STRUCTURAL HEAT LOSS IN BULK TOBACCO BARNS 1/

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INTRODUCTION

Energy consumption has become a major concernin agricultural systems today. Since 1973, energy costs have risen and will continue to rise in the future. In 1973, the Organization of Petroleum Exporting Countries (OPEC) increased oil prices from three dollars to over nine dollars and in December 1980, prices averaged forty-three dollars a barrel. Rising prices and the shortages of fossil fuel have stimulated interest in reducing the amount of energy used to produce farm products.

In the past, bulk curing barns were not insulated and consumed large amounts of petroleum fuel. A study was conducted during the 1977 and 1978 curing seasons to determine the effect of insulating mobile style bulk curing barns. The main objective was to compare energy losses and cost for farm insulated barns and a factory insulated barn with an uninsulated barn.

EXPERIMENTAL METHODS

An agreement was made with a tobacco grower to conduct an on-farm test using four mobile style curing barns located on his farm for 1977 and 1978 seasons. The grower retained full management control. He loaded the barns in response to the harvest

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requirements of his tobacco, and used his own judgement in selecting the curing schedule for each cure.

Barns 1, 2 and 3 were Powell Model 88-648 barns and had no factory installed insulation. The walls, doors and ceiling of Barns 1 and 2 were insulated for the test, and Barn 3 was left as an uninsulated check. The walls and doors were insulated with 3.81 cm of polystyrene, having a thermal resistance of 30.63. Fifteen cm of batt fiberglass insulation (R=93.03) was placed between rafters in the ceiling of Barns 1 and 2. Barn 4 was a Powell Maximiser 126, a new experimental model with factory installed insulation. It was possible to insulate under the concrete slab for this barn as it was installed just prior to the start of the 1977 season. The insulation placed under the concrete pad was 3.81 cm of polystyrene (R=30.06). The thermal resistance of all the curing compartment surfaces is given in Table 1 for each of the four barns.

The barns had equal capacities, 126 bulk racks. Tobacco was hand harvested and placed in bulk racks in an aligned leaf configuration.

Each barn was instrumented to record temperature in the lower plenum, T_l, and in the upper plenum, T_u. A seven day circle chart recorder (Minneapolis-Honeywell Regulator, Brown Instrument Division) was mounted in a cabinet on the exterior wall. The lower plenum probe was positioned at the centerline of the lower plenum under the right room (as viewed from the the furnace compartment) approximately 3 m from the fan. The upper plenum probe was positioned directly above the lower probe at a point one-half the distance between the top of the tobacco and the ceiling.

Petroleum fuel consumption was measured with a LP gas meter (REGO Model AL425-TC) installed in the supply line to each barn. The meters were calibrated for 395 KPa (11 in. WC) gas pressure at the beginning of the season. The burner in each barn was adjusted by the manufacturer's representative to achieve maximum combustion efficiency measured with a combustion testing kit (FYRITE CO_2 Indicator Model CND). Fuel recording were made at 0800 and 2000 hours daily.

Each time a barn was filled, three samples of 10 leaves each were collected; one at 1000, one at 1300 and one at 1600 hours. This was done to insure a representation sampling of all tobacco in the cure. These samples were placed in individual plastic bags, sealed and put into an insulated container with a thin layer of ice between samples. The samples were weighed to the nearest gm and the mid rib was removed from the leaves. The lamina and stem portions of each samples were labeled and placed in containers for oven drying. Samples were dried for 48 hours at 74^{o}C and reweighed to the nearest 0.01 gm using a top loading electronic balance (Mettler P/2000).

When a barn was unloaded three samples of 10 leaves each were again taken. Sample 1 was selected from a rack on the bottom tier at approximately midway the barn. Sample 2 was selected from a rack on the middle tier and sample 3 was taken from the top tier. These samples were sealed in plastic bags and returned to the laboratory for weighing. They were destemed, redried at 74^{o}C for 48 hours and reweighed.

The reordered tobacco from each barn was weighed with a spring scale as the barn was unloaded. The total moisture removed, W, was then determined using the following relation,

$$W= \frac{W_c}{0.95} \frac{\bar{w}_{co}}{\bar{w}_c} \left(\frac{\bar{w}_g}{\bar{w}_{go}} -1 \right) \qquad (1)$$

Where W_c = total mass cured leaf

$\bar{w}_c$ = average mass cured samples

$\bar{w}_{co}$ = average mass oven dry cured samples

$\bar{w}_g$ = average mass green samples

$\bar{w}_{go}$ = average mass oven dry green samples

The derivation of equation (1) includes the assumption of a 5% solids loss (Johnson - 1976) during the cure.

ANALYTICAL METHODS

An experimental rate function for heat losses, $\frac{dE_{se}}{dt}$(empty), was determined by operating each barn empty for seven days using the same thermostat settings used for a "typical cure". The vents were tightly closed to minimize leakage. Fuel usage was recorded every 12 hours, at 0800 and 2000 hrs. just as in the curing tests. The rate for each 12 hour interval was plotted at the mid point of that interval and straight line interpolation was used to determine the rate at each two hour interval.

This rate curve was divided into a leaf coloring part, a leaf drying part and stem drying part based on the temperature measured in the lower plenum. The leaf coloring phase is defined as cure hours when $T < 45$ C, and stem drying is defined as cure hourse when $T > 60$ C. The intermediate phase, or leaf drying phase is defined as cure hours when 45 C$<$ T$<$60 C. The leaf coloring, leaf drying and stem drying hours were determined from the lower plenum temperature recordings for each cure. The three parts of the $\frac{dE_{se}}{dt}$ (empty) function were extended or shortened to obtain a rate function for each cure with the correct number of hours in each of the cure phases. The $\frac{dE_{se}}{dt}$ (empty) cure functions were multiplied by combustion efficiency to obatin $\frac{dE_{se}}{dt}$ cure functions.

The rate function for energy to achieve the enthalpy change in the exchanged air, $\frac{dE_x}{dt}$, was determined from $\frac{dE_x}{dt} = \frac{dE_f}{dt} - \frac{dE_{se}}{dt}$ (2)

where $\frac{dE_f}{dt}$ is a petroleum fuel rate function obtained by multiplying the fuel rate measurements by combustion efficiency.

Fuel consumtpion, heat loss and exhaust energy for the various phases was obtained from numberical integration of the respective rate functions. For example,

$$E_{xlc} = \int_{o}^{t_{lc}} \frac{dE_x}{dt}\, dt \qquad (3)$$

$$E_{xld} = \int_{t_{lc}}^{t_{ld}} \frac{dE_x}{dt}\, dt \qquad (4)$$

$$E_{xsd} = \int_{t_{ld}}^{t_n} \frac{dF_x}{dt}\, dt \qquad (5)$$

where t_{lc} - leaf coloring upper bound

where t_{ld} - leaf drying upper bound

where t_n - total cure time

The percentage of E_f and E_x consumed in each cure phase was computed using the phase totals.

The time average exhaust energy per unit of water removed is given by,

$$e_{xw} = \frac{E_x}{W}, \tag{6}$$

and in like manner,

$$e_{fw} = \frac{E_f}{W} \tag{7}$$

Water removal per cure phase is then,

$$W_{1c} = \frac{E_{x1c}}{e_{xw}} \tag{8}$$

$$W_{1d} = \frac{E_{x1d}}{e_{xw}} \tag{9}$$

$$W_{sd} = \frac{E_{xsd}}{e_{xw}} \tag{10}$$

The percentage of water removed during each phase was then computed.

Fuel energy per unit of cured leaf (oven dry) is given by:

$$e_{fo} = \frac{E_f}{W_{co}}$$

$$W_{co} \quad W_c \frac{\bar{w}_{co}}{\bar{w}_c}. \tag{11}$$

HEAT LOSSES

Heat losses from the structure, Q_s, can be estimated from,

$$Q_x = E_{se} - E_1 \tag{12}$$

where E_{se} is the total energy loss function developed from the experimental data obtained by operating the barns empty, and E_1 is an assumed air leakage.

Structural Heat Losses

It is expedient to divide the Q_s losses into four parts as follows:

Q_{su} - losses which occur above a horizontal plane cutting the entire structure at the top of the bulk tobacco

Q_{ss} - losses through the three vertical planes forming the sides and doors of the curing compartment

Q_{sf} - losses through the bottom of the return duct (furnace room ceiling), rear wall of curing compartment, furnace walls, and top of delivery plenum (furnace room floor)

Q_{sl} - losses which occur below a horizontal plane cutting the entire structure at the drying floor (includes losses from the lower plenum sides and through the concrete slab).

Q_{su} is given by

$$Q_{su} = \frac{A_r}{R_r} + \frac{A_e}{R_e} + \frac{A_l}{R_l} + \frac{A_{su}}{R_{su}}) \int_o^{t_n} \Delta T_u(t)\, dt \qquad (13)$$

where

A_r - roof area, (m^2)

A_e - gable end area, (m^2)

A_l - louver area, (m^2)

A_{su} - side wall area of return duct to furnace, (m^2)

R_r - thermal resistance, roof, $(\frac{^oC}{J/hr\text{-}m^2})$

R_e - thermal resistance, gable end, $(\frac{^oC}{J/hr\text{-}m^2})$

R_l - thermal resistance, louver, $(\frac{^oC}{J/hr\text{-}m^2})$

R_{su} - thermal resistance, return duct $(\frac{^oC}{J/hr\text{-}m^2})$

and $\Delta T_u(t) = T_u(t) - T_a(t)$, ($^oC$).

Q_{ss} is given by

$$Q_{ss} = \left(\frac{A_s}{R_s} + \frac{A_d}{R_d}\right) \int_0^{t_n} \Delta T_s(t)\, dt \qquad (14)$$

where A_s - side wall area, (m^2)

A_d - door area, (m^2)

R_s - thermal resistance, side, ($\frac{^oC}{J/hr\text{-}m^2}$)

R_d - thermal resistance, door, ($\frac{^oC}{J/hr\text{-}m^2}$)

and $\Delta T_s(t) = \frac{T_1(t) = T_u(t)}{2} - T_a(t)$, ($^oC$).

Q_{sf} is given by

$$Q_{sf} = \frac{A_{rw}}{R_{rw}} + \frac{A_{ff}}{R_{ff}} + \frac{A_{cf}}{R_{cf}} + \frac{A_{fb}}{R_{fb}} + \frac{A_{fs}}{R_{fs}} \int_0^{t_n} \Delta T_f(t)\, dt \qquad (15)$$

where A_{rw} - area rear wall, (m^2)

A_{ff} - area furnace room floor, (m^2)

A_{cf} - area furnace room ceiling, (m^2)

A_{fs} - area furnace sides, (m^2)

A_{fb} - area furnace, front and back, (m^2)

R_{rw} - thermal resistance, rear wall, ($\frac{^oC}{J/hr\text{-}m^2}$)

R_{ff} - thermal resistance, furnace room floor ($\frac{^oC}{J/hr\text{-}m^2}$)

R_{cf} - thermal resistance, furnace room ceiling ($\frac{^oC}{J/hr\text{-}m^2}$)

R_{fs} - thermal resistance, furnace sides ($\frac{^oC}{J/hr\text{-}m^2}$)

R_{fb} - thermal resistance, furnace front & back ($\frac{^oC}{J/hr\text{-}m^2}$)

and $\Delta T_f(t) = T_1(t) - T_f$, ($^oC$).

An average furnace room temperature, $T_f = 45^oC$, was assumed.

Losses from the lower plenum, Q_{sl}, were determined from

$$Q_{sl} = Q_s - (Q_{su} + Q_{ss} + Q_{sf}) \tag{16}$$

Losses through the concrete slab, Q_{sc}, were then obtained from

$$Q_{sc} = Q_{sl} - \frac{A_{sl}}{R_{sl}} \int_o^{t_n} \Delta T_l(t)\, dt \tag{17}$$

where A_{sl} - area lower plenum side walls, (m^2)

R_{sl} - thermal resistance, lower plenum side wall, $(\frac{^oC}{J/hr\text{-}m^2})$

and $\Delta T_l(t) = T_l(t) - T_a(t)$, (^oC).

An "effective" thermal resistance for the concrete slab was then computed.

$$R_{sc} = \frac{A_{sc}}{Q_{sc}} \int_o^{t_n} \Delta T_g(t)\, dt \tag{18}$$

where A_{sc} - area concrete (m^2)

and $\Delta T_g(t) = T_l(t) - T_g$, (^oC).

A ground temperature, $T_g = 25.5^oC$, was assumed.

The concrete slab thermal resistance was calculated using

$${}_cR_{sc} = \frac{1}{f_o} + \frac{X_c}{k_c} + R_i + \frac{X_s}{k_s}$$

where f_o - surface coefficienct, $(1.22 \times 10^5 \frac{J}{hr/m^2\text{-}^oC})$

X_c - depth of concrete (0.10m)

k_c - thermal conductivity concrete, $(5603 \frac{J}{hr/m^2\text{-}^oC/m})$
(ASHRAE Handbook 1974 Applications, Table 5, p. 12.7)

R_i - thermal resistance insulation (0.04m polystrene board)
$(30.63 \times 10^{-5} \frac{^oC}{J/hr\text{-}m^2})$

X_s - depth of soil (1.5m)

k_s - thermal conductivity soil $(3113 \frac{J}{hr/m^2\text{-}^oC/m})$
(ASHRAE HANDBOOK 1974 applications, Table 5, p. 12.7)

For Barns 1, 2 and 3, $R_i = 0$ and ${}_cR_{sc} = 51.55 \times 10^{-5} \frac{^oC}{J/hr\text{-}m^2}$.

Barn 4 had a ${}_cR_{sc} = 82.18 \times 10^{-5} \frac{^oC}{J/hr\text{-}m^2}$. These calculated values were compared with those calculated with (18).

Air Leakage Losses

The specific enthalpy of moist air is [Wilhelm (1976)],

$$h = 1.0006T + W\,(2501 + 1.775T) \qquad (19)$$

where T - dry blub temperature, (^oC)

W - humidity ratio (dimensionless)

To simplify calculations, a constant humidity ratio was chosen corresponding to "typical" ambient conditions, 27^oC 80% RH. Substitution into (19) gives an enthalpy for ambient air,

$$h_a = 1.034T_a + 38.77 \qquad (20)$$

The leakage enthalpy, h_l is given by

$$h_l = 1.034\,\frac{(T_l + T_u)}{2} + 38.77 \qquad (21)$$

and the change in enthalpy of the leakage air is then,

$$\Delta h = h_l - h_a = 1.034\left[\frac{T_l + T_u}{2} - T_a\right]. \qquad (22)$$

The instantaneous air leakage (kg/hr) is,

$$M_l = 60\,\frac{V_l}{v} \qquad (23)$$

where V_l - leakage volume, (m^3/min)

v - specific volume, (m^3/kg)

From the gas low,

$$v = \frac{R_a\,T_a}{P}$$

P - atmospheric pressure, (101.325kPa)

R_a- gas constant for air, (0.28705J/g°K)

T_a- ambient temperature, °K,

and substituting into (23) gives

$$M_1 = \frac{60P\ V_1}{R_a\ T_a} \tag{24}$$

The air leakage energy for a given cure is then

$$E_1 = \int_o^{t_n} M_1\ \Delta h\ dt = \frac{62.04P}{R_a}\ \overline{V}_1 \int_o^{t_n} \frac{\Delta Ts(t)}{T_a(t)}\ dt \tag{25}$$

Here a time average leakage rate, $\overline{V}_1$, has been defined

The maximum possible air leakage energy, E_{1m}, can be computed by assuming Q_{sc} = o.

$$E_{1m} = E_{se} - (Q_{su} + Q_{ss} + Q_{sf} + A_{s1} \int_o^{t_n} \Delta T_1(t)\ dt) \tag{26}$$

Equation (25) can be solved for, $\overline{V}_{1m}$, the maximum leakage rate. Intermediate leakage rates were assumed as follows:

$$\overline{V}_{1_1} = 0.25\ \overline{V}_{1m}$$

$$\overline{V}_{1_2} = 0.50\ \overline{V}_{1m}$$

$$\overline{V}_{1_3} = 0.75\ \overline{V}_{1m}$$

These leakages were then expressed as a percentage of the total air flow rate, V_T, developed when the barn is operated empty. (The manufacturer gave V_T = 368 m^3/min for Barns 1, 2, and 3 and V_T = 439 m^3/min for Barn 4.) Values of Q_{sc} and R_{sc} were computed for each of the assumed leakage rates using (17) and (18) respectively.

Chang (1977) has computed the heat loss through an uninsulated concrete slab under a bulk barn to be 48.8 MJ/m^2/ cure. Substitution of this value into (18) gives,

$$_{u}R_{sc} = \frac{A_{sc}}{48.8} \int_{o}^{t_n} T_g(t) \quad dt \tag{28}$$

He found the loss through an insulated slab (0.025m thick board insulation) to be 10.2MJ/m^2/cure. A corresponding $_{i}R_{sc}$ for Barn 4 was computed. These thermal resistances, $_{u}R_{sc}$ for Barns 1, 2 and 3, and $_{i}R_{sc}$ for Barn 4, were used to compute an air leakage rate, $\overline{V}_{lo}$.

In the heat loss test for 1977 all cracks were sealed with duct tape. A curing schedule was used as during the season. Fuel consumption and temperature measurements were taken as usual. It was observed that heat energy was being lost through the vent plates in 1977. In 1978, insulated panels were mounted over each vent opening and sealed with duct tape.

RESULTS AND DISCUSSION

Combustion efficiency for the four barns are as follows: Barn 1 - 0.885, Barn 2 - 0.880, Barn 3 - 0.895 and Barn 4 - 0.875. All petroleum fuel consumption data has been corrected for combustion efficiency.

A comparison of fuel energy rate function $\frac{dE_{se}}{dt}$ for Barns 1, 2, 3 and 4 are given in figures 1-5. Figure 1 shows for both years 1977 and 1978 fuel consumption heat loss for Barn 1 and 2 are about the same. But when Barn 3, the uninsulated barn, (Figure 2) is compared to Barn 2, fuel consumption is more in Barn 3 (21 percent more).

The factory insulated barn (Barn 4) used 32 percent less fuel than Barn 3. Figure 4 and 5 show a comparison of consumption rate for each individual barn with respect to the different years. Table 2 and 3 presents total fuel and conductive heat loss data for the two tests. The 1977 heat loss test required 37 percent more fuel than 1978. For the two tests, Barn 1 used 27 percent less than Barn 3; Barn 2 used 16 percent less than Barn 3; and Barn 4 used 32 percent less than Barn 3. The reason for the higher energy consumption is that in 1978 ambient temperatures were warmer (Figures 6 and 7). The heat loss tests were conducted August 19-September 13, 1977 and June 16-25, 1978. To compare the two year data, the calculated conductive heat loss is divided by the number of degree-hours for each barn (Table 4). This shows that the two heat loss tests can be compared.

The remainder of this section will deal with heat loss during the curing seasons. Figure 8 shows how the bulk barn is divided into various sections.

Insulation installed under the concrete pad of Barn 4 reduced energy losses through the pad by an average of 85 percent (Table 5). A reduction of an average of 1.07 MJ/kg cured solids is found. Barn 4 is the only barn that had insulation on the side wall of the delivery plenum. The energy losses through this section is reduced by 95 percent (Table 6). Heat loss through the delivery plenum is lost through the concrete pad, the side walls of delivery plenum and furnace room floor. This loss is reduced by 71 percent in Barn 4 compred to the three other barns (Table 7). Energy losses through the return plenum for the factory insulated barn is reduced by 75 percent compared to Barn 3 (Table 8). Also, in Barns 1 and 2 with farm installed insulation (15 cm of fiberglass batt) energy losses are reduced by 75 percent through the return plenum. When 3.81 cm of expanded polystyrene insulation is inserted into the side walls and doors of Barn 1 and 2, heat loss was reduced by an average of 0.84 MJ/kg cured solids (54 percent, Table 9). Heat loss through side walls and doors of Barn 4 is reduced by 54 percent. In Barns 1 and 2 energy losses totaled 4.48 and 4.31 MJ/kg cured solids, consecutively, compared to Barn 3 - 7.86 MJ/kg cured solids (Table 10); which reduces heat losses by 43 and 45 percent, respectively. In Barn 4 total energy losses was 2.37 MJ/kg cured solids. Therefore, heat loss was reduced by 70 percent for the factory insulated barn.

The amount of energy lost through an uninsulated concrete pad (Barn 1-3) is 6.0 percent of the total fuel energy required to cure tobacco (Table 11). If the concrete pad is insulated, energy losses are 1.1 percent of the total fuel energy required for curing. By placing insulation in the roof (return plenum) of Barn 1 and 2, only 3.3 percent of the amount of fuel required for curing is lost. Also, Barn 4 lost 3.6 percent of the total fuel energy required for curing. But in the uninsulated Barn, 11.4 percent of the total curing energy is lost.

Insulating the side walls and door of Barn 1 and 2, only 3.8 percent of the energy required for curing is lost. Also, Barn 4 side wall and door losses are 3.8 percent of the total amount. But the uninsulated barn losses is 6.96 percent of total energy required to cure.

Table 12 is a comparison of average fuel energy required to cure in Barns 1-4, 1977 and 1978 seasons. Fuel consumption in the farm insulated barns are an average 19.3 MJ/kg cured leaf. Barn 3 used an average of 22.4 MJ/kg cured solids. And Barn 4 consumed an average of 17.9 MJ/kg cured solids for the two seasons.

The petroleum fuel consumption average for the two seasons (Table 13), expressed as MJ/m^3, was 86.3 - Barn 1, 101.1 - Barn 2, 120.2 - Barn 3, and 65.1 - Barn 4. Barn 1 and 2 consumed less energy than Barn 3; 22 percent less. Barn 4 used less energy than Barn 3; 46 percent less.

Calculated conductive heat loss average over the two seasons (Table 14), express as MJ/m^3, was 75.7 - Barn 1, 84.2 - Barn 2, 127.0 - Barn 3, and 46.8 - Barn 4. Barns 1 and 2 lost less energy than Barn 3; 37 percent less. Barn 4 lost less energy than Barn 3; 63 percent less.

Cost-Return

Table 15 presents local cost of insulation materials for the expanded polystyrene and fiberglass batt. Table 15 presents on-farm costs and savings for insulating bulk tobacco barns. The energy saved through the roof and walls amounted to 13.67 and 5.90 dollars/ton (metric) respectively. A savings of 19.57 dollars/ton can be expected by insulating according to this study. Total cost of insulating each barn is 250.72 dollars. If the average grower cures seven cures per season per barn and each barn yields approximately 1 ton (metric) per barn, the return on investment is 1.83 years (Table 16). These figures are based on 0.691 dollars/gallon LP and 4.00 dollars/hour labor for installation.

SUMMARY AND CONCLUSIONS

An on-farm test was conducted with four mobile style bulk rack barns. Barns 1 and 2 had insulation added to side walls and ceiling. Barn 4 was a factory insulated, unmodified conventional barn. The addition of insulation under the concrete pad reduces fuel consumption by 5.1 percent. If it is a new barn with insulation side walls of delivery plenum, it will reduce fuel consumption by 1.4 percent. With the combination of the previous two factors, the losses can be reduced fuel consumption in the delivery plenum by 9.6 percent.

Insulating the roof area can reduce fuel consumption by 8.1 percent. The factory insulated barn reduced fuel consumption through the return by 7.8 percent.

If the side walls and doors are insulated, the losses can be reduced by 3.2 percent. The factory installed barn fuel losses was reduced by 3.2 percent through wall areas.

A grower can reduce his fuel losses by 14.6 percent if he insulates the barn according to this study. If he is buying a new barn, the fuel saving is 20.0 percent.

If the grower does choose to remodel and insulate his bulk barns it will take approximately 2 years to pay for insulating.

REFERENCES

1. Johnson, W. H. 1976. Personal communication. North Carolina State University, Raleigh, North Carolina 27607.

2. Wilhelm, L. R. 1976. Numerical calculation of psychrometric properties in SI units.

Table 1. Thermal resistance of curing compartment surfaces, Barns 1-4.

Thermal Resistance, $\frac{^{o}C}{J/hr\text{-}m^2}$ x10^{-5}

Variable	Barn 1	Barn 2	Barn 3	Barn 4
R_r	99.99	99.99	7.49	27.52
R_e	17.82	17.82	17.82	30.46
R_ℓ	2.66	2.66	2.66	2.66
R_{su}	17.82	17.82	17.82	30.46
R_s	38.12	8.12	17.82	30.46
R_d	38.12	38.12	17.82	30.46
R_{rw}	7.49	7.49	7.49	36.43
R_{ff}	6.27	6.27	6.27	21.54
R_{cf}	3.82	3.82	3.82	19.10
R_{fs}	3.82	3.82	3.82	19.10
R_{fb}	19.10	19.10	19.10	19.10
$R_{s\ell c}$	8.28	8.28	8.28	26.78
$R_{s\ell u}$	2.66	2.66	2.66	19.10

Variable Description:

R_r - roof

R_e - gable end

R_ℓ - front exhaust louver

R_{su} - side of return duct to furnace

R_s - side wall of curing compartment

R_d - loading end doors

R_{rw} - rear wall of curing compartment

R_{ff} - furnace room floor

R_{cf} - furnace room ceiling

R_{fs} - furnace sides

R_{fb} - furnace front and back

$R_{s\ell c}$ - lower plenum side wall covered

$R_{s\ell u}$ - lower plenum side wall uncovered

Table 2. TOTAL PETROLEUM FUEL CONSUMPTION HEAT LOSS TEST, GJ

	BARN 1	BARN 2	BARN 3	BARN 4
1977	6.1	8.0	8.5	4.8
1978	3.8	3.6	5.3	4.7
MEAN	5.0	5.8	6.9	4.7

Table 3. TOTAL CALCULATED CONDUCTIVE HEAT LOSS, GJ

	BARN 1	BARN 2	BARN 3	BARN 4
1977	5.2	6.0	8.9	3.2
1978	3.5	3.6	5.7	2.2
MEAN	4.4	4.8	7.3	2.7

Table 4. COMPARISON CONDUCTIVE HEAT LOSS BASED ON DEGREE-HOURS, MJ/^{O}C-h

	BARN 1	BARN 2	BARN 3	BARN 4
1977	0.98	0.98	1.50	0.53
1978	1.02	0.92	1.40	0.55
MEAN	1.00	0.95	1.45	0.54

Table 5. HEAT LOSS THROUGH CONCRETE PAD, TALLEY FARM, MJ/kg CURED SOLIDS

	BARN 1	BARN 2	BARN 3	BARN 4
1977	1.03	0.98	0.88	0.18
1978	1.13	1.51	2.09	0.23
MEAN	1.08	1.25	1.48	0.20
DIFFERENCE COMPARED WITH BARN 4	0.88	1.05	1.28	

Table 6. HEAT LOSS THROUGH SIDE DELIVERY PLENUM, TALLEY FARM, MJ/kg CURED SOLIDS

	BARN 1	BARN 2	BARN 3	BARN 4
1977	0.35	0.33	0.29	0.06
1978	0.35	0.41	0.35	0.05
MEAN	0.35	0.37	0.32	0.06
DIFFERENCE COMPARED WITH BARN 4	0.29	0.31	0.26	

Table 7. HEAT LOSS THROUGH DELIVERY PLENUM, TALLEY FARM, MJ/kg CURED SOLIDS

	BARN 1	BARN 2	BARN 3	BARN 4
1977	2.53	2.38	3.10	0.69
1978	2.73	3.06	3.63	0.99
MEAN	2.63	2.72	3.37	0.84
DIFFERENCE COMPARED WITH BARN 4	1.79	1.88	2.53	

Table 8. HEAT LOSS THROUGH RETURN PLENUM, TALLEY FARM, MJ/kg CURED SOLIDS

	BARN 1	BARN 2	BARN 3	BARN 4
1977	0.63	0.60	2.51	0.53
1978	0.72	0.58	2.59	0.77
MEAN	0.68	0.59	2.55	0.65
DIFFERENCE COMPARED WITH BARN 3	1.87	2.04		1.90

Table 9. HEAT LOSS THROUGH SIDE WALLS TALLEY FARM, MJ/kg CURED SOLIDS

	BARN 1	BARN 2	BARN 3	BARN 4
1977	0.72	0.68	1.53	0.56
1978	0.80	0.70	1.58	0.79
MEAN	0.76	0.69	1.56	0.68
DIFFERENCE COMPARED WITH BARN 3	0.80	0.87		0.88

Table 10. TOTAL HEAT LOSS, TALLEY FARM, MJ/kg CURED SOLIDS

	BARN 1	BARN 2	BARN 3	BARN 4
1977	4.30	4.04	7.63	1.96
1978	4.66	4.57	8.09	2.77
MEAN	4.48	4.31	7.86	2.37
DIFFERENCE COMPARED WITH BARN 3	3.38	3.55		5.49

Table 11. COMPARISON OF HEAT LOSS (%) FROM VARIOUS SECTIONS OF THE STRUCTURE, MEAN 1977-1978

Section	Barn 1	Barn 2	Barn 3	Barn 4
Concrete pad	5.7	6.3	6.6	1.1
Side delivery plenum	1.8	1.9	1.4	0.3
Delivery plenum	14.0	13.8	15.0	4.7
Return plenum	3.6	3.0	11.4	3.6
Side wall & doors	4.0	3.5	7.0	3.8

Table 12. COMPARISON OF AVERAGE FUEL ENERGY MJ/kg CURED LEAF (OVEN DRIED) USED IN BARNS 1-4, 1977-1978

Season	Barn 1	Barn 2	Barn 3	Barn 4
1977	19.2	18.6	20.2	16.0
1978	18.3	20.8	24.6	19.8
MEAN	18.8	19.7	22.4	17.9

Table 13. TOTAL PETROLEUM FUEL CONSUMPTION FOR HEAT LOSS TEST, MJ/m^3

	BARN 1	BARN 2	BARN 3	BARN 4
1977	107.1	139.2	148.8	82.9
1978	65.5	62.9	91.6	47.2
MEAN	86.3	101.1	120.2	65.1

Table 14. CALCULATED CONDUCTIVE HEAT LOSS, MJ/m^3

	BARN 1	BARN 2	BARN 3	BARN 4
1977	89.8	105.4	155.2	55.6
1978	61.6	63.0	98.8	37.9
MEAN	75.7	84.2	127.0	46.8

Table 15. QUOTED COST OF INSULATION

MATERIAL	R $\left(\frac{^{o}C}{J/h\text{-}m} \times 10^{-5}\right)$	COST \$ $\left(\$/m^2\right)$
EXPANDED POLYSTYRENE	30.63	2.15
FIBERGLASS BATT	93.03	3.66

Table 16. COST OF INSULATING

Component	Cost (\$)	Savings (\$/ton-metric)[1]
Roof	97.20	13.67
Walls	89.52	5.90
Total	186.72	19.57
Installation	64.00[2]	
Total	250.72	

1 - \$0.691/Gal. LP
2 - \$4.00/H

AVERAGE GROWER - 7 CURES/SEASON/BARN

AVERAGE GROWER - 1 TON (METRIC)/BARN

7 TONS · \$19.57/TON = \$136.99/YEAR

RETURN INVESTMENT SAVINGS
\$250.72/\$136.99 = 1.83 YEARS

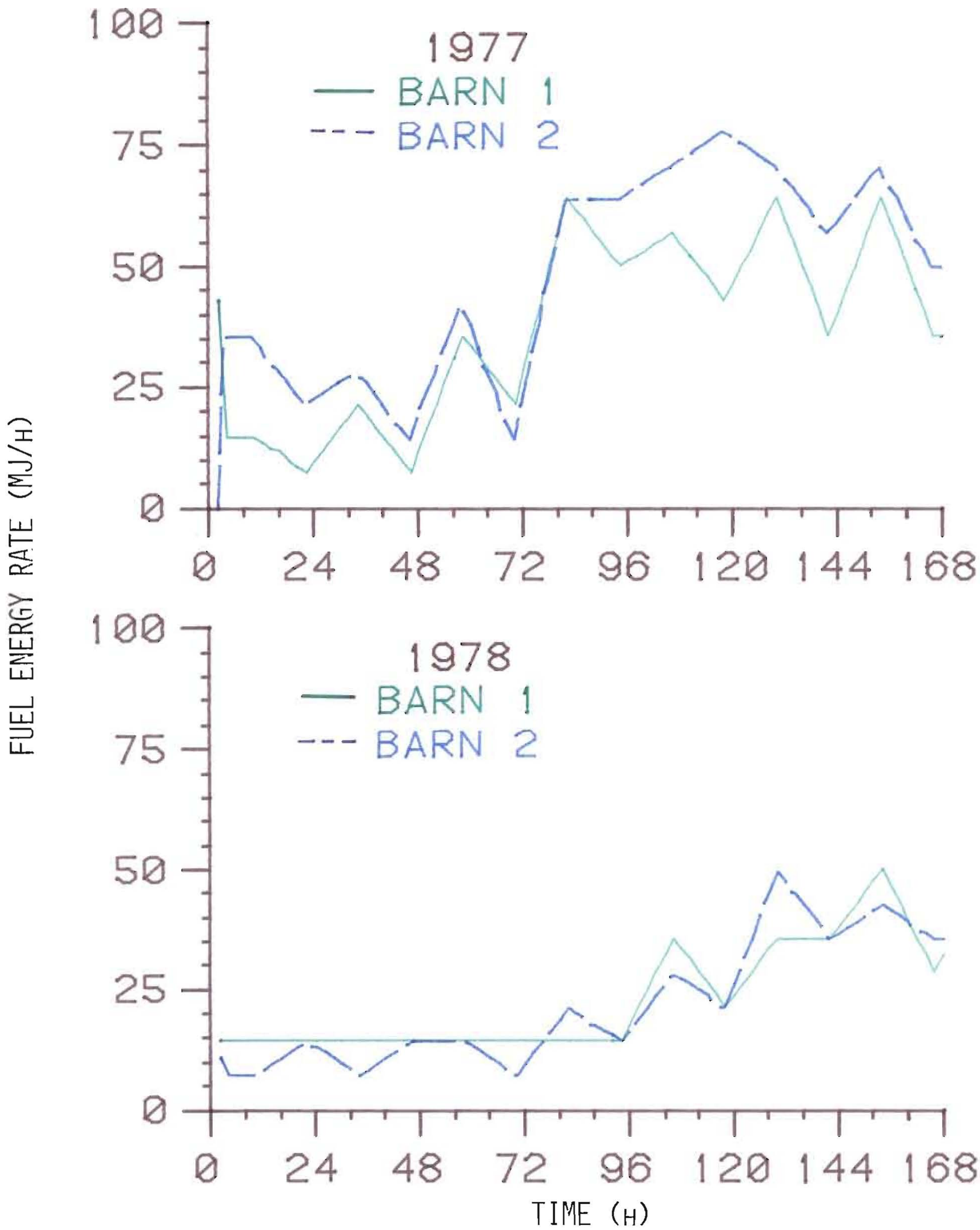

Figure 1. FUEL CONSUMPTION RATE FOR EMPTY BARNS, TALLEY FARM.

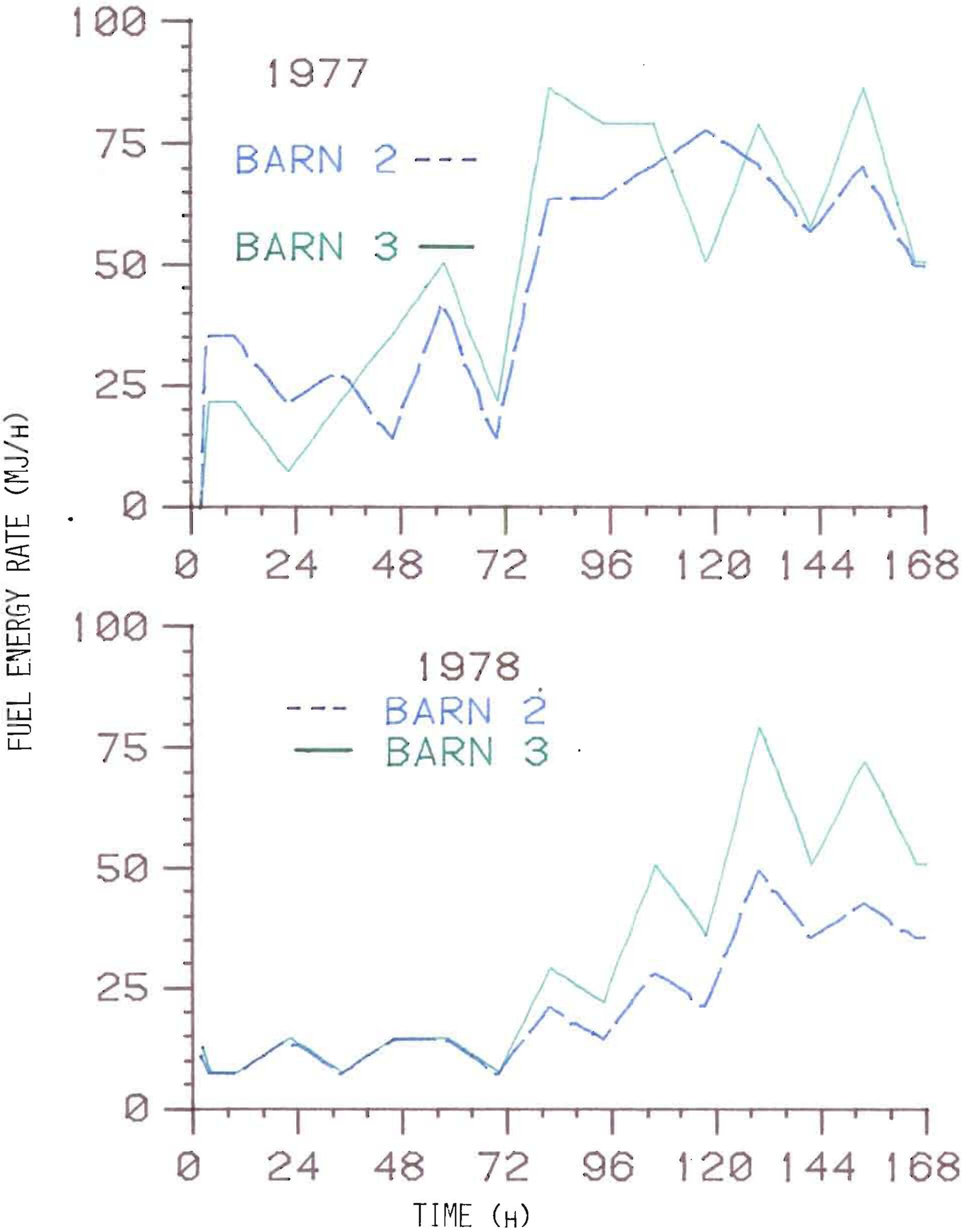

Figure 2. FUEL CONSUMPTION RATE FOR EMPTY BARNS, TALLEY FARM.

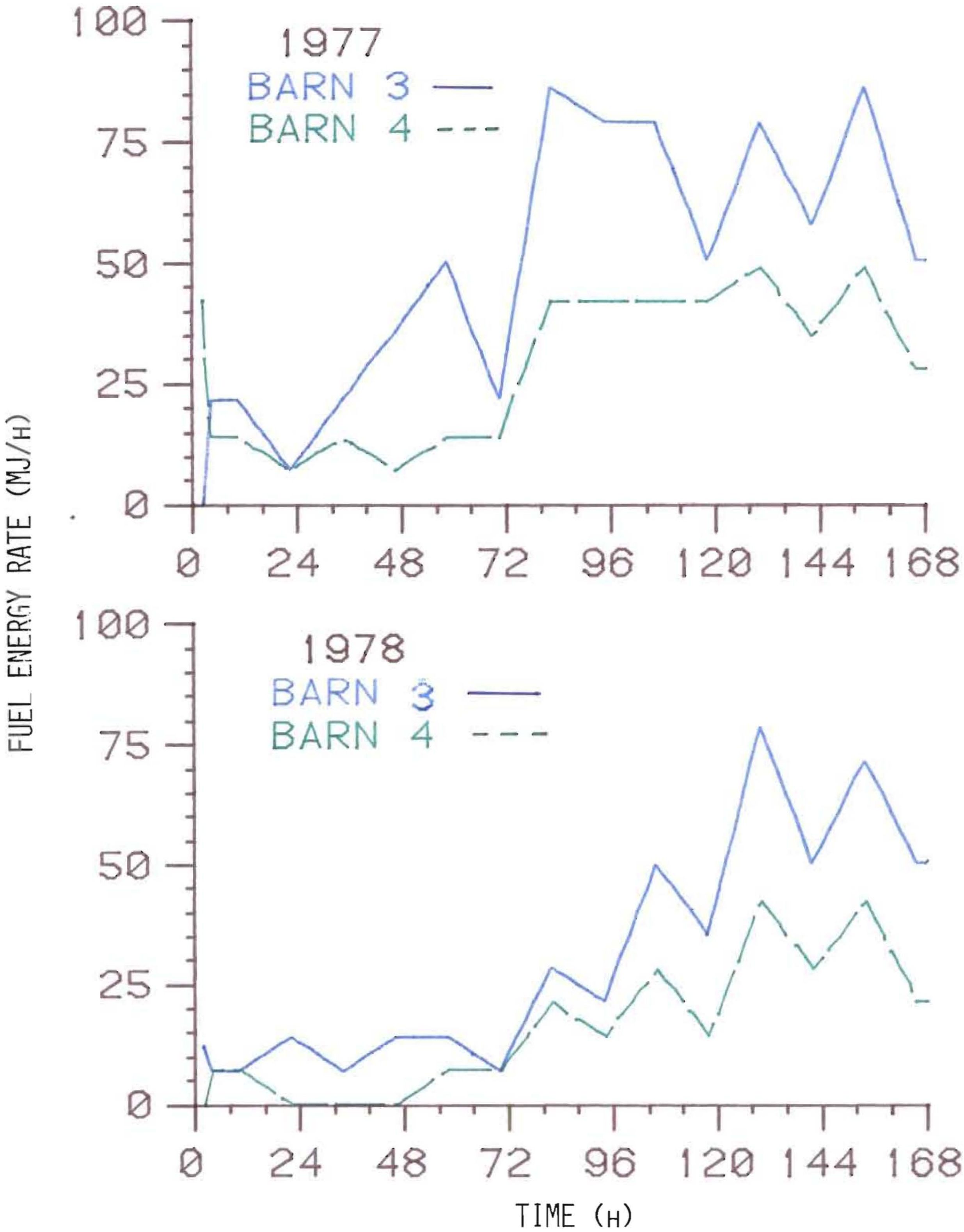

FIGURE 3. FUEL CONSUMPTION RATE FOR EMPTY BARNS, TALLEY FARM.

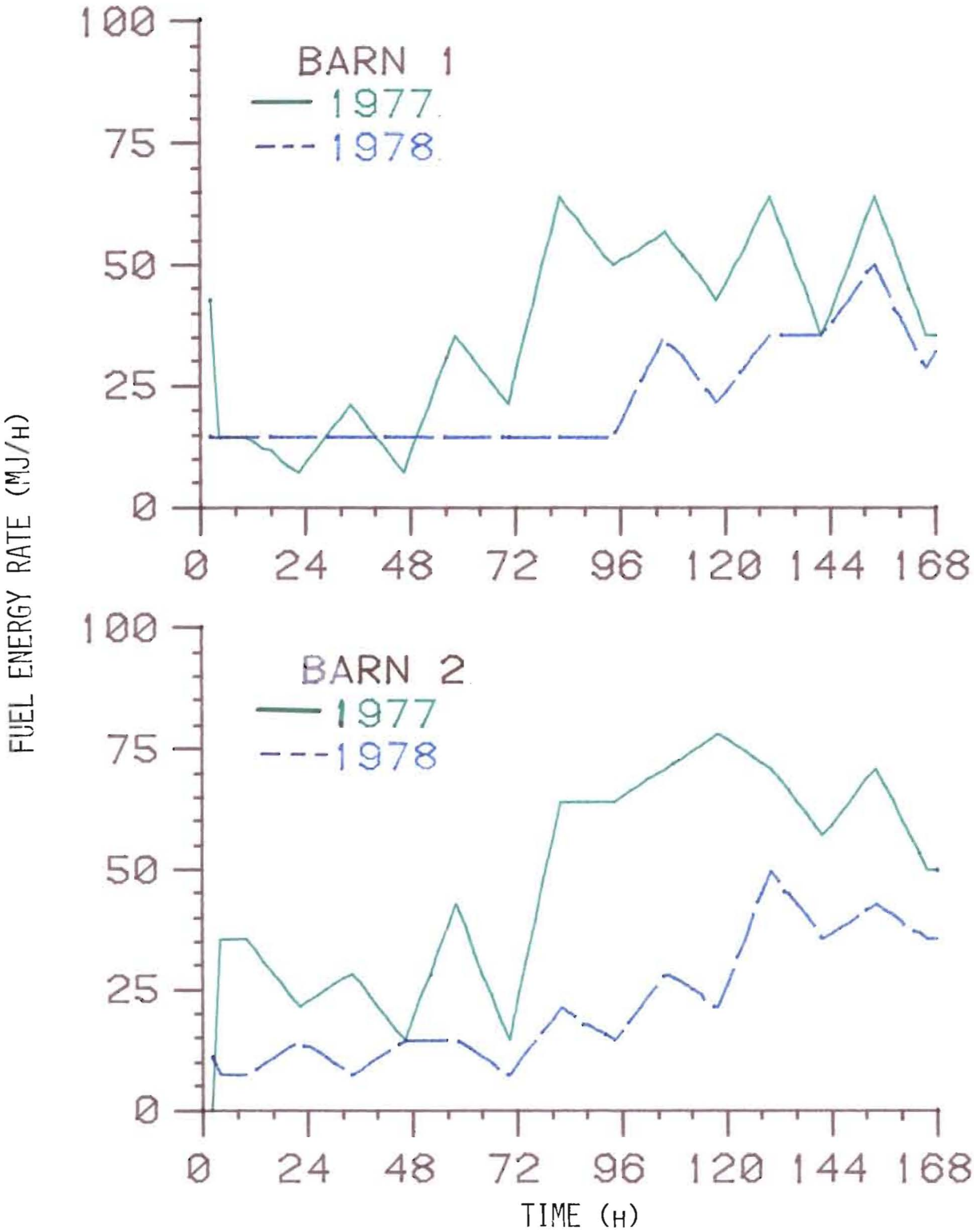

FIGURE 4. FUEL CONSUMPTION RATE FOR EMPTY BARNS, TALLEY FARM.

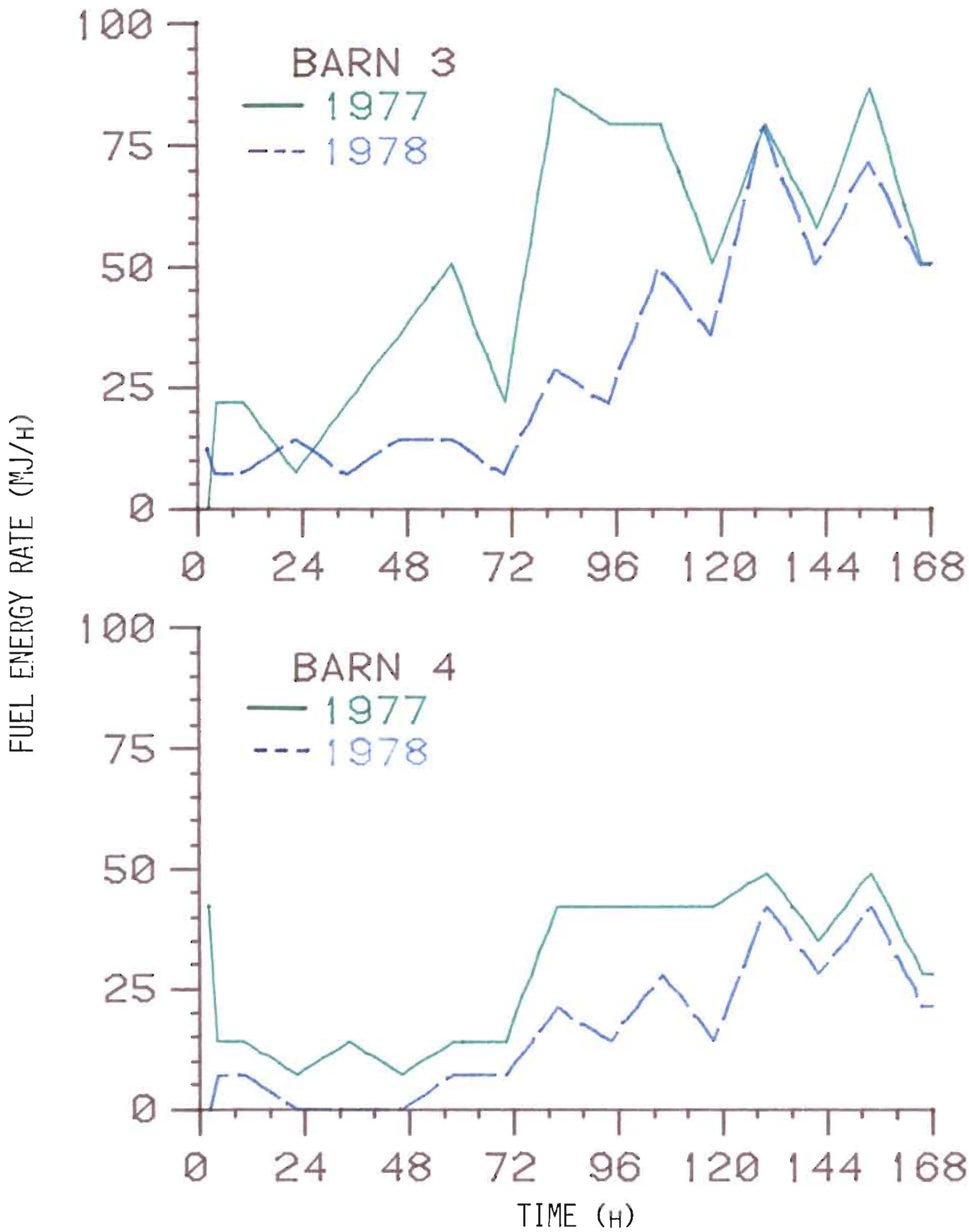

FIGURE 5. FUEL CONSUMPTION RATE FOR EMPTY BARNS, TALLEY FARM.

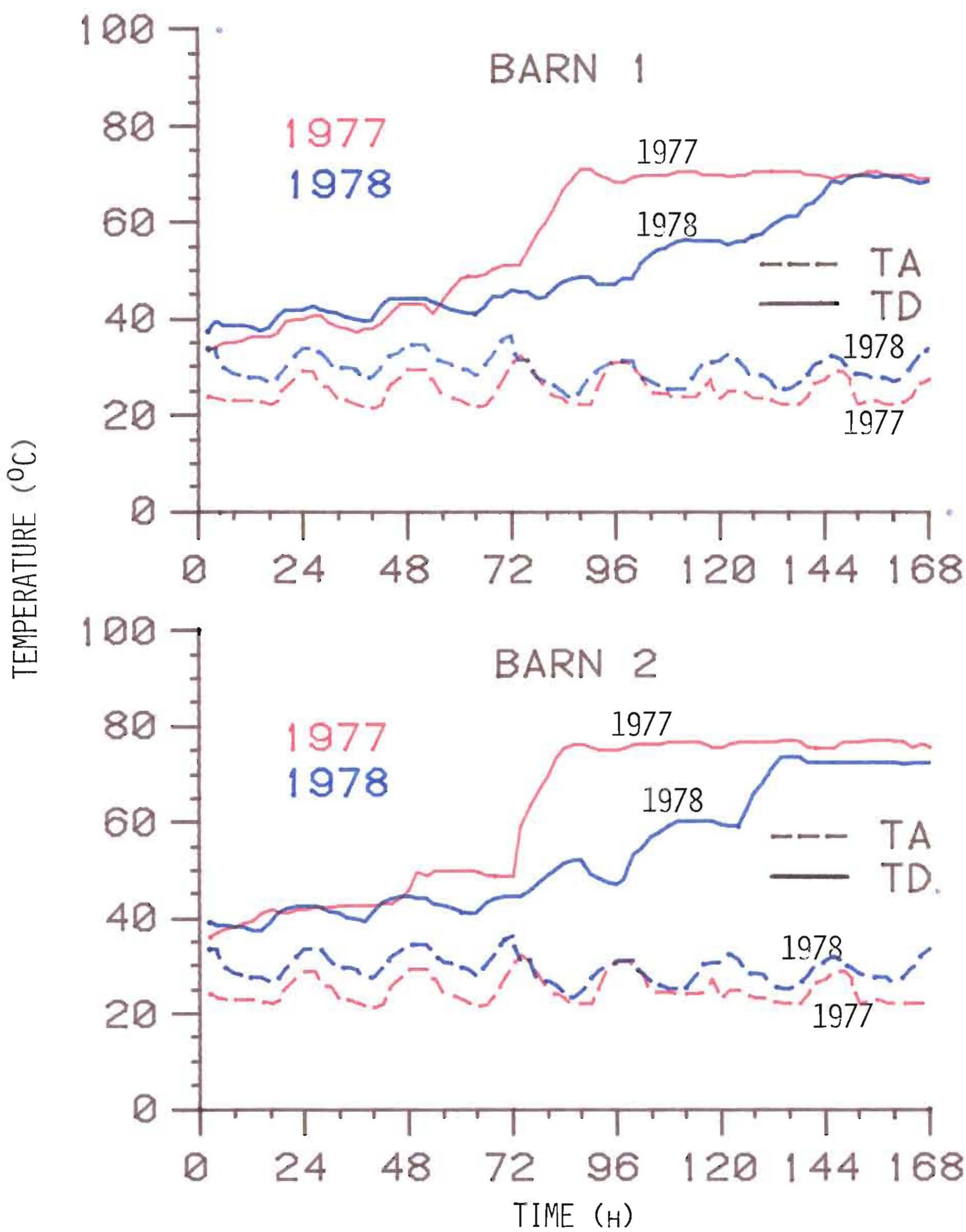

FIGURE 6. COMPARISON OF DELIVERY PLENUM AND AMBIENT, TEMPERATURES FOR EMPTY BARNS, TALLEY FARM

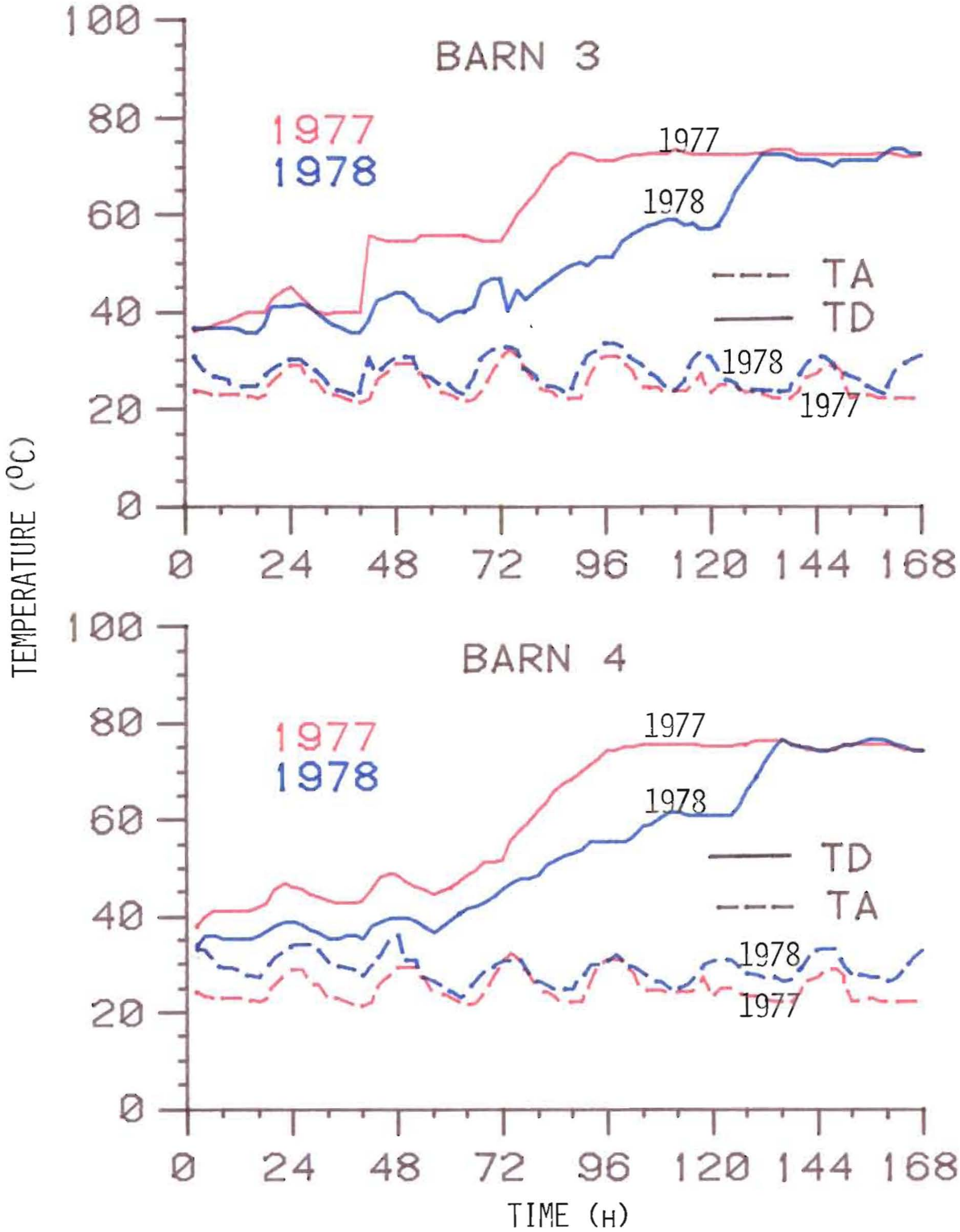

FIGURE 7. COMPARISON OF DELIVERY PLENUM AND AMBIENT, TEMPERATURES FOR EMPTY BARNS, TALLEY FARM

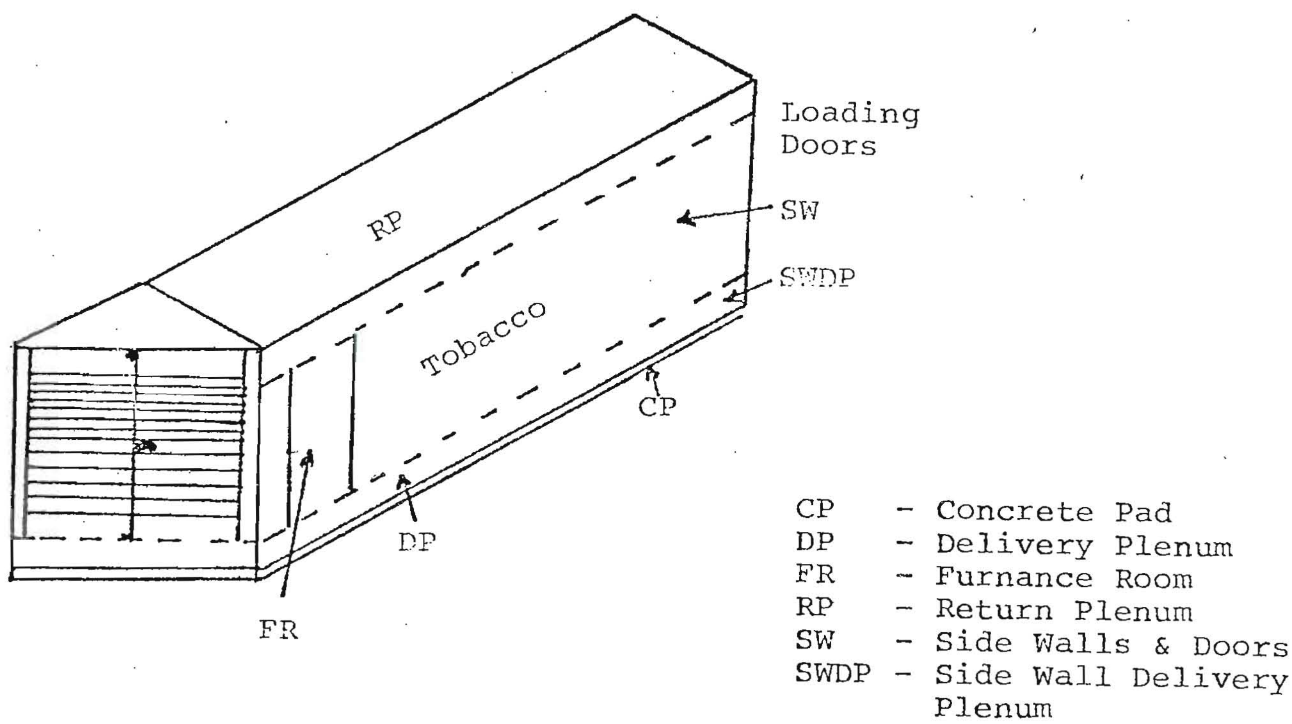

FIGURE 8. IDENTIFICATION OF VARIOUS PARTS OF THE CURING BARN