

# SHORT-TERM ENERGY TESTS OF A CREDIT UNION BUILDING IN IDAHO

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## SUMMARY

This report describes tests and results of the energy performance of a credit union building in Idaho. The building is in the Energy Edge Program administered by the Bonneville Power Administration (BPA). BPA provided incentives to incorporate innovative features designed to conserve energy use by the building. It is of interest to determine the actual performance of these features.

The objective of this project was to evaluate the applicability of the SERI short-term energy monitoring (STEM) method to nonresidential buildings. The work was carried out by the Solar Energy Research Institute with funding by the Director's Development Fund. The monitoring is part of the research being performed under the STEM project. The tests were performed in collaboration with Charles Cramer and Les Lambert of Lambert Engineering, Bend, Oregon; Lambert Engineering was primarily responsible for the data acquisition. The Lambert effort is part of contractual work done for the Bonneville Power Administration.

The most significant results of this evaluation are (1) the building loss coefficient is lower than expected indicating the success of the Energy Edge conservation features, and (2) the heat-pump system operates at a very low efficiency. The poor performance of the HVAC system is the principle reason that the building does not meet performance expectations. In fact, better performance could have been achieved with simple electric-resistance baseboard heating than with the system as it was found to be operating. The problem has been traced to excessive intake of outside air and could be remedied through a simple change in control strategy. If this critical HVAC problem were to be fixed, the building should perform beyond expectations.

STEM tests are designed to extract the important building responses through a three-day test. The tests on the credit union building were performed during the period from 5 pm on Friday, March 9 to 8 am Monday, March 12. From these tests, the building load coefficient, the thermal capacitance and solar gains characteristics were determined. By using the building as a calibrated-calorimeter, the heat delivered by the heating system determined. By performing five tracer decay tests, the infiltration and ventilation characteristics were determined.

The building load coefficient was found to be 519 Btu/hr°F compared to an estimate based on an audit of the building of over 700 Btu/hr°F. The solar gains were only 56% of the predicted solar gains, and the heat storage and release in the masses is 141% of that predicted by the simulation model. The natural infiltration and additional flow induced by the distribution fan were determined under certain conditions, and found to be significantly different from audit estimates. The measured overall efficiency of the heating system is 86%.

The energy-saving features - additional wall and roof insulation, and, low-E window and skylights - appear to be highly successful in reducing the building load coefficient, which in turn reduces skin-related heating and cooling loads. In fact, these features appear to be performing appreciably better than expected.

The former was measured from SF<sub>6</sub> tests to be 1.0 ACH. The latter (corresponding to the conditions of the heating system test - a T of 48°F, and wind speed of 18 knots), can be obtained from the model of Eq. (1) to be 0.74 ACH.

The magnitudes of the differences seen in this building between the audit characteristics, and those from measurements are quite typical of those observed on other STEM tests. The energy use and peak loads are a combination of the above (and other) characteristics; the magnitudes of the differences between audit and measurement-based estimates of energy and peak loads can be larger or smaller than the above differences in the characteristics depending on whether differences tend to amplify or cancel one another.

## GENERAL ASSESSMENT

This building has several innovative energy conservation measures incorporated into the design. Some of them can be evaluated based on the results of the tests.

The energy-saving features - additional wall and roof insulation, and, low-e window and skylights - appear to be highly successful in reducing the building load coefficient, which in turn reduces skin-related heating and cooling loads. In fact, these features appear to be performing considerably better than expected.

The heating system appears to be operating overall at a low efficiency. The adequacy of natural ventilation for fresh air supply should be explored; if it is found to be adequate the outdoor air dampers can be shut and the fans operated in the "unoccupied" mode at all times.

The economizer performance which is intended to reduce cooling loads could not be assessed because the tests were conducted during the heating season.

## ACKNOWLEDGEMENT

Edward Hancock assisted with the STEM tests. Charles Cramer and Les Lambert of Lambert Engineering, Bend, Oregon provided much needed assistance during and after the tests.

## REFERENCES

1. K. Subbarao, "PSTAR - Primary and Secondary Terms Analysis and Renormalization - A Unified Approach to Building Simulations and Short-Term Testing," SERI/TR-254-3175, Solar Energy Research Institute, Golden, CO 80401, September 1988. This reference provides the mathematical basis of the evaluation method.
2. K. Subbarao, J. D. Burch, C. E. Hancock, A. Lekov, and J. D. Balcomb, "Short-Term Energy Monitoring (STEM): Application of the PSTAR Method to a Residence in Fredricksburg, Virginia," SERI/TR-254-3356, Solar Energy Research Institute, Golden, CO 80401, September 1988. This reference gives a detailed example of the application of the method.
3. L. Palmiter and T. Wheeling, SUNCODE- PC, Ecotope, Seattle, WA.
4. G. Mitalas, "Calculation of Below-Grade Residential Heat Loss; Low-Rise Residential Building", ASHRAE Transactions 1987, vol. 93, pt.1.

5. "The Measured Energy Impact of Infiltration in a Test Cell", Journal of Solar Energy Engineering, Vol 112, May 1990.

**Appendix**

**TABLE I**

Data Channels Monitored during the Short-Term Tests

	OUTSIDE TEMPERATURE	DEG F
	OUTSIDE RELATIVE HUMIDITY	PERCENT
	HORIZONTAL INSOLATION	BTUH/FT2
	SOUTH VERTICAL INSOLATION	BTUH/FT2
	WIND SPEED	KNOT
	SERVICE ENTRANCE	WATT HR
	OUTSIDE LIGHTS	WATT HR
BASEMENT:	TEMPERATURE IN ROOM 011	DEG F
	TEMPERATURE IN ROOM 03	DEG F
	LIGHTS	WATT HR
	RECEPTACLES	WATT HR
	HEAT PUMP	WATT HR
	REVERSING VALVE STATUS	
	RESISTANCE HEAT	WATT HR
FIRST FLOOR (SOUTHEAST)	TEMPERATURE IN ROOM 102	DEG F
	LIGHTS	WATT HR
	RECEPTACLES (TOTAL FIRST FLOOR)	WATT HR
	HEAT PUMP	WATT HR
	REVERSING VALVE STATUS	
	RESISTANCE HEAT	WATT HR
FIRST FLOOR (NORTHWEST)	TEMPERATURE IN ROOM 119	DEG F
	LIGHTS	WATT HR
	HEAT PUMP	WATT HR
	REVERSING VALVE STATUS	
	RESISTANCE HEAT	WATT HR
SECOND FLOOR	TEMPERATURE IN ROOM 201	DEG F
	LIGHTS	WATT HR
	RECEPTACLES	WATT HR
	HEAT PUMP	WATT HR
	REVERSING VALVE STATUS	
	RESISTANCE HEAT	WATT HR

## **Solar Gains**

The total solar gains are 56% of that estimated from an audit description. This difference is quite large; this is not surprising considering the difficulty of determining shading from venetian blinds and complex-shaped overhangs for which the shading was apparently underestimated.

## **Ventilation**

Tracer decay measurements were made under two sets of forced-ventilation conditions (in addition to the aforementioned natural infiltration measurements):

1. With only the fans running, and all fresh air dampers and grills closed, the air flow rate was 0.71 air changes per hour ( T of 36°F and wind speed of 13 knots). The infiltration model (eq. 1) gives 0.59 ACH under these conditions; operation of the fan affects the pressure distributions in the building, and the measured value of 0.71 ACH is due to the combination of all the effects.
2. With the heat pumps operating to provide the necessary space heating requirements, and with the fresh air dampers and grills in their normal state, the air flow rate was measured to be 1.0 ACH ( T of 48°F and wind speed of 18 knots). This corresponds to 650 cfm. Natural infiltration would have been, according to the model Eq. (1), 0.74 ACH or 480 cfm. Opening of the fresh air dampers and fan operation combine with natural infiltration to give a net 1 ACH under the conditions of the measurement.

The measured results may be compared with audit estimates made in developing a DOE-2 simulation-program input file prepared by an engineering firm. The audit assumptions were a constant 0.2 ACH, or, equivalently 130 cfm due to natural infiltration, and an additional 509 cfm when the fans are running; these estimates are independent of T and wind speed. By an (unjustified) linear addition of the two flows, the net estimated air flow is 639 cfm. The closeness of this to the measured (under the conditions given before) value of 650 cfm is fortuitous. It is important to correctly model infiltration with and without the fan operation because the fans are scheduled to run continuously during the occupied periods (about 10 hours during a weekday) and are shut off during the unoccupied periods.

## **Heating System Efficiency**

The net efficiency of the heating system consisting of three heat pumps and the distribution system supplying heat to the first floor and second floor was determined from measurements to be 86%.

The efficiency is obtained as (net heat delivered to the main floors)/(electrical input to the heat pumps and the fans). The net heat delivered to the main floors is obtained from building calorimetry: having determined the dynamic characteristics of the building from the other tests, the building can be used as a dynamic calorimeter to determine the heat input from the heating system.

It is important to recognize that the above efficiency is a system characteristic and should not be confused with the COP of the heat pump, which is usually defined as the ratio of the heat output of the heat pump to the electrical energy input to the compressor. The heat delivered by the heating system can be disaggregated into

(Heat Pump output)-(Additional heat loss from ventilation due to HP operation)-  
(Duct Losses).

We do not have the necessary additional data to assess each of the terms. We will simply note that the second term can be rewritten as

(additional ventilation due to HP operation) = (net air exchange due infiltration and ventilation) - (natural infiltration in the absence of mechanical ventilation).

$T$  = temperature difference in °F  
 $V$  = wind velocity in knots

Infiltration from the main two floors under coheating conditions above (approximately  $T$  of 44°F, and wind speed of 0.2 knots) was measured using SF<sub>6</sub> tracer gas to be 0.48 air change per hour. The equivalent UA associated with this infiltration (ACH times volumetric specific heat of air) is 300 Btu/hr.°F.

### The Building Load Coefficient:

The Building Load Coefficient is estimated from measurements to be 519 Btu/hr.°F.

This includes skin conductance, infiltration under coheating conditions, losses from the floor slab, and a small heat flow to the basement through the wood floor. The basement is considered a separate zone, and the heat loss from the basement is not included.

The value of 519 Btu/hr.°F was obtained from an analysis of coheating data from 5 am to 7 am on Saturday. The "raw" value, (electric heat)/ $T$ , is 491 Btu/hr.°F. Several corrections to this are made as follows (Btu/hr.°F):

Corrections due to thermal mass effects:	
non-constancy of indoor temperature:	2.7
non-constancy of outdoor temperature:	29.9
Residual solar gains:	15.1
Correction due to sky temperature depression:	-20.0
Total correction	27.7

The value of 519 Btu/hr.°F should be compared with an audit estimate greater than 705 Btu/hr.°F obtained by summing the following components:

402	for skin conductance
300	for infiltration corresponding to the measured ACH
3	for heat flow through the wood floor to the basement

plus concrete slab losses (not estimated)

The difference is substantial and follows the general trend seen in several other buildings in which the audit description was found to overestimate the building load coefficient. Some of the overestimation appears to be in the skin conductance. Particularly noteworthy is the fact that there are 312 sq. ft. of double glazing with the following features whose effect on the conductance is not accurately modeled in audit simulations: (a) a substantial part has venetian blinds in between glazings, and (b) a substantial part of the glazing is enclosed by a glass entry vestibule. It is difficult, however, to attribute all of the difference to an overestimation of the skin conductance.

Even though the infiltration air flow was measured, the corresponding heat flow may be substantially smaller than determined from an equivalent UA because of heat recovery that occurs during infiltration [ref. 5]. Mechanisms of such heat recovery in real buildings are not well understood.

### Heat Capacitance

The effective heat capacitance of the building is estimated from the test data to be 12210 Btu/°F. This is 41% higher than the estimate from an audit. (Note that the heat capacitance of a building is really not a single number; the above number is based on diurnal heat storage.)

flow terms are renormalized using linear least squares to give a best fit to the energy balance. The renormalization is done by minimizing the energy balance error over selected periods through adjustment factors for each of the three primary calculated heat flows and the phasing of the solar gains.

Each heat-flow term is computed from the audit description and the measured driving functions. Some comments on the computation of these terms are noted below:

#### *Loads due to Indoor and Outdoor Temperatures*

The static loads due to differences between indoor and outdoor temperatures, as well as dynamic loads due to variations in indoor and outdoor temperatures are determined from a transfer function formulation given in Ref. 1.

#### *Solar Gains*

The audit description is converted to a SUNCODE computer model (a simulation program written by Ecotope, ref.3). A simulation is performed using the measured solar radiation in which the indoor temperature and outdoor temperatures are equal and constant. The cooling-load output of this simulation calculation is the solar-gain term required for the PSTAR analysis. In modeling the building on SUNCODE the shading from the frames and louvres on the windows was accounted by multiplying the shading coefficient of the glazing by 0.6 or 0.5 depending on the position of the louvres; all the louvres were left in the positions in which they were found at the beginning of the test.

The measured solar radiation on a global horizontal pyranometer and on a vertical pyranometer in the plane of the dominant glazing (approximately due south) were processed to give average daily ground reflectivity, hourly normal and global horizontal radiation values and then used in the SUNCODE simulation. The data from radiation processing are displayed in Figures 9-15. 10-11

#### *Infiltration*

From the tracer decay data, a model of infiltration was determined. As will be seen later, even if a reliable model of airflow due to infiltration is available, the resultant heat flow may not be easily determined. In order to mitigate this problem, a base value of infiltration is subsumed in the definition of the load coefficient; only variations around this base value need to be modeled. The base value is chosen to be the average value during the coheating period. Thus, the infiltration measurements/model have no impact on the BLC estimated from the data; they only affect the separation of BLC into envelope and infiltration components. The variation of infiltration heat flow above or below the base value is treated as a secondary term.

#### *Ground Heat Flow*

The first floor is partly on a slab-on-grade which is directly ground-coupled. The corresponding heat flow was modeled using a method developed by Mitalas [Ref. 4].

## RESULTS

A summary of the results is given in Table III. Each of these results is discussed in further detail below. The disaggregated heat flows are shown in Figures 4a-b. 12-13

#### **Infiltration:**

Tracer gas measurements yielded infiltration values shown in Table 2. From these data, the following model of natural infiltration model deduced ( $T$  denotes the difference between indoor and outdoor temperatures):

$$ACH = [ T/200 + (V/32)^2 ]^{1/2} \quad (1)$$

where ACH = air changes per hour

testing, a cooldown test on the second night, and heating system tests on the third night. Daytime data are used to determine the effect of solar gains.

The building was available for tests from 5 p.m. on Friday March 9, 1990 till 8 a.m. Monday, March 11. During this weekend period, the only activities in the building were test-related. Lambert Engineering was scheduled to perform certain tests of their choosing on Saturday night-Sunday morning. In order to limit the scope of the project, the testing was focussed on determining the thermal characteristics of the upper two levels only; the basement was included only to the extent it affected the energy flows in the two main floors.

In conformity with the above constraints the test protocol was modified as follows: During Friday night and Saturday, all heating was done with portable electric heaters controlled by thermostats in the extension cords. (Thermostats tend to have some overshoot and droop. A preferable method is to individually control the heaters based on the measured temperatures through the data-acquisition computer; this method, normally used in STEM tests, was not employed in this project because of constraints on instrumentation.) The nighttime indoor temperatures were relatively constant and constitute a near steady-state test; daytime Saturday was sunny and the temperatures rose above the set point due to solar gains. During Saturday night - Sunday morning, Lambert Engineering performed their tests; data from this period was not used in our analysis. Sunday turned out to be heavily overcast, and, the decision was made to perform heating system tests during daytime Sunday. A cooldown test was performed during Sunday night - Monday morning, and the building was returned to normal temperatures and the test terminated before 8 a.m. on Monday.

A wide range of weather conditions from clear skies to snow was experienced during the test period, and the outside temperatures were not unusual for the time of the year. Plots of the measured temperatures, solar radiations, wind velocity, electric power and humidity are shown in Figures 3-7. 4-8

Infiltration/ventilation was measured using sulfur hexafluoride decay. At four selected times during the course of the tests SF<sub>6</sub> was released and the subsequent decay measured using an infrared analyzer.

## DATA ANALYSIS

Analysis of the test data is by the STEM 1.2 computer program, which incorporates the PSTAR method (described in full detail in Refs. 1 and 2). This method is based on an hourly dynamic energy balance equation for each zone of the building. The building was modeled as consisting of two zones, the first and second floors constituting one zone and the basement the other. In order to limit the scope of the project as mentioned before, a renormalized energy balance was performed for only the first zone. The averaged zone temperatures are displayed in Figure 3. 4

Heat flows are calculated using the reduced model and measured temperatures. Upstairs air temperature is a weighted average of the three temperature sensors, and the basement air temperature is a weighted average of two sensors. The calculated primary heat-flow terms are the steady-state conduction from inside to outside, the internal mass storage effect due to inside temperature changes, and all solar-gain effects, both prompt and delayed. The other large heat flow is the total measured electric heat. Secondary calculated heat flows include heat lost through the floor to the basement zone, variations in infiltration around the base value, extra heat loss due to sky infrared temperature depression, and dynamic effects due to variations in outside air temperature.

The net of all these heat-flow terms normally does not yield an hourly energy balance because neither the model nor the audit description is exactly correct. The primary heat

## DESCRIPTION OF THE BUILDING

The East Idaho Federal Credit Union building is a 5300 sq. ft., two-story structure with a finished basement located in Idaho Falls, Idaho, at a latitude of approximately 42N and a longitude of approximately 112W, and an elevation of approximately 4710 ft. above sea level.

The floor plans of the building are sketched in Figures 1, 2, and 3. The floor areas are 2799 sq. ft. on the first floor, 960 sq. ft. on the second floor, and 1554 sq. ft. on the basement. The 2x4 walls, insulated with 3 1/2 inch batts, have, on the exterior side, plywood sheathing, 1" rigid insulation board and face brick, giving a total R value of about 20. All second floor wall area adjoins unconditioned, ventilated attic space; the walls are insulated with R-19 batts. The ceiling has sheetrock under 2x6 ceiling joists. The attic has 9" batt insulation with 8" loose-fill insulation over it, for a total R- value of about 49.

The windows primarily face south and west. They are of low-e type with operable venetian blinds between two glazings. The main entrance has a glazed air-lock vestibule. A drive-through window with a covered porch is located on the east side of the building.

The building is equipped with four split-system air-to-air heat pumps with rated capacities of 33000, 40000, 32000, and 39000 Btu/hour; two of the units serve the first floor, one serves the second floor, and one the basement. The condensing units are located outside on the northeast side. The indoor unit of each heat pump is equipped with an air handler, DX cooling coil, 15 KW back-up resistance heaters, and economizer. Two of the indoor units are located in a mechanical room in the basement, and the other two in a mechanical room on the second floor.

Ventilation air is brought in through ductwork located under a stairwell, and under a soffitted overhang. The return and supply air ducts of the first and second floors are partially located in the unconditioned attic space adjacent to and above the second floor conditioned space; the ducts in the unconditioned space are insulated. Exhaust fans, three on the first floor and one in the basement, provide ventilation to the bathrooms and the janitor's closet.

The following energy conservation measures were incorporated into the building:

1. increased insulation in the walls and ceiling
2. motorized economizer control of ventilation air during cooling periods
3. low-emittance glazing

A brochure prepared by the Pacific Power and Light Company and Bonneville Power Administration is attached as Appendix and contains additional details.

## DATA ACQUISITION

Data-acquisition systems designed for long- term data acquisition was installed by Lambert Engineering. The data channels used in our analysis are listed in Table I; additional data channels, important for other analyses were acquired by Lambert Engineering. In addition, four tracer gas decay tests were conducted during the experiments. Sulfur hexafluoride was injected and its concentration measured using an infrared analyzer.

## TEST PROCEDURE

The test procedure, or protocol, is designed to elicit the important building responses. The typical protocol consists of data near a steady-state condition during the first night of



The adequacy of natural ventilation for fresh air supply should be explored; if it is found to be adequate (for example, under sufficiently low outdoor temperatures), the outdoor air dampers can be shut and the fans operated in the "unoccupied" mode at all times.

The economizer performance which is intended to reduce cooling loads could not be assessed because the tests were conducted during the heating season.

The STEM tests were found to be quite suitable for nonresidential buildings that are small enough to be heated entirely by portable heaters during the test. Building calorimetry provided a powerful way to study HVAC performance.

## **INTRODUCTION: WHY SHORT-TERM TESTING?**

Although it is tempting to judge the thermal quality of a building on the basis of utility bill data, there are potential large inaccuracies in this approach. Differences in weather from one year to the next can make a large difference in energy use, although techniques do exist to make corrections for temperature. The biggest problem is that differences in the behavior of different occupants can change the results by a factor of two. This can completely obscure any estimate of the thermal quality of the building. A third problem with utility bill analysis is that it is necessary to wait for the results until the building has been lived in for about one year.

An alternative and frequently used approach is to estimate building energy performance based on mathematical models using data taken from building plans using an hour-by-hour simulation analysis. In this approach, the weather data are normally based on observations taken over several years, and a "standard" building occupancy pattern is assumed, based on an accepted norm. But there are other problems with this approach. Buildings are complex and describing an adequate mathematical model is a major undertaking that is subject to significant error. Furthermore, the properties of materials and the details of actual construction (many of which are hidden) can have a major influence. The siting of the building is also important. Given that these uncertainties affect energy predictions by about 50 percent, it is clear that building-specific energy measurements are needed.

To overcome these problems the Solar Energy Research Institute (SERI) has developed a method that combines measurement and theory. The method, called PSTAR (Primary and Secondary Terms Analysis and Renormalization), is based on a renormalization of a building simulation model using data from a short-term test conducted with the building unoccupied. Because the simulation model is to be adjusted, it can be made fairly simple based on a quick audit. In the data analysis, adjustment factors are identified for each of three key building heat flows as follows: (1) heat flow per degree of inside-outside temperature difference under steady-state conditions (normally called the building loss coefficient, or BLC), (2) heat stored in the building internal mass, and (3) heat from solar gains. This process is called renormalization of the model. The renormalized model is then used to determine HVAC performance by employing the building as a dynamic calorimeter, and to estimate long-term performance using typical weather data and occupancy patterns.

The objective of the present tests is to evaluate the applicability of the PSTAR monitoring and analysis technique to nonresidential buildings. This report describes the results. This activity is part of SERI's ongoing effort to extend the class of buildings for which the short-term energy monitoring (STEM) methodology is applicable. In particular, application to nonresidential buildings is important because of the utility emphasis on demand-side management in such buildings.

**TABLE II: INFILTRATION MEASUREMENTS**

Hour (Thu-Fri Midnite = 0)	Indoor Temp(F)	Outdoor Temp(F)	Wind (knots)	ACH
29	74.9	30.8	0	0.48
30	74.8	30.2	0.5	
67	75.5	29.5	13.0	0.62
68	74.8	29.3	12.8	

**TABLE III: SUMMARY OF THE RESULTS**

	Estimated from Audit	Estimated from Meas.
Building Load Coefficient	>700 Btu/hr°F	519
Infiltration	0.2	0.48ach <sup>(1)</sup>
Heating System Efficiency <sup>(2)</sup>	?	86%
Solar Gains (Audit = 1)	1	0.56
Thermal Mass (Audit = 1)	1	1.41
Additional Ventilation from HP	506 cfm <sup>(3)</sup>	310 cfm <sup>(4)</sup>

(1) during SF<sub>6</sub> tracer measurement conditions

(2) Obtained as (Net Delivered Heat)/(Electrical Energy into Heat Pump including Fans). Net delivered heat measured from building calorimetry; includes heat pump output, duct losses and ventilation due to heat pump operation.

(3) From fan cfm ratings and assumed outdoor air fraction

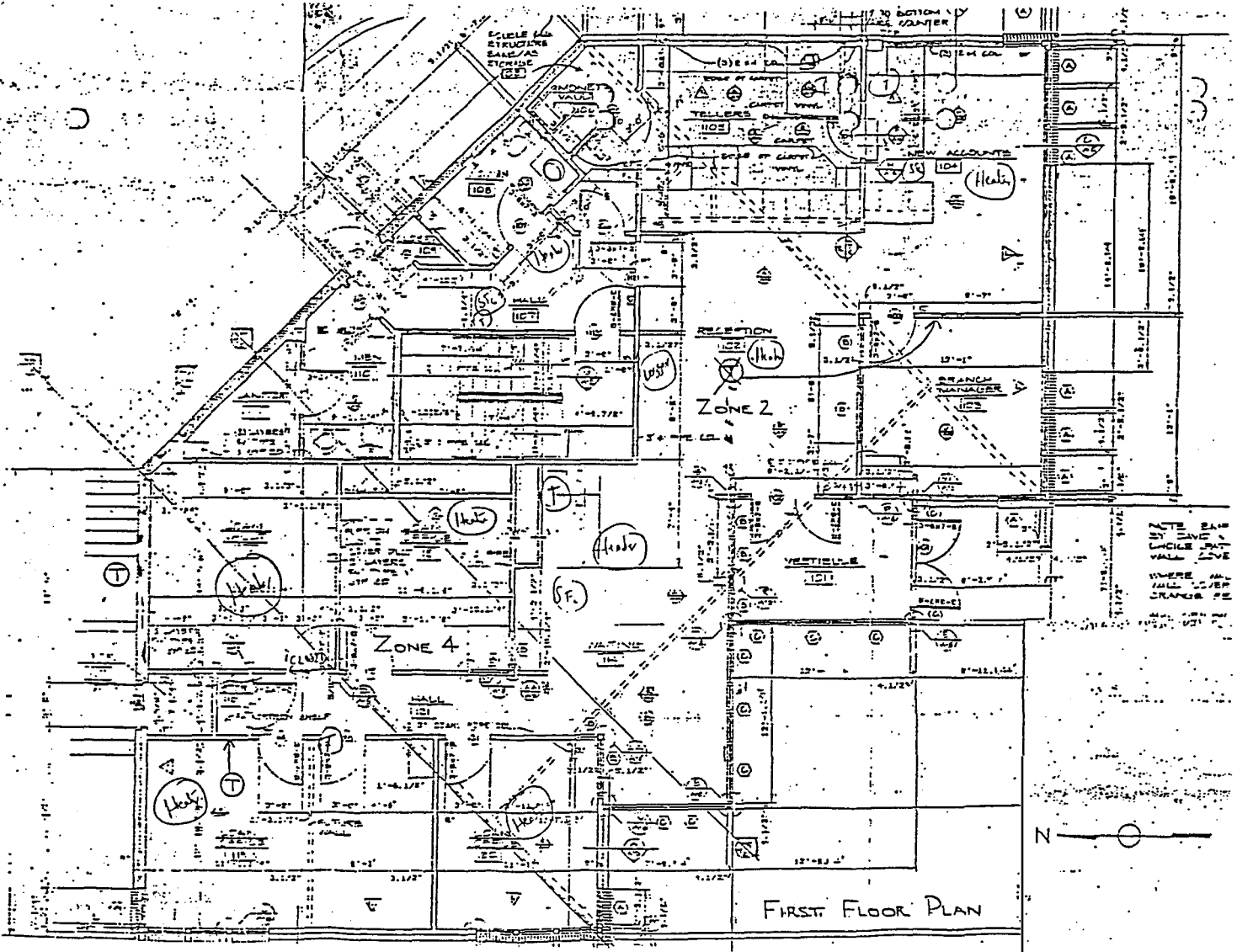
(4) Inferred from tracer gas measurements in building; includes fresh air introduced from ducts as well as from a **change** in infiltration.

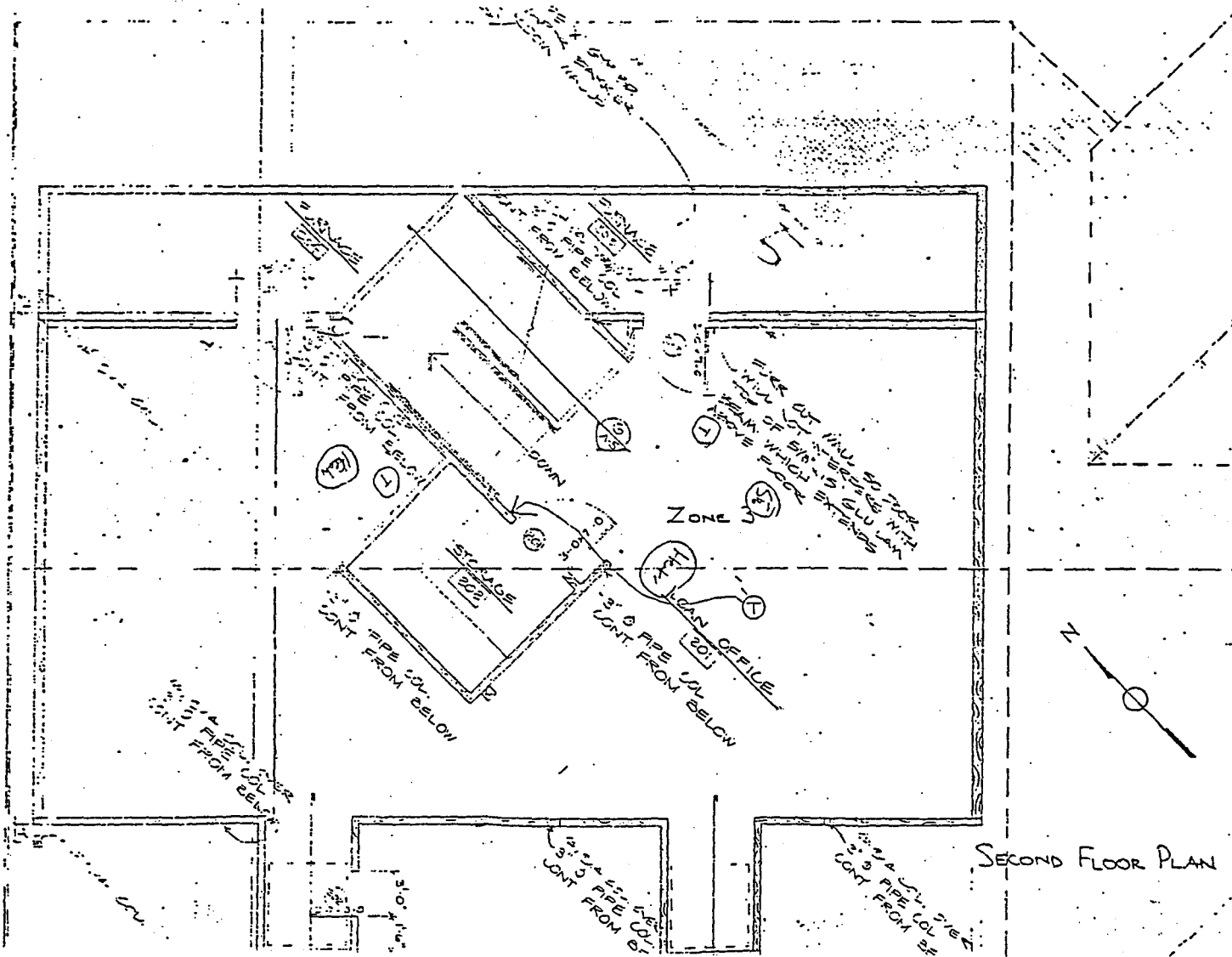
Each item is discussed in greater detail in the text.

## Figure Captions

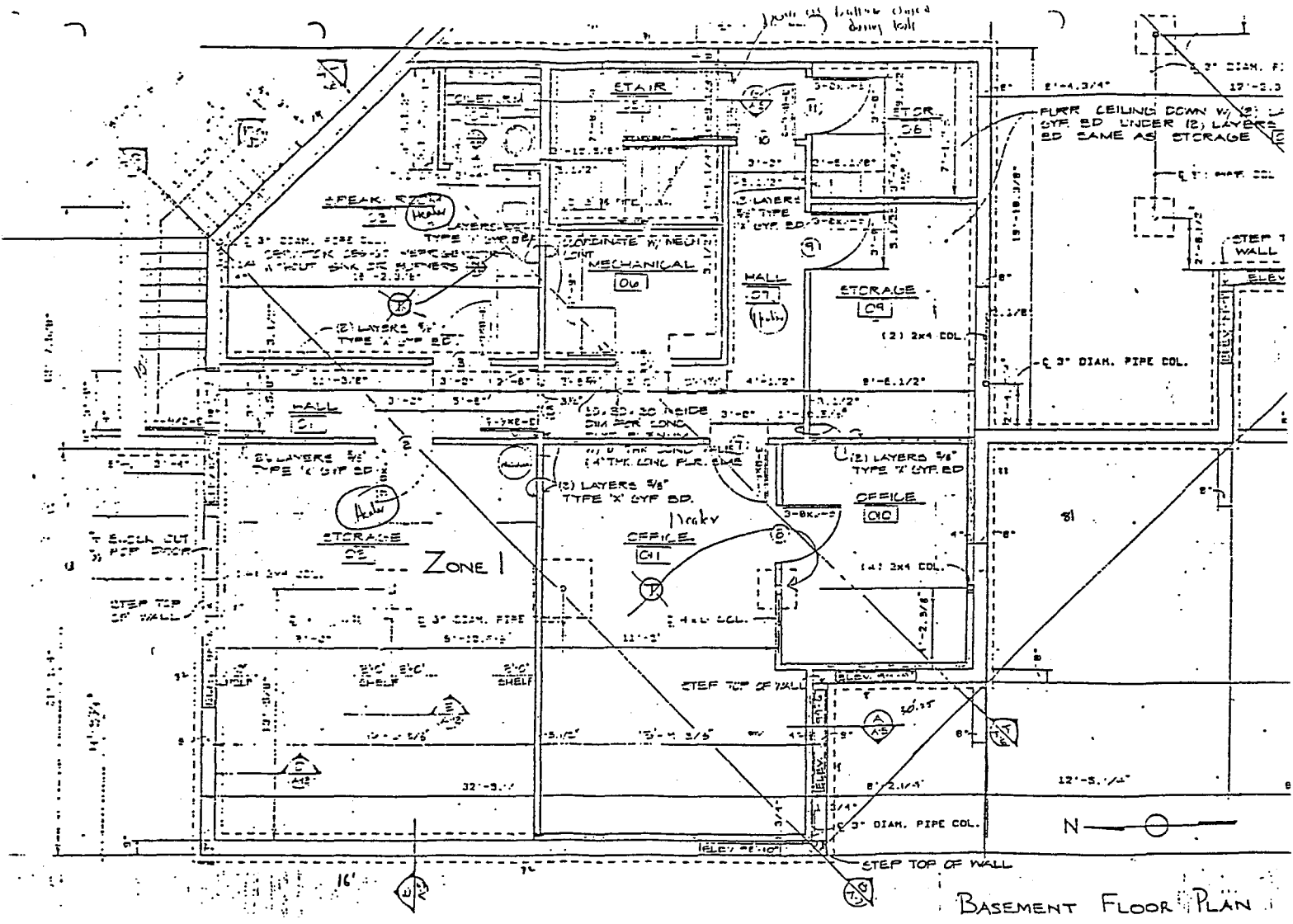
- Figure 1: Plan of the First Floor of the building
- Figure 2: Plan of the Second Floor of the building
- Figure 3: Plan of the Basement of the building
- Figure 4: Measured Indoor Temperatures during the tests. T1A and T1B represent the two first floor temperatures, and, T2A the second floor temperature. (The tests actually started after 1700 hrs; since the long-term data acquisition system was operational, data starting from 0100 hrs are shown)
- Figure 5: The ambient and the two basement temperatures during the test period
- Figure 6: Incident Solar Radiation on a horizontal pyranometer and a vertical pyranometer parallel to the principal glazing of the building as well as wind speed during the test period
- Figure 7: Internal Gains and Power to Heat Pump during the test period
- Figure 8: Relative Humidity during the test period
- Figure 9: Average temperature of the first two floors, and the basement during the test period. (Outdoor temperatures are also shown)
- Figure 10: Global horizontal radiation inferred from the two pyranometer readings and the weighted values used in the analysis
- Figure 11: Normal beam inferred from the two pyranometer readings as well as the weighted values used in the analysis
- Figure 12: Primary heat flows, House 1, upstairs. The steady-state term "In-Out" tends to dominate and, during coheating, counterbalanced mostly by the electric heaters and other internal gains ("Int"). "Instorage" accounts for storage effects due to inside temperature variations; it is large during cool down. Solar gains "Sun", are large during daytime. "Sun" is calculated using audit-based SUNCODE model. Also shown is heat imbalance after renormalization - "Net". Note the large imbalance during hours 61 to 67 due to heat pump operation; this imbalance is attributed to the output of the heating system. Data from the hours 44 to 60 have been blanked out; Lambert Engineering performed certain tests during this time and the data are not used in the STEM analysis.
- Figure 13: Secondary heat flows, House 1, upstairs (note the scale on the y-axis). The term "In-Bsm" is heat flow through floor from upstairs to basement. "Sunshift" renormalizes time phasing of solar gains. "OutStorage" accounts for storage effects arising from variations in outside temperature. "Infil" is the difference between infiltration heat flow term and its value during the coheat period; it is calculated using the ASHRAE-recommended wind and stack coefficients. The term "Sky" is the heat flux due to sky temperature depression below ambient.
- Figure 14: Comparison of the internal temperature as a result of measurements, as modeled with the audit house description and as modeled after the renormalization process for House 1. Note the improvement due to renormalization. The comparison is terminated at hour 43. During

subsequent hours (a) Lambert Engineering performed certain tests, (b) heating system tests and cooldown tests were done as part of STEM. This deviation from the standard protocol created problems for this particular temperature prediction process that could not be easily addressed in the existing software.





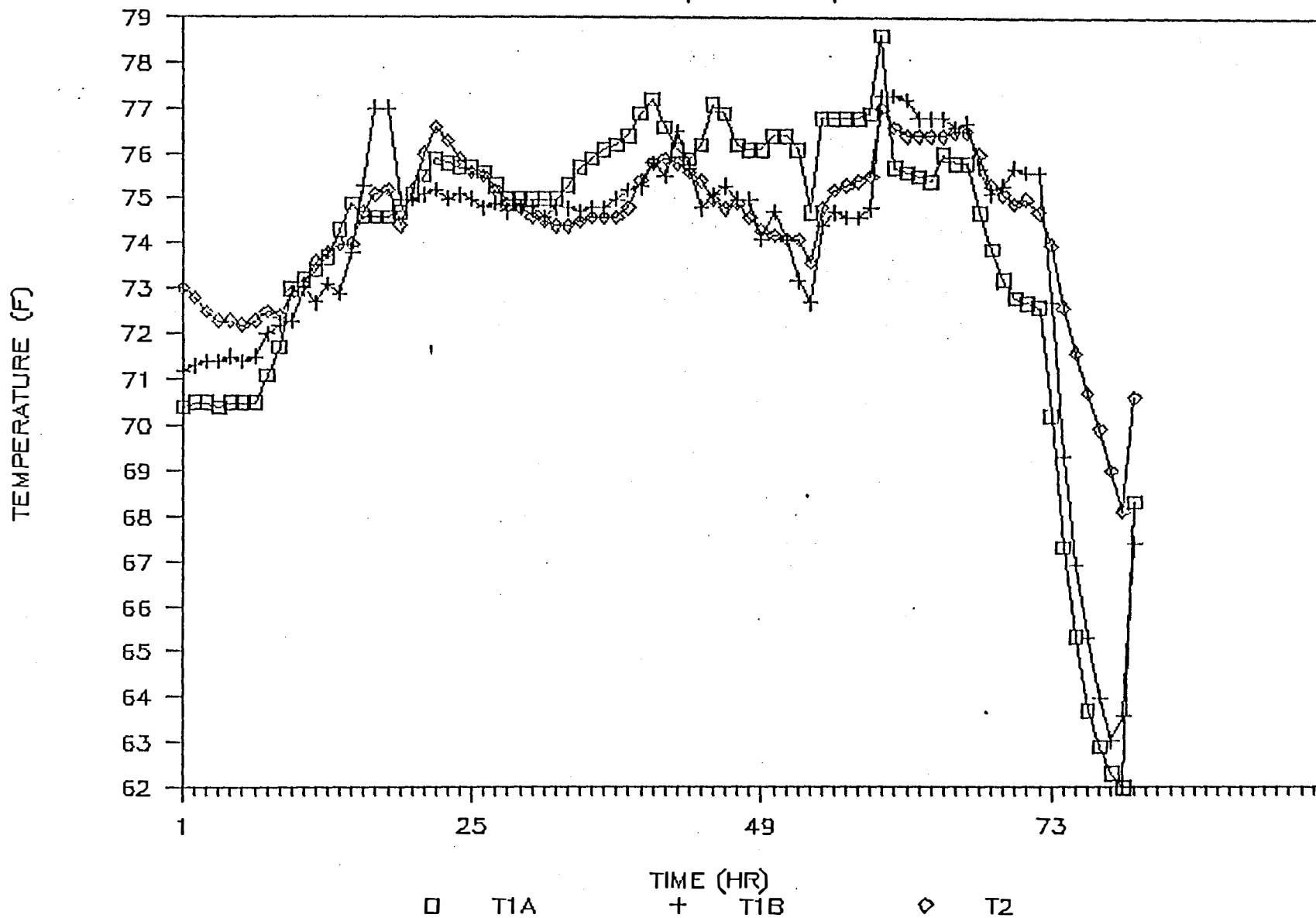
SECOND FLOOR PLAN



BASEMENT FLOOR PLAN

# Internal Temperatures

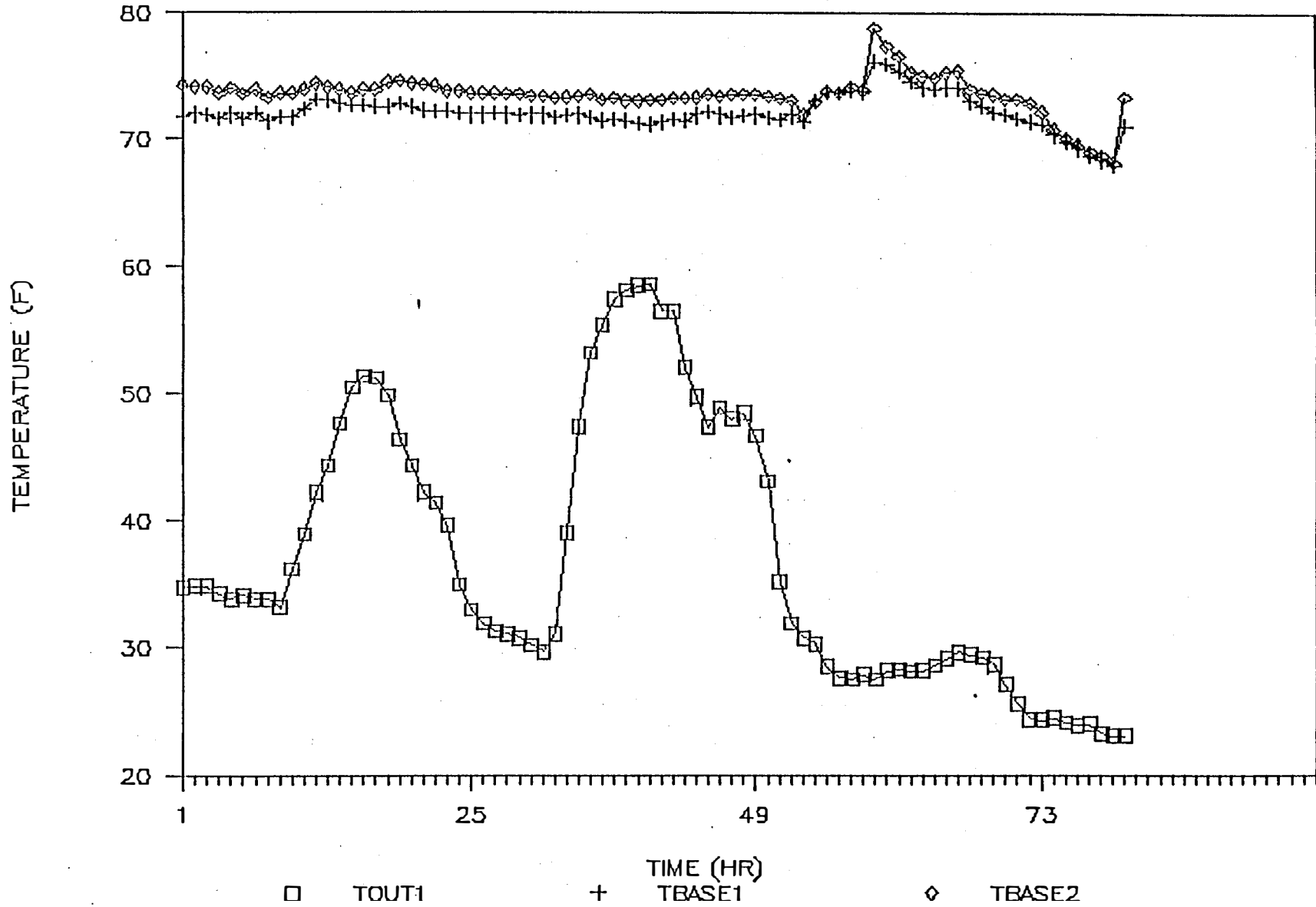
EIFCU TEST1, DAYS=068,071





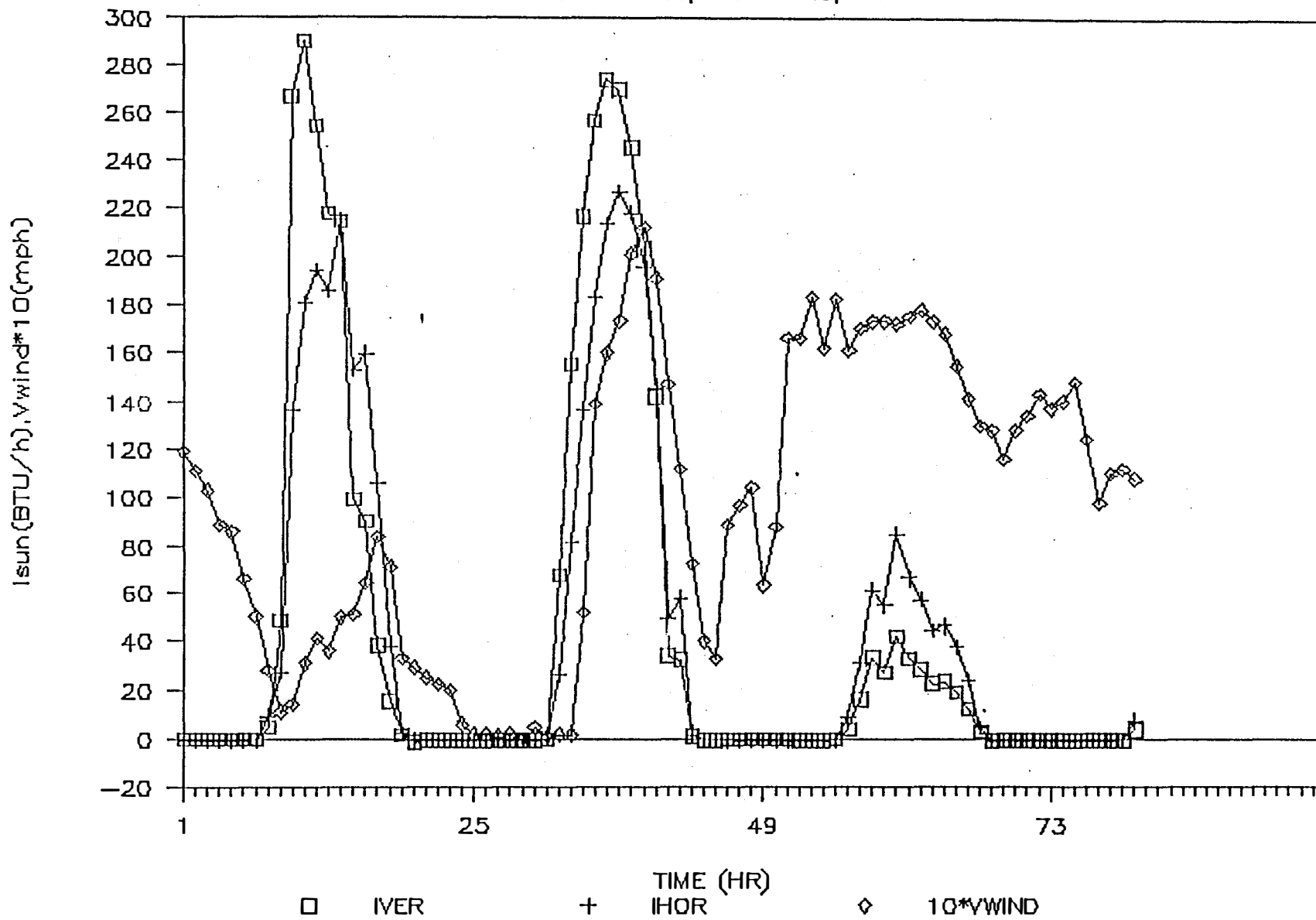
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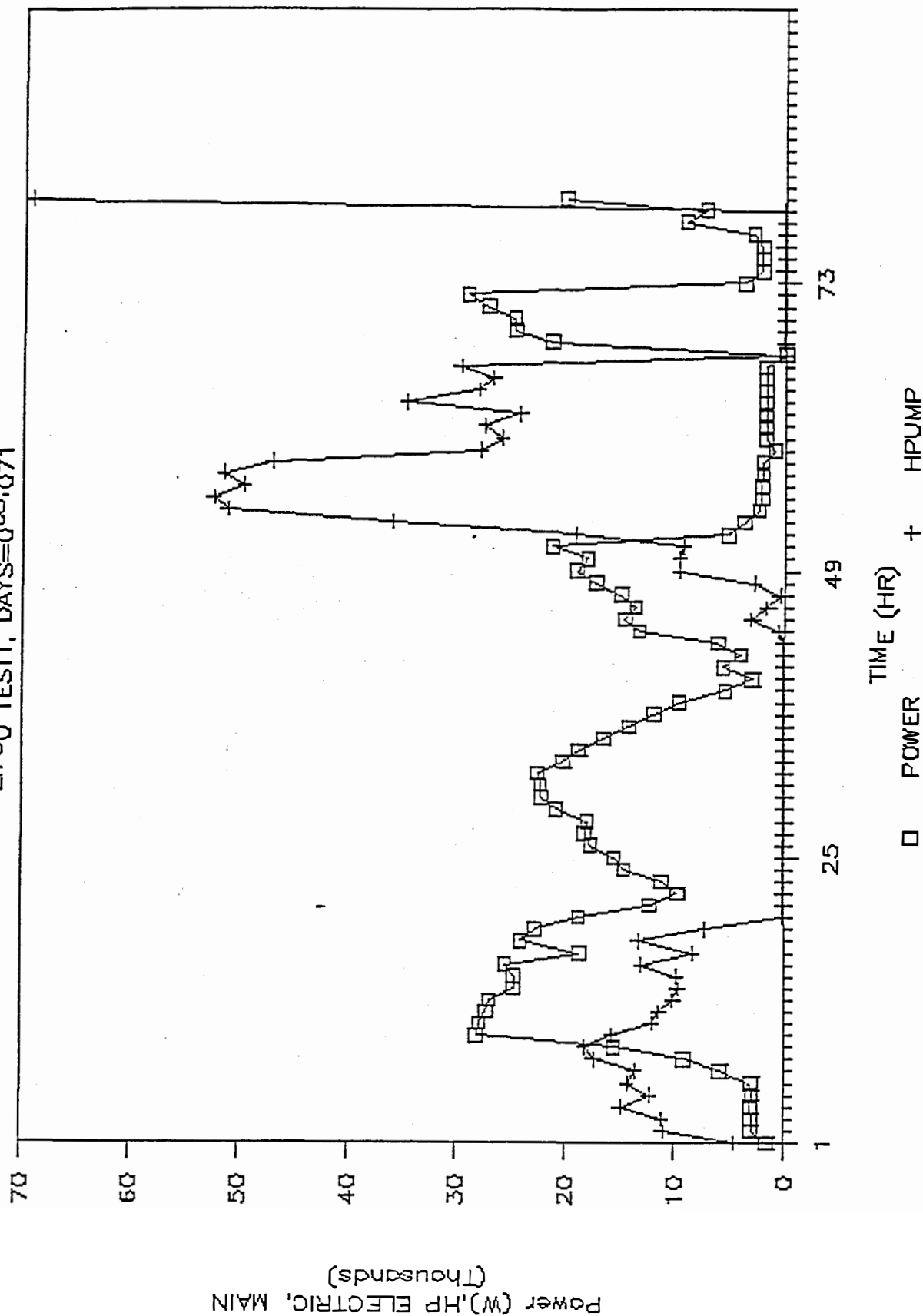
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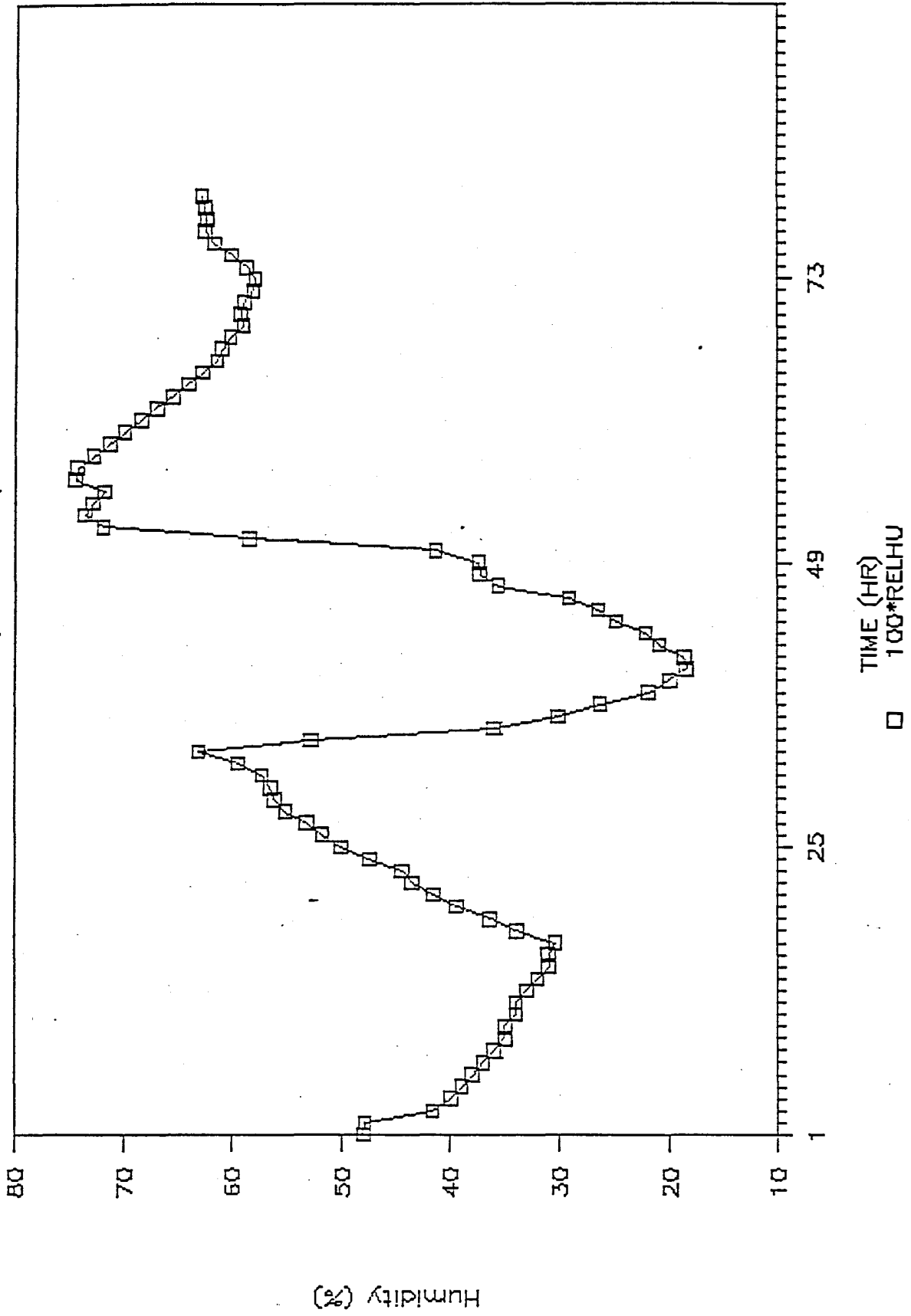
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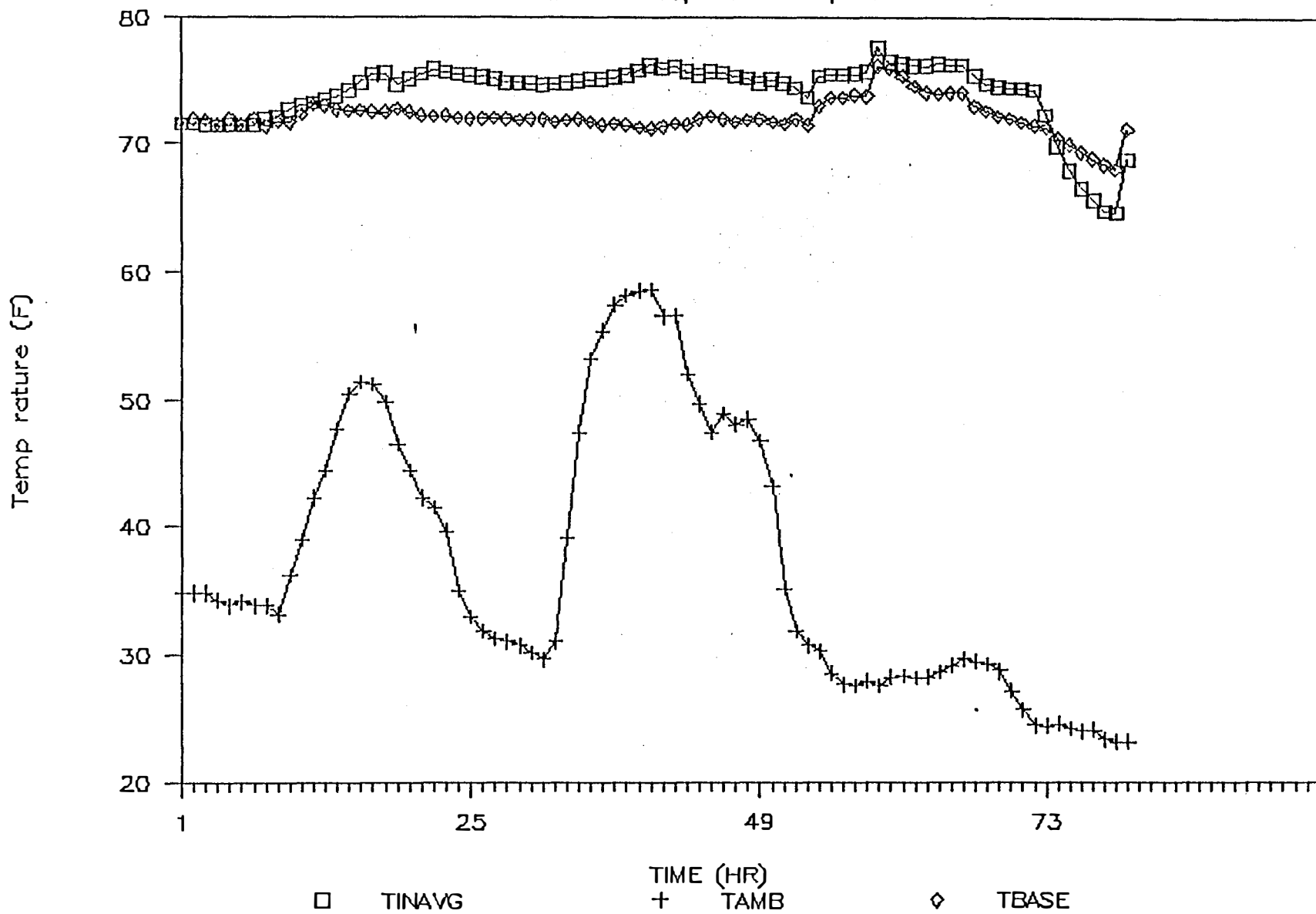
# Relative Humidity

EIFCU TEST1, DAYS=068,071



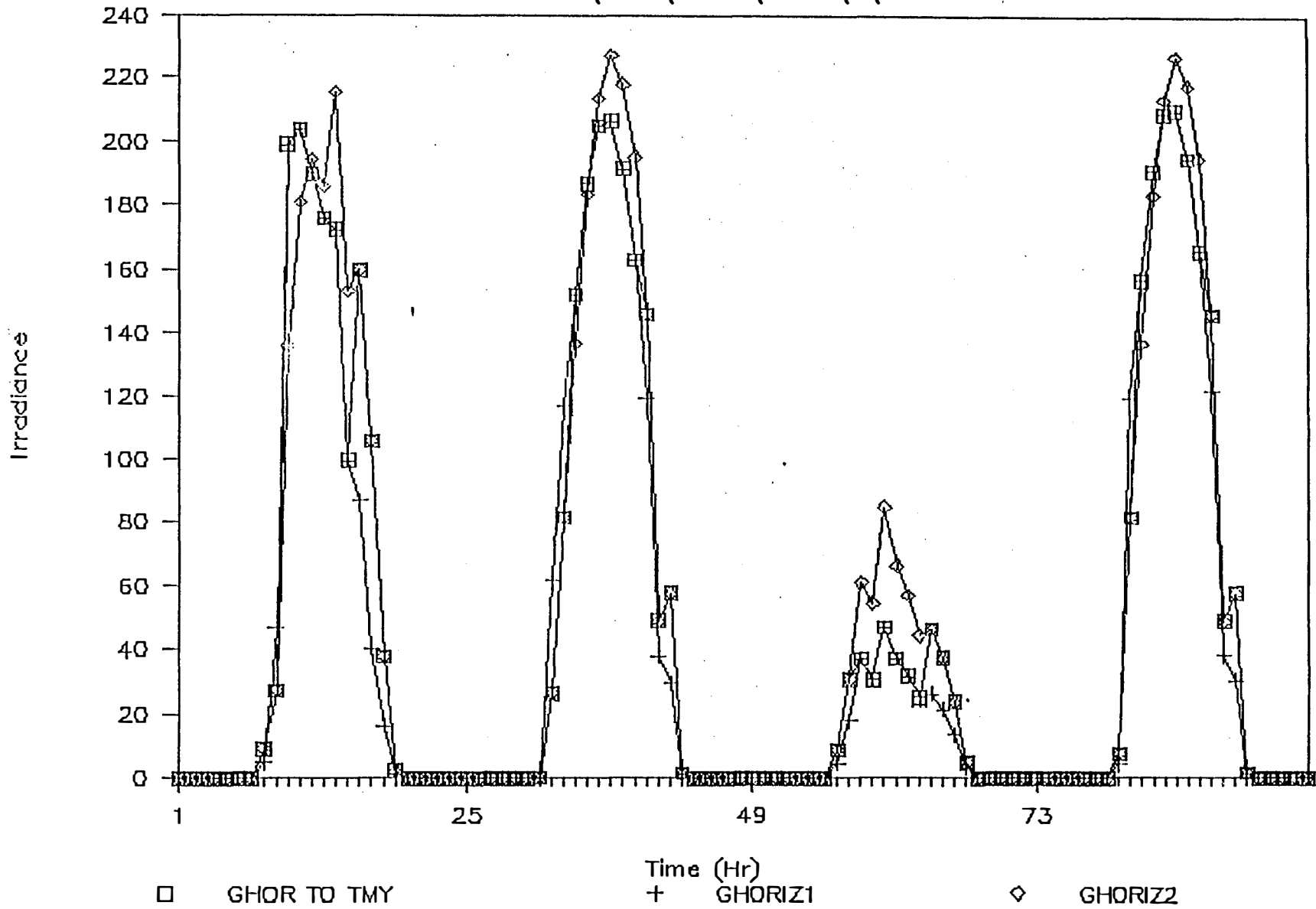
# Derived Data

EIFCU TEST1, DAYS=068,071



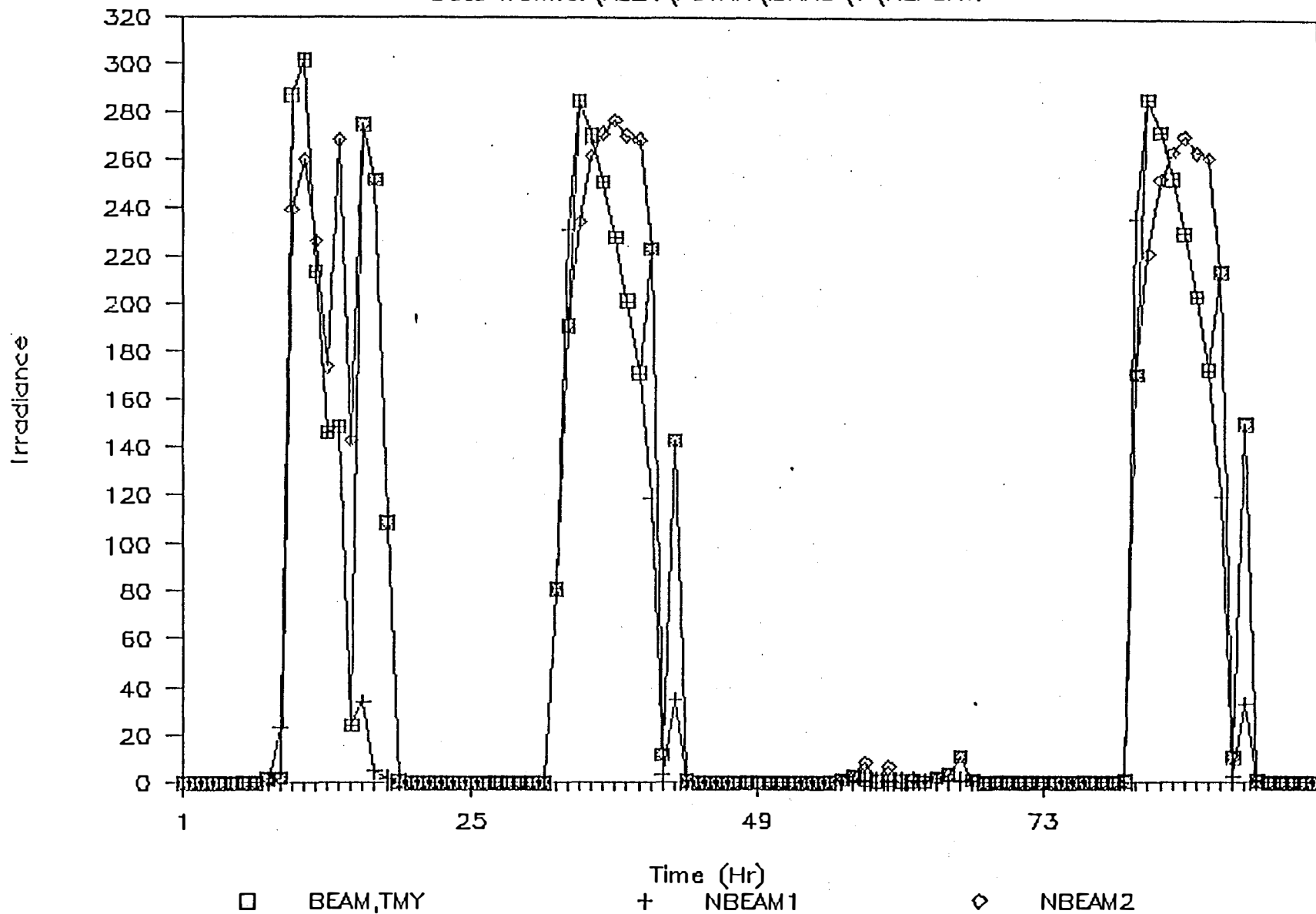
# GLOBAL HORIZONTAL

Data from: C:\ALEX\PSTAR\IDAHO\1\REPORT.



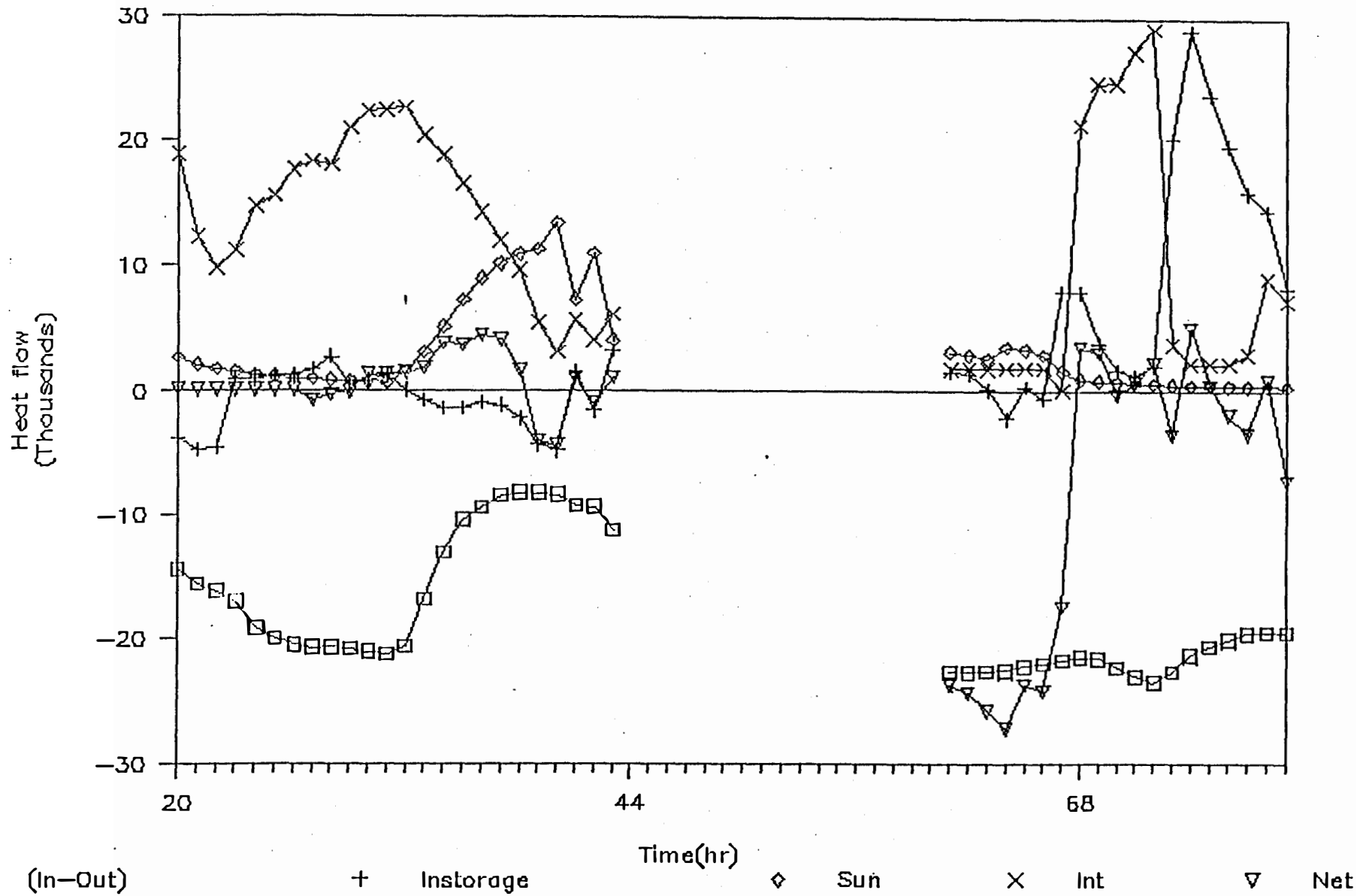
# NORMAL BEAM

Data from: C:\ALEX\PSTAR\IDAHO\1\REPORT.



# Heat Flows - I and Energy Imbalance

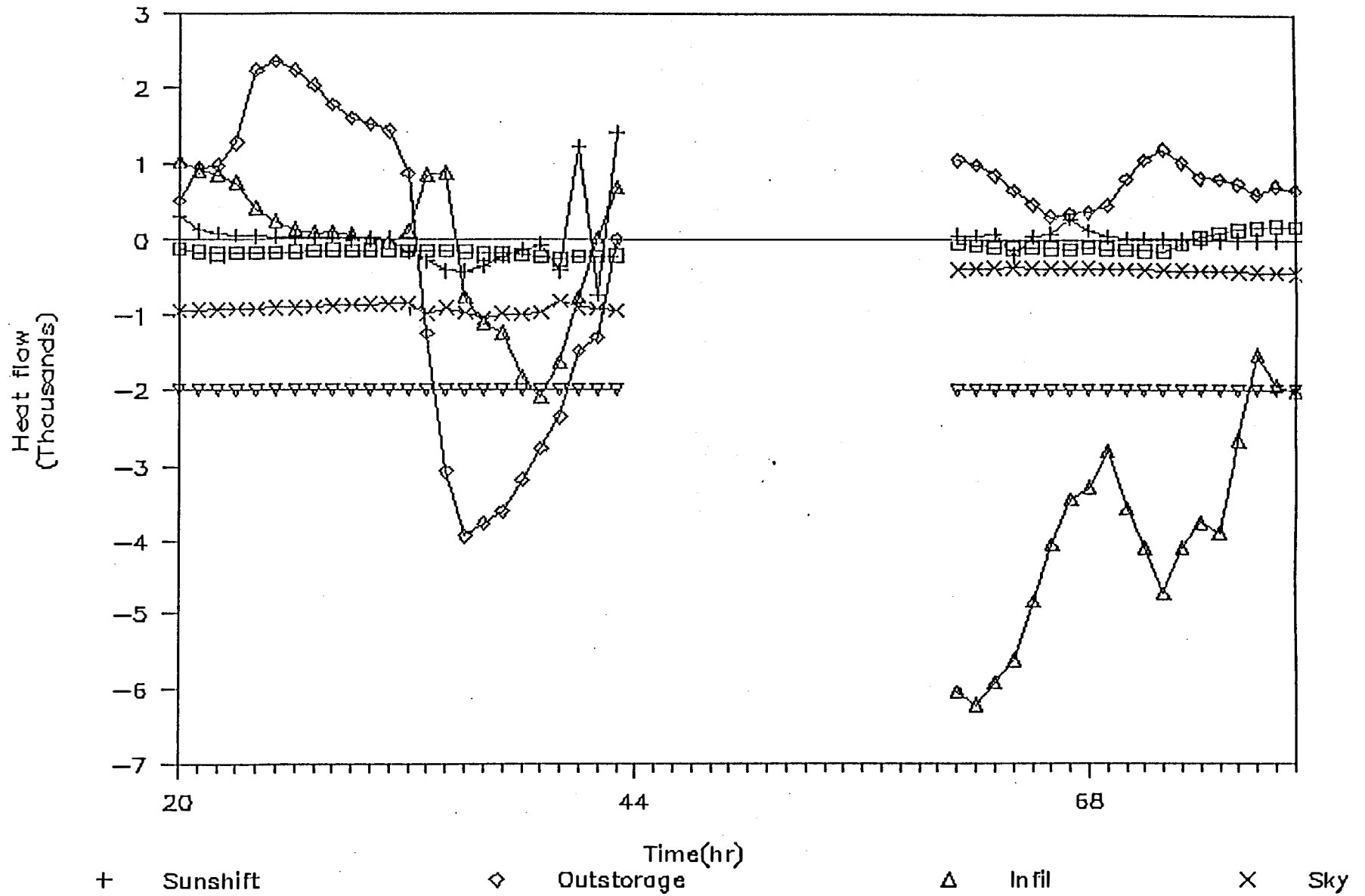
Renormalization factors included





# Heat Flows - II

Renormalization factors included



# Comparison of Inside Temps

Measured, Audit, and Renormalized

