Lawrence Berkeley Laboratory
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ENERGY & ENVIRONMENT DIVISION

PROJECT REPORT: FIELD TESTING OF WIND COOLING EFFECTS ON NAVY BUILDINGS

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M.H. Sherman and D.J. Dickerhoff*

Energy Performance of Buildings Group
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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This work was funded by the Department of Defense, Naval Material Command and the Naval Civil Engineering Laboratory, Port Hueneme, CA 93043, under Contract Number N-68305-82-MP20017.

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The Department of the Navy is interested in using prevailing winds to cool certain Navy housing and buildings and save air conditioning energy in locations such as Hawaii, Florida and Puerto Rico. Many investigations of the effect of winds on buildings have been conducted. Most of these efforts concentrate on external wind/building aerodynamics or wind pressure loads on buildings. Only a few are devoted to energy-related wind cooling and ventilation. The purpose of this project was to fully measure wind pressures on three Navy buildings at the Kanehoe Marine Corp Air Station (KMACS), Hawaii. In addition to pressure measurements, both indoor and outdoor environmental variables were measured; these included temperature (dry bulb and wet bulb or relative humidity), wind speed, and wind direction. This field data will be used to verify computer simulations of buildings and wind tunnel results.

Keywords: natural ventilation, field measurements, wind tunnel

This work was funded by the Department of Defense, Naval Material Command and the Naval Civil Engineering Laboratory, Port Hueneme, Ca. 93043, under Contract No. N-68305-82-MP20017.

EXPERIMENTAL TECHNIQUE

Three sites were chosen by the Naval Civil Engineering Laboratory (NCEL) for testing at KMACS during July, 1982. The three sites were a two-story VEQ, a single-story duplex, and a two-story fourplex--all with good wind exposure. Each site was tested for five days. The tests included exterior surface pressures on at least three sections of the windward and leeward faces and one section of each side face. Pressures of accessible interior spaces were also measured. Wind speed and direction were measured with an on-site weather tower that gave results to be compared with those from the KMACS weather station. Interior and exterior dry-bulb temperatures and relative humidities were also measured.

Frequent, time-series measurements of all relevant parameters must be recorded for full-scale measurements to be useful in theoretical or wind-tunnel modeling. We elected to do this with a microprocessor-based data-acquisition system[1] that was programmed to make frequent measurements and record half-hour averages and standard deviations. Data are stored on floppy disks for easy transportation and further analysis at the laboratory. This system has been used repeatedly in the Mobile Infiltration Test Unit (MITU),[2] from which a great deal of information regarding infiltration, weather, and pressure correlations has already been collected.[3,4] Individual components, as used in this project, are described in the sections below.

Pressure Measurement

The pressure measurements were carried out with six Validyne DP103 pressure transducers having a range of ±70 Pa full scale. The transducers were electronically connected to a demodulator box in the computer rack; these output voltages went directly to the analog to digital (ADC) equipment in the computer. The reference side of each Validyne measured the static pressure at the six-meter (6m) height on the on-site weather tower.

The static pressure in the wind was measured using a static pressure probe that was designed, built, and calibrated by Dr. David Wilson from the mechanical engineering department of the University of Alberta in Edmonton, Canada. The probe is relatively insensitive to horizontal wind direction, having a pressure coefficient of 0.07. It is also insensitive to the vertical component of the wind within ten degrees of the horizontal. Using the static pressure in the wind allowed us to measure the external (and internal) pressure coefficients as well as the outside-inside pressure differences.

The signal end of each pressure transducer was connected to a manifold of up to eight different pressures taps that were located up to 300 feet from the transducers. Each pressure tap was a set of cross-shaped pipes that could be tapped to the outside (or inside) of a building and connected to the manifold through a length of flexible tubing. (This tubing was covered in aluminum foil wherever it might be exposed to direct sunlight.) The tubing terminated at a solenoid valve connected to the manifold for each pressure transducer. The tap to be measured was selected by computer control of the solenoids; each connected tap was sampled repeatedly during each half-hour cycle, and the results were stored individually. All six transducers and attendant solenoid valves were stored in one rack for easy transport and set-up.

Of the six transducers, three were allocated for external use (levels 1,2,3) and three were allocated for corresponding internal use (levels 4,5,6). Since the wind is not constant during any half-hour period, average pressure coefficients cannot be calculated from average surface pressures. Our arrangement of transducers and taps allowed the on-line calculation of the instantaneous pressure coefficients for both the outside and inside pressures. We could also calculate outside-inside differential pressures across each face of the building.

Wind Measurements

Because pressure coefficients are the ratio of absolute surface pressures to dynamic wind pressures, measurement of the wind is very important. Exterior wind speeds and directions were measured in two ways: an on-site weather tower with weather heads at ten and seven meters (10m, 7m), and by the KMACS weather station. Each weather head was made by Weather Measure of Pasadena, California and measured wind speed and direction relative to the building face. When our weather tower was erected at each site, it was aligned with the building face. The three sites were chosen so that their front faces had maximum exposure to the wind. Accordingly, the direction perpendicular to the front face of each site is designated as LBL north and all our directions are relative to that; the KMACS wind direction is relative to true north.

As mentioned previously, the static pressure probe was mounted at 6m to measure the static pressure in the wind. In addition to outdoor wind velocity, internal air speed was measured for most of the time. A DISA omnidirectional velocity probe was used to measure the air speed. Its range is 0.05 to 2 m/s.

Psychometric Measurements

Temperatures and humidities were measured for both the internal and external environment. Dry-bulb temperature was measured on the weather tower at the 6.5 m height, air temperature and relative humidity were measured at the 2m height; air temperature and relative humidity were also measured at several locations in the interior of the test space. A sling psychometer measured dry-bulb and wet-bulb temperatures at all humidity measurement locations daily. These daily measurements served to calibrate the humidity sensors. For comparison, dry-bulb temperature, dew point, and barometric pressure were recorded from the KMACS weather station.

Calibration

All sensors (i.e., pressure transducers, temperature probes, humidity sensors, and the computer) were fully calibrated at the laboratory both before and after the field trip. Quoted results have been corrected for any change in equipment calibration. The accuracies of the various sensors as calculated from the calibrations are shown below:

Table 1: SENSOR ACCURACY

Parameter	Sensor Type	Units	Accuracy
Pressure	Differential	Pascals	0.5
Wind direction	Vane	deg LBL	1.0
Wind speed	Anemometer	m/s	0.1
Internal air speed	Hot wire	m/s	0.02
Temperature	Air/Globe	^oC	1.0
Humidity	Relative	%	12

No measurement accuracies were supplied with the data from the MCAS weather station (i.e., MCAS dry-bulb temperature, dew point temperature, wind speed, wind direction and barometric pressure).

DATA REDUCTION

Many interesting quantities for natural ventilation-- infiltration, dew point, mean internal air speed, and comfort levels-- can be derived or estimated from the measured data. There are several methods of estimating mean internal air speed. The most straightforward method is spot measurement made by an air speed probe. Unfortunately there is no way to know whether a single probe represents the average wind speed in a space. If we assume that occupants are seated directly in front of an open window, we can use the orifice velocity of the window as our air speed:

$$v_o = \sqrt{\frac{2}{\rho}\Delta P} \tag{1}$$

where

v_o is the orifice velocity [m/s],
ρ is the density of air (1.2 kg/m^3), and
ΔP is the pressure drop across the window [Pa].

Another method is to estimate the natural ventilation and divide it by an appropriate cross section to determine the mean wind speed; it is, however, difficult to determine the appropriate cross section. (In the simplest case, that of wind pushing slugs of air through the windward windows and out the leeward windows, the cross section would be that of the room area.) We have elected to use an experimental relationship, given by Givoni,[5] that relates the average indoor air speed to the outdoor wind speed as a function of open area, assuming approximately equal windward and leeward openings:

$$\bar{v} = 0.45 \left[1 - e^{-3.84X} \right] v_w \tag{2}$$

where

$\bar{v}$ is the mean internal air speed [m/s],
v_w is the outdoor wind speed [m/s], and
X is the ratio of window area to wall area.

Regardless of its use in predicting air speed, the natural ventilation is an interesting property to estimate. We have estimated it in two ways: combining open areas and pressure coefficients with wind speed, and using the LBL infiltration model.[6-8] To use the open areas and pressure differences we multiply the orifice velocity of each opening by its effective leakage area and sum the infiltration and exfiltration separately:

$$Q_+ = \sum_+ A_+ v_+ \tag{3.1}$$

$$Q_- = \sum_- A_- v_- \tag{3.2}$$

where

$Q_{+/-}$ is the infiltration/exfiltration [m^3/s],
$A_{+/-}$ is the effective leakage area [m^2], and
$v_{+/-}$ is the positive/negative orifice velocity [m/s].

To estimate leakage area of buildings with closed windows, we used a specific leakage of 4 cm^2/m^2 (i.e., 4 cm^2 for every m^2 of floor area); to estimate the leakage with open windows, we have used the open area and multiplied by an appropriate discharge coefficient (0.6 in most cases).

Ideally, the infiltration, Q_+, and the exfiltration, Q_-, should balance, but, because of experimental uncertainties in pressure measurements, they are not likely to. Previous studies have shown that a small error in the internal pressure measurement can cause a large disagreement between infiltration and exfiltration.[9] The best solution is to adjust the internal pressure (within experimental uncertainty) to minimize the difference between the two flows. Otherwise, a simple average of the two (unbalanced) flows is usually sufficient. The LBL model does not use measured pressures or pressure coefficients, but instead internally estimates pressures from wind speed and terrain around the structure. Both estimates of infiltration are presented in the data.

We did not always measure dry-bulb temperature and globe temperature. But, because the inside-outside temperature difference was small and because there was little direct sun on the wall surfaces, we assume that the internal mean radiant temperature is equal to the air temperature and, therefore, the dry-bulb and globe temperatures are interchangeable. Dew point was not directly measured, but relative humidity was, Standard psychometric formulae[10] were used to convert the humidity from one form to another (e.g., dew point, relative humidity, wet bulb, etc.).

SITE DESCRIPTIONS

The recorded data contain all the information measured and calculated as described in the previous sections. But, to use it for modeling purposes, a more detailed description of each site, including tap configuration, open (window) area, occupancy schedule, etc., is needed. The sections below contain this information as well as anything unusual that occurred during the experimental runs.

Site #1 - VEQ

Site 1 was a large two-story building used for training and billeting enlisted men. Figures 1 and 2 are sketches of this building and include dimensions and the locations of pressure taps over the surface of the building; the positions of the computer and indoor climate-measuring devices are also indicated. Table 2 shows tap positions and numbers. The equipment was set up on the second floor. Because there was no access to the inside of the first floor, all differential pressures are relative to the second floor. Pressure transducers 3,4 and 6 measured the pressure in the computer room; transducer 5 measured in the central area of the second floor.

Window schedule: Because occupancy on the first floor was irregular, the windows on that floor were opened and closed at irregular intervals. They were always closed at night for security reasons. We controlled the windows on the second floor and set them according to the schedule in Table 3.

Table 3: DATA LOG FOR SITE #1

Date	Time	Windows	Comments
1 July	15:30		Began setup.
4 July	17:00	closed	All systems functioning.
5 July	01:00	closed	Weather tower down (approx.).
5 July	13:00	closed	Began using single weather head.
6 July	09:30	open	Removed water from east-face taps.
7 July	10:30	half	
8 July	09:00		Stopped taking data.

LBL north is 19^{o} east of true north

Table 2: LOCATION AND CONFIGURATION OF SITE #1 PRESSURE TAPS

Transducer 1: Floor 1

Tap No.	Location
1,1	East face
1,2	North face, east side
1,3	North face, center
1,4	North face, west side
1,5	South face, west side
1,6	South face, center
1,7	South face, east side
1,8	West face

Transducer 2: Floor 2*

Tap No.	Location	Full open leakage area [m^2]
2,1	East face	0.00
2,2	North face, east side	1.02
2,3	North face, center	3.74
2,4	North face, west side	4.08
2,5	South face, west side	4.08
2,6	South face, center	3.40
2,7	South face, east side	1.36
2,8	West face	0.00

Transducer 3: Computer room
Transducer 4: Computer room
Transducer 5: Second floor central area
Transducer 6: Computer room

* X = 9.0% with open windows; X = 0.1% with closed windows.

Set-up procedures were completed at 17:00 on 4 July, but much of the data from the previous 24 hours is valid. Sometime at about 01:00 on 5 July, the weather tower fell for some unknown reason. One weather head and the dry-bulb temperature sensor were damaged beyond repair. By 13:00 on 5 July, the tower had been reconstructed, but without its weather head at the 10m height and without the dry-bulb temperature. The remaining weather head was operational at 7m, and sufficient temperature data were collected from the temperature/humidity equipment at the 2m height as well as ground level. This was the configuration of the weather tower for the remainder of the time at this site as well as at sites 2 and 3.

Occupancy schedule: The building was, in general, unoccupied after 17:00 on 3 July; but we went in and out of the building unscheduled, as did officers and instructors. For the most part, these unscheduled incursions were in the eastern segment of both floors. Our own occupancy-- 13:00 to 17:00 on 4 July, 09:00 to 10:30 on 6 July, and 10:00 to 10:30 on 7 July-- was kept to a minimum during periods of data acquisition.

Site #2 - Single-Story Duplex

Site 2 was a single-story residence consisting of two mirror-image units. Figures 3 and 4 are sketches of this building and include dimensions as well as the location of pressure taps on the building's surface. The positions of the computer and indoor climate-measuring devices are also indicated. Table 4 shows the positions of the taps and their numbers. The computer equipment was set up in the kitchen/dinette area and the internal pressure, temperature and internal air velocity were measured in the central living room.

Window schedule: Although the unit adjacent to the test unit was occupied by a family, and their windows were not controlled, we can assume that the windows were normally closed because the air conditioner was operating most of the time. That unit's internal pressure was not measured. The window configuration of the test unit is included in the following table.

Table 4: LOCATION AND CONFIGURATION OF SITE #2 PRESSURE TAPS

Transducer 1: Exterior*

Tap No.	Location	Full open leakage area [m^2]
1,1	North face, east side	1.27
1,2	West face	1.51
1,3	North face, west side	1.27
1,4	North face, center↓	0.91 x 2
1,5	East face	1.51
1,6	South face, center↓	1.05 x 2
1,7	South face, east side	1.11
1,8	South face, west side	1.11

Transducer 2: Computer room (kitchen)
Transducer 3: Computer room (kitchen)
Transducer 4: Central space (living room)
Transducer 5: Central space (living room)
Transducer 6: Computer room (kitchen)

* X = 15% for open windows; X = 1% for closed windows.
↓ Half of the total leakage area is allocated to each apartment.

Table 5: DATA LOG FOR SITE #2

Date	Time	Windows	Comments
8 July	19:30		Setup data acquisition system.
10 July	17:00	Closed	Air Conditioner on.
11 July	08:30	Open	Air Conditioner off.
11 July	20:00	Closed	
12 July	11:00	Half	
12 July	19:30	Closed	
13 July	09:00	Half	
13 July	18:00	Closed	
14 July	08:30		End data taking.

LBL north is 68° east of true north

Note that from 17:00 on 10 July to 08:30 on 11 July the air conditioner was operating in the test apartment; its operation will have an effect on both the internal pressure and the external pressure as measured by the pressure tap nearby.

Occupancy schedule: With the exception of the periods near the change of window configuration, the building was unoccupied.

Site #3 - Two-Story Fourplex

Site 3 was a four-unit, two-story residence. Figures 5 and 6 are sketches of this building and include dimensions and the location of pressure taps on the surface of the building; the positions of the computer and indoor climate-measuring devices are also indicated. Table 6 shows the positions of the taps and their tap numbers. The computer equipment was set up in the living room of the upstairs east apartment. Initially, the internal temperature and air speed were measured in the lanais (screened porches), which were open to the living spaces. Each apartment had a lanai with screen covers that should have been operable but were not. Hence, during the measurements the screens on the lanais were loosely covered with cloth that kept the rain out but allowed a fair amount of air flow.

Window schedule: Because the lower unis were occupied by families, their windows were not controlled. The internal pressure of those units was not measured. The window configuration of the two test units is included in the following table:

Table 6: LOCATION AND CONFIGURATION OF SITE #3 PRESSURE TAPS

Transducer 1: Upstairs Exterior East Apt.*

Tap No.	Location	Full open leakage area† [m²]
1,1	North face, west side	1.95
1,2	North face, east side	1.21
1,3	East face↓	1.43/0.56
1,4	South face, east side↓	1.95/1.34
1,5	South face, west side	1.38
1,8	Lanai	/0.02

Transducer 2: Upstairs Exterior West Apt.*

Tap No.	Location	Full open leakage area [m²]
2,1	North face, east side	1.95
2,2	North face, west side	1.21
2,3	West face↓	1.43
2,4	South face, west side↓	1.95
2,5	South face, east side	1.38

Transducer 3: Downstairs Exterior

Tap No.	Location
3,1	North face, west side
3,2	North face, center
3,3	North face, east side
3,4	East face
3,5	South face, east side
3,6	South face, center
3,7	South face, west side
3,8	West face

Transducer 4: Internal upstairs, east apartment (central area)
Transducer 5: Internal upstairs, west apartment (central area)
Transducer 6: Internal upstairs, east apartment (near equipment)

↓ The lanai windows were assumed to have a discharge coef. of 0.25.
* X = 9.9%/16.2% with open windows; X = 3.7%/0.05% with closed windows.
† The numbers after the "/" refer to the isolated lanai configuration.

Table 7: DATA LOG FOR SITE #3

Date	Time	East Windows	West Windows	Comments
15 July	13:00			Set up data-acquisition system.
15 July	17:00	Closed	Closed	Started taking data.
16 July	09:30	Open	Open	Repaired fallen taps.
16 July	20:00	Closed	Closed	
18 July	08:00	Half	Half	Isolated east lanai.
18 July	20:00	Closed	Closed	
19 July	10:00	Open	Half	
19 July	21:30	Closed	Closed	
20 July	08:00	Closed	Open	
21 July	09:00			Stopped taking data.
LBL north is 57° east of true north				

Sometime during the night of 15 July to 16 July, taps (1,1), (1,4), (1,5), (2,1), and (3,1) fell because of rain; they were repaired on the morning of 16 July and did not fall again. On 18 July the lanai in the east upstairs apartment (i.e., the one with the computer) was isolated from the living space by closing all connecting doors. At that time the internal temperature and wind speed sensors were moved from the lanai to the central living space. An additional pressure tap (1,8) was installed in the lanai to record the pressure there.

Occupancy schedule:

The downstairs apartments were not monitored for occupancy or window configuration because they were occupied. The west apartment was occupied only at the times indicated in the preceding table. In addition to those times the east apartment occupants were in the building as follows: 21:00 to 21:30 on 15 July; 20:00 to 20:30 on 17 July; 07:00 to 07:15 on 19 July; 18:30 to 19:00 on 20 July; 23:30 to 24:00 on 20 July; and 00:00 to 06:40 on 21 July.

RESULTS

The measured data from this experiment comprise more than 700 pages of information. Each page represents a particular half-hour set of data from one of the three sites. On each page are the averages and standard deviations (indicated by parentheses) of the following measured quantities: differential pressure and pressure coefficient for each pressure tap; air temperature and relative humidity for the active temperature/humidity probes; wind speed and direction from the on-site weather tower as well as the MCAS weather station; and internal air velocity as measured by the omni-directional probe (DISA). Several quantities derived from measured data are also displayed for each half-hour: dew point, estimated internal air speed, effective temperature, wind-driven infiltration, wind-driven exfiltration and total infiltration as estimated from the LBL model.

At scattered times throughout the data-taking, some of the sensors (temperature, humidity, wind speed, or pressure) were not working or not working correctly. We dealt with this in one of two ways: 1) if only a few sensors gave bad readings, the data were included but the bad measurements were marked; 2) if a large portion of the data (e.g., all of the pressures or all of the weather) was bad, the data were eliminated. The first method was typically used for the temperature and humidity sensors that were outside. On occasion rain would get into the sensors and cause them to give faulty readings until they dried out. Faulty temperature and humidity readings are indicated by a negative value. Faulty (off-scale) pressure measurements are indicated by an asterisk next to the entry. Some readings were suspicious but possible; these were indicated by negative standard deviations. Due to start-up delays and the weather tower crash, most of the data prior to 5 July were bad and, accordingly, were excluded from the report*.

Time-Series Data

In order to see the trend of the environmental data, we have plotted the wind speed and direction, temperatures, and air flows as functions of time for each of the three sites. Natural ventilation is calculated from both the pressure coefficient data and the LBL infiltration model. Some of the unusual internal behavior is explained by the building and occupancy schedules.

In the plots described below, all indoor (inside) measurements were made by our on-site instruments, as were all on-site outdoor (outside) measurements. The data extracted from the KMACS weather station are labeled "MCAS". Since our on-site outdoor humidity sensors were often unreliable, we have assumed for all three sites that the on-site outdoor

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*All the data are available on magnetic tape and include data taken between the following dates: site #1--5 July to 8 July, site #2--9 July to 14 July, site #3--15 July to 21 July.

dew point is the dew point measured by the MCAS weather station. The figures of ventilation air flows compare predicted ventilation rates using pressure coefficients and the LBL infiltration model.

Site 1: Figures 7 and 8 show air temperature and dew point (respectively) for inside and outside conditions at site 1. Because of instrumental problems, most of the on-site exterior temperature data before 13:00 on 6 July were poor. We have, therefore, not graphed the temperatures before that time. Figure 9 contains both wind speed and direction measured by our on-site weather tower and by the MCAS weather station. Figure 10 compares predicted ventilation rates using pressures, pressure coefficients, and the LBL infiltration model for those periods having measured pressures and wind speeds.

Site 2: The site 2 air temperature and dew point are shown in Figs. 11 and 12 for the inside, outside, and MCAS sensors. Figure 13 displays wind data for both on-site and MCAS weather towers. The on-site wind direction and the KMACS wind direction appear to disagree by about 20-30 degrees; we attribute this discrepancy to a large hill southwest of the site that would tend to divert the wind locally. This effect would shift the on-site direction northerly, as is observed in that data. Figure 14 shows the calculated air flow rates for the site-2 apartment.

Site 3: Because there were two interior apartments measured at site 3, one of our outdoor temperature/humidity sensors was put in the west apartment to measure its interior condition. Figures 15 and 16 show the air temperature and dew point in both apartments as well as outside. To check the difference between air temperature and mean radiant temperature, we installed a globe temperature sensor in the east apartment. Figure 17 compares the air temperature, globe temperature, and dew point for conditions inside the east apartment. Figure 18 displays the measured wind information for site 3, and Figure 19 displays the predicted ventilation rates for both apartments. Because there was no leakage from one apartment to the other, the air flows through the apartments are independent. Furthermore, since the window schedules of the two apartments were not identical, the ventilation patterns are different.

REFERENCES

1. Smith, B.V., and Condon, P.E., LBL/EPB Data Acquisition System: Description and User Instructions, Lawrence Berkeley Laboratory Report LBL-11739 (1983)

2. Blomsterberg, A.K., Modera, M.P., and Grimsrud, D.T., The Mobile Infiltration Test Unit-- Its Design and Capabilities: Preliminary Experimental Results. Lawrence Berkeley Laboratory Report LBL-12259 (1981).

3. Sherman, M.H., Modera, M.P., and Grimsrud, D.T., A Predictive Air Infiltration Model-- Field Validation and Sensitivity Analysis, Proceedings of Third (CIB) International Symposium on Energy Conservation in the Built Environment, 6.A.1 March 1982. Lawrence Berkeley Laboratory Report LBL-13520 (1981).

4. Modera, M.P., Sherman, M.H., and Grimsrud, D.T., A Predictive Air Infiltration Model-- Long-term Field Test Validation, ASHRAE Trans. 88 I, (1982). Lawrence Berkeley Laboratory Report LBL-13509 (1981).

5. Givoni, B, Man, Climate, and Architecture, Applied Science Publishers, London, p. 293, 1976.

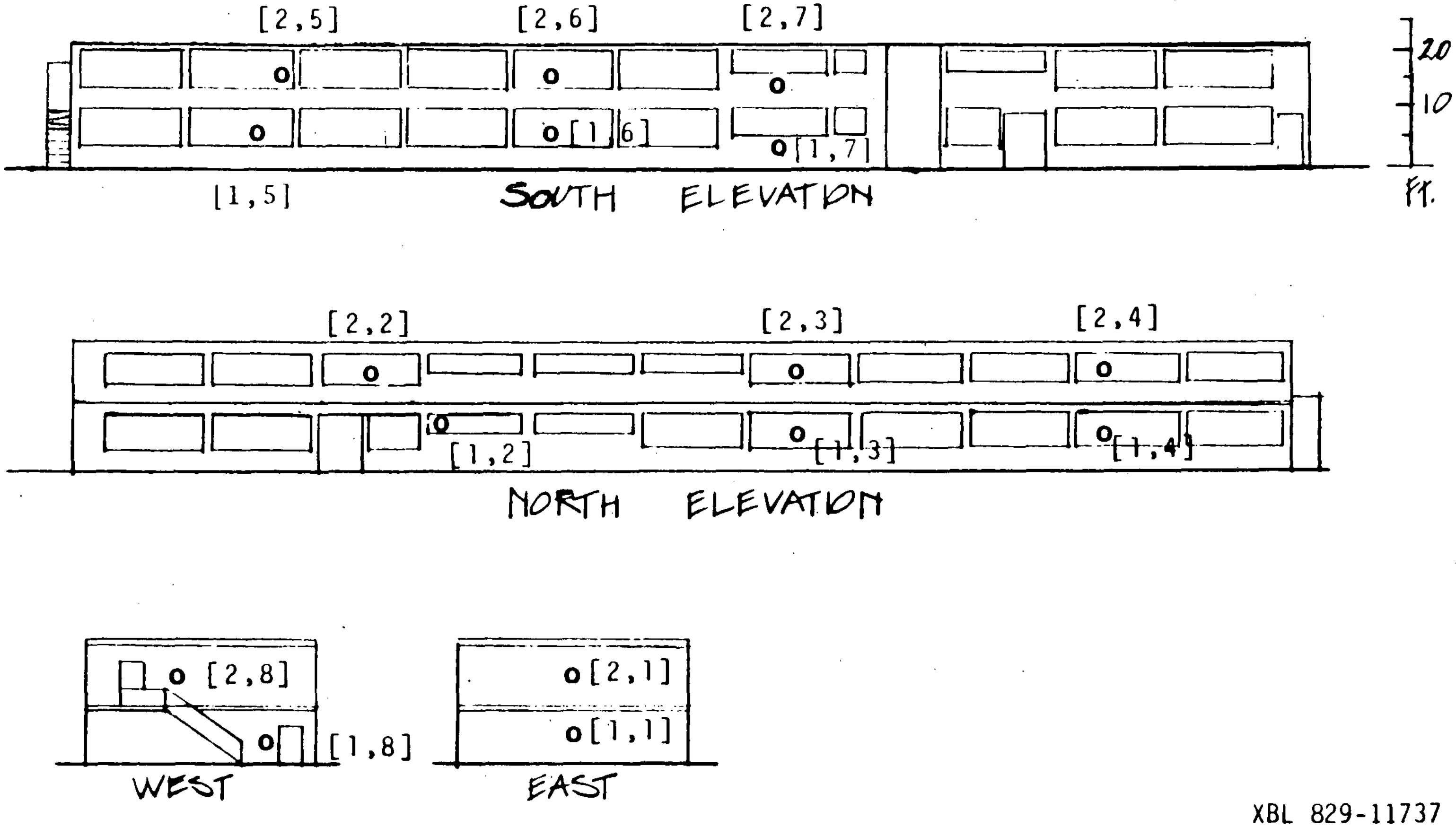
6. Sherman, M.H., Sonderegger, R.C., and Grimsrud, D.T., The LBL Infiltration Model, Unpublished.

7. Sherman, M.H., Air Infiltration in Buildings, Ph.D Thesis, University of California, 1980. Lawrence Berkeley Laboratory Report LBL-10712 (1980).

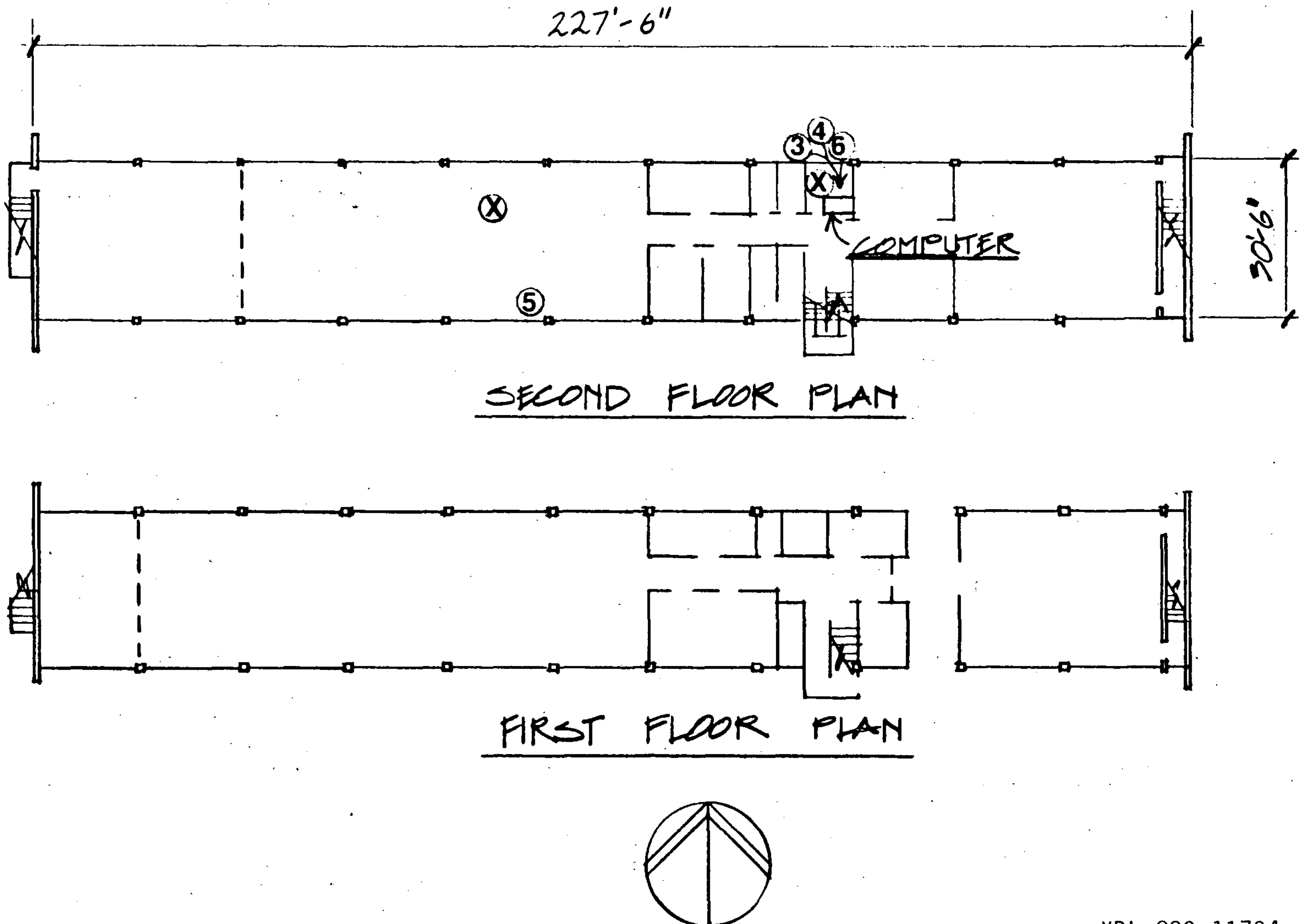
8. Sherman, M.H., and Grimsrud, D.T. The measurement of Infiltration Using Fan Pressurization and Weather Data, Proceedings of 1st AIC Conference, London. 1980.
Lawrence Berkeley Laboratory Report LBL 10852.

9. Modera, M.P., Sherman, M.H., and Grimsrud, D.T., Long-term Infiltration Measurements in a Full-scale Test Structure, Proceedings of Air Infiltration Center Conference on Building Design for Minimum Air Infiltration, September 1981. Lawrence Berkeley Laboratory Report LBL-13504 (1981).

10. American Society of Heating, Refrigerating and Air conditioning Engineers, Handbook of Fundamentals, ASHRAE, Atlanta, Ch. 5, 1981.

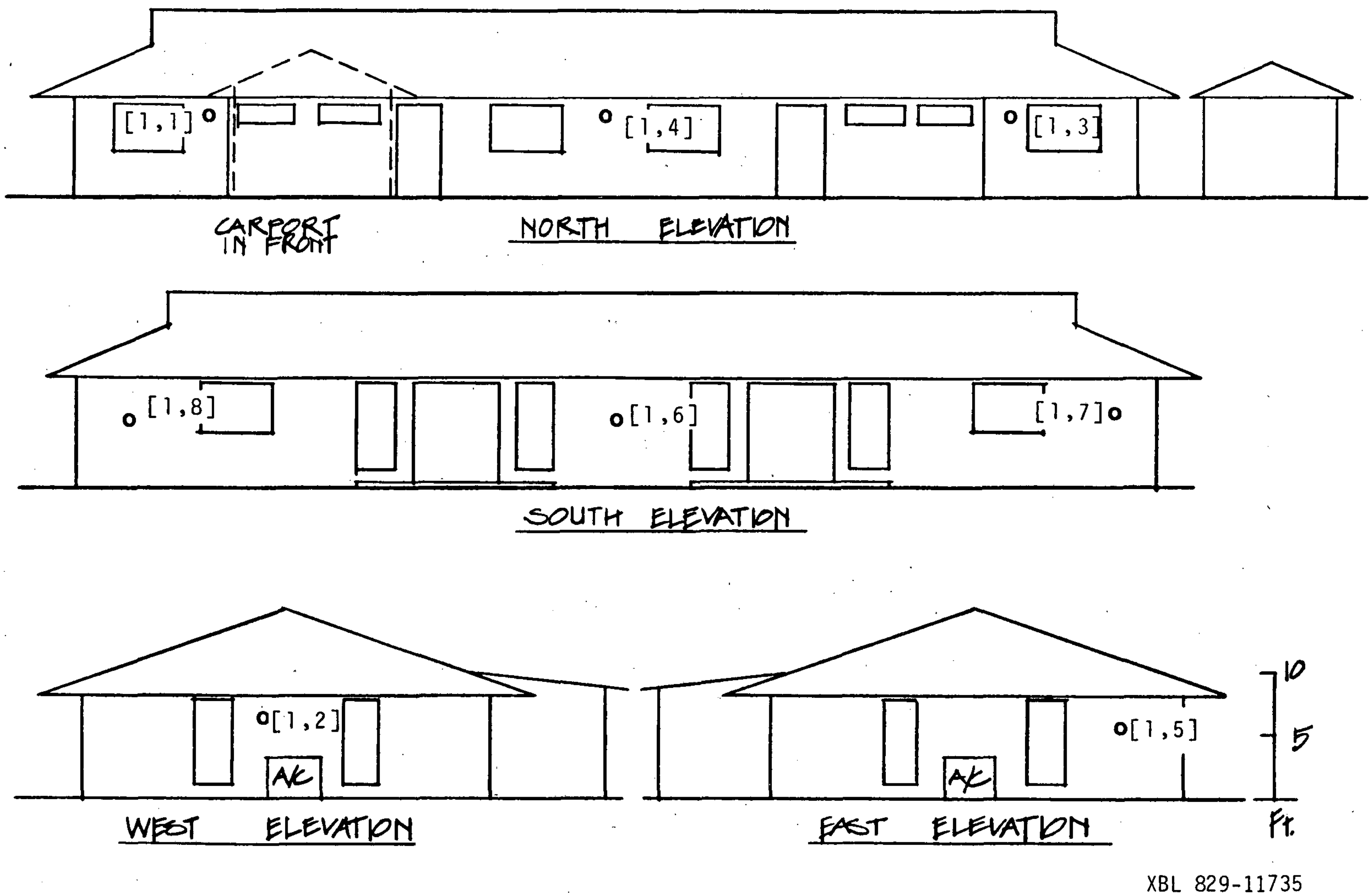


1) Elevations for site #1.

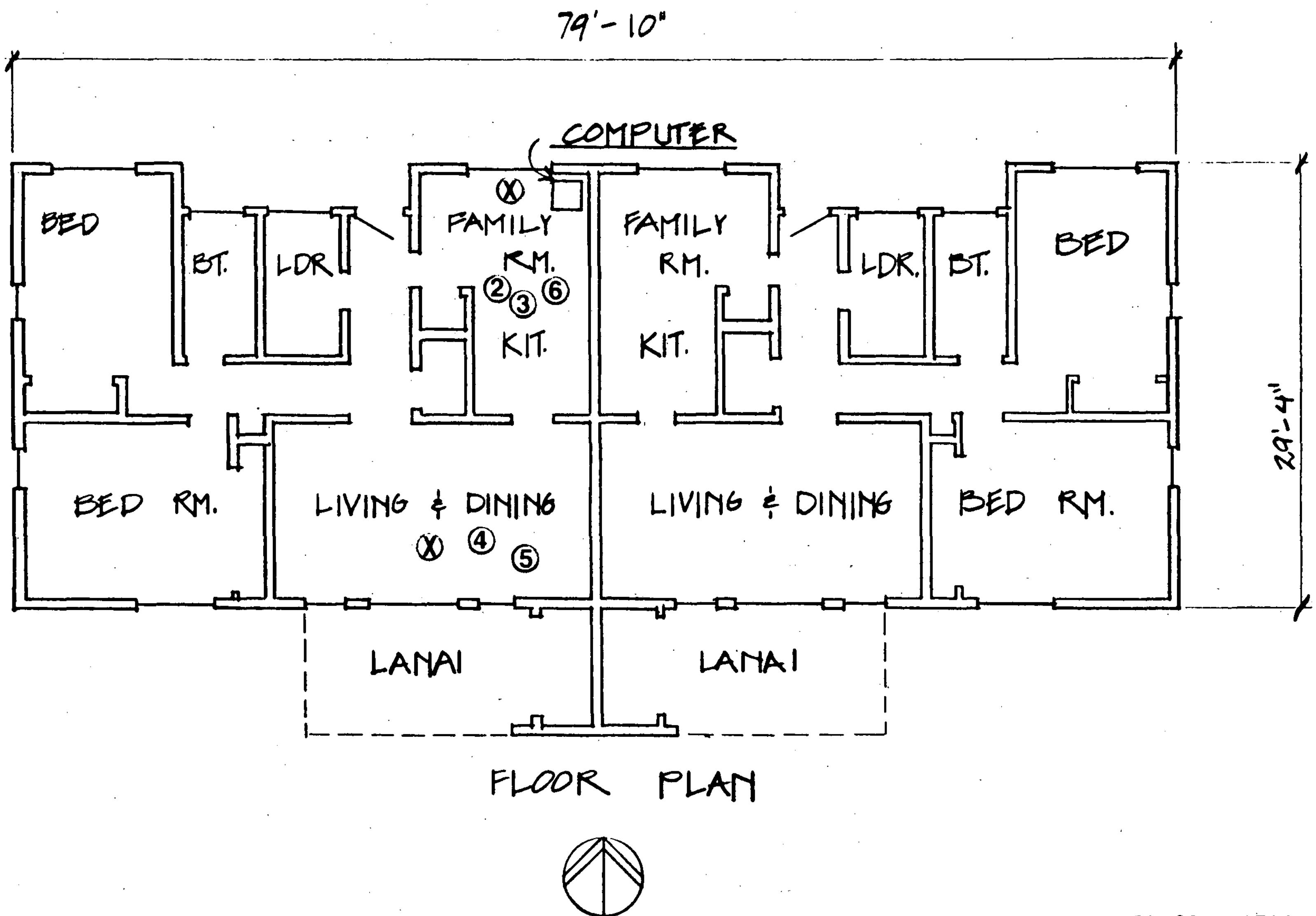


XBL 829-11734

2) Plan view of site #1.

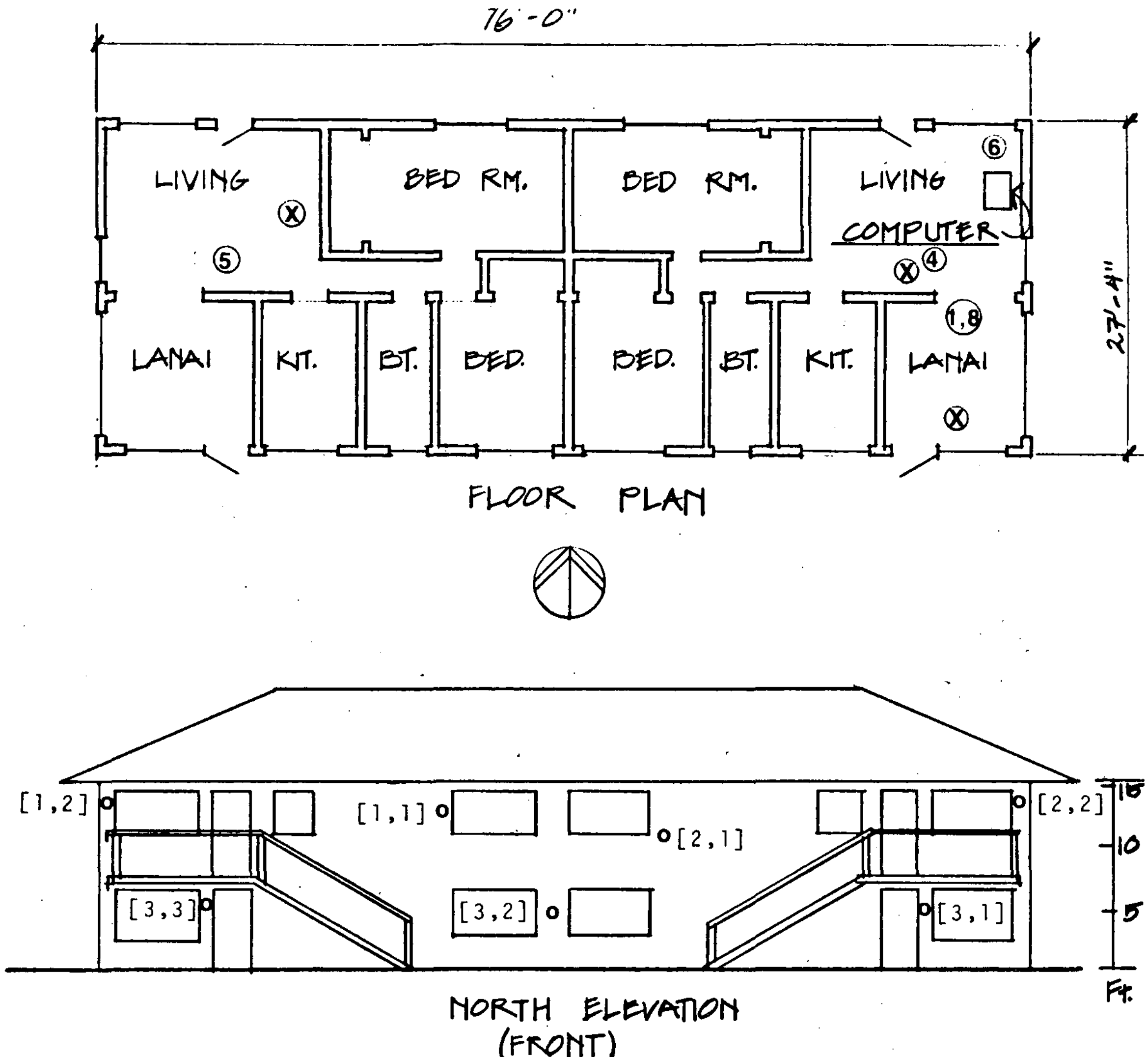


3) Elevations for site #2.



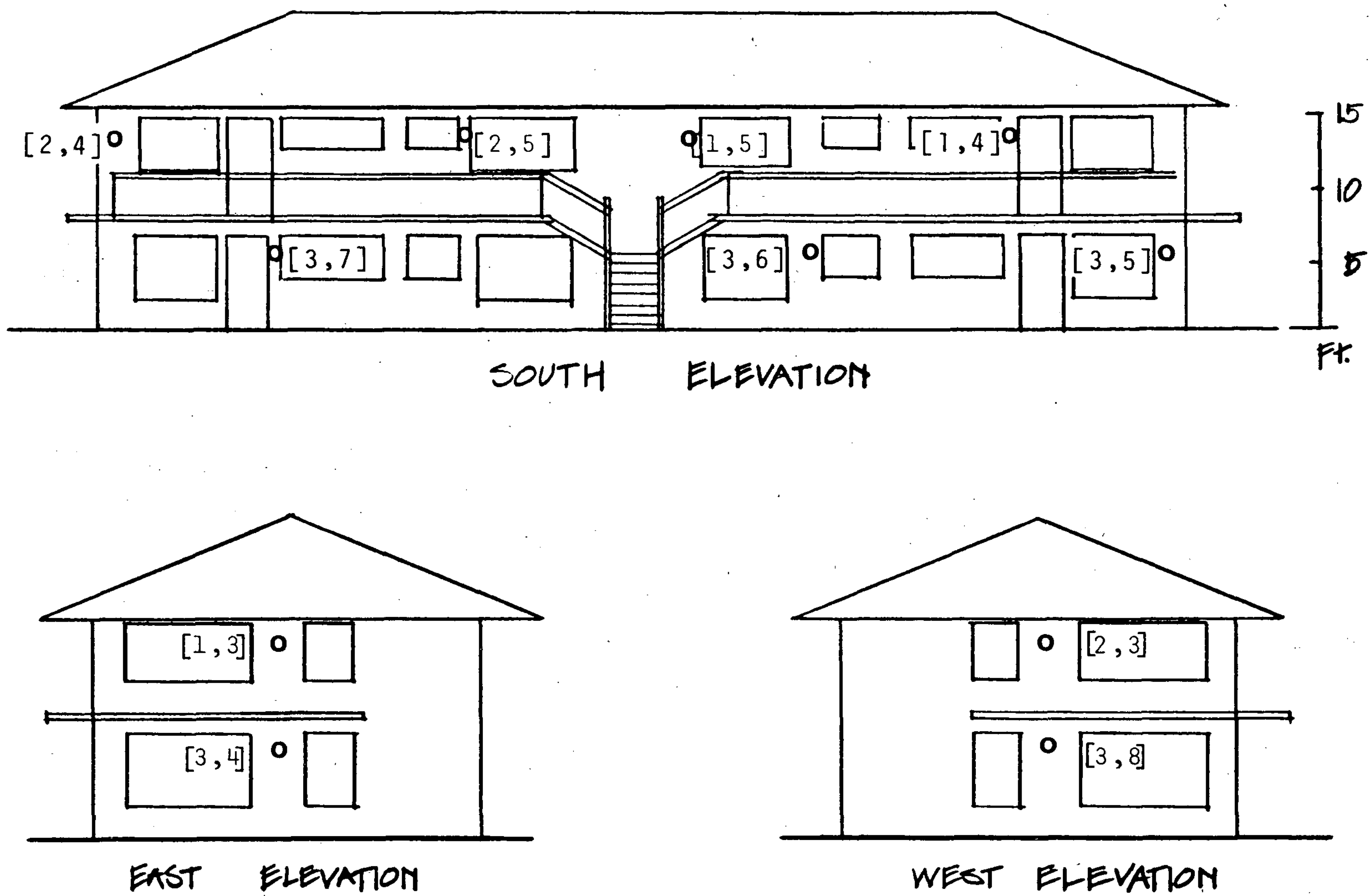
4) Plan view of site #2.

XBL 829-11736



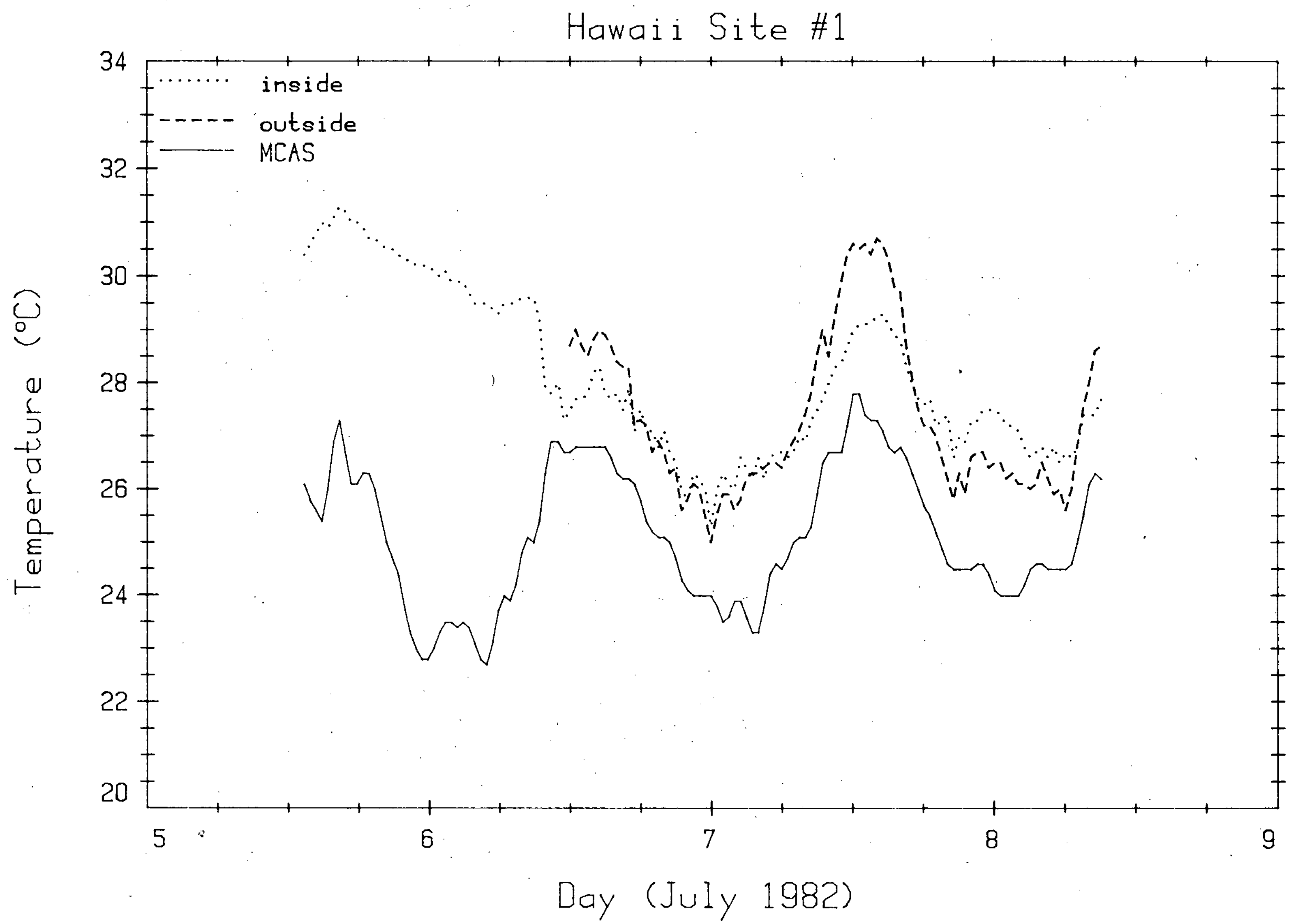
XBL 829-11732

5) Windward elevation and plan view of site #3.



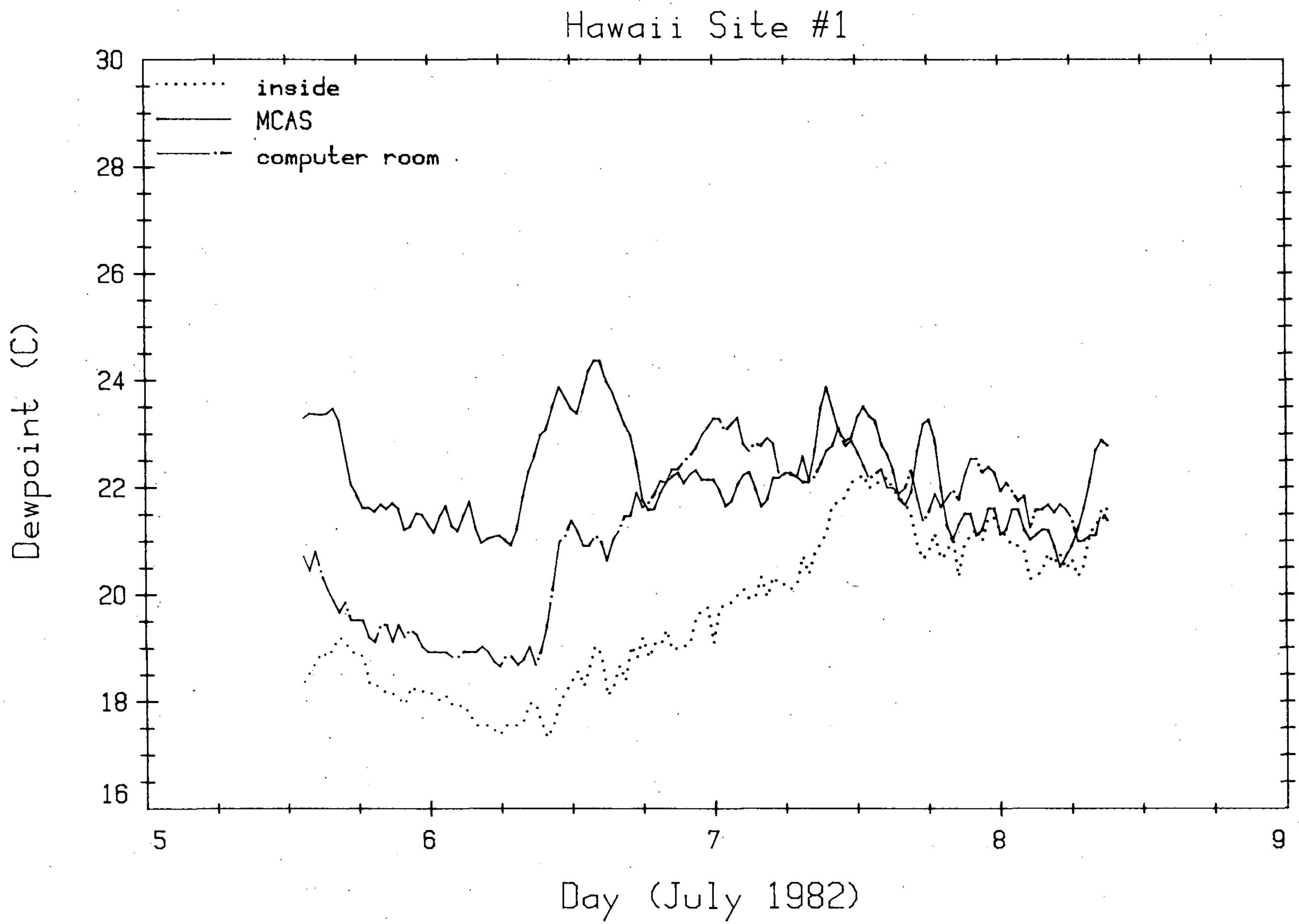
XBL 829-11733

6) Side and leeward elevations for site #3.



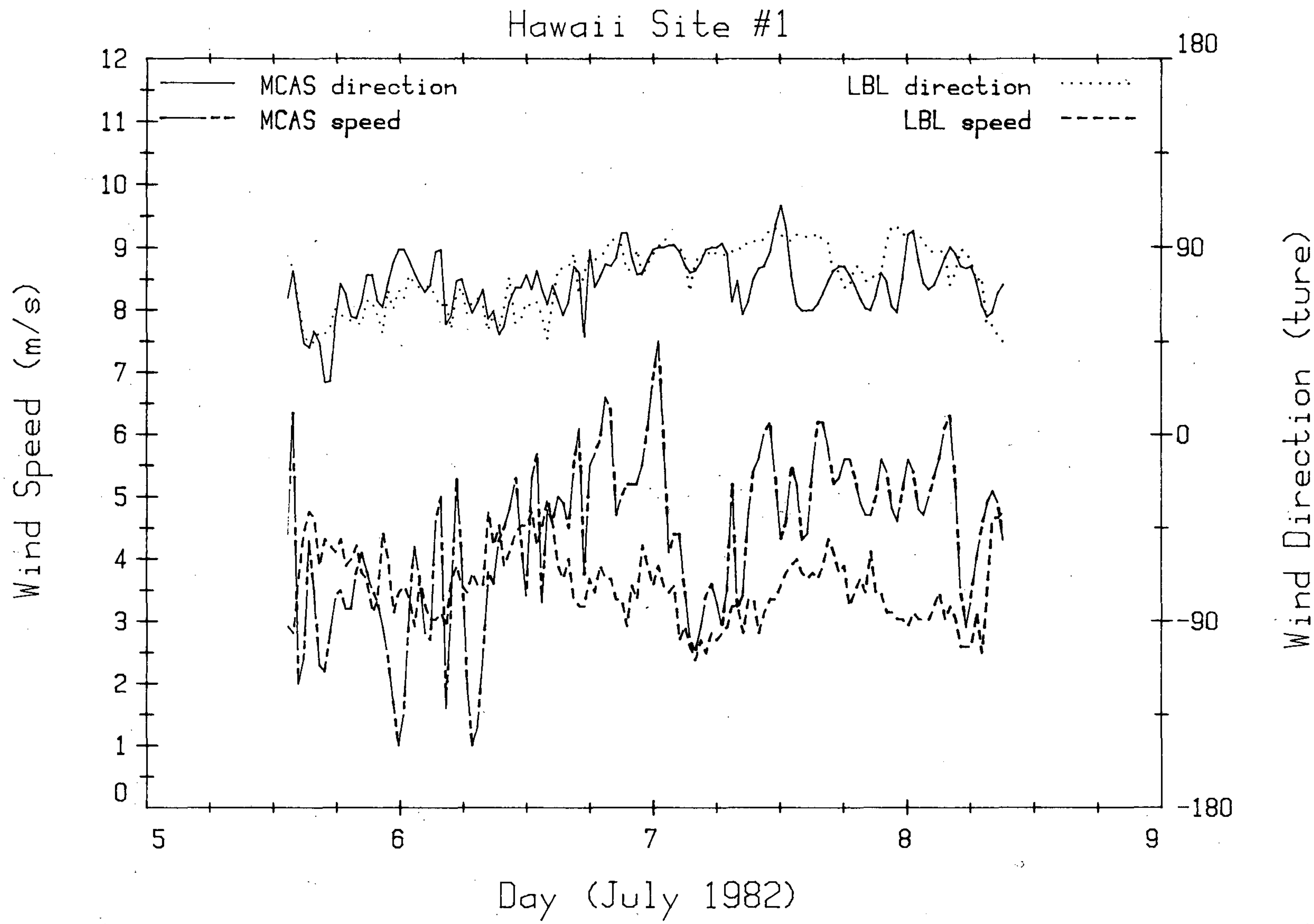
XBL 834-9362

7) Air temperature from site #1.



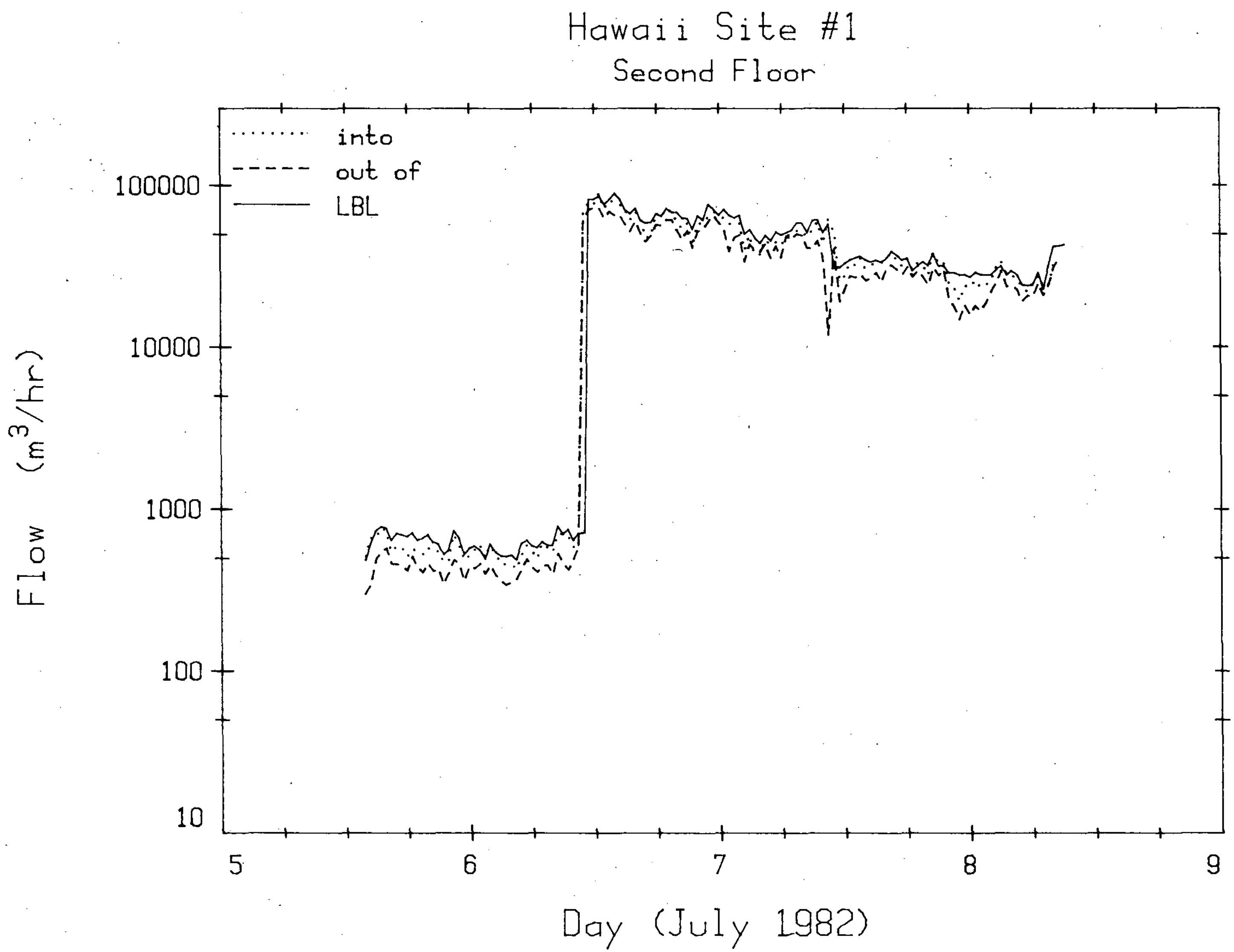
XBL 834-9363

8) Dew point from site #1.



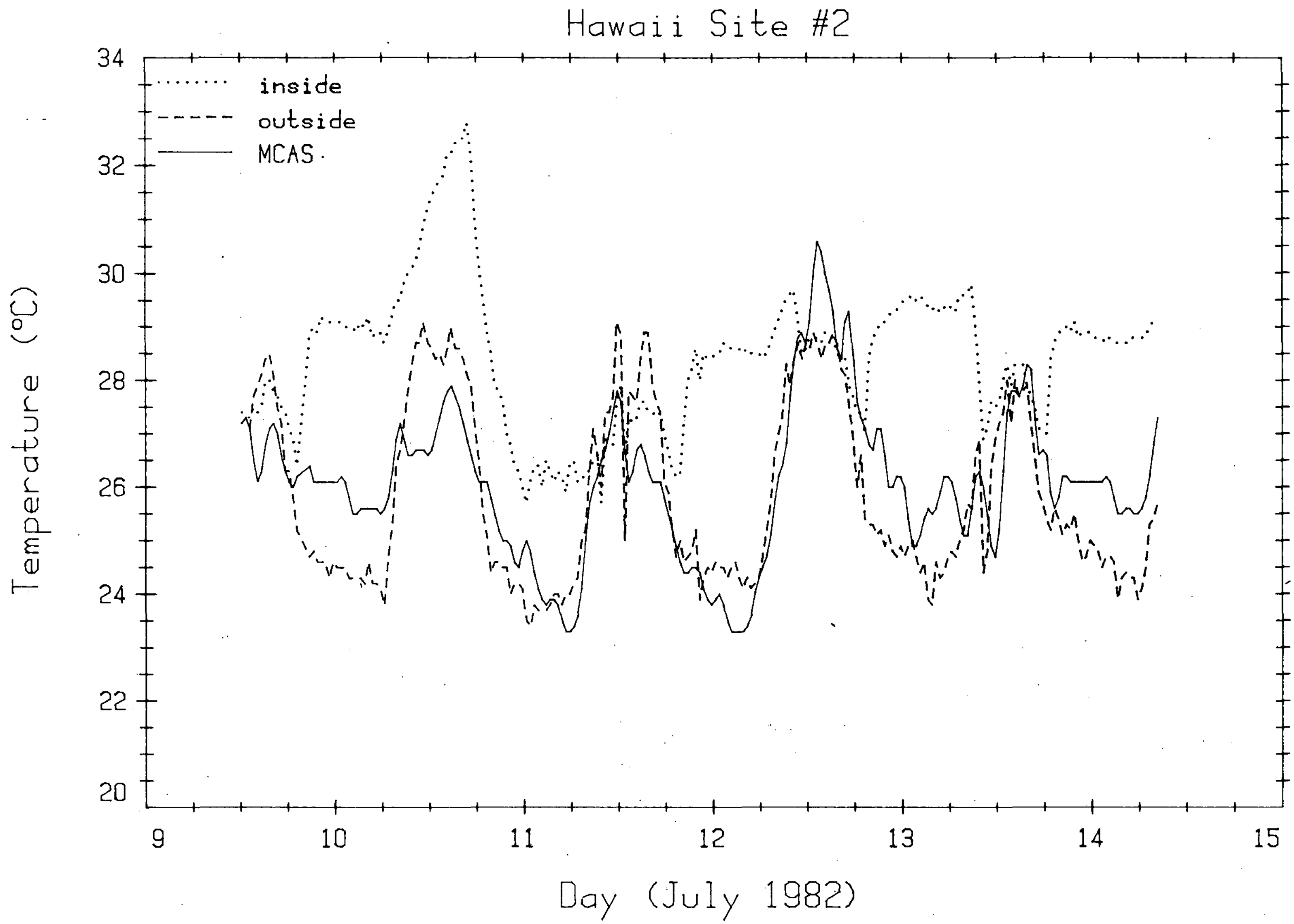
XBL 834-9364

9) Wind speed and direction from site #1.



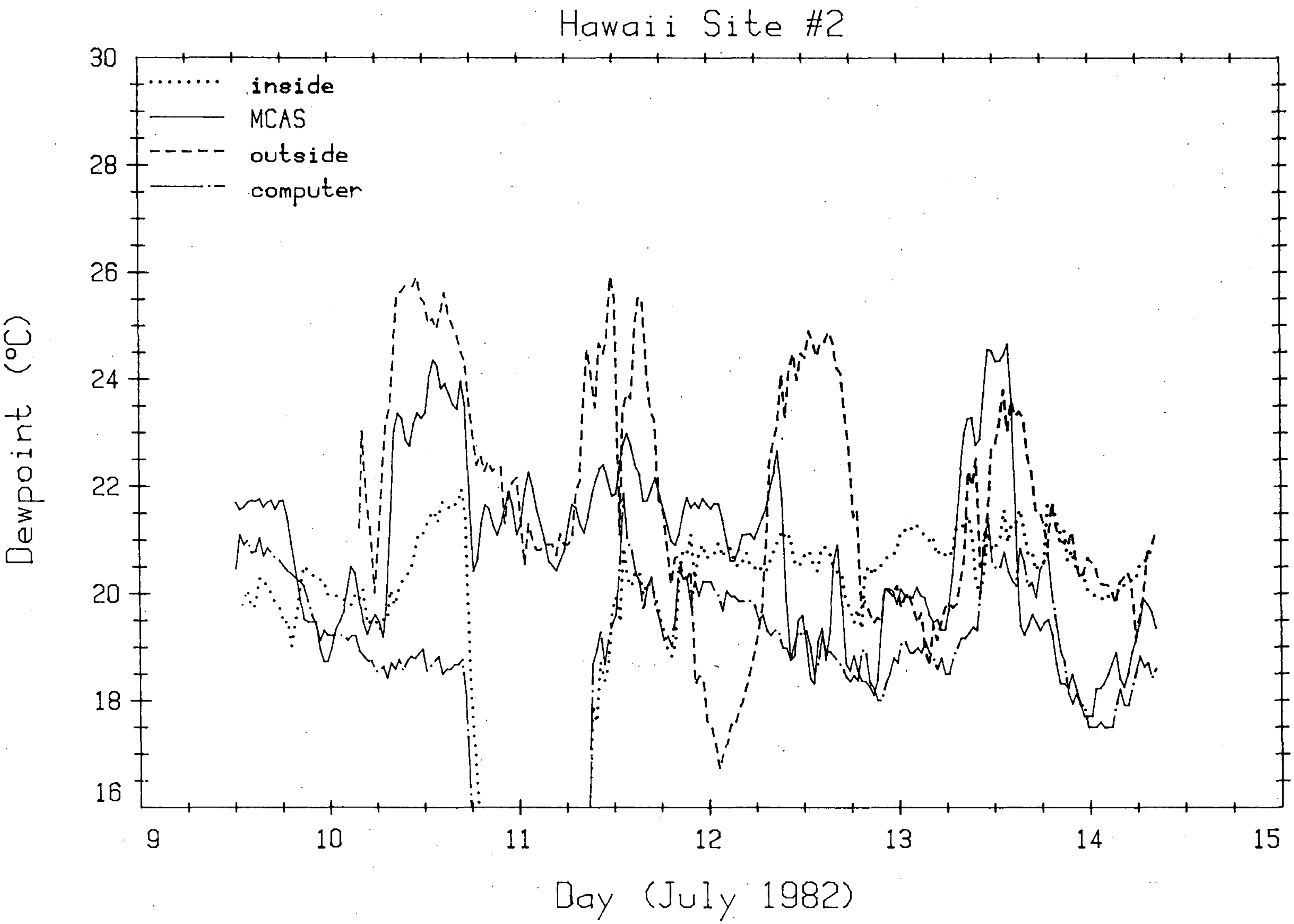
XBL 834-9365

10) Predicted ventilation from site #1.



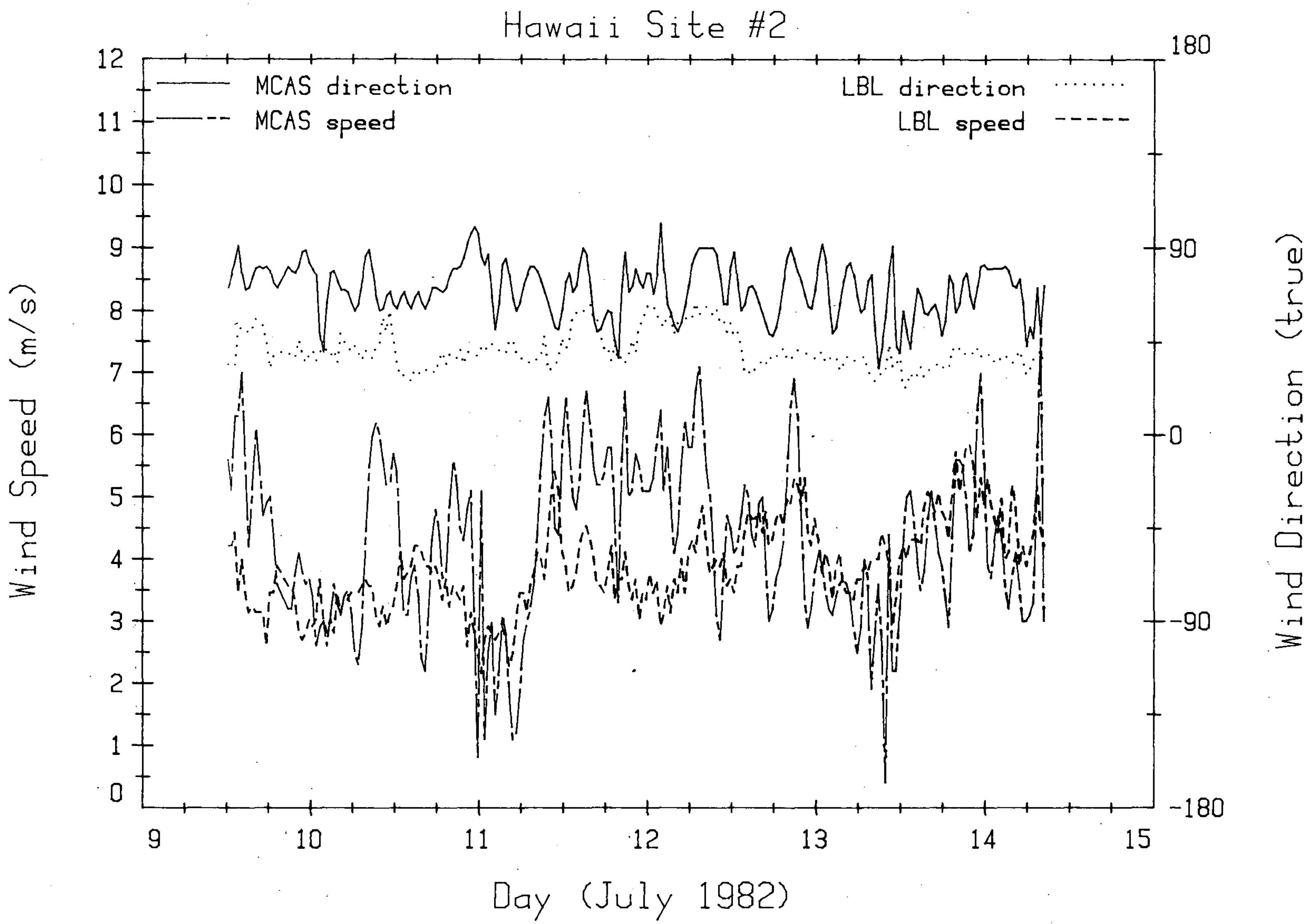
XBL 834-9366

11) Air temperature from site #2.



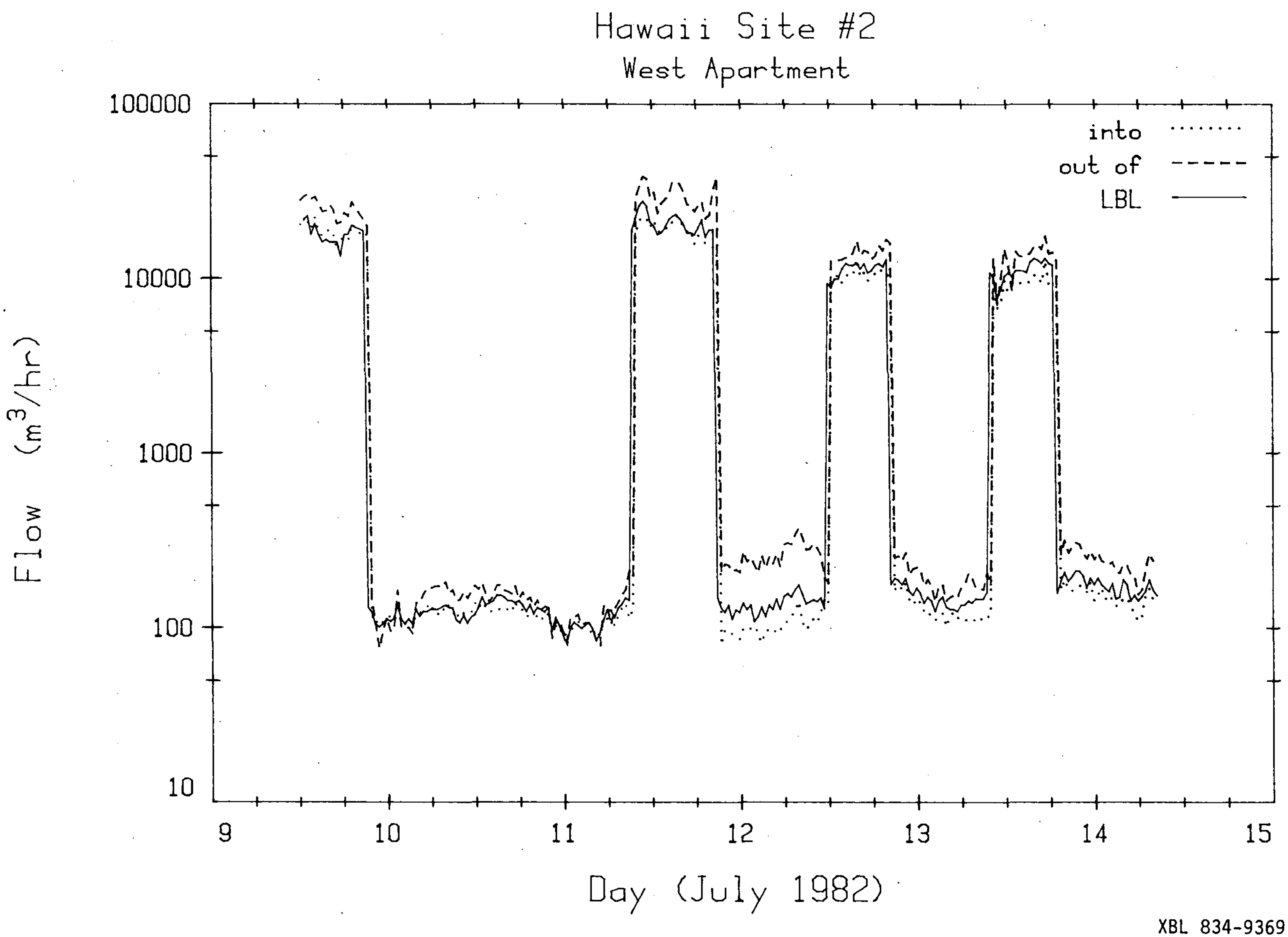
XBL 834-9367

12) Dew point from site #2.

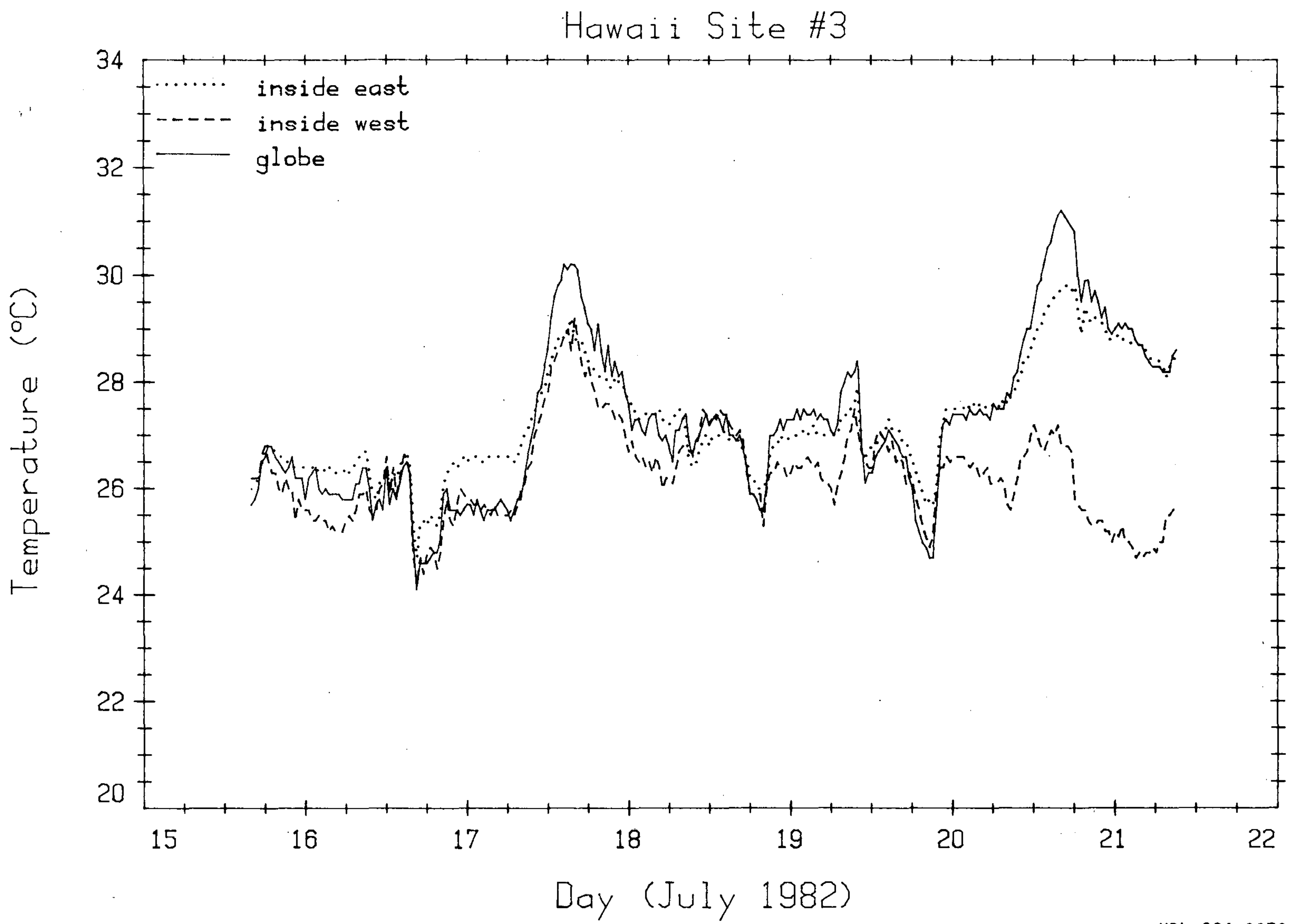


XBL 834-9368

13) Wind speed and direction from site #2.

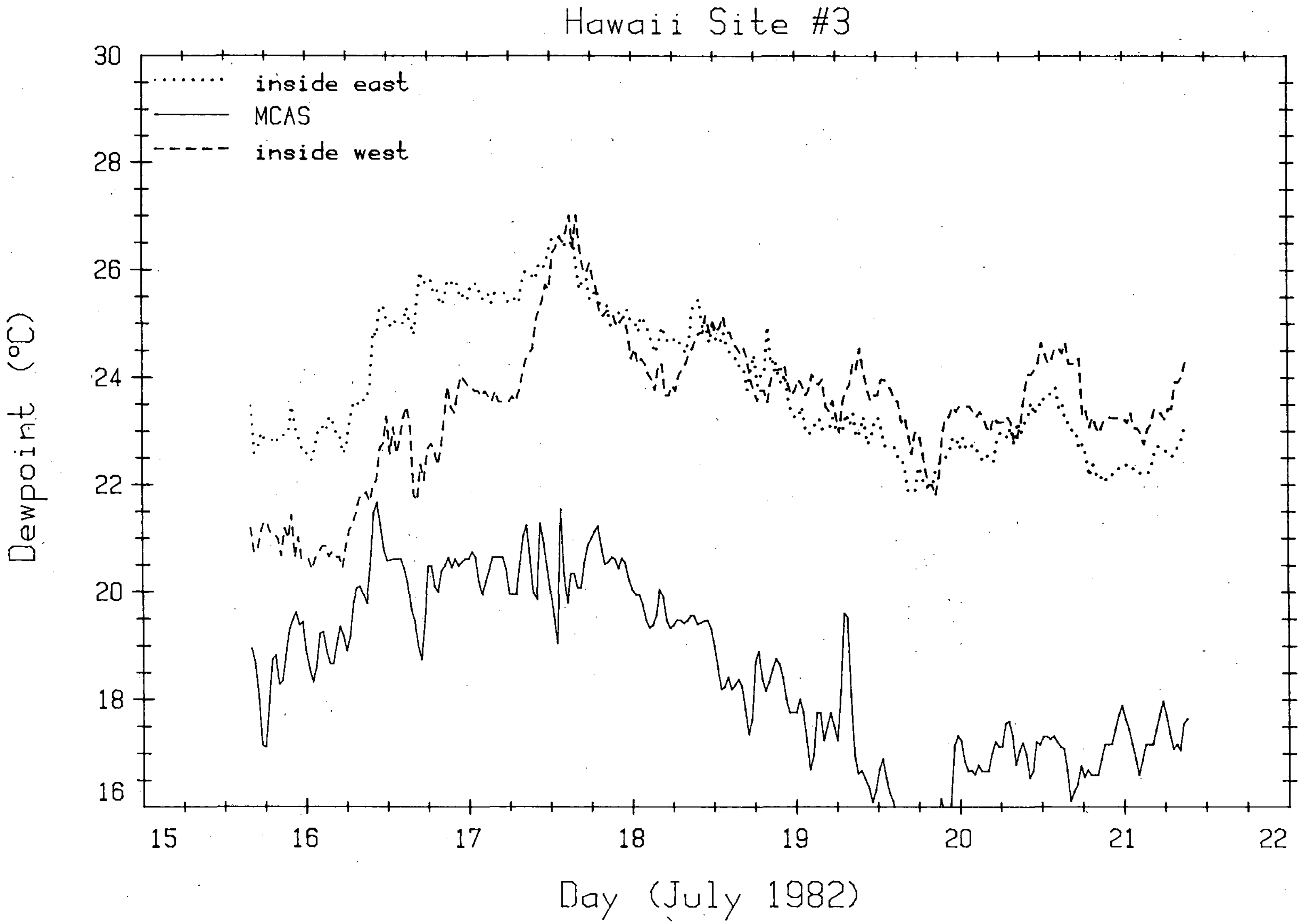


14) Predicted ventilation from site #2.



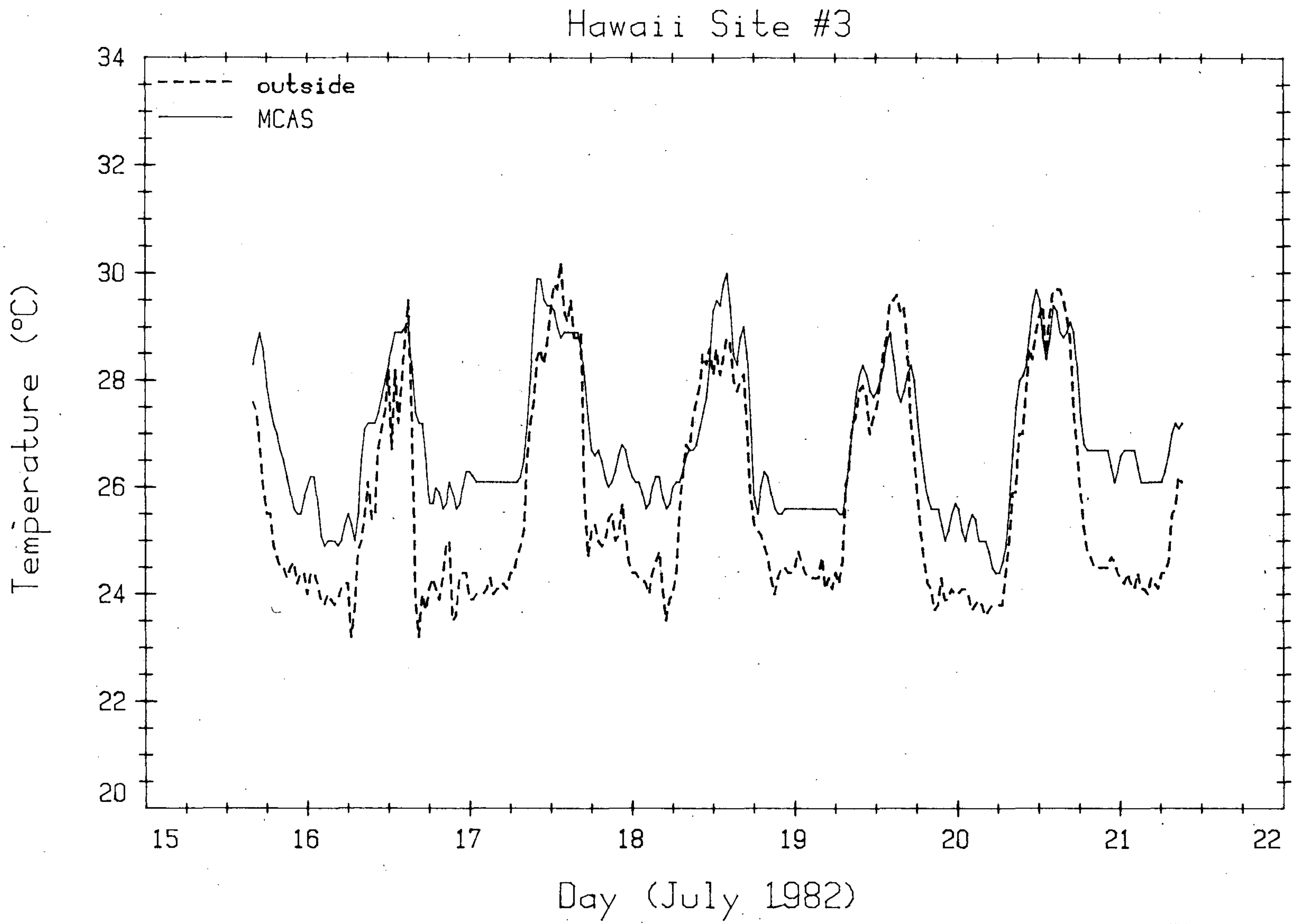
XBL 834-9370

15) Inside air temperature from site #3.



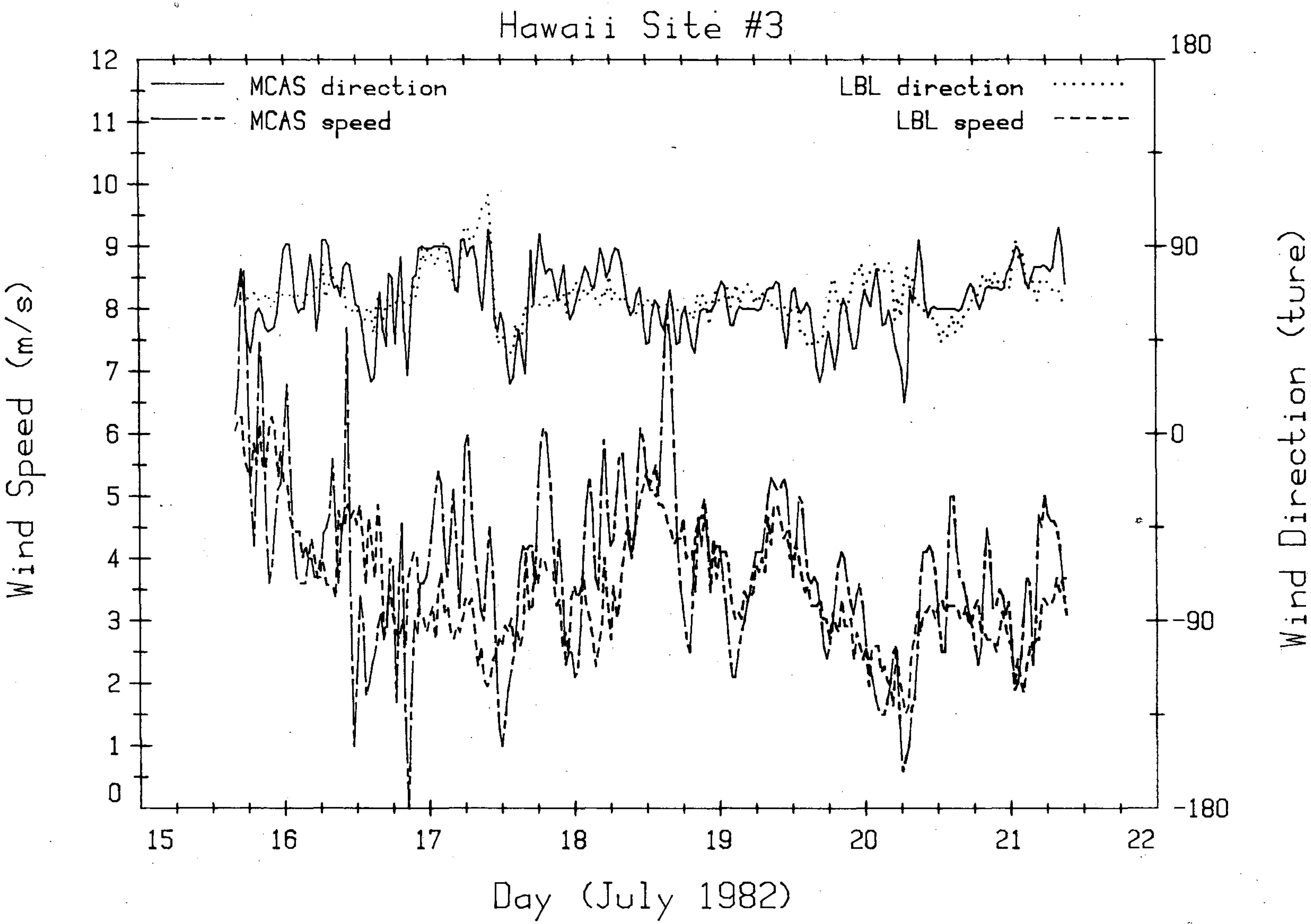
XBL 834-9371

16) Dew point from site #3.



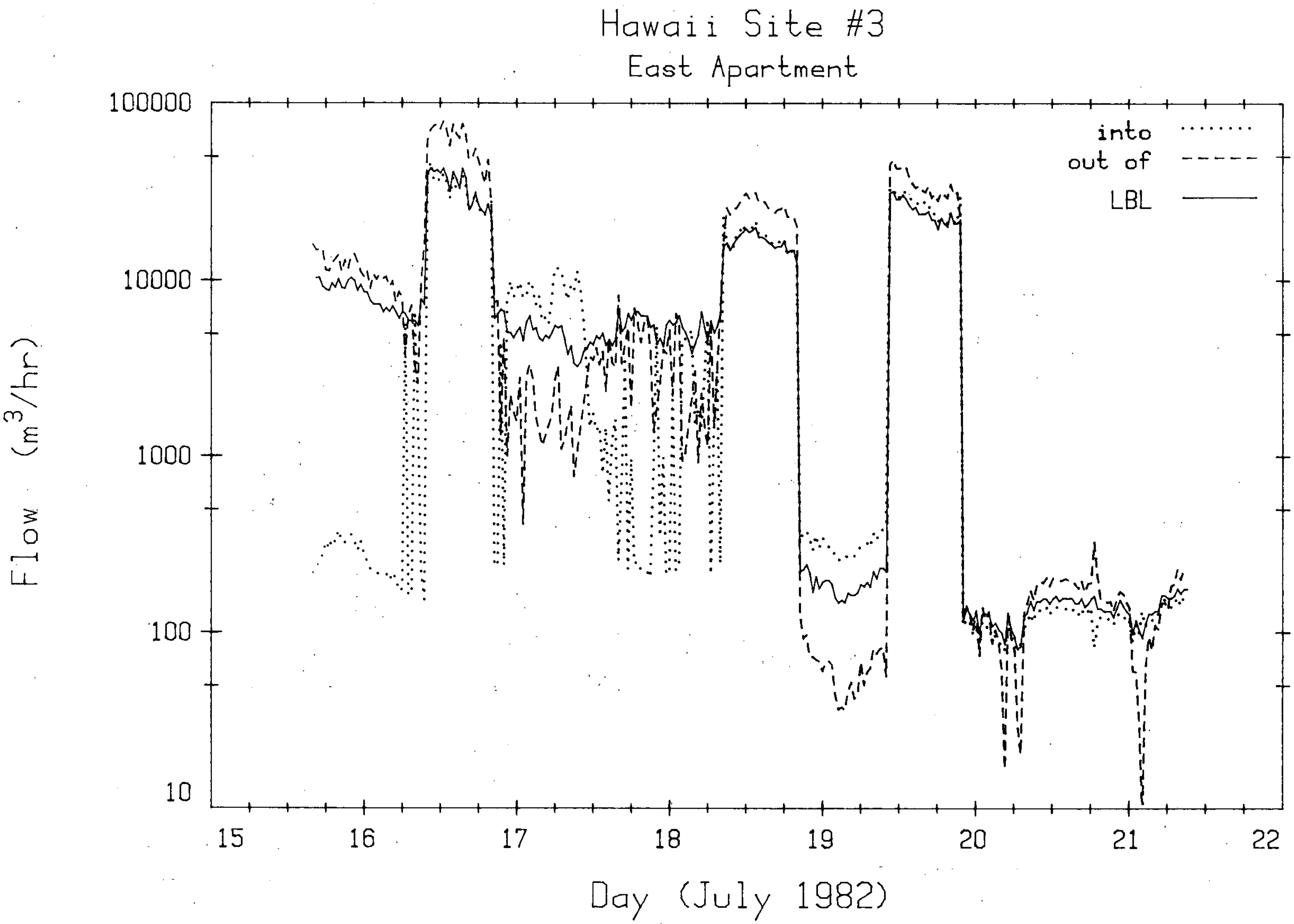
XBL 834-9372

17) Outside air temperatures from site #3.



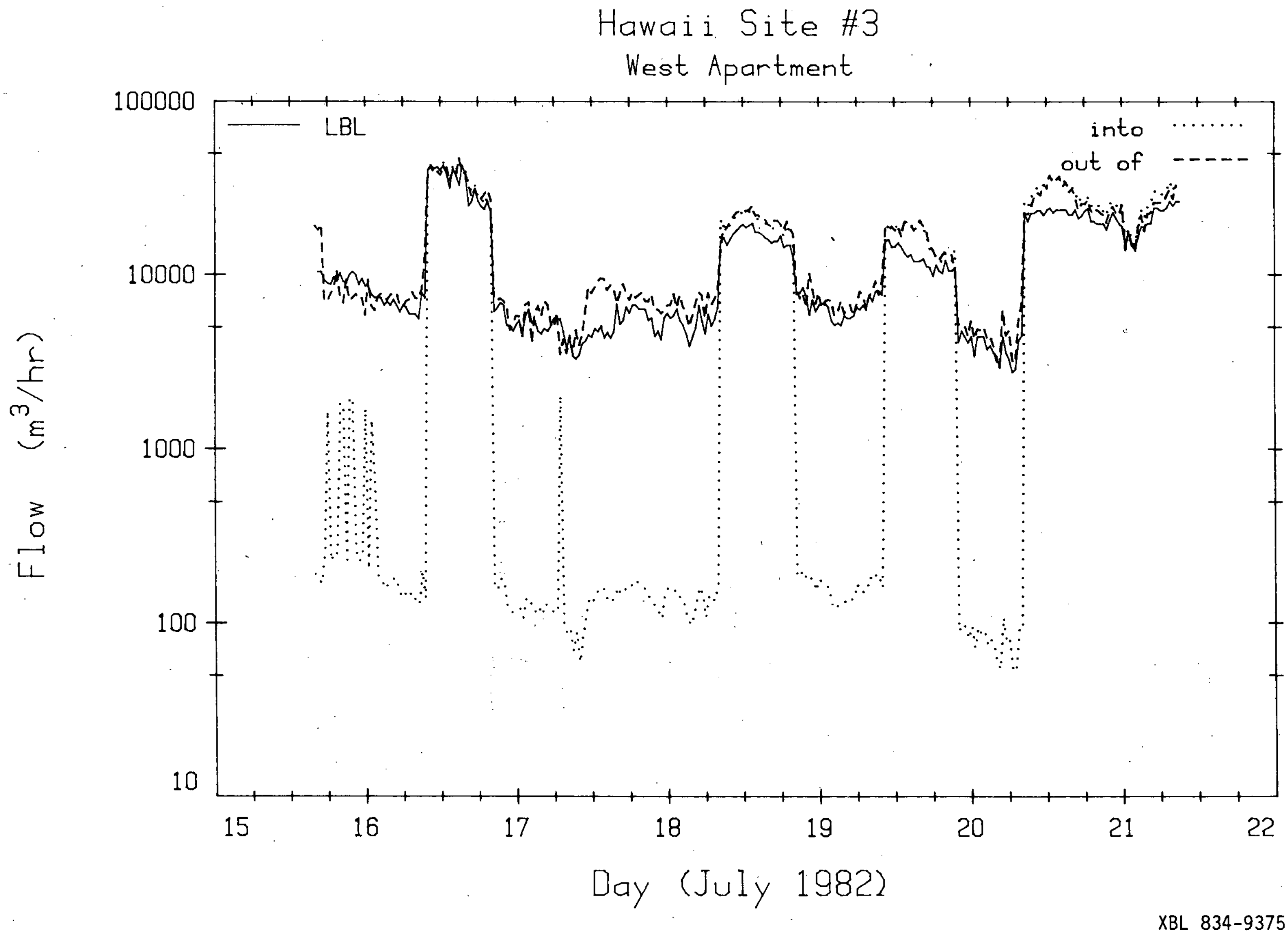
XBL 834-9373

18) Wind speed and direction from site #3.



XBL 834-9374

19a) Predicted ventilation from site #3, east apartment.



19b) Predicted ventilation from site #3, west apartment.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720