Kansas, longitude = 96 deg.

Solution: Local standard time is actually 12:30 P.M. as Manhattan is in the Central Zone and uses Daylight Saving Time. The equation of time from Table 2 is -6.2 minutes and the Central Zone is 90 deg east of Greenwich

AST = 12:30 + (-6.2) -4 (96-90)

AST = 12:00 P.M.

Table 1. Equation of Time for the Twenty-first Day of Each Month

Month	Day of the year	Equation of time, minutes
January	21	-11.2
February	52	-13.9
March	80	- 7.5
April	111	+ 1.1
May	141	+ 3.3
June	173	- 1.4
July	202	- 6.2
August	233	- 2.4
September	265	+ 7.5
October	294	+15.4
November	325	+13.8
December	355	+ 1.6

Source: ASHRAE Applications, 1974b.

Table 2. Central Standard Time and Corresponding Solar Time for Manhattan, Kansas

Month, date	CST	Solar time
January 21	8:00 A.M.	7:25 A.M.
February 21	8:00 A.M.	7:22 A.M.
March 21	8:00 A.M.	7:29 A.M.
April 21	8:00 A.M.	7:37 A.M.
May 21	8:00 A.M. DST	6:39 A.M.
June 21	8:00 A.M. DST	6:35 A.M.
July 21	8:00 A.M. DST	6:30 A.M.
August 21	8:00 A.M. DST	6:34 A.M.
September 21	8:00 A.M. DST	6:43 A.M.
October 21	8:00 A.M. DST	6:51 A.M.
November 21	8:00 A.M.	7:50 A.M.
December 21	8:00 A.M.	7:38 A.M.

APPENDIX F

DATA INPUT PROCEDURE

The input data can be divided naturally into four groups. These divisions as well as the input order and format are shown in Table 4. The first data set contains those data which are common to all three of the options considered in this study. The first three items, solar heat gain factors, external temperatures and external relative humidities, are entered on an hourly basis for one day of each month. Thus, one day occupies 2 full cards. Four sets of solar heat gain factors are required in order to accomodate the one horizontal and three vertical surfaces considered. The convention used here is that the first value read in for any particular day corresponds to 1 A.M.

The remaining three data sets are comprised of the data specific to any one option. Each of these groups can in turn be divided into three subsets. For each option, three types of data must be supplied:

1) general plant characteristics such as wall surface areas, room temperatures, and personnel requirements,
2) exterior transmission parameters for the vertical surfaces,
3) exterior transmission parameters for the roofs.

As programmed, each subroutine calculates the exterior transmission load for the walls prior to that for the roofs. Consequently, the wall data must be entered first, as notated in Table 4.

A system has been devised whereby each room and surface considered in the current plant configuration is assigned an identifying number. The primary purpose of this is to define the input order of the general plant

Table 4. Data Input

Card	Input Variables	Format
1	IDLT	(I2)
2-25	((TEMPDB(I,J), J=1, 24), I=1, 12)	(12F6.0)
26-49	((RHDB(I,J), J=1, 24), I=1,12)	(12F6.0)
50-145	(((SHGFDB(I,J,K), K=1, 24), J=1, 12), I=1,4)	(12F6.0)
146	NCARC, PROD1, PROD2, SPHT1, SPHT2, QPEOPL	(I6,11F6.0)
147	(SRFA(I), I=1, 13)	(13F6.0)
148	(U(I), I=1, 13)	(13F6.0)
149	(TEMP(I), I=1,4), T1EXIT, T2EXIT, T3EXIT, (ENTHIN(I), I=1,3)	(13F6.0)
150	(CFM(I),I=1,3), (WATT(I),I=1,3), (USE(I), I=1,3), (SAF(I),I=1,3)	(13F6.0)
151	WTRMS, SPHTWT, TSHRD, HFGWTR	(13F6.0)
152	(HP(I), I=1,3)	(13F6.0)
153	(NPEOPL(I), I=1,3)	(3I6)
154	NB, ND, C, A, EPSLN, HO (Walls)	(2I3,4F10.0)
155	(B(I), I=1, NB)	(8F10.0)
156	(D(I), I=1, ND)	(8F10.0)
157	DELTAR	(8F10.0)
158	NB, ND, C, A, EPSLN, HO (Roofs)	(2I3, 4F10.0)
159	(B(I), I=1, NB)	(8F10.0)
160	(D(I), I=1, ND)	(8F10.0)
161	DELTAR	(8F10.0)
162	(SRFA(I), I=1,9)	(13F6.0)
163	(U(I), I=1,9)	(13F6.0)
164	(TEMP(I), I=1,2) T1EXIT, T2EXIT, (ENTHIN(I), I=1,2)	(13F6.0)
165	(CFM(I),I=1,2), (WATT(I),I=1,2), (USE(I),=1,2), (SAF(I), I=1,2)	(13F6.0)
166	(HP(I), I=1,2)	(13F6.0)
167	(NPEOPL(I), I=1,2)	(3I6)
168	NB, ND, C, A, EPSLN, HO (Walls)	(2I3,4F10.0)
169	(B(I), I=1, NB)	(10F8.0)
170	(D(I), I=1, ND)	(10F8.0)
171	DELTAR	(10F8.0)
172	NB, ND, C, A, EPSLN, HO (Roofs)	(2I3,4F10.0)
173	(B(I), I=1, NB)	(10F8.0)
174	(D(I), I=1, ND)	(10F8.0)
175	DELTAR	(10F8.0)

Table 4. (continued)

Card	Input Variables	Format
176	(SRFA(I), I=1,5)	(13F6.0)
177	(U(I), I=1,5)	(13F6.0)
178	TEMP(1), TIEXIT, ENTHIN(1)	(13F6.0)
179	CFM(1), WATT(1), USE(1), SAF(1)	(13F6.0)
180	HP(1)	(13F6.0)
181	NPEOPL(1)	(13F6.0)
182	NB, ND, C, A, EPSLN, HO (Walls)	(2I3,4F10.0)
183	(B(I), I=1, NB)	(10F8.0)
184	(D(I), I=1, ND)	(10F8.0)
185	DELTAR	(10F8.0)
186	NB, ND, C, A, EPSLN, HO (Roofs)	(2I3,4F10.0)
187	(B(I), I=1, ND)	(10F8.0)
188	(D(I), I=1, ND)	(10F8.0)
189	DELTAR	(10F8.0)

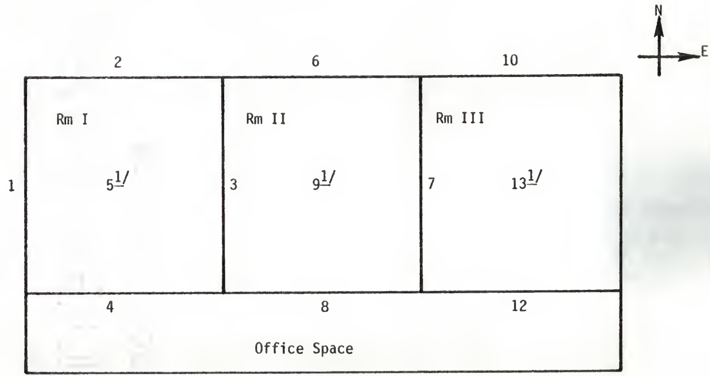
data. A hypothetical plant is shown in Figure 17 where the Roman numerals refer to rooms while the Arabic numerals serve to identify specific surfaces.

The general form of a READ statement in the program HEATLD is where

READ (5, J) (VALUE(I), I=1, NVALS)

J refers to a specific format statement. VALUE represents some vector of required data while NVALS is a constant equal to the number of values required. For example, to read in the necessary surface areas for the cold boning option, NVALS would become 13 and the value for surface 1 would be entered on the card first. Surface 2, 3, ... 13 would follow sequentially according to Figure 17.

However, for the hot-processing option I, NVALS would be 9 because of the differences in plant layout, i.e. disregard room III in Figure 17. For hot-processing option II, one must disregard both rooms II and III in Figure 17.



1/ Refers to roof surface.

Figure 17. Surface Area Denotation

APPENDIX G. COMPUTER PROGRAM

```
      COMMON SHGF(4,12,24),TO(12,24),TE(12,24),CFM(3),WATT(3),USE(3),
     1SAF(3),NPEOPL(3),ENTHLP(12,24),ENTHIN(3),PROD1,PROD2,IDLT,B(10),
     2D(10),C,NB,ND,A,EPSLN,DELTAR,HO,CPECPL,NHOUR,MONTH(12),SPHT1,
     3SPHT2,HP(3),NCARD,TOTAL(12)
      DIMENSION SRFA(13),TEMP(4),U(13),TEMPDB(12,24),RHDB(12,24),
     1SHGFDB(4,12,24),COEFF1(8),COEFF2(6),RELHUM(12,24)
      DATA COEFF1/.2405,.448,.01763,864.7168,.2405,.448,.01377,862.3629/
      DATA COEFF2/54.6329,12301.69,5.16923,23.3924,11286.65,.46057/
      READ(5,1)IDLT,ISTRT
    1 FORMAT(I2,I3)
      NHOUR=24/IDLT+.5
C     ******************************************************************
C     READ IN EXTERNAL TEMPERATURES AND RELATIVE HUMIDITIES
C     ******************************************************************
      READ(5,2)((TEMPDB(I,J),J=1,24),I=1,12)
      READ(5,2)((RHDB(I,J),J=1,24),I=1,12)
C     ******************************************************************
C     READ IN SOLAR HEAT GAIN FACTORS, SHGF(I,J,K), AS A FUNCTION OF
C     ORIENTATION, MONTH, AND TIME
C
C     I=1, WESTERN EXPOSURE
C     I=2, NORTHERN EXPOSURE
C     I=3, EASTERN EXPOSURE
C     I=4, ROOF
C     ******************************************************************
      READ(5,2)(((SHGFDB(I,J,K),K=1,24),J=1,12),I=1,4)
    2 FORMAT(12F6.0)
      DO 7 I=1,12
      DO 7 J=1,24
      INDEX=J+ISTRT-1
      IF(INDEX.GT.24) INDEX=INDEX-24
      TO(I,J)=TEMPDB(I,INDEX)
    7 RELHUM(I,J)=RHDB(I,INDEX)
      DO 8 K=1,4
      DO 8 I=1,12
      DO 8 J=1,24
      INDEX=J+ISTRT-1
      IF(INDEX.GT.24) INDEX=INDEX-24
    8 SHGF(K,I,J)=SHGFDB(K,I,INDEX)
      DO 3 I=1,12
      INDEX=0
      DO 3 J=1,NHOUR
      TO(I,J)=TO(I,INDEX+1)
      RELHUM(I,J)=RELHUM(I,INDEX+1)
    3 INDEX=INDEX+IDLT
      DO 4 K=1,4
      DO 4 I=1,12
      INDEX=0
      DO 4 J=1,NHOUR
      SHGF(K,I,J)=SHGF(K,I,INDEX+1)
    4 INDEX=INDEX+IDLT
C     ******************************************************************
C     CALCULATE ENTHALPY VALUES
C     ******************************************************************
      DO 6 I=1,12
      DO 6 J=1,NHOUR
      KK=1
      IF(TO(I,J).LT.32.) KK=4
      VAL=COEFF2(KK)-COEFF2(KK+1)/(TO(I,J)+459.69)-COEFF2(KK+2)*ALOG(TO(
     1I,J)+459.69)
```

```
      COMMON SHGF(4,12,24),TO(12,24),TE(12,24),CFM(3),WATT(3),USE(3),
     1SAF(3),NPEOPL(3),ENTHLP(12,24),ENTHIN(3),PROD1,PROD2,IDLT,B(10),
     2D(10),C,NB,ND,A,EPSLN,DELTAR,HO,CPEOPL,NHOUR,MONTH(12),SPHT1,
     3SPHT2,HP(3),NCARD,TOTAL(12)
      DIMENSION SRFA(13),TEMP(4),U(13),TEMPDB(12,24),RHDB(12,24),
     1SHGFDB(4,12,24),COEFF1(8),COEFF2(6),RELHUM(12,24)
      DATA COEFF1/.2405,.448,.01783,864.7168,.2405,.448,.01377,862.3629/
      DATA COEFF2/54.6329,12301.69,5.16923,23.3924,11286.65,.46057/
      READ(5,1)IDLT,ISTRT
    1 FORMAT(I2,I3)
      NHOUR=24/IDLT+.5
C     ******************************************************************
C     READ IN EXTERNAL TEMPERATURES AND RELATIVE HUMIDITIES
C     ******************************************************************
      READ(5,2)((TEMPDB(I,J),J=1,24),I=1,12)
      READ(5,2)((RHDB(I,J),J=1,24),I=1,12)
C     ******************************************************************
C     READ IN SOLAR HEAT GAIN FACTORS, SHGF(I,J,K), AS A FUNCTION OF
C     ORIENTATION, MONTH, AND TIME
C
C     I=1, WESTERN EXPOSURE
C     I=2, NORTHERN EXPOSURE
C     I=3, EASTERN EXPOSURE
C     I=4, ROOF
C     ******************************************************************
      READ(5,2)(((SHGFDB(I,J,K),K=1,24),J=1,12),I=1,4)
    2 FORMAT(12F6.0)
      DO 7 I=1,12
      DO 7 J=1,24
      INDEX=J+ISTRT-1
      IF(INDEX.GT.24) INDEX=INDEX-24
      TO(I,J)=TEMPDB(I,INDEX)
    7 RELHUM(I,J)=RHDB(I,INDEX)
      DO 8 K=1,4
      DO 8 I=1,12
      DO 8 J=1,24
      INDEX=J+ISTRT-1
      IF(INDEX.GT.24) INDEX=INDEX-24
    8 SHGF(K,I,J)=SHGFDB(K,I,INDEX)
      DO 3 I=1,12
      INDEX=0
      DO 3 J=1,NHOUR
      TO(I,J)=TO(I,INDEX+1)
      RELHUM(I,J)=RELHUM(I,INDEX+1)
    3 INDEX=INDEX+IDLT
      DO 4 K=1,4
      DO 4 I=1,12
      INDEX=0
      DO 4 J=1,NHOUR
      SHGF(K,I,J)=SHGF(K,I,INDEX+1)
    4 INDEX=INDEX+IDLT
C     ******************************************************************
C     CALCULATE ENTHALPY VALUES
C     ******************************************************************
      DO 6 I=1,12
      DO 6 J=1,NHOUR
      KK=1
      IF(TO(I,J).LT.32.) KK=4
      VAL=COEFF2(KK)-COEFF2(KK+1)/(TO(I,J)+459.69)-COEFF2(KK+2)*ALOG(TO(
     1I,J)+459.69)
```

```
      PS=EXP(VAL)
      PV=RELHUM(I,J)*PS/100.
      XCALC=.6219*PV/(14.656-PV)
      KK=1
      IF(TO(I,J).LT.32.) KK=5
      ENTHLP(I,J)=COEFF1(KK)*TO(I,J)+XCALC*((TO(I,J)+459.69)*(COEFF1(KK+
     11)-COEFF1(KK+2))+COEFF1(KK+3))
    6 CONTINUE
      WRITE(6,10)
   10 FORMAT('1',T45,'OUTSIDE TEMPERATURES IN DEGREES FAHRENHEIT',/,T55,
     1'(MONTH 1 IS JANUARY)',//,T74,'MONTH',/)
      DO 15 I=1,12
   15 MONTH(I)=I
      WRITE(6,20)(MONTH(I),I=1,12)
   20 FORMAT(T8,'HOUR',T18,11(I2,7X),I2)
      DO 25 J=1,NHOUR
       JJ=IDLT*(J-1)+ISTRT
      IF(JJ.GT.24) JJ=JJ-24
   25 WRITE(6,30)JJ,(TO(I,J),I=1,12)
   30 FORMAT(/T9,I2,6X,12(F4.0,5X))
      WRITE(6,35)
   35 FORMAT(//,T54,'SOLAR HEAT GAIN FACTORS')
      DO 40 I=1,4
      WRITE(6,45)I,(MONTH(J),J=1,12)
   45 FORMAT(//,T61,'EXPOSURE=',I2,/,T74,'MONTH',/,T8,'HOUR',T18,11(
     1I2,7X),I2)
      DO 40 J=1,NHOUR
      JJ=IDLT*(J-1)+ISTRT
      IF(JJ.GT.24) JJ=JJ-24
   40 WRITE(6,30)JJ,(SHGF(I,K,J),K=1,12)
      WRITE(6,46)(MONTH(I),I=1,12)
   46 FORMAT(//T58,'ENTHALPY VALUES',/,T74,'MONTH',/,T8,'HOUR',T18,11(I2
     1,7X),I2)
      DO 47 I=1,NHOUR
      JJ=IDLT*(I-1)+ISTRT
      IF(JJ.GT.24) JJ=JJ-24
   47 WRITE(6,48)JJ,(ENTHLP(J,I),J=1,12)
   48 FORMAT(/T9,I2,6X,12(F4.1,5X))
      READ(5,49)NCARC,PROD1,PROD2,SPHT1,SPHT2,CFEOPL
   49 FORMAT(I6,11F6.0)
      PROD1=PROD1*NCARC
      PROD2=PROD2*NCARC
C     ******************************************************************
C     COLD BONING OPTION
C     ******************************************************************
      READ(5,5)(SRFA(I),I=1,13)
      READ(5,5)(U(I),I=1,13)
      READ(5,5)(TEMP(I),I=1,4),T1EXIT,T2EXIT,T3EXIT,(ENTHIN(I),I=1,3)
      READ(5,5)(CFM(I),I=1,3),(WATT(I),I=1,3),(USE(I),I=1,3),
     1(SAF(I),I=1,3)
      READ(5,5)WTRMS,SPHTWT,TSHRD,HFGWTR
      READ(5,5)(HP(I),I=1,3)
    5 FORMAT(13F6.0)
      READ(5,55)(NPEOPL(I),I=1,3)
   55 FORMAT(3I6)
      CALL CLDCPT(SRFA,MODE,TEMP,T1EXIT,T2EXIT,T3EXIT,WTRMS,SPHTWT,
     1TSHRD,HFGWTR,U)
      IF(MODE.EQ.1) GO TO 1000
C     ******************************************************************
C     HOT BONING OPTION 1
```

```
C     ******************************************************************
      READ(5,5)(SRFA(I),I=1,9)
      READ(5,5)(U(I),I=1,9)
      READ(5,5)(TEMP(I),I=1,2),T1EXIT,T2EXIT,(ENTHIN(I),I=1,2)
      READ(5,5)(CFM(I),I=1,2),(WATT(I),I=1,2),(USE(I),I=1,2),
     1(SAF(I),I=1,2)
      READ(5,5)(HP(I),I=1,2)
      READ(5,55)(NPEOPL(I),I=1,2)
      CALL OPT1(SRFA,MODE,U,TEMP,T1EXIT,T2EXIT)
      IF(MODE.EQ.1) GO TO 1000
C     ******************************************************************
C     HOT BONING OPTION 2
C     ******************************************************************
      READ(5,5)(SRFA(I),I=1,5)
      READ(5,5)(U(I),I=1,5)
      READ(5,5)TEMP(1),T1EXIT,ENTHIN(1)
      READ(5,5)CFM(1),WATT(1),USE(1),SAF(1)
      READ(5,5)HP(1)
      READ(5,55)NPEOPL(1)
      CALL OPT2(SRFA,MODE,U,TEMP,T1EXIT)
 1000 WRITE(6,1001)
 1001 FORMAT('1')
      STOP
      END
      SUBROUTINE CLDOPT(SRFA,MODE,TEMP,T1EXIT,T2EXIT,T3EXIT,WTRMS,
     1SPHTWT,TSHRD,HFGWTR,U)
      COMMON SHGF(4,12,24),TO(12,24),TE(12,24),CFM(3),WATT(3),USE(3),
     1SAF(3),NPEOPL(3),ENTHLF(12,24),ENTHIN(3),PROD1,PROD2,
     2IDLT,B(10),D(10),C,NB,ND,A,EPSLN,DELTAR,HO,QPEOPL,NHOUR,MONTH(12),
     3SPHT1,SPHT2,HP(3),NCARC,TOTAL(12)
      DIMENSION SRFA(13),TEMP(4),QESUM(12),QSUM(3,12),STOR(3,12),U(13)
      REAL INFLT1,INFLT2,INFLT3
      WRITE(6,1)(MONTH(I),I=1,12)
    1 FORMAT('1',T47,'COLD BONING OPTION',//T45,'EXTERIOR TRANSMISSION B
     1Y SURFACE (BTU/DAY)',//T74,'MONTH',/T7,'SOURCE',T18,11(I2,7X),I2)
C     ******************************************************************
C     CALCULATE EXTERIOR TRANSMISSION
C
C     WALLS 1, 2, 6, 10, 11
C     ******************************************************************
      DO 2 I=1,3
      DO 2 J=1,12
    2 QSUM(I,J)=0.
      READ(5,5)NB,NC,C,A,EPSLN,HO
    5 FORMAT(2I3,4F10.0)
      READ(5,10)(B(I),I=1,NB)
      READ(5,10)(D(I),I=1,ND)
   10 FORMAT(8F10.0)
      JJ=0
      J=1
C
C     KJ IS A PARAMETER DESIGNATING THE ORIENTATION OF THE SURFACE
C
      KJ=1
      READ(5,10)DELTAR
      DO 25 I=1,5
      LL=I+JJ
      CALL TRANEX(SRFA(LL),TEMP(J),U(LL),MODE,QESUM,KJ)
      IF(MODE.EQ.1) RETURN
      DO 20 KK=1,12
```

```
   20 QSUM(J,KK)=QESUM(KK)+QSUM(J,KK)
      IF(I.EQ.1) GO TO 21
      IF(I.EQ.2) GO TO 22
      IF(I.EQ.3) GO TO 23
      IF(I.EQ.4) GO TO 24
      GO TO 25
   21 KJ=2
      GO TO 25
   22 J=2
      JJ=3
      GO TO 25
   23 J=3
      JJ=6
      GO TO 25
   24 KJ=3
   25 WRITE(6,26)LL,(QESUM(L),L=1,12)
   26 FORMAT(T2,'SURFACE   ',I2,T15,11(F8.0,1X),F8.0)
C     ******************************************************************
C     ROOFS 5, 9, 13
C     ***************************T**************************************
      READ(5,5)NB,ND,C,A,EPSLN,HO
      READ(5,10)(E(I),I=1,NB)
      READ(5,10)(D(I),I=1,ND)
      READ(5,10)DELTAR
      J=1
      KJ=4
      DO 35 I=5,13,4
      CALL TRANEX(SRFA(I),TEMP(J),U(I),MODE,QESUM,KJ)
      IF(MODE.EQ.1) RETURN
      DO 30 KK=1,12
   30 QSUM(J,KK)=QSUM(J,KK)+QESUM(KK)
      J=J+1
   35 WRITE(6,26)I,(QESUM(L),L=1,12)
      WRITE(6,36)
   36 FORMAT(//T5,'EXTERIOR TRANSMISSION TOTALS (BTU/DAY)')
      DO 37 II=1,3
   37 WRITE(6,38)II,(QSUM(II,L),L=1,12)
   38 FORMAT(//T8,'RM ',I2,T15,11(F8.0,1X),F8.0)
C     ******************************************************************
C     CALCULATE INTERIOR TRANSMISSION
C     ******************************************************************
      VAL12=U(3)*SRFA(3)*(TEMP(2)-TEMP(1))*24.
      VAL14=U(4)*SRFA(4)*(TEMP(4)-TEMP(1))*24.
      VAL24=U(8)*SRFA(8)*(TEMP(4)-TEMP(2))*24.
      VAL23=U(7)*SRFA(7)*(TEMP(3)-TEMP(2))*24.
      VAL34=U(12)*SRFA(12)*(TEMP(4)-TEMP(3))*24.
      WRITE(6,41)VAL12,VAL14,VAL24,VAL23,VAL34
   41 FORMAT(//,T6,'INT TRAN',/,T6,'RM 1->2',T73,F8.0,/,T6,'RM 1->4',T73
     1,F8.0,/,T6,'RM 2->4',T73,F8.0,/,T6,'RM 2->3',T73,F8.0,/,T6,'RM 3->
     24',T73,F8.0)
C     ******************************************************************
C     CALCULATE INFILTRATION LOSS
C     ******************************************************************
      DO 45 I=1,12
      INFLT1=0.
      INFLT2=0.
      INFLT3=0.
      DO 40 J=1,NHOUR
      INFLT1=INFLT1+4.5*CFM(1)*IDLT*(ENTHLP(I,J)-ENTHIN(1))
      INFLT2=INFLT2+4.5*CFM(2)*IDLT*(ENTHLP(I,J)-ENTHIN(2))
```

```
   40 INFLT3=INFLT3+4.5*CFM(3)*IDLT*(ENTHLP(I,J)-ENTHIN(3))
      STOR(1,I)=INFLT1
      STOR(2,I)=INFLT2
      STOR(3,I)=INFLT3
      CSUM(1,I)=QSUM(1,I)+INFLT1
      CSUM(2,I)=QSUM(2,I)+INFLT2
   45 CSUM(3,I)=QSUM(3,I)+INFLT3
      WRITE(6,44)
   44 FORMAT(//T4,'INFILTRATION')
      DO 42 J=1,3
   42 WRITE(6,43)J,(STOR(J,I),I=1,12)
   43 FORMAT(/T8,'RM ',I2,T15,11(F8.1,1X),F8.1)
C     ******************************************************************
C     CALCULATE PERSONNEL LOAD
C     ******************************************************************
      QPERS1=NPEOPL(1)*QPEOPL*8.
      CPERS2=NPEOPL(2)*CPEOPL*8.
      QPERS3=NPEOPL(3)*QPEOPL*8.
      WRITE(6,46)CPERS1,CPERS2,QPERS3
   46 FORMAT(//,T6,'PERSONNEL',/,T8,'RM 1',T73,F8.0,/,T8,'RM 2',T73,F8.0
     2,/,T8,'RM 3',T73,F8.0)
C     ******************************************************************
C     CALCULATE PRODUCT LOAD
C     ******************************************************************
      PROD=PROD1*SPHT1
      VAL1=(56.5-T1EXIT)*PROD
      VAL2=(T1EXIT-T2EXIT)*PROD
      VAL3=(T2EXIT-T3EXIT)*PROD2*SPHT2
      WRITE(6,47)VAL1,VAL2,VAL3
   47 FORMAT(/,T3,'PRODUCT LOAD',/T8,'RM 1',T73,F9.0,/,T8,'RM 2',T73,F9.
     10,/,T8,'RM 3',T73,F9.0)
C     ******************************************************************
C     CALCULATE ELECTRICAL MOTOR LOAD
C     ******************************************************************
      ELECT1=HP(1)*2545.*24.
      ELECT2=HP(2)*2545.*24.
      ELECT3=HP(3)*2545.
      WRITE(6,48)ELECT1,ELECT2,ELECT3
   48 FORMAT(/,T3,'ELECTRICAL LOAD',/,T3,'RM 1',T73,F8.0,/,T8,'RM 2',T73
     1,F8.0,/,T8,'RM 3',T73,F8.0)
C     ******************************************************************
C     CALCULATE LIGHTING LOAD
C     ******************************************************************
      ALGHT1=WATT(1)*USE(1)*SAF(1)*81.84
      ALGHT2=WATT(2)*USE(2)*SAF(2)*81.84
      ALGHT3=WATT(3)*USE(3)*SAF(3)*81.84
      WRITE(6,49)ALGHT1,ALGHT2,ALGHT3
   49 FORMAT(/,T4,'LIGHTING LOAD',/,T8,'RM 1',T73,F8.0,/,T3,'RM 2',T73,F
     18.0,/,T8,'RM 3',T73,F8.0)
C     ******************************************************************
C     CALCULATE SHROUD LOAD
C     ******************************************************************
      QSHRD=WTRMS*SPHTWT*(TSHRD-TEMP(1))+HFGWTR*WTRMS
      WRITE(6,51)QSHRD
   51 FORMAT(/,T5,'SHROUD LOAD',/,T8,'RM 1',T73,F8.0)
      DO 50 I=1,12
      QSUM(1,I)=(QSUM(1,I)+VAL12+VAL14+QSHRD+QPERS1+VAL1+ELECT1+ALGHT1)/
     1PROD2
      CSUM(2,I)=(QSUM(2,I)-VAL12+VAL24+VAL23+QPERS2+VAL2+ELECT2+ALGHT2)/
     1PROD2
```

```
   50 CSUM(3,I)=(QSUM(3,I)-VAL23+VAL34+QPERS3+VAL3+ELECT3+ALGHT3)/PRCD2
      WRITE(6,55)((CSUM(I,J),J=1,12),I=1,3),PROD1,PROD1,PROD2
   55 FORMAT(/,T52,'***TOTAL FOR COLD BONING***',/,T52,'(BTU/LB OF FINIS
     1HED PRODUCT',/T8,'RM 1',T15,11(F8.1,1X),F8.1,/T8,'RM 2',T15,11(F8.
     21,1X),F8.1,/T8,'RM 3',T15,11(F8.1,1X),F8.1,//,T77,'ROOM',/T52,'1',
     3T78,'2',T104,'3',/T17,'PRODUCT MASS (LBS)',T49,F9.0,T74,F9.0,T100,
     4F9.0)
      DO 56 I=1,12
      TOTAL(I)=0.
      DO 56 J=1,3
   56 TOTAL(I)=TOTAL(I)+CSUM(J,I)
      WRITE(6,57)(TOTAL(I),I=1,12)
   57 FORMAT(/T2,'TOTALS BY MONTH',/T15,11(F8.1,1X),F8.1)
      WRITE(6,60)NCARC
   60 FORMAT(/T20,'NUMBER OF CARCASSES PER DAY :  ',I4)
      RETURN
      END
      SUBROUTINE OPT1(SRFA,MODE,U,TEMP,T1EXIT,T2EXIT)
      COMMON SHGF(4,12,24),TO(12,24),TE(12,24),CFM(3),WATT(3),USE(3),
     1SAF(3),NPEOPL(3),ENTHLP(12,24),ENTHIN(3),PROD1,PROD2,IDLT,B(10),
     2D(10),C,NB,ND,A,EPSLN,DELTAR,HO,QPEOPL,NHOUR,MONTH(12),SPHT1,
     3SPHT2,HP(3),NCARC,TOTAL(12)
      DIMENSION SRFA(13),TEMP(4),QSUM(3,12),QESUM(12),STOR(3,12),U(13)
      REAL INFLT1,INFLT2
      WRITE(6,1)(MONTH(I),I=1,12)
    1 FORMAT('1',T47,'HOT BONING OPTION 1',//T45,'EXTERIOR TRANSMISSION
     1BY SURFACE (BTU/DAY)',//T74,'MONTH',/T7,'SOURCE',T18,11(I2,7X),I2)
C     ******************************************************************
C     CALCULATE EXTERIOR TRANSMISSION
C
C     WALLS 1, 2, 6, 7
C     ******************************************************************
      DO 2 I=1,3
      DO 2 J=1,12
    2 QSUM(I,J)=0.
      READ(5,5)NB,ND,C,A,EPSLN,HO
    5 FORMAT(2I3,4F10.0)
      READ(5,10)(B(I),I=1,NB)
      READ(5,10)(D(I),I=1,ND)
   10 FORMAT(10F8.0)
      READ(5,10)DELTAR
      KJ=1
      J=1
      JJ=0
      DO 20 I=1,4
      LL=I+JJ
      CALL TRANEX(SRFA(LL),TEMP(J),U(LL),MODE,QESUM,KJ)
      IF(MODE.EQ.1) RETURN
      DO 25 KK=1,12
   25 QSUM(J,KK)=QESUM(KK)+QSUM(J,KK)
      IF(I.EQ.1) GO TO 26
      IF(I.EQ.2) GO TO 27
      IF(I.EQ.3) GO TO 28
      GO TO 20
   26 KJ=2
      GO TO 20
   27 JJ=2
      J=2
      GO TO 20
   28 KJ=3
```

```
   20 WRITE(6,29)LL,(CESUM(L),L=1,12)
   29 FORMAT(T2,'SURFACE ',I2,T15,11(F8.0,1X),F8.0)
C     *****************************************************************
C     ROOFS 5, 9
C     *****************************************************************
      READ(5,5)NB,ND,C,A,EPSLN,HO
      READ(5,10)(B(I),I=1,NB)
      READ(5,10)(D(I),I=1,ND)
      READ(5,10)DELTAR
      KJ=4
      J=1
      DO 30 I=11,12
      CALL TRANEX(SRFA(I),TEMP(J),U(I),MODE,CESUM,KJ)
      DO 35 KK=1,12
   35 QSUM(J,KK)=QSUM(J,KK)+CESUM(KK)
      J=J+1
   30 WRITE(6,29)I,(CESUM(L),L=1,12)
      WRITE(6,33)
   33 FORMAT(//T4,'EXTERIOR TRANSMISSION TOTALS (BTU/DAY)')
      DO 31 I=1,2
   31 WRITE(6,32)I,(QSUM(I,LK),LK=1,12)
   32 FORMAT(/T8,'RM',I2,T15,11(F8.0,1X),F8.0)
C     *****************************************************************
C     CALCULATE INFILTRATION LOSS
C     *****************************************************************
      DO 45 I=1,12
      INFLT1=0.
      INFLT2=0.
      DO 40 J=1,NHOUR
      INFLT1=INFLT1+4.5*CFM(1)*(ENTHLP(I,J)-ENTHIN(1))*IDLT
   40 INFLT2=INFLT2+4.5*CFM(2)*(ENTHLP(I,J)-ENTHIN(2))*IDLT
      STOR(1,I)=INFLT1
      STOR(2,I)=INFLT2
      QSUM(1,I)=QSUM(1,I)+INFLT1
   45 QSUM(2,I)=QSUM(2,I)+INFLT2
      WRITE(6,44)
   44 FORMAT(//T4,'INFILTRATION')
      DO 46 I=1,2
   46 WRITE(6,47)I,(STOR(I,J),J=1,12)
   47 FORMAT(/T8,'RM',I2,T15,11(F8.0,1X),F8.0)
C     *****************************************************************
C     CALCULATE INTERIOR TRANSMISSION
C     *****************************************************************
      VAL12=U(3)*SRFA(3)*(TEMP(2)-TEMP(1))*24.
      VAL14=U(4)*SRFA(4)*(TEMP(4)-TEMP(1))*24.
      VAL24=U(8)*SRFA(8)*(TEMP(4)-TEMP(2))*24.
      WRITE(6,48) VAL12,VAL14,VAL24
   48 FORMAT(//,T6,'INT TRAN',/T6,'RM 1->2',T73,F8.0,/T6,'RM 1->4',T73,F
     18.0,/T6,'RM 2->4',T73,F8.0)
C     *****************************************************************
C     CALCULATE PRODUCT LOAD
C     *****************************************************************
      VAL1=PROD1*SPHT1*(98.5-T1EXIT)
      VAL2=PROD2*SPHT2*(T1EXIT-T2EXIT)
      WRITE(6,49)VAL1,VAL2
   49 FORMAT(/,T2,'PRODUCT LOAD',/,T8,'RM 1',T73,F9.0,/,T8,'RM 2',T73,F9
     1.0)
C     *****************************************************************
C     CALCULATE PERSONNEL LOAD
C     *****************************************************************
```

```
      QPERS1=NPEOPL(1)*600.*8.
      QPERS2=NPEOPL(2)*QPEOPL*8.
      WRITE(6,51)QPERS1,QPERS2
   51 FORMAT(//,T6,'PERSONNEL',/,T8,'RM 1',T73,F9.0,/,T8,'RM 2',T73,F9.0
     1)
C     ******************************************************************
C     CALCULATE ELECTRICAL MOTOR LOAD
C     ******************************************************************
      ELECT1=HP(1)*2545.*24.
      ELECT2=HP(2)*2545.*24.
      WRITE(6,52)ELECT1,ELECT2
   52 FORMAT(/,T2,'ELECTRICAL LOAD',/,T8,'RM 1',T73,F8.0,/,T8,'RM 2',T73
     1,F8.0)
C     ******************************************************************
C     CALCULATE LIGHTING LOAD
C     ******************************************************************
      ALGHT1=WATT(1)*USE(1)*SAF(1)*81.84
      ALGHT2=WATT(2)*USE(2)*SAF(2)*81.84
      WRITE(6,53)ALGHT1,ALGHT2
   53 FORMAT(/,T4,'LIGHTING LOAD',/,T8,'RM 1',T73,F8.0,/,T8,'RM 2',T73,F
     18.0)
      DO 50 I=1,12
      QSUM(1,I)=(QSUM(1,I)+VAL12+VAL14+VAL1+QPERS1+ELECT1+ALGHT1)/PROD2
   50 QSUM(2,I)=(QSUM(2,I)-VAL12+VAL24+VAL2+QPERS2+ELECT2+ALGHT2)/PROD2
      WRITE(6,56)((QSUM(I,J),J=1,12),I=1,2),PROD1,PROD2
   56 FORMAT(/,T51,'TOTAL FOR HOT BONING OPTION 1',/,T52,'(BTU/LB OF FIN
     1ISHED PRODUCT)',/T8,'RM 1',T15,11(F8.1,1X),F8.1,/T8,'RM 2',T15,11(
     2F8.1,1X),F8.1,//T77,'ROOM',/T52,'1',T78,'2',/T17,'PRODUCT MASS (LB
     3S)',T49,F9.0,T74,F9.0)
      DO 57 I=1,12
      TOTAL(I)=0.
      DO 57 J=1,2
   57 TOTAL(I)=TOTAL(I)+QSUM(J,I)
      WRITE(6,58)(TOTAL(I),I=1,12)
   58 FORMAT(/T2,'TOTALS BY MONTH',/T15,11(F8.1,1X),F8.1)
      WRITE(6,60)NCARC
   60 FORMAT(/T20,'NUMBER OF CARCASSES PER DAY:  ',I4)
      RETURN
      END
      SUBROUTINE OPT2(SRFA,MODE,U,TEMP,T1EXIT)
      COMMON SHGF(4,12,24),TO(12,24),TE(12,24),CFM(3),WATT(3),USE(3),
     1SAF(3),NPEOPL(3),ENTHLP(12,24),ENTHIN(3),PROD1,PROD2,IOLT,B(10),
     2D(10),C,NB,ND,A,EPSLN,DELTAR,HO,QPEOPL,NHOUR,MONTH(12),SPHT1,
     3SPHT2,HP(3),NCARC,TOTAL(12)
      DIMENSION SRFA(13),U(13),TEMP(4),QESUM(12),QSUM(3,12),STOR(3,12)
      REAL INFLT1
      WRITE(6,1)(MONTH(I),I=1,12)
    1 FORMAT('1',T56,'HOT BONING OPTION 2',//,T45,'EXTERIOR TRANSMISSION
     1 BY SURFACE (BTU/DAY)',//T74,'MONTH',/T7,'SOURCE',T18,11(I2,7X),I2
     2)
C     ******************************************************************
C     CALCULATE EXTERIOR TRANSMISSION
C
C     WALLS 1, 2, 3
C     ******************************************************************
C     ******************************************************************
      DO 2 I=1,12
    2 QSUM(1,I)=0.
      READ(5,5)NB,ND,C,A,EPSLN,HO
    5 FORMAT(2I3,4F10.0)
```

```
      READ(5,10)(B(I),I=1,NB)
      READ(5,10)(C(I),I=1,ND)
      READ(5,10)DELTAR
   10 FORMAT(1CF8.C)
      KJ=1
      DO 20 I=1,3
      CALL TRANEX(SRFA(I),TEMP(1),U(I),MODE,QESUM,KJ)
      IF(MODE.EQ.1) RETURN
      DO 25 J=1,12
   25 CSUM(1,J)=QESUM(J)+QSUM(1,J)
      KJ=KJ+1
   20 WRITE(6,21)I,(QESUM(L),L=1,12)
   21 FORMAT(T2,'SURFACE',I2,T15,11(F8.0,1X),F8.0)
      READ(5,5)NB,ND,C,A,EPSLN,HO
      READ(5,10)(B(I),I=1,NB)
      READ(5,10)(D(I),I=1,ND)
      READ(5,10)DELTAR
      KJ=4
C     ******************************************************************
C     ROOF 5
C     ******************************************************************
      CALL TRANEX(SRFA(5),TEMP(1),U(5),MODE,CESUM,KJ)
      IF(MODE.EQ.1) RETURN
      I=5
      WRITE(6,21)I,(CESUM(L),L=1,12)
      DO 30 I=1,12
   30 CSUM(1,I)=CSUM(1,I)+CESUM(I)
      I=1
      WRITE(6,22)I,(QSUM(1,L),L=1,12)
   22 FORMAT(//,T5,'EXTERIOR TRANSMISSION TOTALS (BTU/DAY)',/T8,'RM',I2,
     1T15,11(F8.C,1X),F8.0)
C     ******************************************************************
C     CALCULATE INFILTRATION LOSS
C     ******************************************************************
      DO 40 I=1,12
      INFLT1=0.
      DO 35 J=1,NHOUR
   35 INFLT1=INFLT1+4.5*CFM(1)*IDLT*(ENTHLP(I,J)-ENTHIN(1))
      STOR(1,I)=INFLT1
   40 CSUM(1,I)=CSUM(1,I)+INFLT1
      I=1
      WRITE(6,23)I,(STOR(1,J),J=1,12)
   23 FORMAT(//,T4,'INFILTRATION',/,T8,'RM',I2,T15,11(F8.0,1X),F8.0)
C     ******************************************************************
C     CALCULATE INTERIOR TRANSMISSION
C     ******************************************************************
      VAL14=U(4)*SRFA(4)*(TEMP(4)-TEMP(1))*24.
      WRITE(6,24)VAL14
   24 FORMAT(//,T6,'INT TRAN',/,T6,'RM 1->4',T73,F8.0)
C     ******************************************************************
C     CALCULATE PERSONNEL LOAD
C     ******************************************************************
      QPERS1=NPEOPL(1)*QPEOPL*8.
      WRITE(6,26)QPERS1
   26 FORMAT(//,T6,'PERSONNEL',/,T8,'RM 1',T73,F8.C)
C     ******************************************************************
C     CALCULATE PRODUCT LOAD
C     ******************************************************************
      VAL1=PROD2*SPHT2*(98.5-T1EXIT)
      WRITE(6,27) VAL1
```

```
   27 FORMAT(/,T2,'PRODUCT LOAD',/,T8,'RM 1',T73,F10.0)
C      *****************************************************************
C      CALCULATE ELECTRICAL MOTOR LOAD
C      *****************************************************************
       ELECT1=HP(1)*2545.*24.
       WRITE(6,28)ELECT1
   28 FORMAT(/,T3,'ELECTRICAL LOAD',/,T8,'RM 1',T73,F8.0)
C      *****************************************************************
C      CALCULATE LIGHTING LOAD
C      *****************************************************************
       ALGHT1=WATT(1)*USE(1)*SAF(1)*81.84
       WRITE(6,31)ALGHT1
   31 FORMAT(/,T4,'LIGHTING LOAD',/,T8,'RM 1',T73,F8.0)
       DO 45 I=1,12
   45 QSUM(1,I)=(QSUM(1,I)+VAL14+QPERS1+VAL1+ELECT1+ALGHT1)/PROD2
       WRITE(6,29)(QSUM(1,I),I=1,12),PROD2
   29 FORMAT(/,T51,'TOTAL FOR HOT BONING OPTION 2',/,T52,'(BTU.LB OF FIN
     1ISHED PRODUCT)',/T8,'RM 1',T15,11(F8.1,1X),F8.1,//T77,'ROOM',/T79,
     2'1',/T17,'PRODUCT MASS (LBS)',T75,F9.0)
       WRITE(6,50)NCARC
   50 FORMAT(//T20,'NUMBER OF CARCASSES PER DAY    ',I4)
       RETURN
       END
       SUBROUTINE TRANEX(AREA,TEMP,J,MODE,QESUM,KJ)
       COMMON SHGF(4,12,24),TO(12,24),TE(12,24),CFM(3),WATT(3),USE(3),
      1SAF(3),NPEOPL(3),ENTHLP(12,24),ENTHIN(3),PROD1,PROD2,IDLT,B(10),
      2D(10),C,NB,ND,A,EPSLN,DELTAR,HO,QPEOPL,NHOUR,MONTH(12),SPHT1,
      3SPHT2,HP(3),NCARC,TOTAL(12)
       DIMENSION QESUM(12),QE(12,24),TEAVG(12)
C      *****************************************************************
C      CALCULATE SOL-AIR TEMPERATURE
C      *****************************************************************
       DO 5 I=1,12
       DO 5 J=1,NHOUR
       SOLRAD=1.15*SHGF(KJ,I,J)
       TE(I,J)=A*SOLRAD-(EPSLN*DELTAR)/HO+TO(I,J)
    5 QE(I,J)=0.
       DO 10 I=1,12
       QESUM(I)=0.
       JCOUNT=1
       ICOUNT=1
   15 DO 20 J=1,NHOUR
       BSUM=0.
       INDEX=J+1
       DO 25 K=1,NB
       INDEX=INDEX-1
       IF(INDEX.LE.0)INDEX=NHOUR
       BSUM=BSUM+B(K)*TE(I,INDEX)
   25 CONTINUE
       DSUM=0.
       INDEX=J
       DO 35 K=2,ND
       INDEX=INDEX-1
       IF(INDEX.LE.0) INDEX=NHOUR
       DSUM=DSUM+D(K)*QE(I,INDEX)/AREA
   35 CONTINUE
       QE(I,J)=AREA*(BSUM-DSUM-TEMP*C)
   20 QESUM(I)=QESUM(I)+QE(I,J)*IDLT
       IF(JCOUNT.EQ.1) GO TO 50
       CHECK=(QESUM(I)-QSTOR)/QSTOR*100.
```

```
      IF(CHECK.LT.1.) GO TO 10
      IF(ICOUNT.GE.20) GO TO 40
   50 CSTOR=CESUM(I)
      JCOUNT=2
      ICOUNT=ICOUNT+1
      CESUM(I)=0.
      GO TO 15
   40 WRITE(6,45)ICOUNT,I
   45 FORMAT(///,5X,'NONCONVERGENCE AFTER',I3,1X,'ITERATIONS',///,5X,'I=
     1',I3)
      MODE=1
      RETURN
   10 CONTINUE
      MODE=0
      RETURN
      END
```

ENERGY COMPARISON OF HOT AND COLD BEEF PROCESSING

by

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ABSTRACT

A prevalent practice in beef packing plants is to slaughter the animal and chill the carcass for approximately 24-72 hours. Frequently, following the cooling period, the excess fat and bone are removed as the carcass is fabricated into muscles and muscle systems before packaging and shipment. Recent studies on product quality indicate that a procedure usually termed hot boning or hot processing can be applied to produce beef steak, roast, and ground products. Hot processing entails the removal of excess fat and bone from the beef carcass soon after slaughter. The traditional cooling period after slaughter is either shortened or eliminated, thus, the carcass is warm when cut and the resultant cuts are subsequently chilled.

This study compares two hot-processing procedures to conventional centralized beef processing to determine what method is the most energy efficient. A computer program was written to calculate the total refrigeration energy of each option. The results showed that a 32 percent energy savings was achieved for carcasses conditioned for 8 hours before boning and a 42 percent savings for carcasses boned immediately after slaughter. This comparison determines the difference in the average energy requirements of the various options and is not applicable to equipment sizing.

The energy comparisons are based upon model facilities that slaughter sixty head of cattle an hour for eight hours a day. However, conclusions found for this size hot-processing facility should not be unreservedly ascribed to other sized plants.