HAWAII'S K-12 PORTABLE CLASSROOMS

Bioclimatic Monitoring, Assessment & Design Recommendations

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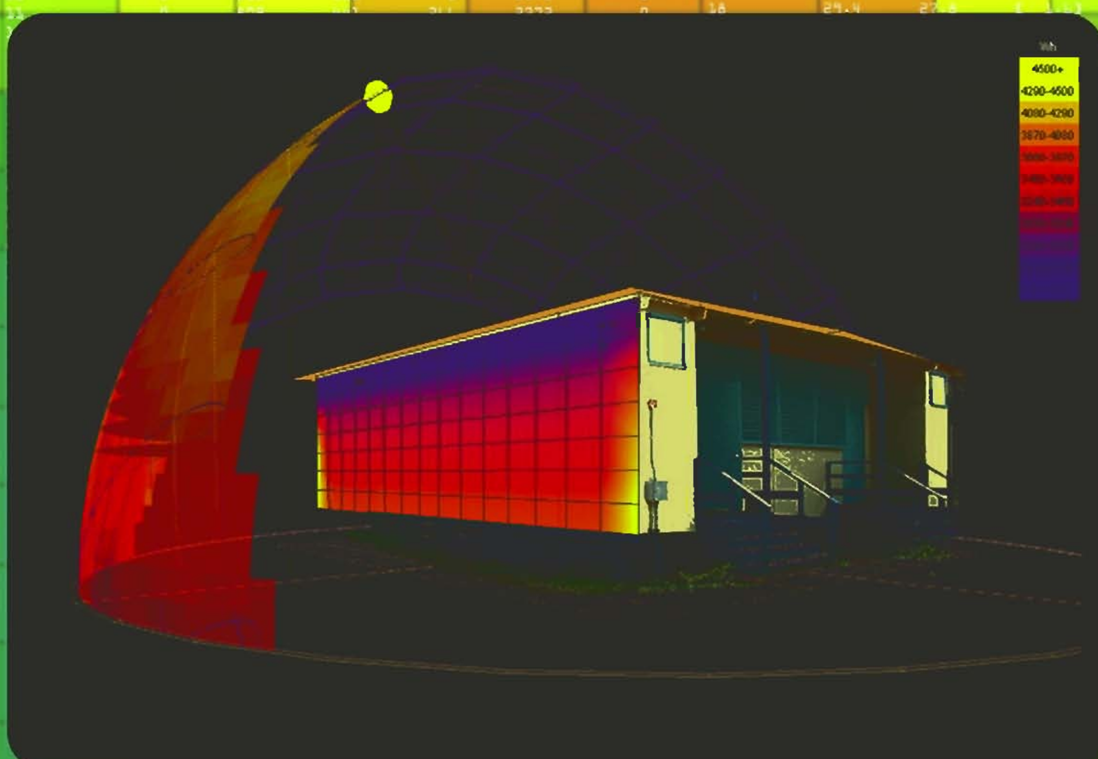

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1.0 – Introduction

1.1 – Executive Summary

The purpose of this project was to monitor and assess the bioclimatic conditions within typical State of Hawaii Department of Education (DoED), portable classroom buildings. The team collected temperature, both interior and exterior to the classrooms, humidity, air flow and light levels within the portable classroom settings. The research team was to determine the level of occupant comfort within these educational environments and to make recommendations for improving the occupant's level of comfort if the conditions were assessed to be outside the appropriate comfort levels. Towards this end the research team from the University of Hawai`i School of Architecture (SoA) installed data logging instruments in a variety of portable classroom buildings on three separate DoED campuses on Oahu. The three campuses monitored were Waianae High School, Kaimuki High School and Koko Head Elementary School. Of these three campuses, the portable units on the Waianae campus were deemed to be the most uncomfortable. These are also typical portable classroom designs used by the DoED and are the specific focus of this report.

There are four fundamental conditions that influence human comfort; temperature, air flow, humidity and radiant temperature from surrounding surfaces. These four elements are considered in combination to determine comfort. For example, when temperatures increase beyond the typical comfort range, air flow across the body can be increased to improve the sensation of comfort. When humidity is higher than what is comfortable and airflow drops, exacerbating the level of discomfort, temperature can be lowered to improve the comfortable conditions. Humidity is the most difficult factor to control. Regional acclimatization allows the comfort zone to be adjusted. From earlier studies we know that people in locations like Hawaii can find slightly higher levels of temperature and humidity more acceptable than people living in cooler regions. The acceptable levels of temperature and humidity have been adjusted upward in this study to accommodate Hawaii's acclimatization. Having modified the acceptable range upward, the results of the monitoring were still extremely uncomfortable. Temperatures through the ceiling were 100^{0}F plus, 93^{0}F transferring through the walls and nearly 90^{0}F at desk level. These temperatures—coupled with the teacher's and student's anecdotal evidence that they are driven to distraction by the uncomfortable conditions--left no doubt in the minds of the researchers that these classrooms are not conducive learning environments.

There has been a substantial amount of information transfer and follow-up by the research team since this study began. Early findings were relayed to the Department of Education, the Department of Accounting and General Services (DAGS) through a series of direct meetings with high level representatives from each of these departments, including the Vice Superintendent of Facilities and Operations Ms. Rae Louie. Larger presentations were made to DoEd, DAGS, State Energy Office and US DoE representatives at a variety of state meetings as well as at the regional level at Rebuild America Peer Exchange Forums in Santa Monica in March of 2003 and in Phoenix in January 2004. The former meetings, especially the direct and focused sessions with the DoED, were especially productive and have led to improvements initiated by DoED. The latter meetings, especially on the regional level, have provided a valuable ongoing exchange of ideas and information on the issues surrounding improved classroom design.

This report provides testing results and recommendations in section 3, and design guidelines in section 4, for improving the conditions within the portable classroom buildings. These guidelines combine a number of strategies such as maximizing envelope heat transfer, decreasing heat gain through buildings' exterior surfaces, increasing passive cooling via building configuration and orientation, and minimizing internal gain. These analyses indicate that an integrated approach will be most effective in creating an optimal thermal environment.

The team tested these recommendations using computer models and full scale physical models. Using both the computational and the physical models allowed the team to propose, test and verify the various design strategies in ways that would not have been possible if either the full scale mock ups or the computer capabilities were not available at the School of Architecture Laboratory.

Beyond the assessment and recommendations provided in this report, the SoA research team has sought additional support to take the project to the next level. In the fall of 2003 the SoA team combined efforts with the Honolulu Chapter of the American Institute of Architects (AIA) Committee on the Environment (COTE), to apply for a design grant from a local charitable foundation sponsored by the Honolulu based architectural firm of Group 70 International. The proposed activity is to utilize the combined professional and academic expertise to develop two viable portable classroom designs for the Hawaii Department of Education. The grant has been awarded. It is a small $7000 grant. This will provide funding for student work but the bulk of services will be provided pro-bono by the practicing and academic professionals. It will build on the work performed under the support of this grant, use the physical and computational facilities at the SoA lab and provide the DOE, the teachers and children of this state with a portable classroom design that will be attractive, energy and resource efficient, comfortable and an environment that is conducive to learning.

1.2 – Tasks in Review

The following lists the tasks executed in the performance of the project:
These tasks are further explored in the proceeding chapters.

A. Coordinate with the Department of Education personnel to identify two appropriate portable buildings for testing.

B. Assemble the appropriate monitoring instrumentation to use based on site evaluation. The School of Architecture will use existing equipment wherever possible and use present funding to purchase any additional instruments that are needed for the classroom monitoring.

C. Monitor portable classroom buildings using data loggers, which will be placed in 4 to 6 positions in and around the building. The loggers will record temperatures, air movement, and relative humidity values several times an hour for a period of several weeks. The sensors will record data during the time students are in the buildings and at times when the classrooms are unoccupied. Overall design, construction type, and materials will be evaluated for their respective abilities to maintain a comfortable climate within the classrooms. Data will be collected and analyzed by the School of Architecture Environmental Research & Design Laboratory.

D. Analyze initial site data to determine the specific range of comfort zone deviation. Strategies to remediate these conditions will be proposed and tested. The school of Architecture research team will test the potential solutions at the Environmental Research & Design Laboratory, using both physical and digital models. From these tests, recommendations will be offered to make the portable school classrooms more comfortable for the teachers and students.

E. Develop a set of design guidelines with recommendations for improved portable classroom conditions. The guidelines will address thermal transmission and mitigation, ventilation strategies and material choices. The recommendations will be issued in both hard copy and on the School of Architecture website.

2.0 – Monitoring & Data Analysis

2.1 – Project Location

The research team first identified the schools that will provide the testing grounds. Waianae High school, located on the leeward side of Western Oahu [Fig. 01], was chosen for its particularly hot climate, on average warmer than most regions of the State. Selecting a warmer than usual location to perform the monitoring allows the research team to develop worst-case scenario design strategies, applicable to most conditions encountered in the State.
Other selection criteria were the age and construction type of the portables.
Within the Waianae High school, two portables were chosen as monitored units, next to one another to facilitate comparisons and avoiding microclimatic derivations; the first one, named P-26, is an older style of portable [Fig. 02] designed in 1974. The second one, P-25, is a newer portable, designed in 2000 [Fig. 03].
The research team subsequently monitored another pair of portable on the same campus, this time, to assess the thermal comfort of a 2000 retrofitted portable, P-1 [Fig. 04], compared to an adjacent, older portable, P-2, designed in 1977 [Fig. 05].
Lastly, four additional portables were monitored for a brief period, on the Eastern side of the island: two 1966 concrete portables, P-021 and P-020, at Koko Head Elementary School [Fig. 06], and two portable, TB-1 (1997)and P-3 (1974) [Fig. 07] located on the grounds of Kaimuki High School in Honolulu.

The following table outlines the location, construction type and design year of each monitored portable:

Table – 01: Portable Location, Construction Type, and Design Year.

LOCATION	PORTABLE	CONSTRUCTION	YEAR
Waianae High School	P-26	Light frame	1974
Waianae High School	P-25	Light frame Insulated ceiling	2000
Waianae High School	P-1	Remodeled Floor Vents Insulated ceiling and walls	2000
Waianae High School	P-2	Light Frame	1977
Koko Head Elementary School	P-021	Concrete	1966
Koko Head Elementary School	P-020	Concrete	1966
Kaimuki High School	P-3	Light frame	1974
Kaimuki High School	TB-1	Light frame Insulated Ceiling On-slab	1997

Fig. 01 – Location Map of Monitored Portables.

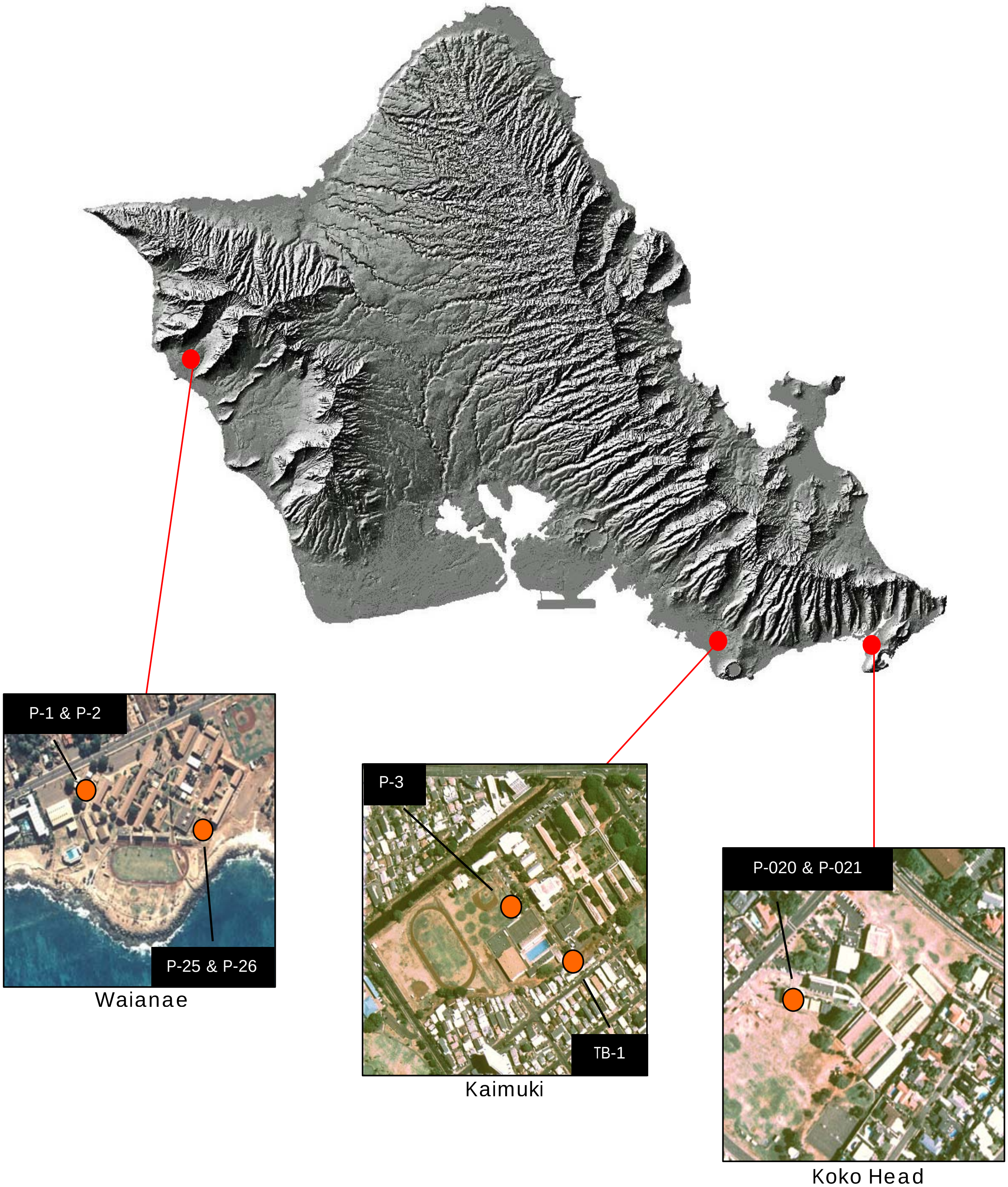

Fig. 02 – Portable P-26.

Fig. 03 – Portable P-25.

Fig. 04 – Portable P-1.

Fig. 05 – Portable P-2.

Fig. 06 – Portable P-020 and P-021.

Fig. 07 – Portable P-3.

2.2 – Instruments Setup & Protocols

All portables were monitored for indoor air temperature, and relative humidity, two important components that influence human comfort. A third component, airflow velocity was measured sporadically as it is a highly variable environmental factor.
Two to three data loggers [Appendix A] were installed within each portable at locations that would provide valuable information without compromising the security of the equipment.
In all cases, a data logger was placed at a height of 7 feet, while another was installed at an approximate 4-feet high level. In some instances, an additional data logger was placed close to the ceiling.
The following analysis is based on measurements taken at the 7-feet high level. This height corresponds to the top of a portable built-in cabinet, common to all monitored portables. The research team acknowledges that this height is one foot higher than the standard *Occupied Zone*, defined at 72 inches in height above floor level. This method allowed a more accurate performance comparison between the portables and eliminated the doubts of any eventual tampering with any of the more accessible data loggers placed within the occupied zone.
In addition to monitoring the indoor environment of the portables, data loggers were set up outside to record ambient exterior air temperature and relative humidity. Comparing indoor and outdoor environmental conditions enables an assessment of the portable fabric's thermal response efficacy.
The monitoring of Waianae High School's P-01, a remodeled portable, included an anemometer connected to a data logger, measuring airflow velocities at air inlet.

The portable monitoring spanned over a period of 8 months, broken into 3 phases. The first of these phases ranged from October 25th 2002 to December 20th 2002 when portables P-26 and P-25 at Waianae High School were monitored. The second phase ranged from January 20th 2003 to April 09th 2003 when portable P-1 and P-2 of Waianae High School were monitored. Finally, phase three took place from June 2nd 2003 to June 9th 2003, monitoring portables P-020 and P-021 at Koko Head Elementary School and portables P3 and TB-1 at Kaimuki High School.

All data loggers were synchronized and programmed to record data at 20 minutes intervals. During the third phase, the data loggers were set to record at 15 minutes intervals to make up for the shorter monitoring period.

The following table outlines the monitoring phases for each portable:

Table – 02: Portables Monitoring Phases Duration.

PORTABLE	LOCATION	MONITORING PERIOD	DAYS
P-26	Waianae	10/25/02-12/20/02	57
P-25	Waianae	10/25/02-12/20/02	57
P-01	Waianae	01/20/03-04/09/03	80
P-02	Waianae	01/20/03-04/09/03	80
P-021	Hawaii Kai	06/02/03-06/09/03	8
P-020	Hawaii Kai	06/02/03-06/09/03	8
P-3	Honolulu	06/02/03-06/09/03	8
TB-1	Honolulu	06/02/03-06/09/03	8

2.3 – Data Analysis

Monitoring data were imported into a spreadsheet for analysis.
For each portable, two datasets were extracted representing recorded values during all time and during occupied times. Occupied time was defined by the research team as ranging from 0800 to 1400, times during which portable classrooms are usually occupied by school children and instructors.
Temperature and relative humidity data points were plotted against bioclimatic and psychrometric charts to assess the level of human comfort inside the classrooms at all times during the monitoring period. Bioclimatic charts allow us to quickly identify how the comfort level of an occupied space. If data points fall outside of the outlined comfort zone, the chart will suggest the airflow velocity (or amount of radiant heat) necessary to extend the comfort zone.

Psychrometric charts, devised by ASHRAE, are similar to bioclimatic charts in that they allow an assessment of human comfort. Additionally, an overlay showing potential cooling strategies can be applied to the chart to evaluate an appropriate design approach. A clothing (clo) and activity rate (met) values were assigned to both instructor and students. A clothing value of 0.4 clo, reflecting light shirt and light pants was set for the instructor. The students clothing factor was set to 0.2 clo.
The activity rate of the instructor was set to 1.6 met, or *light activity*, while the students have a lower met value of 1.2, or *sedentary activity*.
The airflow velocity was set to 0.5 m/s (100 ft/min).
The Mean Radiant Temperature (MRT) value was set to be equal to the average monthly maximum indoor temperature for one of the month of the monitoring period. Note that The Mean Radiant Temperature was not measured inside the portables due to the limitation of the monitoring equipment. Instead, the average monthly maximum indoor air temperature is used for the psychrometric analysis. It should be emphasized that in this study, the MRT is generally higher than the indoor temperatures. Surface temperatures of ceilings and interior walls were measured sporadically about the monitored portables; ceiling surface temperatures reached over 100°F, while the interior walls surface temperatures were commonly found to be above 92°F. Due to the high emissivity of most construction materials (>90%) and the very high absorptivity of the human skin (97%), the surface temperature of interior element becomes critical to the human comfort. Thus, even when indoor temperatures and relative humidity falls within the comfort zone, hot surface temperatures can radiate enough heat to create uncomfortable conditions.
With all these factors accounted for, a PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied people) can be calculated. These two values are statistical figures that are used for evaluating human thermal comfort.

Other graphs represent temperature distribution and trend over a twenty four-hour period, overlaid over a comfort zone band. This comfort band, set from 73°F to 85°F, was derived from the bioclimatic chart and adjusted to the tropical latitude of Hawaii. This type of graph is useful in determining and comparing the time of the day at which highest and lowest temperatures occur, and how much of the time is above or below the comfort zone.
Lastly, comparative graphs were produced to assess the relative thermal performance of the different pairs of portable monitored during similar monitoring periods. These graphs plot the interior temperatures of two portables against one another. It features a *slope of one* diagonal line that represents equal temperatures between the two portable. The more centered along the line the data points are, the more similar the thermal properties of the two compared portables.

2.3.1 - Portable P-26 & P-25

Portable P-26 is an older type of portable. It was designed in 1974 and is a light wood-frame construction. The walls are made of a 4 in. air gap sandwiched between two-¾ in. plywood sidings. The roof is built-up roofing on ¾ in. plywood deck. The portable is elevated 3 feet above grade and oriented on a near East-West axis.
An average of 22 students occupy the space during class hours. The portable has a floor surface area of 895 square feet. The openings to floor area ratio is 18.6%.
Airflow velocity within the space was measured several times. The air speeds were recorded to range from 50 ft/min (0.25 m/s) to 200 ft/min (1.0 m/s).

The trend of the data points plotted on a bioclimatic chart clearly shows that the classroom environment is out of the human comfort range during occupied times [Fig. 08]. An airflow velocity of 100 ft/min (0.5 m/s) throughout the classroom would increase the comfort level to an acceptable range, although on the upper threshold of the comfort zone. An air velocity of 100 ft/min is considered a pleasant breeze. A 200 ft/min (1.0 m/s) air velocity is considered too draughty for natural ventilation, as it makes hair and papers move.

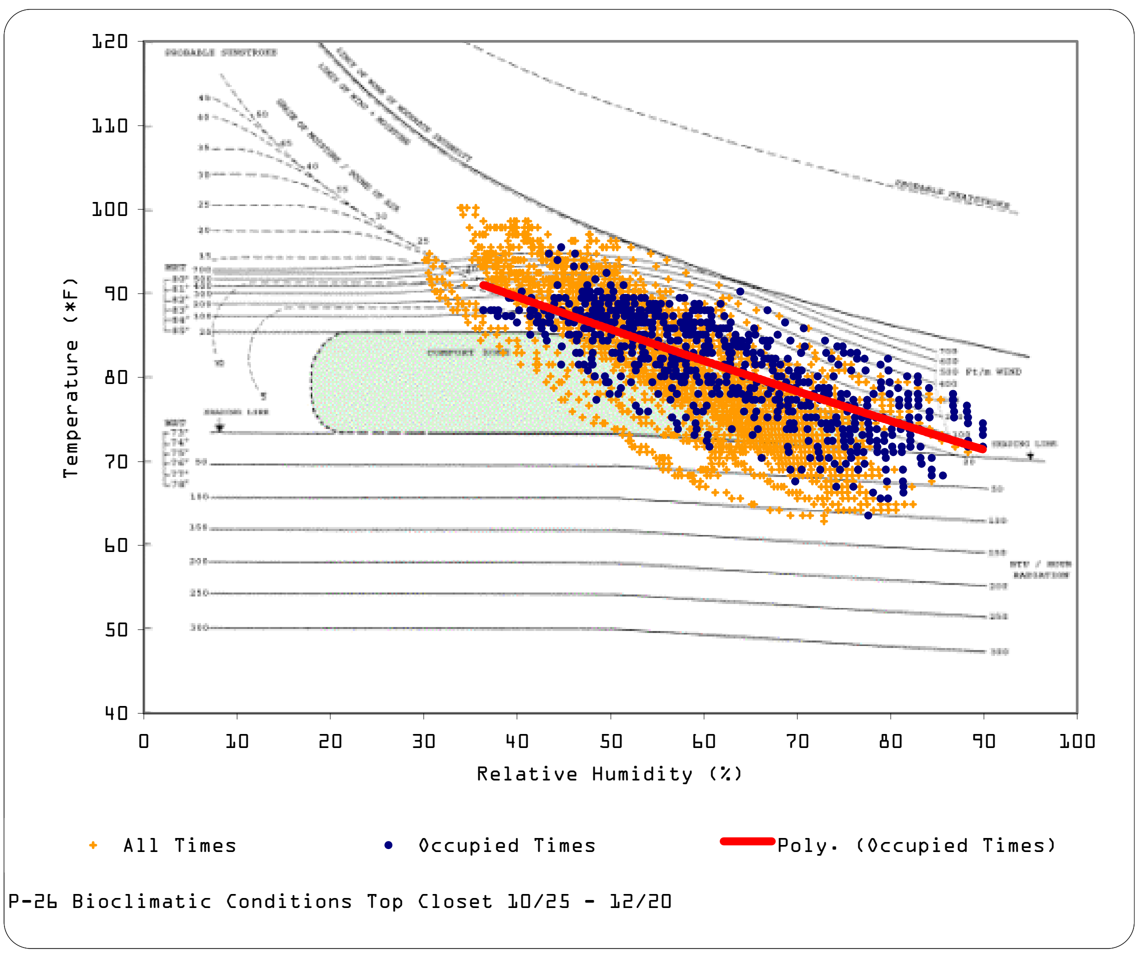

Fig. 08 – Bioclimatic Chart of P-26 from 10/25/02 to 12/20/02.

When plotted against a psychrometric chart [Fig. 09], a cooling-strategies overlay suggests that natural ventilation would be beneficial to the space for at least a third of the time.

At a Mean Radiant Temperature (MRT) value equal to the average monthly maximum indoor temperature for the month of November (93°F), the PMV (Predicted Mean Vote) for the instructor would be 2.80, while the PPD (Predicted Percentage of Dissatisfied people) would be 97%. The PMV and PPD for students are 2.90 and 98% respectively.

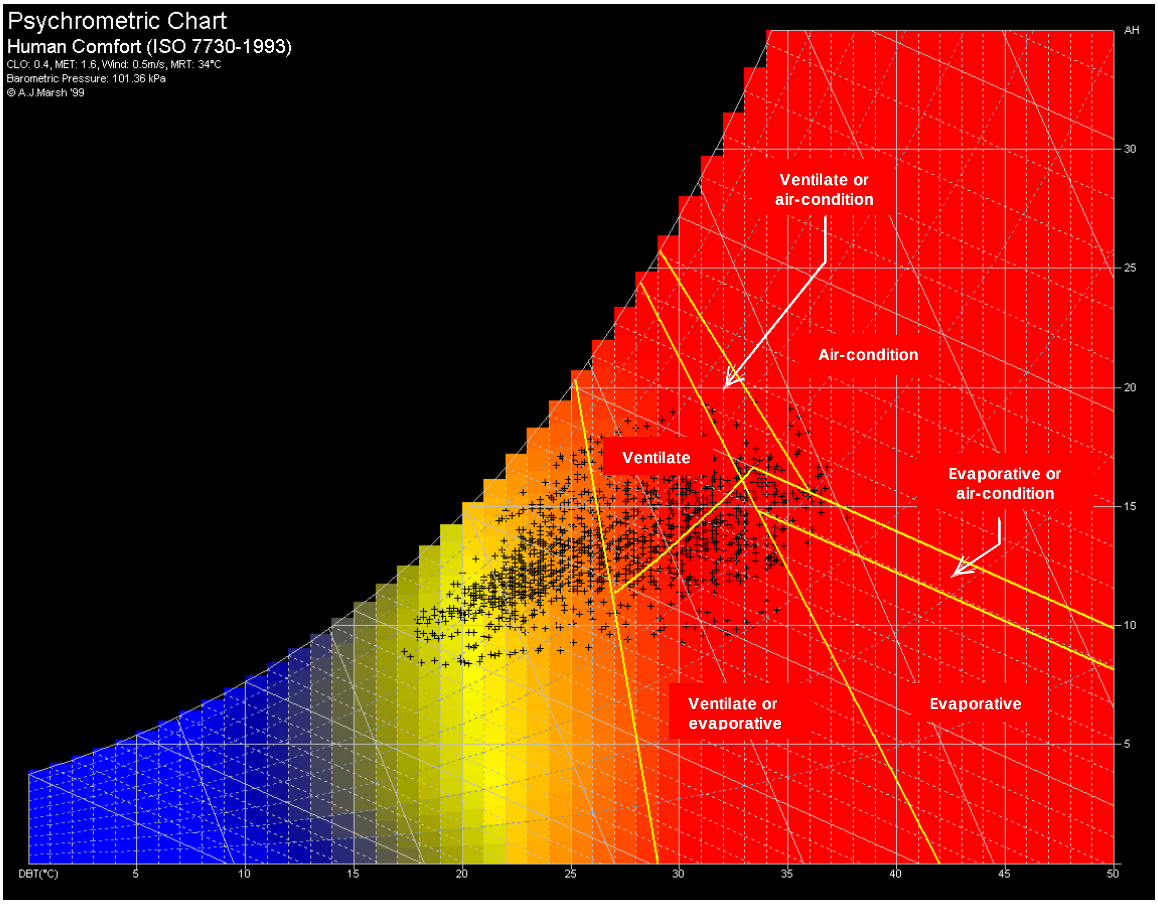

Fig. 09 – Psychrometric Chart of P-26 from 10/25/02 to 12/20/02.

A Temperature Distribution graph [Fig. 10] shows that within P-26, temperatures rise above the comfort zone after 1200 noon to summit around 1600 near 92°F. The trend shows that there is a large temperature fluctuation throughout the day (large standard deviation of the data set); certainly caused by the low heat capacity of the building's fabric. The interior temperature seems to follow the exterior temperature pattern with a 2-hours time lag.

The Temperature Distribution over the Occupied Time period [Fig. 11] shows a rise in temperatures above the comfort zone starting at 1140; the trend stops at 1340, around 88°F.

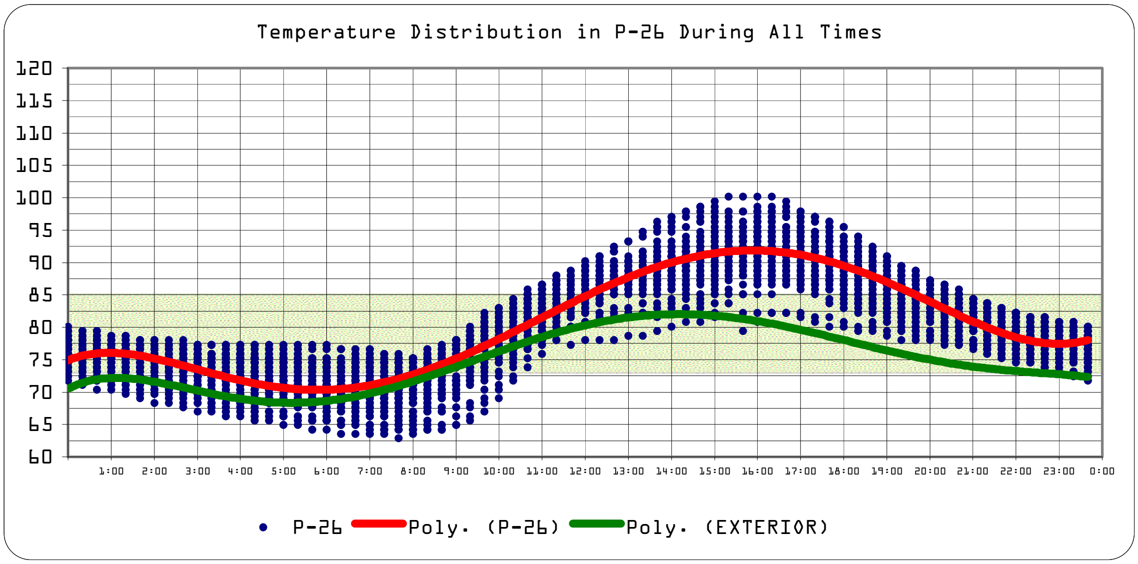

Fig. 10 – Temperature Distribution [all times] of P-26 from 10/25/02 to 12/20/02.

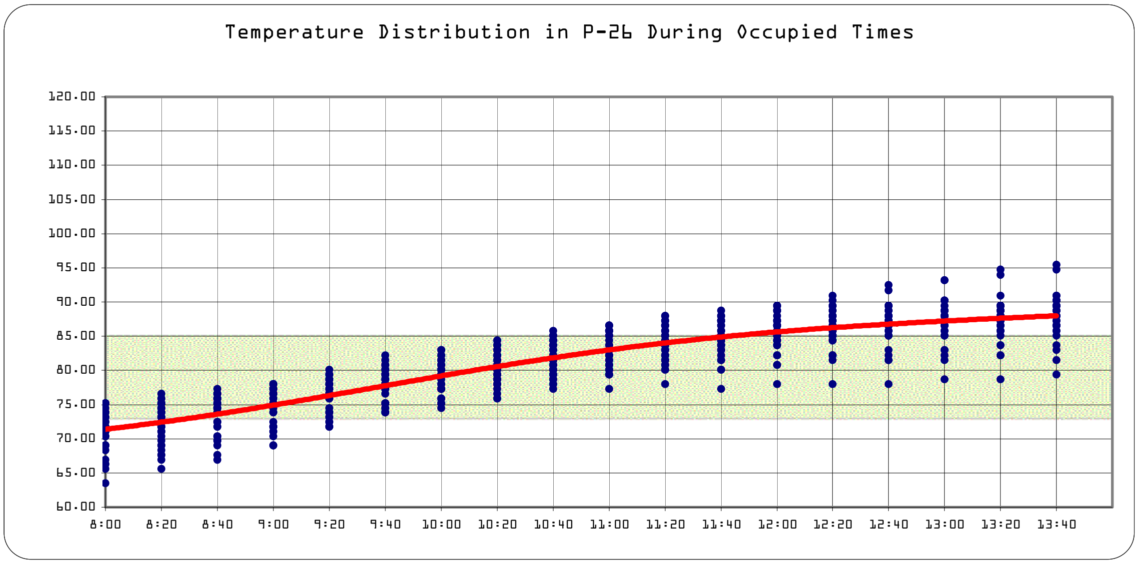

Fig. 11 – Temperature Distribution [occupied times] of P-26 from 10/25/02 to 12/20/02.

The following table summarizes the statistical data of Portable P-26:

Table – 03: P-26 Thermal Statistics.

57 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	100.12	95.49
MIN. T	62.24	63.54
AVG. T	80.24	81.17
STDV	7.81	6.03

Portable P-25 is a recent addition to Waianae High School. It was designed in 2000 and features an insulated ceiling. The portable fabric is made of a 4 in. air gap sandwiched between 5/8 in. exterior and 3/8 in. interior plywood siding. The roof is build-up roofing on ¾ in. plywood decking. The ceiling is made of 3½ in. foil-faced glass fiber insulation on 3/8 in. plywood. The portable is elevated 3 feet above grade and is oriented on a near East-West axis. Up to 26 students and instructor occupy the space. The portable has a floor surface area of 812 square feet. The openings to floor area ratio is 14.7%.
The air speeds were recorded to range from 40 to 50 ft/min (0.2 to 0.25 m/s).

The data points plotted on the bioclimatic chart suggest that during occupied times the comfort level in the classroom is marginally acceptable, and restricted to periods when the relative humidity is between 50% and 70% [Fig. 12].

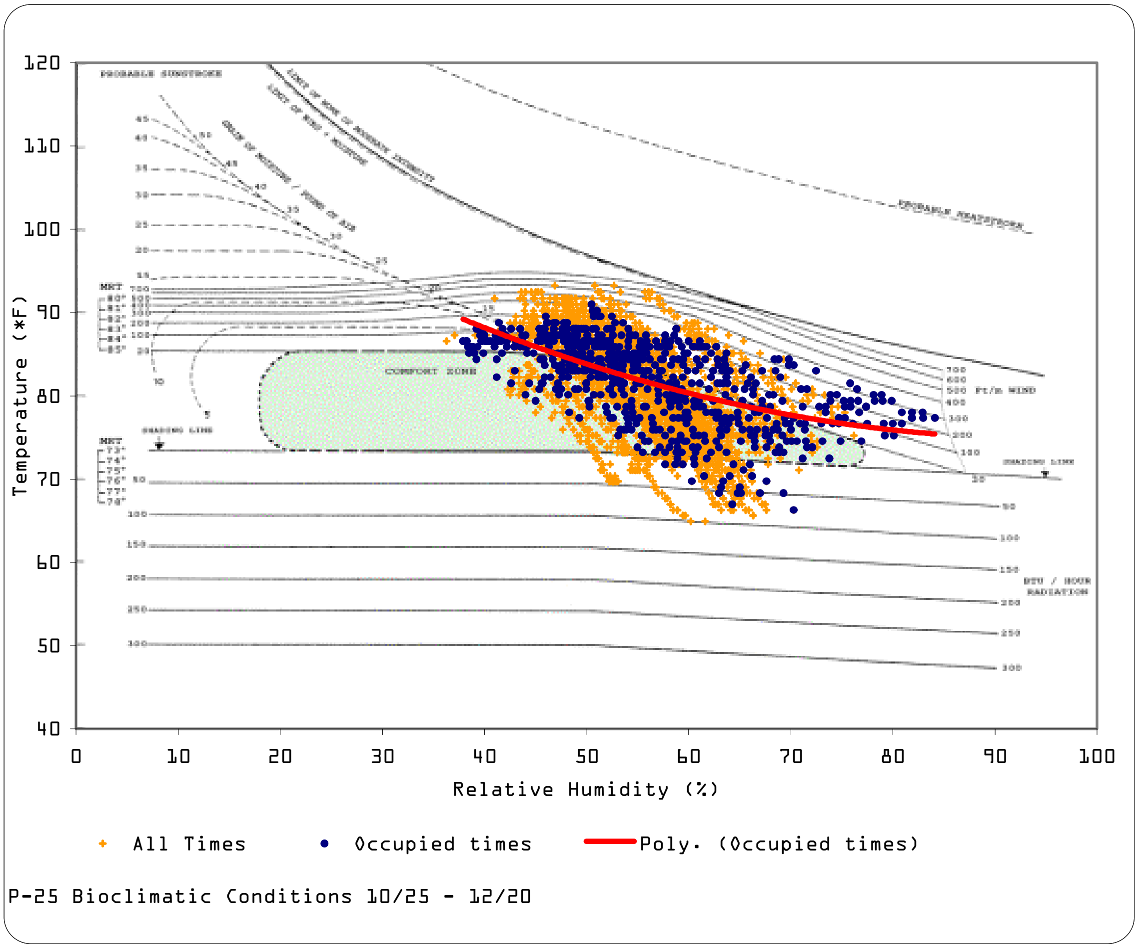

Fig. 12 - Bioclimatic Chart of P-25 from 10/25/02 to 12/20/02.

Similarly to P-26, a psychrometric chart shows that P-25 could benefit from natural ventilation [Fig. 13].
At a value equal to the average monthly maximum indoor temperature for the month of November (88°F), the PMV (Predicted Mean Vote) for the instructor would be 2.00, while the PPD (Predicted Percentage of Dissatisfied people) would be 78%. The PMV and PPD for students are 1.80 and 65% respectively. The Mean Radiant Temperature was set equal to the average monthly maximum indoor temperature for the month of November.

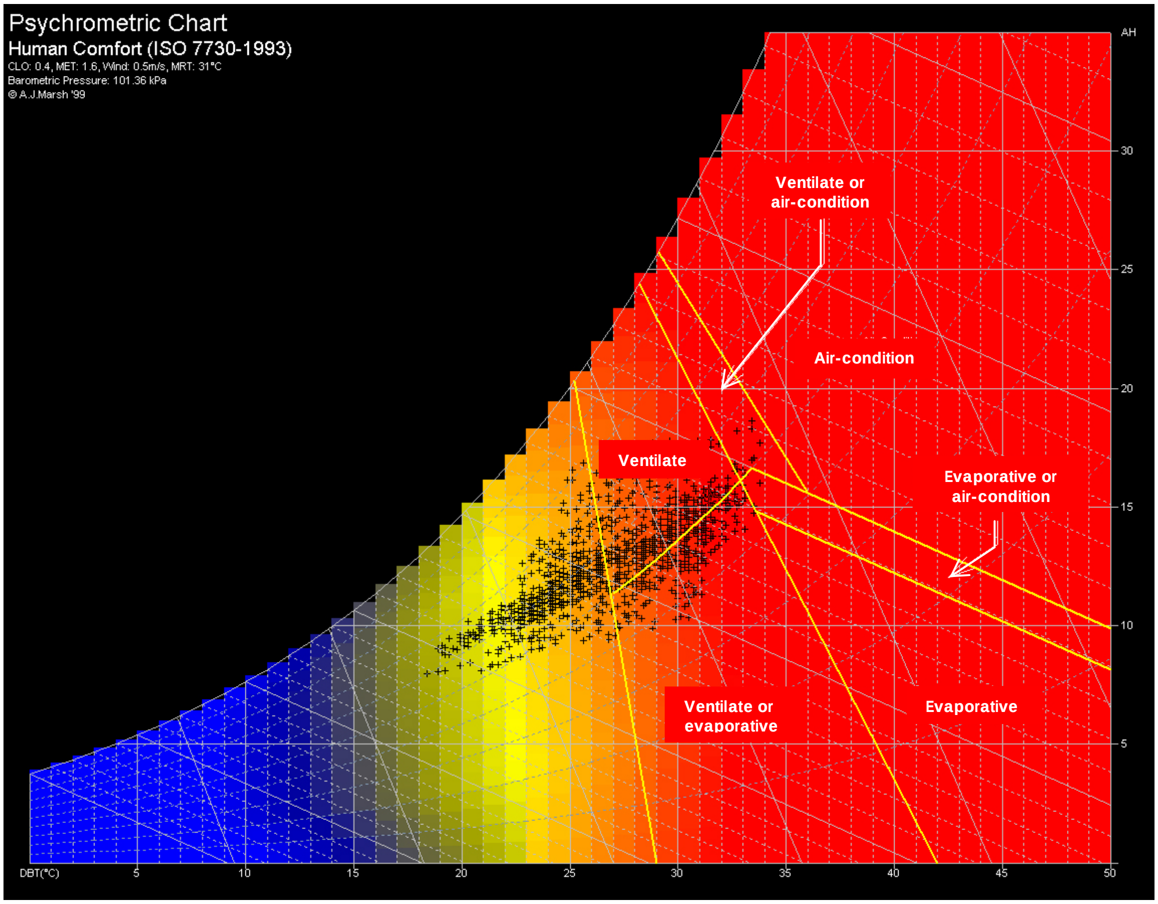

Fig. 13 - Psychrometric Chart of P-25 from 10/25/02 to 12/20/02.

A temperature distribution graph of the data points shows a similar time lag as P-26 [Fig. 14]. However, the diurnal temperature fluctuation is not as pronounced, as reflected in a smaller standard deviation statistical analysis of the data set compared to P-26. The indoor temperature trend extends above the comfort zone around 1230 – half an hour later than in P-26. The maximum temperature seems to be about 5°F below that of P-26, at around 88°F.

During the occupied times, the temperature rises above the comfort zone between 1140 and 1200, but remains a couple of degrees below the temperatures experienced in P-26 after 1200 [Fig. 15]. It is worth noticing that during the morning period, P-25 is consistently warmer than P-26 by about 2.5°F. Because P-26's internal temperatures fluctuate more readily with exterior temperatures than P-25 does, it also becomes cooler during nighttime, as noted on the temperature distribution graphs. This gives P-26 a cooler "head start" than P-25, which has a minimum nighttime temperature about 2.5°F warmer than P-26.

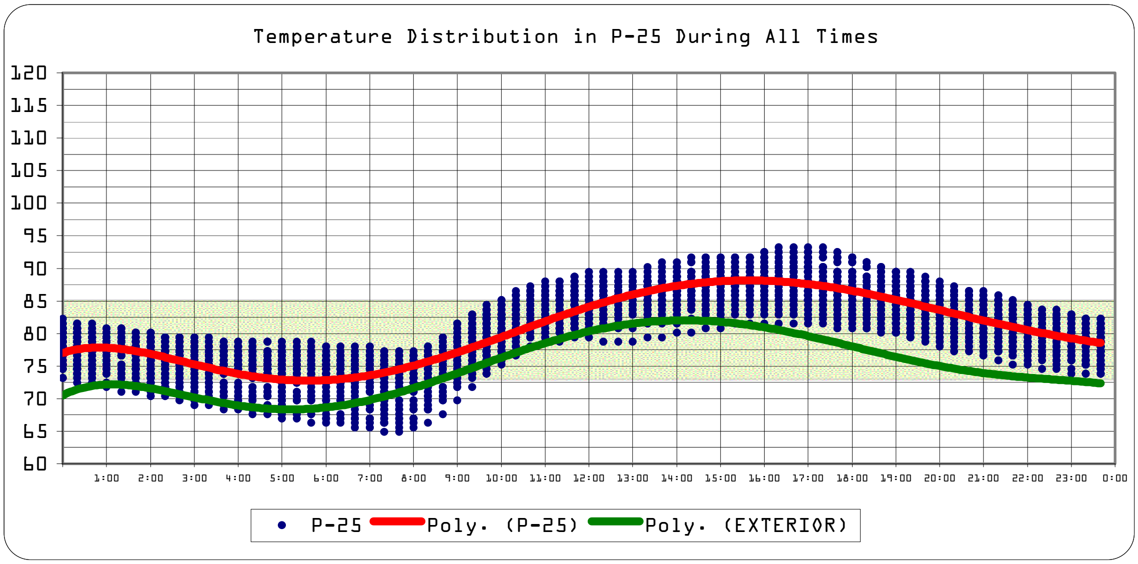

Fig. 14 - Temperature Distribution [all times] of P-25 from 10/25/02 to 12/20/02.

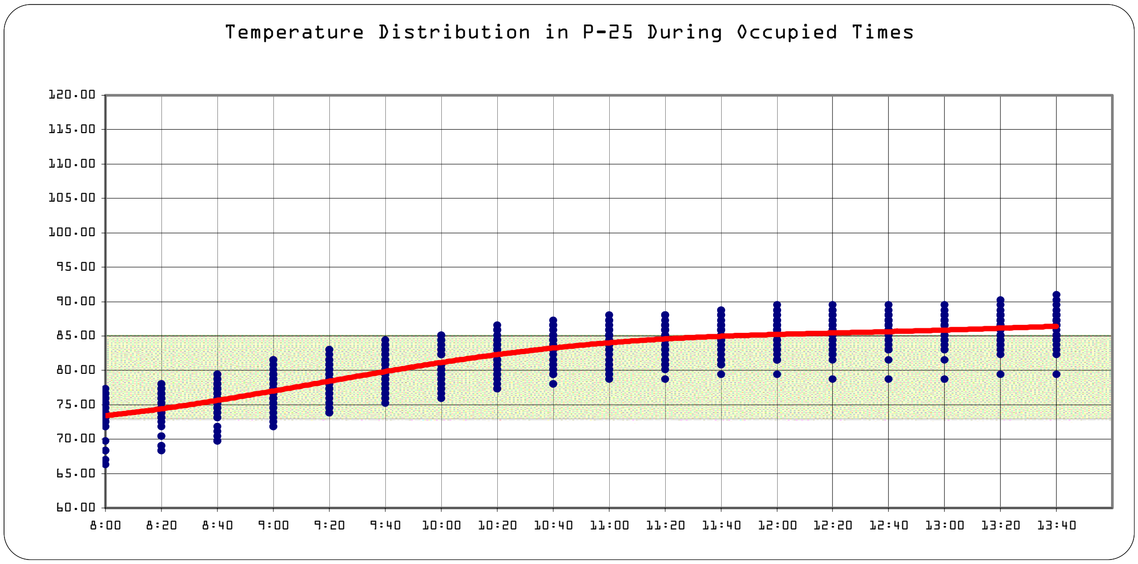

Fig. 15 - Temperature Distribution [occupied times] of P-25 from 10/25/02 to 12/20/02.

The following table summarizes the statistical data of Portable P-25:

Table – 04: P-25 Thermal Statistics.

57 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	93.21	90.96
MIN. T	64.91	66.28
AVG. T	80.50	81.85
STDV	5.79	4.87

2.3.2 - Portable P-1 & P-2

Portable P-1 is a remodeled portable, designed in 2000 by architect Virginia McDonald. The portable is well insulated, has four large vented skylights, and floor vents. The initial design intent was to utilize convective airflow to draw in cool air through the floor vents, while the warmer air would be draw out through the skylight vents. Because the temperature difference between the indoor and outdoor is not sufficient to produce adequate convective flow (the indoor air temperature right below the skylights can reach over 100°F, approaching the outdoor radiant temperature of the roof), photovoltaic wall-mounted fans are used to force warm air out and draw cool air in.
The portable is elevated three feet off the ground and is aligned on an east-west axis. Although P-1 features small windows, they are usually left closed. The airflow coming out of the vents was monitored over a period of 13 days. Data were collected every 20 minutes and averaged an airflow velocity of 51.61 feet per minute (0.26 m/s) and a temperature of 73.26°F.
No further details about the construction are known to the research team, as the blue prints were unavailable.

Once plotted onto a bioclimatic chart [Fig. 16], the data points show that the trend of thermal conditions recorded in P-1 fall well inside the comfort zone. Exception occurs for data points with recorded relative humidity above 77%, at which point airflow need to be increased between 20 and 100 feet per minute (0.1 to 0.5 m/s) to extend the comfort zone.

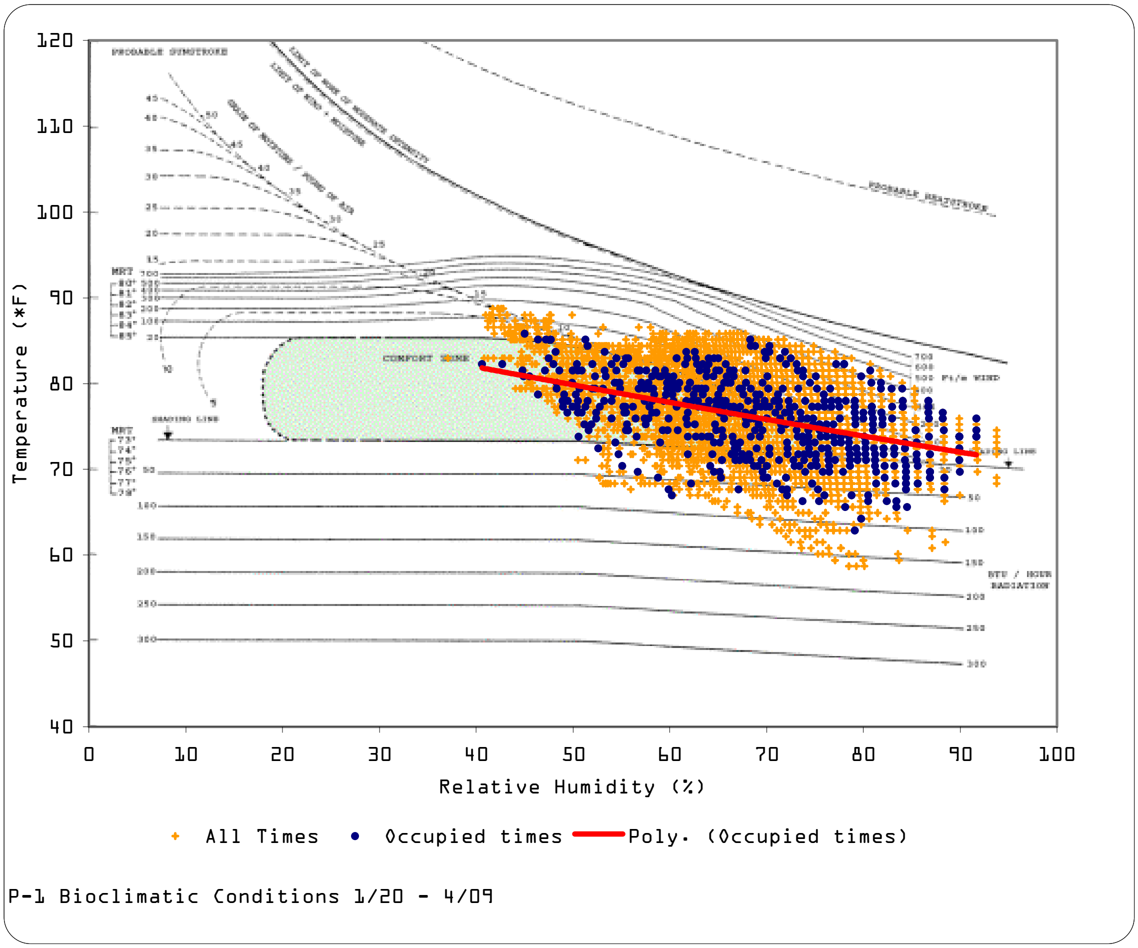

Fig. 16 - Bioclimatic Chart of P-1 from 01/20/03 to 04/09/03.

A psychrometric plot shows that the data points are fairly well centered and natural ventilation would suffice to improve the comfort of the occupants [Fig. 17].
At a value equal to the average monthly maximum indoor temperature for the month of March (84.2°F), the PMV (Predicted Mean Vote) for the instructor would be 1.40, while the PPD (Predicted Percentage of Dissatisfied people) would be 44%. The PMV and PPD for students are 0.75 and 16% respectively. The Mean Radiant Temperature was set equal to the average monthly maximum indoor temperature for the month of March.

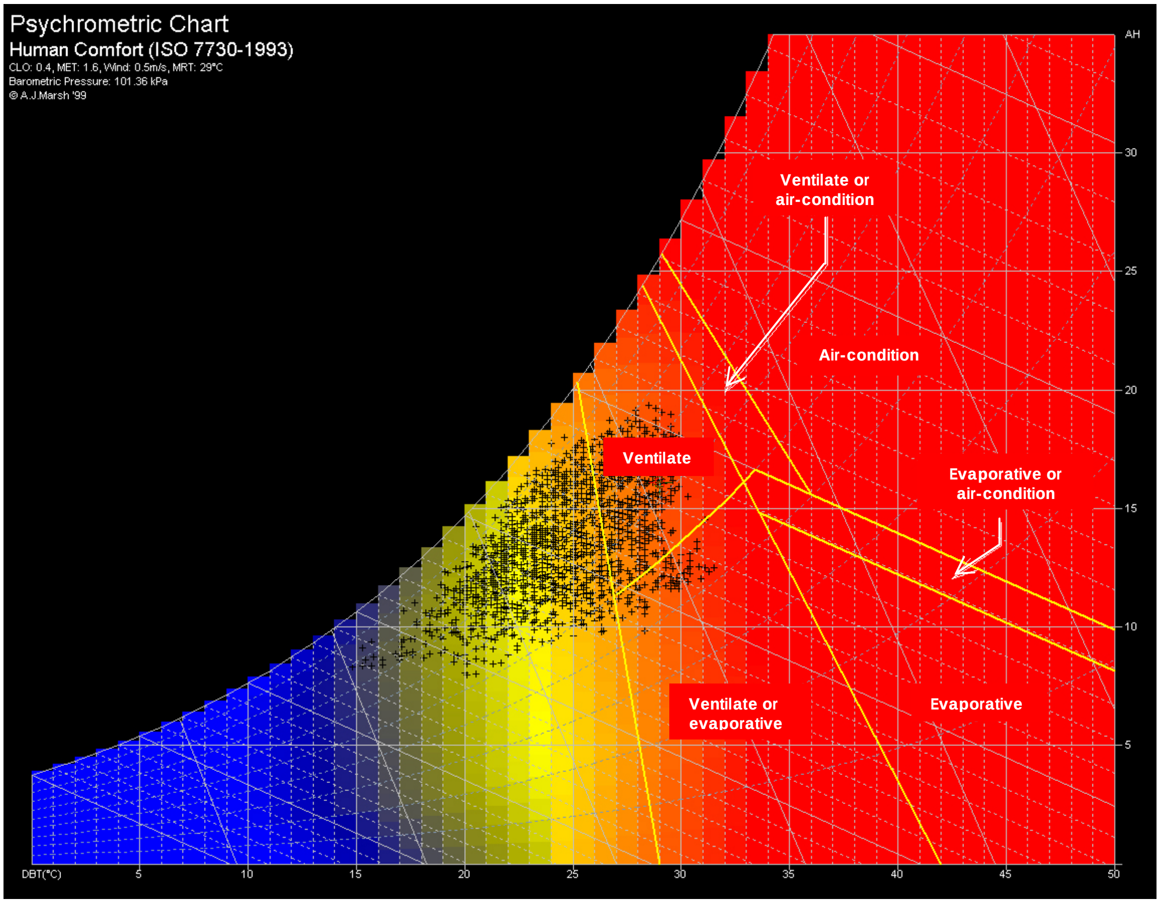

Fig. 17 - Psychrometric Chart of P-1 from 01/20/03 to 04/09/03.

A temperature distribution chart shows that the interior temperatures follow very closely the exterior temperatures [Fig. 18]. Interior temperatures fall out of the comfort zone only during the cool hours of the early morning. The trend line reaches a maximum temperature of 83°F around 1600. The diurnal temperature fluctuation is relatively small. During occupied times, the temperatures enter the comfort zone shortly after 0900, and remain well within the comfort zone during the entire occupied time period [Fig. 19].

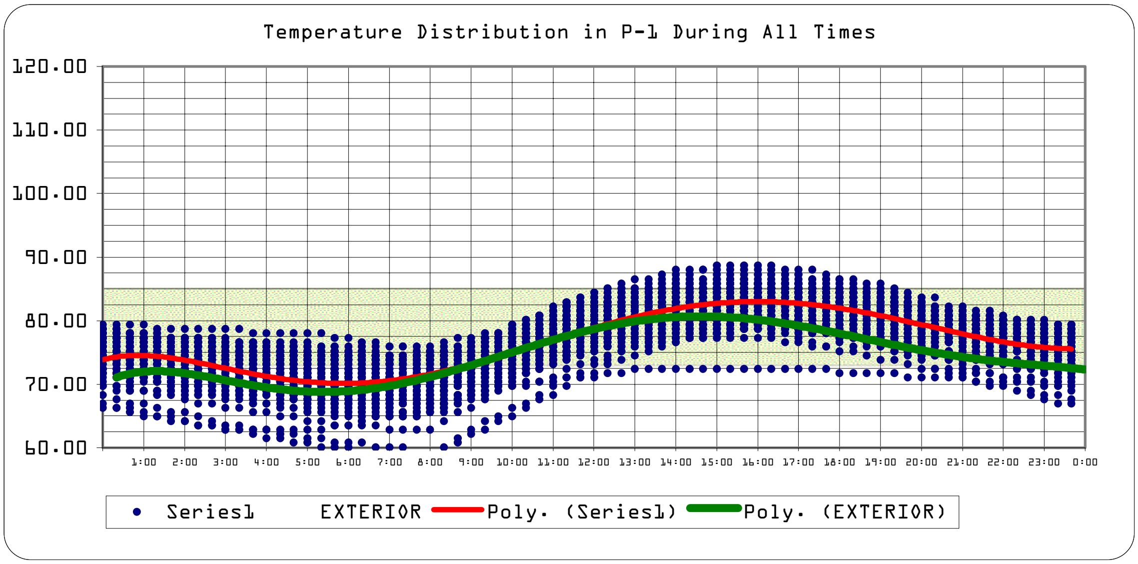

Fig. 18 - Temperature Distribution [all times] of P-1 from 01/20/03 to 04/09/03.

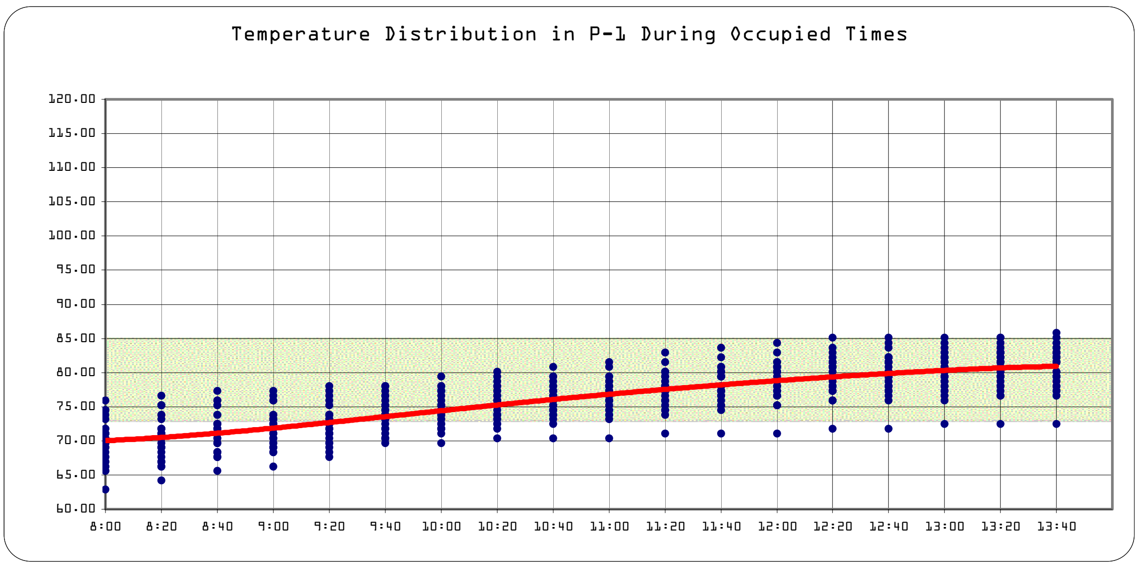

Fig. 19 - Temperature Distribution [occupied times] of P-1 from 01/20/03 to 04/09/03.

The following table summarizes the statistical data of Portable P-1:

Table – 05: P-1 Thermal Statistics.

80 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	88.74	85.83
MIN. T	58.73	62.85
AVG. T	76.51	76.01
STDV	5.19	4.42

Portable P-2 is an older construction portable, designed in 1977. It is very similar to P-26 in its construction type: light wood-frame construction, no insulation. P-2 is directly adjacent to P-1 and follows a similar orientation. The opening-to-floor area ration is similar to P-26's: 18.6%

Data points of occupied times plotted onto a bioclimatic chart [Fig. 20] show a trend within the upper limit of the comfort zone. Note the extreme range of data points speeded about the graph, compared to the bioclimatic graph of P-1, and their shift toward a hotter and dryer environment.

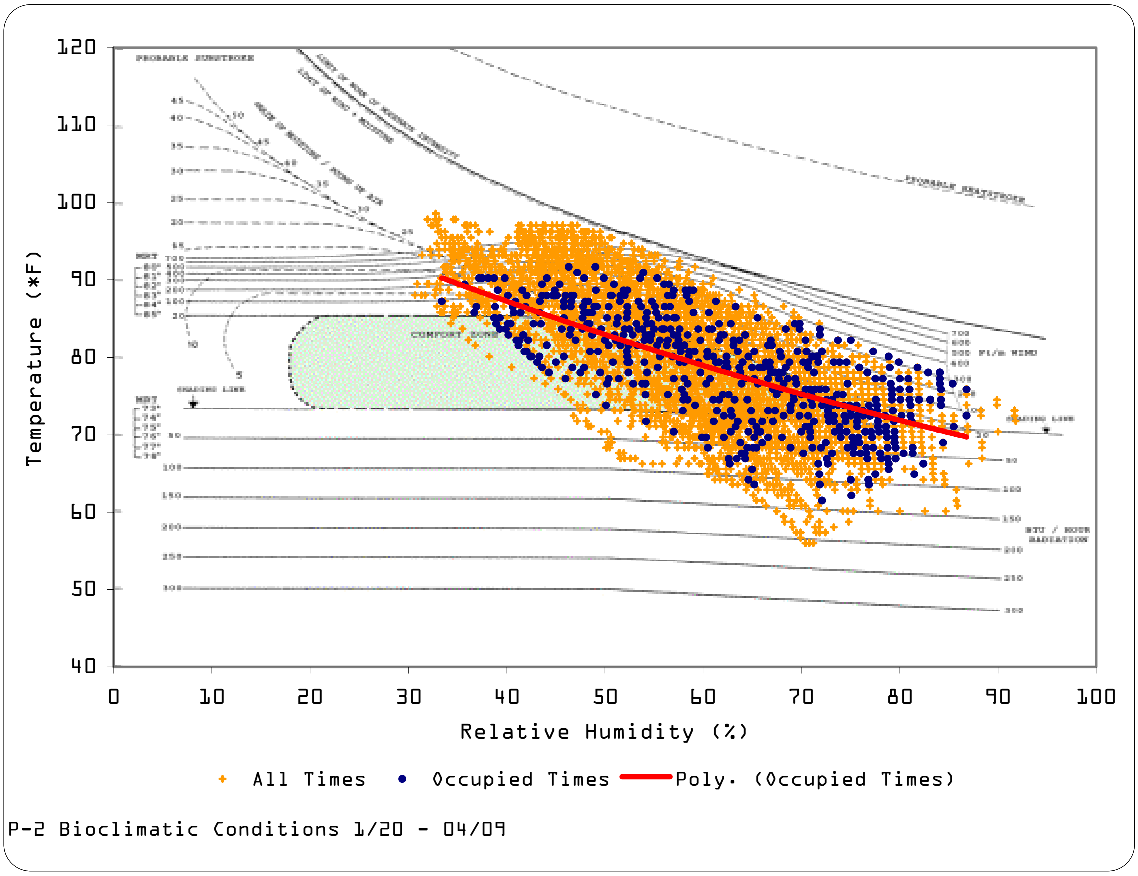

Fig. 20 - Bioclimatic Chart of P-2 from 01/20/03 to 04/09/03.

The psychrometric chart plot clearly shows how extremely uncomfortable the classroom environment can become [Fig. 21]. Adequate ventilation strategies could increase the comfort for most of the uncomfortable times.

At a value equal to the average monthly maximum indoor temperature for the month of March (93.2°F), the PMV (Predicted Mean Vote) for the instructor would be 2.90, while the PPD (Predicted Percentage of Dissatisfied people) would be 98%. The PMV and PPD for students are 3.00 and 98% respectively. The Mean Radiant Temperature was set equal to the average monthly maximum indoor temperature for the month of March.
Note that at this time, students would statistically be more uncomfortable than the instructor would.

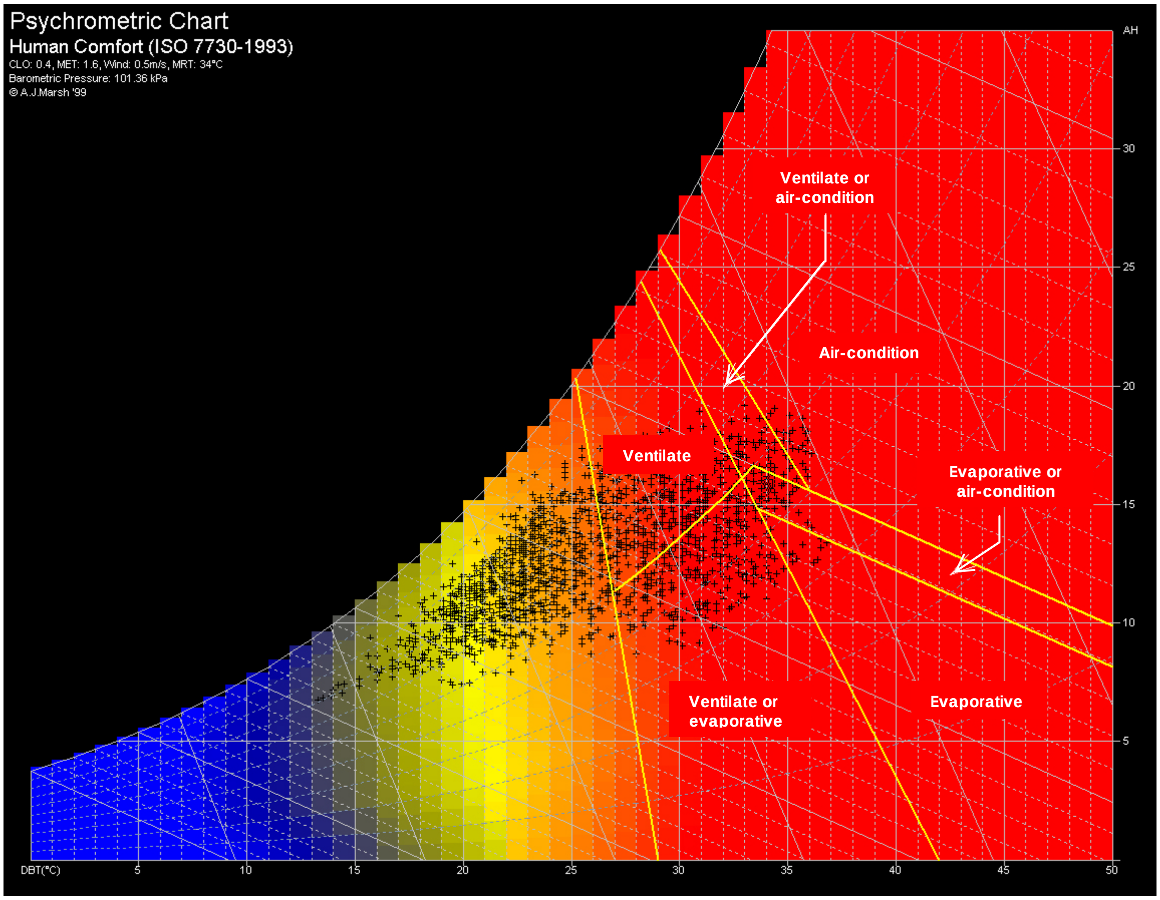

Fig. 21 - Psychrometric Chart of P-2 from 01/20/03 to 04/09/03.

A temperature distribution graph shows a large indoor diurnal temperature fluctuation [Fig. 22]. Temperatures exceed the comfort zone as early as 1240 and keep rising to 91°F around 1630 in the afternoon, a couple of hours after the outdoor maximum temperature.

During occupied times, the indoor temperatures exceed the comfort range a little before 1300. In the morning, the temperatures remain below the comfort zone up until 0930 [Fig. 23].

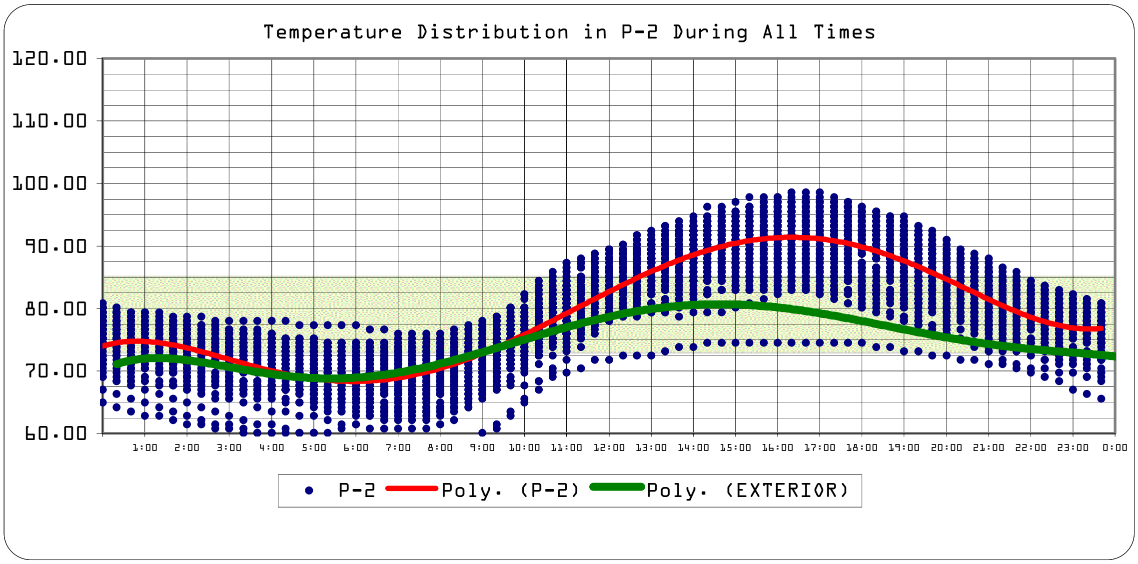

Fig. 22 - Temperature Distribution [all times] of P-2 from 01/20/03 to 04/09/03.

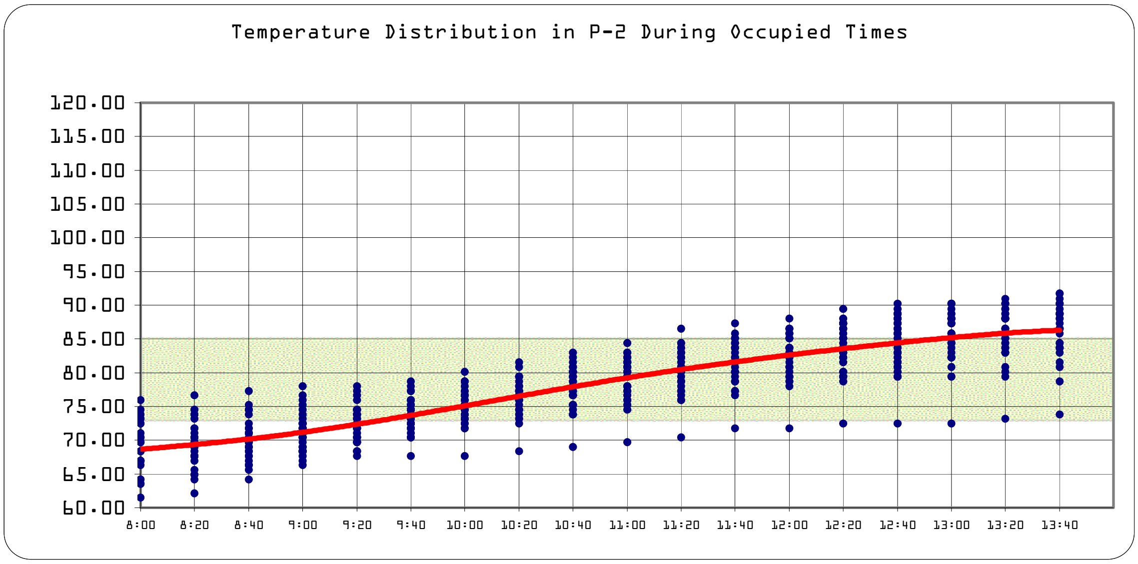

Fig. 23 - Temperature Distribution [occupied times] of P-2 from 01/20/03 to 04/09/03.

The following table summarizes the statistical data of Portable P-2:

Table – 06: P-2 Thermal Statistics.

80 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	98.60	91.71
MIN. T	55.97	61.48
AVG. T	79.07	78.03
STDV	8.66	6.75

2.3.3 - Portable P-020 & P-021

These two portables, located on the grounds of Koko Head Elementary School are similar in construction: Tilt-up 2½ in. pre-stressed concrete walls, concrete slab, and roof.
The recorded temperatures in both portables show similar thermal patterns. The slight temperature difference between the two might be caused by the difference in occupancy. While P-020 is used as an office with computers, P-021 is used as a classroom for preschool children.

For both portables, the bioclimatic chart shows the recorded data falling out of the comfort zone, mostly due to high relative humidity (rains) rather than temperature [Fig. 24 & 25]. Thus, an increase in airflow velocity could bring the occupied space to a reasonable level of comfort.

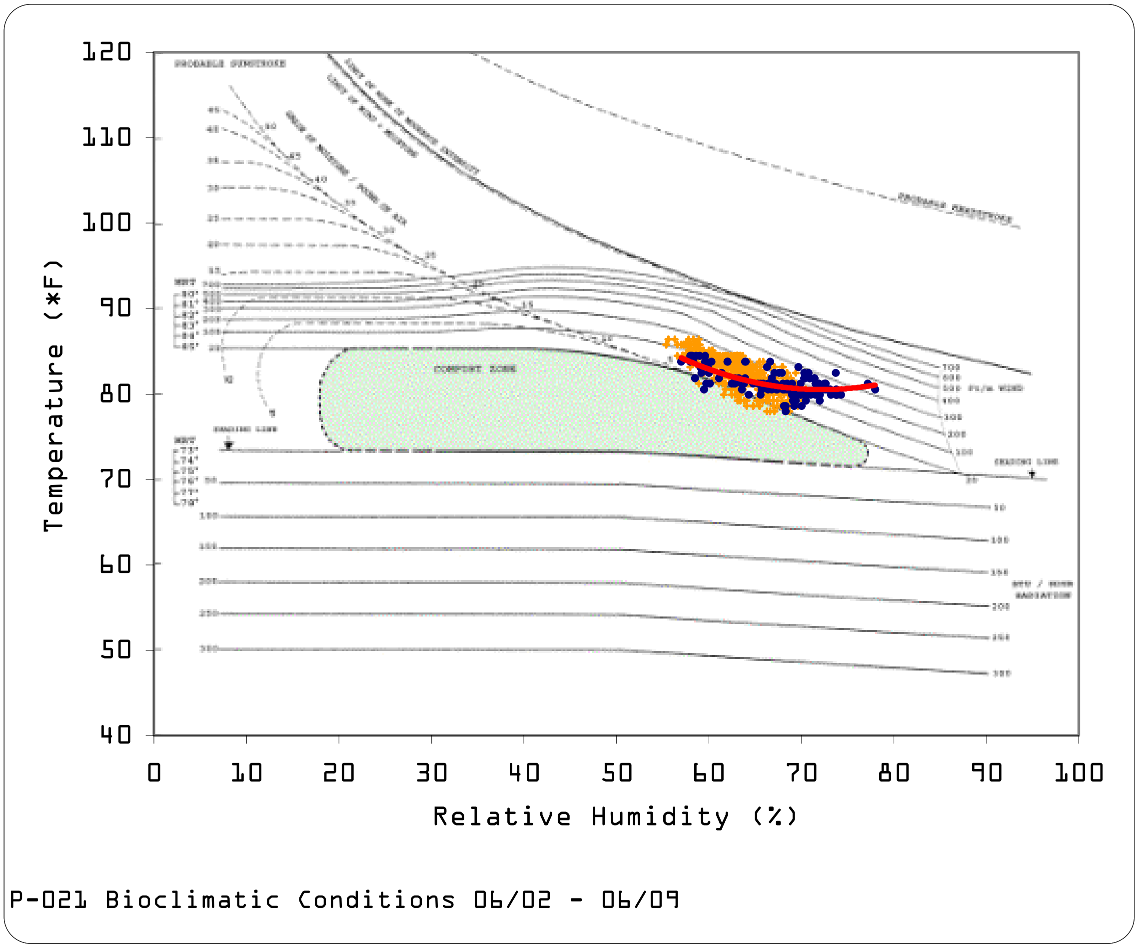

Fig. 24 - Bioclimatic Chart of P-021 from 06/02/03 to 06/09/03.

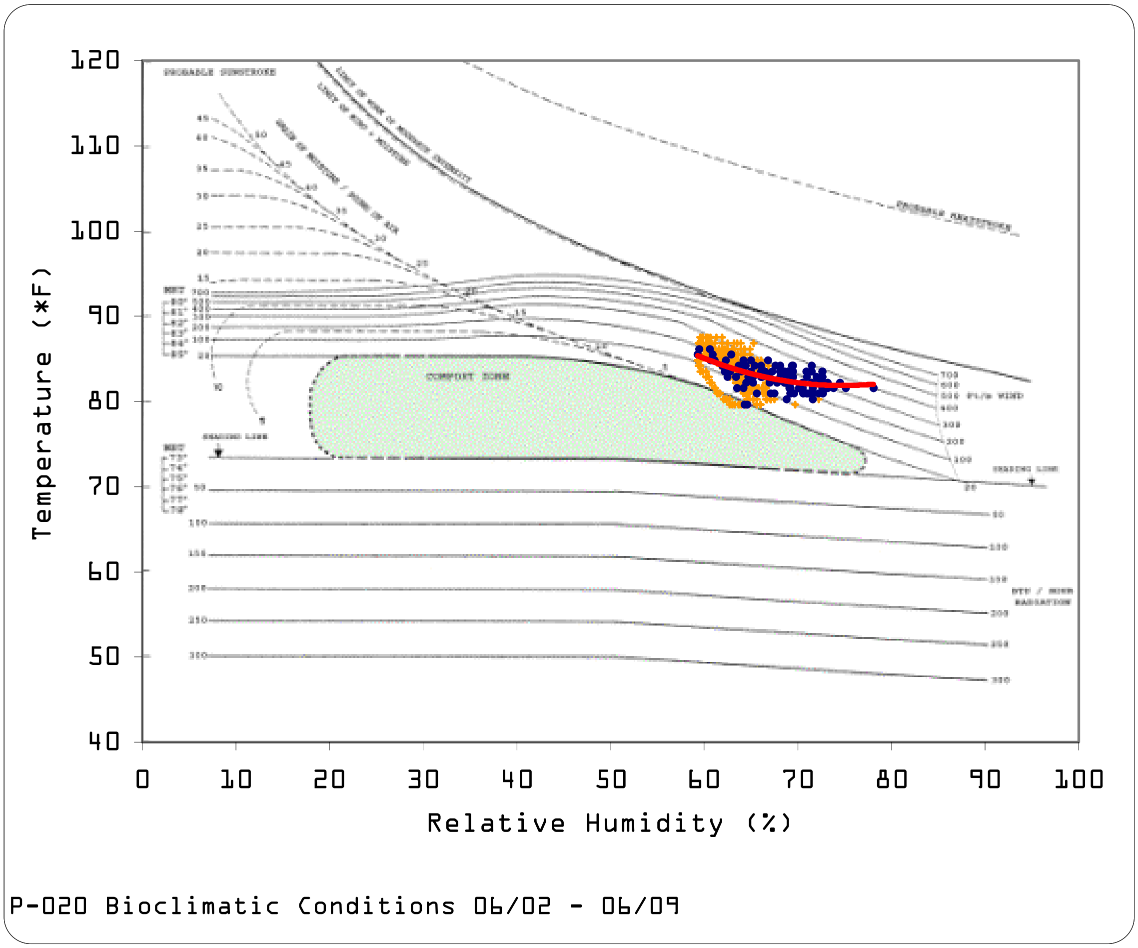

Fig. 25 - Bioclimatic Chart of P-020 from 06/02/03 to 06/09/03.

The temperature distribution graph for both portable shows the slight difference in temperature [Fig. 26]. Both portables have a very small interior diurnal temperature fluctuation, with maximum temperatures approaching 86°F around 1800.

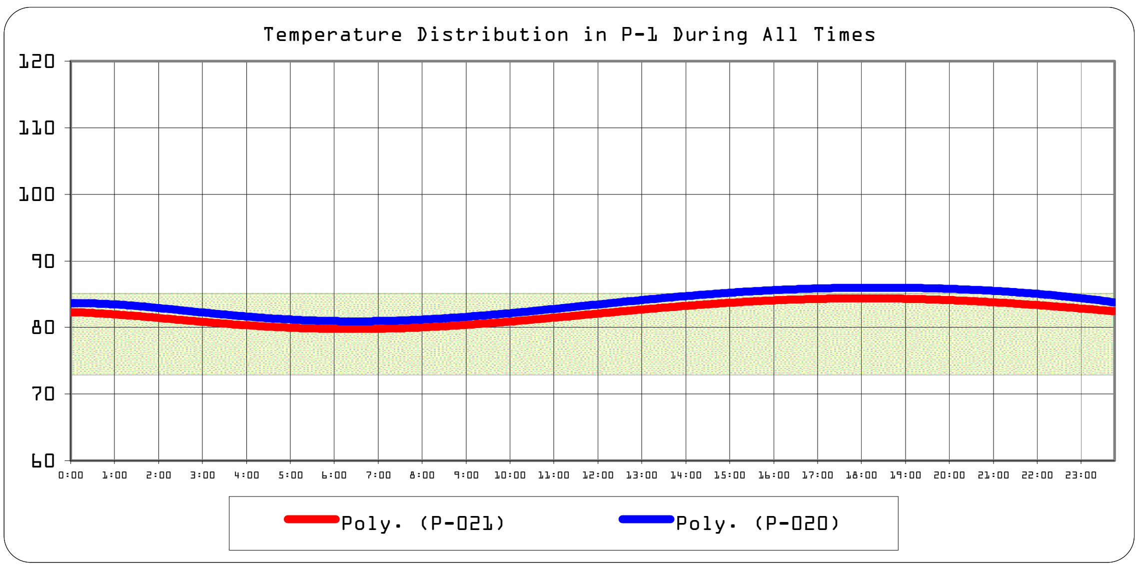

Fig. 26 – Temperature Distribution for P-020 and P-021 from 06/02/03 to 06/09/03.

The following table summarizes the statistical data of Portable P-020:

Table – 07: P-020 Thermal Statistics.

8 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	87.49	86.15
MIN. T	79.63	79.63
AVG. T	83.59	82.74
STDV	1.94	1.40

The following table summarizes the statistical data of Portable P-021:

Table – 08: P-021 Thermal Statistics.

80 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	86.43	84.44
MIN. T	77.97	77.97
AVG. T	82.15	81.33
STDV	1.88	1.53

2.3.4 - Portable TB-1 & P-3

Portable TB-1 was designed in 1997. It is original in that it is the only monitored portable with a 4 in. concrete slab on 6 in. of basaltic termite barrier (BTB). The construction is otherwise similar to portable P-25 in Waianae, with 6¼ in. fiberglass insulation in the ceiling. The surrounding of TB-1 has also been carefully landscaped by the instructor so that grass is actually growing around it. This can reduce the infiltration of dust (a common problem in portable classrooms) as well as cooling the ambient air via evapotranspiration.
Portable P-3 is similar to P-2 in construction.

The bioclimatic charts show that the occupied space of TB-1 remains relatively consistent in temperature and relative humidity during the monitoring period [Fig. 27], as seen from the well-centered data points on the graph; P-3, however, has widely-distributed data points, well off the comfort zone [Fig. 28].

It is obvious from a temperature distribution graph that P-3 has much higher diurnal temperature fluctuation than TB-1 [Fig. 29]. Temperature trend in P-3 reached 90°F around 1600, while in TB-1 temperature trend barely exceeded 85°F. In P-3, the temperature was recorded out of the comfort zone as early as 1200.

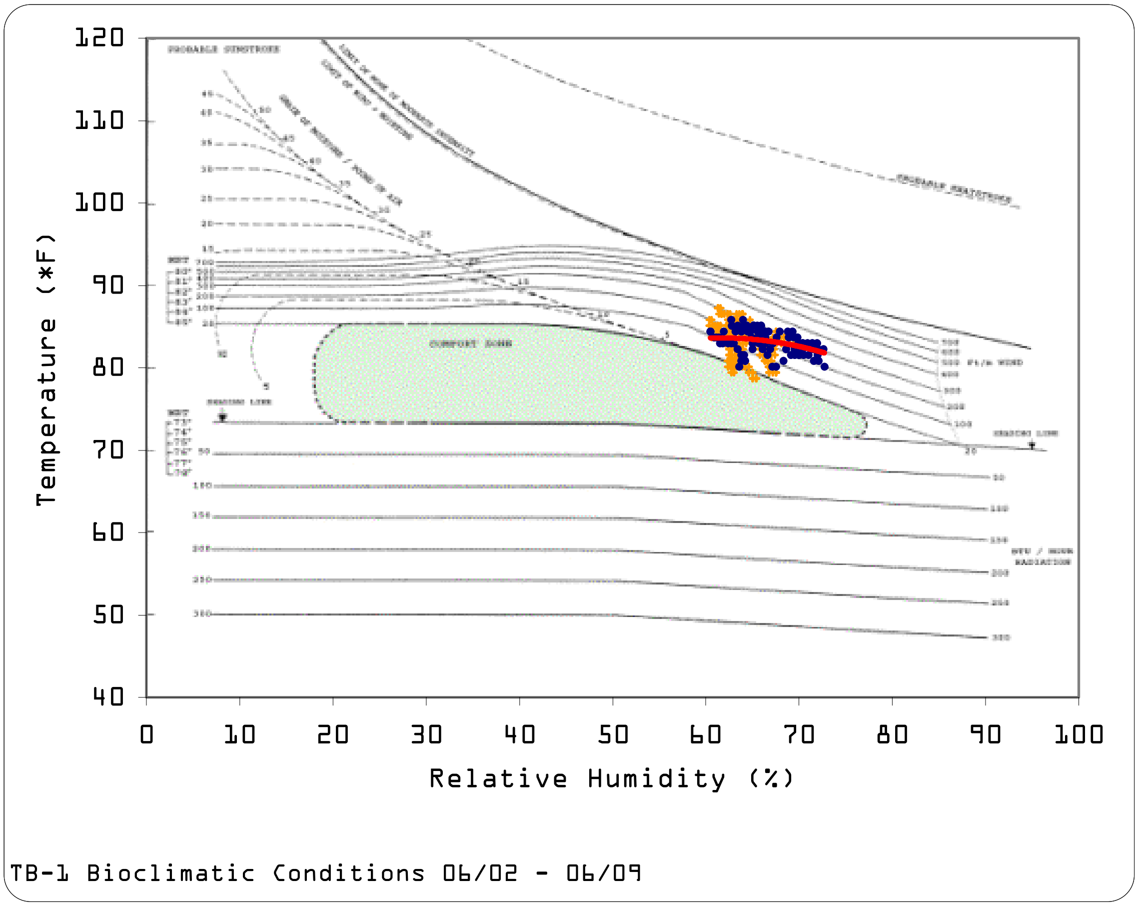

Fig. 27 - Bioclimatic Chart of TB-1 from 06/02/03 to 06/09/03.

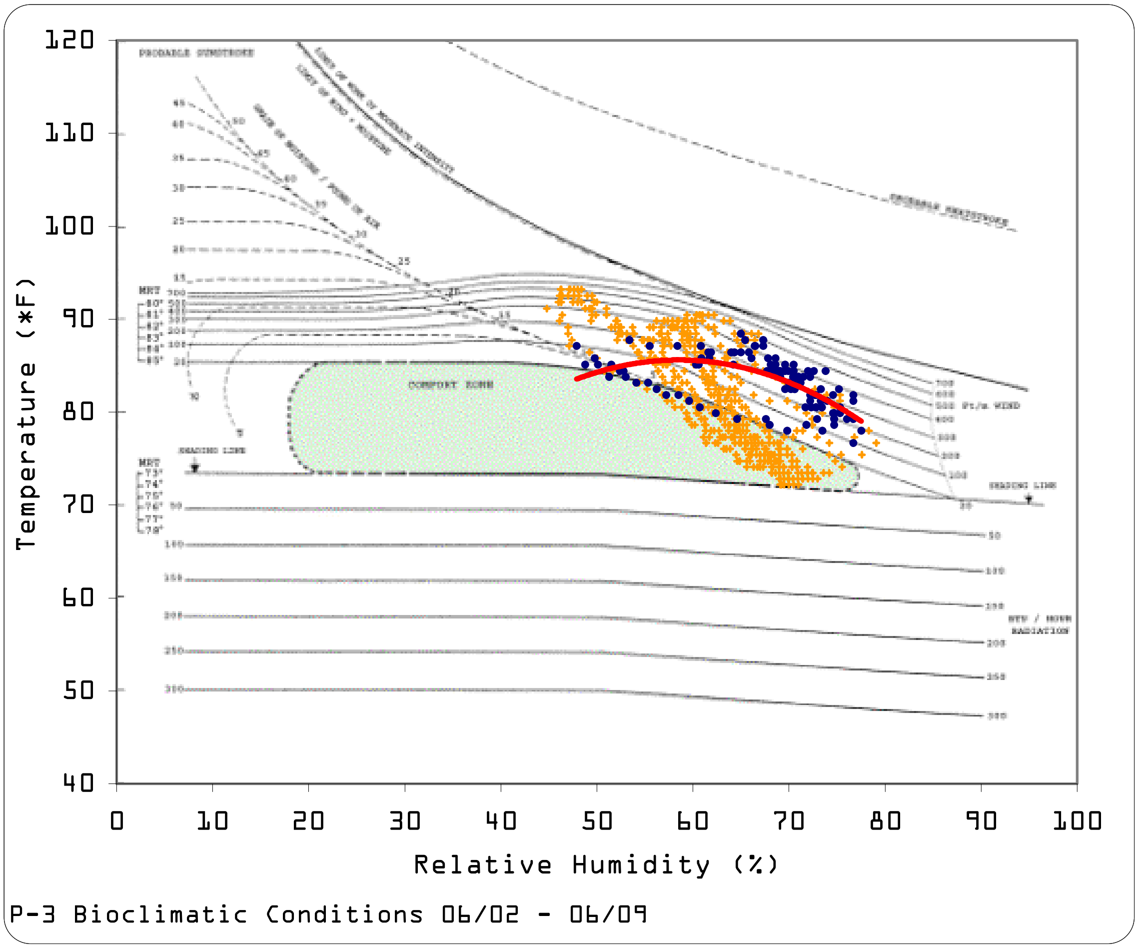

Fig. 28 - Bioclimatic Chart of P-3 from 06/02/03 to 06/09/03.

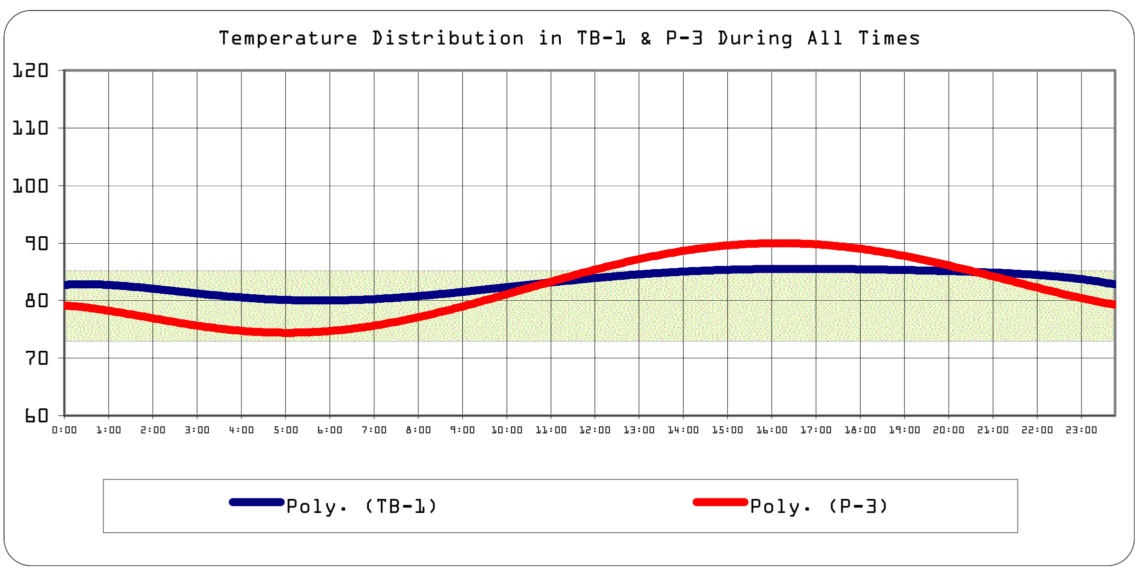

Fig. 29 - Temperature Distribution for TB-1 and P-3 from 06/02/03 to 06/09/03.

The following table summarizes the statistical data of Portable TB-1:

Table – 09: TB-1 Thermal Statistics.

80 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	87.28	85.83
MIN. T	78.71	80.12
AVG. T	83.16	83.05
STDV	2.09	1.39

The following table summarizes the statistical data of Portable P-3:

Table – 10: P-3 Thermal Statistics.

80 DAYS	ALL TIMES	OCCUPIED TIMES
MAX.T	93.22	88.44
MIN. T	72.20	76.68
AVG. T	82.02	83.21
STDV	5.55	2.64

It is interesting to note that the concrete portables have about a two hours thermal time lag difference with the two wood construction portables, possibly four with external temperatures. Also, and perhaps consequently to the aforementioned comment, both concrete portables have their all-time lowest temperatures occurring during the occupied time period.

2.4 – General Discussion

The above analysis provides good insight for assessing the efficacy of various portable construction types, building materials, and design strategies aimed at reducing heat gains. Following are some general comments that arose from the analysis:

During the first monitoring phase, from October to December, the efficiency of the insulated ceiling in P-25 is not directly evident. The insulation does seem to reduce the diurnal thermal fluctuation and extremes in high and low temperatures. However, it appears that the insulation has for effect to slow the heat transfer – in either direction. Thus, although it slows down some of the mid-day heat from entering the occupied space, it also slows the accumulated heat, generated by occupants, from escaping the building. In effect, the occupied space remains relatively warmer than P-26's during the cooler nighttime. This higher morning temperature remains about 2.5°F higher than in P-26 for most of the early hours of the occupied time, from 0800 to 1000. At 1100, the solar radiations are quickly increasing the interior temperatures of the non-insulated P-26, beyond the temperatures of P-25, by about 2.5°F. In effect, although the temperatures recorded in P-25 were not as extreme as the ones recorded in P-26, both portables have very similar average temperatures.
Psychrometric and bioclimatic charts do however show a noticeable difference between the two portables. P-26's extreme temperatures can exceed the comfort zone by as much as 5°F in at by end of the occupied time period, while P-25's temperatures exceed the comfort zone by no more than 2.5°F. Furthermore, Mean Radiant Temperatures (MRT) are more pronounced in P-26 than in P-25, where ceiling temperatures in excess of 100°F were measured. The insulated ceiling of P-25 can reduce this radiant temperature by 10°F.

During the second monitoring phase, from January to April, the remodeled portable P-1 was monitored and compared to its non-remodeled, adjacent counterpart P-2.
Although little is known about the exact construction details of P-1, it is clear and evident that its indoor environment is cooler than in P-2. It is not clear whether P-1 features insulated ceiling or walls, but the data show that night temperatures are in par with P-2. If P-1 is indeed insulated, this would demonstrate that adequate night flushing is occurring throughout the occupied space, thus getting rid of any accumulated heat. The convective heat system might, in the end, work solely during the night hours, when outdoor temperatures drop below indoor temperatures, and the photovoltaic fans are not operating.
During the occupied time, P-1's temperatures remain well within the comfort zone from 0900 until 1400, when P-2's temperatures exceed the comfort zone by as much as 4°F.
The cool air entering P-1 from the floor vents seems to drastically reduce internal temperatures.
Because the floor vents installed in P-1 deliver the cool air from underneath the portable, some environmental indoor air quality issues were raised by the research team. Presently, the crawl space of every monitored portable has been poorly maintained, partially due to lack of adequate accessibility. Litters, feral cats, mongooses, and fleas seem to all benefit from the protection of the portable crawl spaces. Feces, molds, and other potentially airborne pathogens could easily be drawn into the occupied space. Appropriate maintenance, drainage, and surfacing of the crawl space could help annihilate this concern.

The last monitoring phase, which took place in June, is interesting in that very different construction type of portables were monitored.
It is apparent from the data that the two concrete portables located on the grounds of Koko Head Elementary School have a very small diurnal temperature fluctuation. In fact, TB-1, in Kaimuki High School, also has a very small diurnal temperature fluctuation. This can be attributed to both the thick 6¼ in. insulation and the 4 in. thick concrete slab.
The additional thermal mass intrinsic to the 2 concrete portables adds an additional 2 hours thermal lag to the interior temperatures, compared to wood frame construction.
During the weeklong monitoring, the indoor temperature of the concrete portables remained between 78°F and 87.5°F – less than a 10°F difference.
During the same period, portable P-3 in Kaimuki, (wood frame construction and very responsive to exterior thermal fluctuation) experienced temperatures ranging from 72°F to 93°F: a 21°F difference.

It is obvious to the research team that the construction materials used in the portables are crucial factors to the thermal comfort of their occupants. Other important factors, such as orientation, color, and protection from the sun are also to be taken into consideration.
The following chapter presents results from the modeling of various heat-mitigating strategies; these results could be influential catalysts to spur prototypical design solutions.

3.0 – Modeling, Testing, and Recommendations

3.1 – Digital Modeling & Testing

Portables P-26 and P-25 were modeled into the Environmental Analysis Software ECOTECT from Square One Research PTY LTD[1] [Fig. 30].
The software makes use of Typical Meteorological Year (TMY2) weather data file to simulate thermal behaviors of the models under study. Although one should be cautious with the actual validity of the computed numbers (such as computed interior temperatures), the software allows efficiency evaluation of different strategies, when compared to a base model. For our study, the base model was the existing P-26, as this portable seems to be the least comfortable.

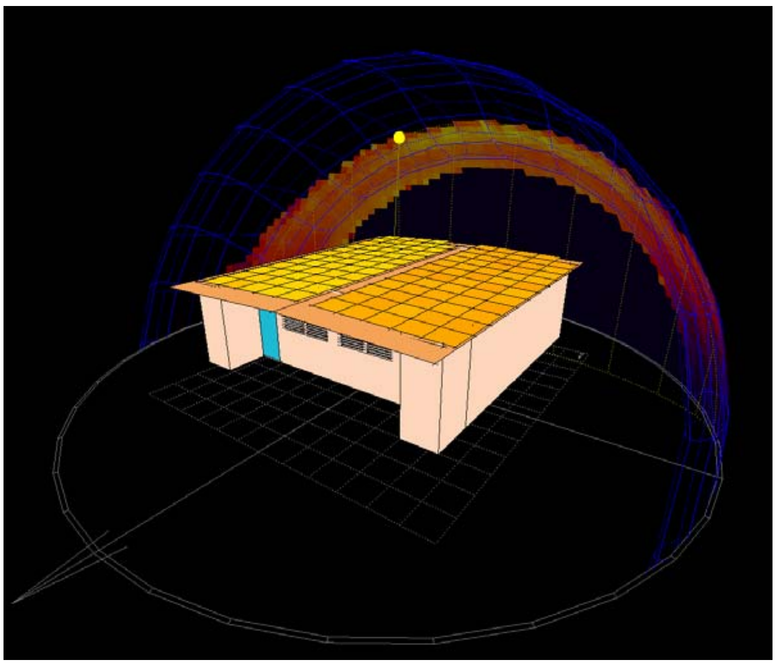

Fig. 30 – Solar Stress Simulation on P-26 using Ecotect.

For the simulation, a weather file derived directly from an existing TMY2 was loaded into the software. The data were compiled over a period of 30 years, and typical temperature and radiation data were selected to make up the overall weather file. Thus, while a designer will not be able to predict exactly how hot it will get in a particular space for a particular day of the year, the software will give a reasonable result based on data representative of that day. Hence, the software is more useful in comparing the thermal performance of one strategy against another, rather than to draw absolute results such as temperatures and cooling loads.

The thermal analysis done for the study included modeled interior temperatures during the hottest average day of the year (October 5th), annual percentage of comfort (the percentage of time interior temperatures felt within a comfort range set from 73 to 85 °F), sol-air effects (the thermal effects of solar radiations upon a material's surface), and the construction material heat-conductive properties. The analysis also included the cooling load necessary to bring the occupied space within the comfort range temperatures.

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[1] SQUARE ONE research PTY LTD. 2003. [www.squ1.com]

Occupant load (students generating heat) was also simulated, and incorporated to the model on a preset scheduled, representing the occupied time period.

3.2 – Heat-Mitigating Strategies

Solar radiation simulation under the Hawaiian latitudes (from Honolulu airport weather data) suggest that on an annual basis, the flat roof of a structure receives 39% of the total incident radiations, due to the high altitude of the sun in the sky throughout most of the year. Next, the eastern elevation of a structure receives 20% of the total insolation, followed by the southern elevation with 17%, western elevation with 16%, and northern elevation with 9% of the total incident radiations. The 4% difference between the eastern and western insolation is due to the increase cloud cover during the afternoons. Thermal modeling of the portable confirms these figures [Fig. 30]. This information is valuable in order to prioritize the building element on which heat mitigation is the most needed.

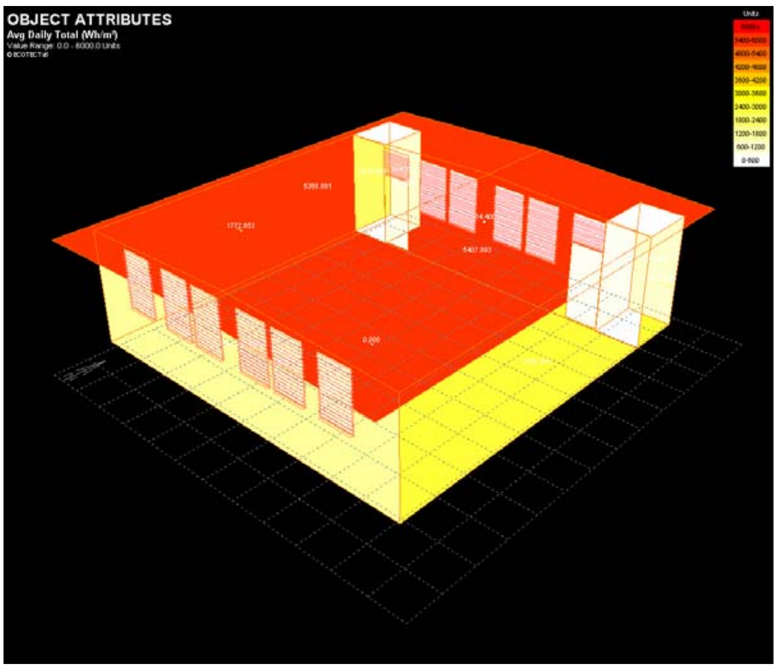

Fig. 30 – Surface Insolation incident to P-26.

Thermal simulation of the portables shows that the annual internal heat gained during the occupied time account for over one and a half time the combined gains of sol-air and conduction effects. Thus, since little can be done to reduce the internal occupant load, designers should keep in mind the efficiency of the building's fabric to rid itself of the accumulated internal heat.

Numerous heat-mitigating strategies were modeled using the thermal analysis feature of the software.
Strategies tested included various combinations of the following:

- White reflective coating on roof.
- White reflective coating on walls.
- Radiant barrier in ceiling and walls.
- Fiberglass insulation in ceiling.

- Double roof.
- Concrete slab and roof.

Overall, over twenty different combinations of heat-mitigating strategies were tested and evaluated against one another for a period ranging from 0800 to 1400.
The research team concluded that the best heat-mitigating designs incorporated a combination of strategies. The designs incorporating strategies that reduce the effect of sol-air temperatures while allowing heat conduction from inside out performed best.

The following describes different heat-mitigating strategies and general comments on their thermal performances when applied to portable classrooms.

Reflecting coatings and paints are perhaps the first and simplest approach to avoid the effect of solar radiations. Because the majority of the external heat gains come through the roof surface, an application of reflective paint, membrane, or built-up roofing can reduce the overall fabric thermal gain by 70%.
To further reduce interior heat gained through wall surfaces, all facades of the portables can be painted with a reflective color. Although all colors will give the walls a similar absorptivity to long wave radiations (from adjacent buildings, ground, etc.), some colors will reflect solar radiation (short waves) better than others[2]. Interestingly, studies demonstrate that the most reflective colors to solar radiations are those approaching infrared and, on the other end of the scale, those approaching ultra violets[3].
The following scale can provide an easy guide to choosing an appropriate paint color:

Radiant barriers, when properly installed, are very efficient at blocking the heat gain caused by the radiation of sun-heated materials such as a roof deck (by about 95%). They are unfortunately as efficient to block the radiant heat transfer flowing from inside out, thus inhibiting the internal radiant heat gain from escaping the occupied space.

Fiberglass insulation and similar products also perform very well to minimize the exterior heat entering the occupied space. Rather than reducing the radiant heat gain as radiant barriers do, they reduce conductive heat gains. A 3.5 inch thick fiberglass blanket reduces heat gain similarly to a radiant barrier; although it does not physically block the radiation from the roofing deck, it reduces the heat transmission between the hot attic and the living space. It also reduces the heat exchange between inside and out, creating a thermos effect.

Double roofs are used to stop solar radiations from reaching the occupied interior. They are, in effect, the most efficient design strategy in reducing the surface temperature of the building's exterior fabric. When building materials reach high temperatures, the thermal transmission potential increases between the indoor temperature and the envelope. The rate of heat-flow through an assembly is proportional to the temperature differential between both sides of the assembly. Reducing the material temperature on one fabric side of the assembly will reduce the rate of heat flow.
Another advantage of double roof is the cavity created between the two roof decks. This cavity can be used as a ventilation space, where thermal-convective and wind-driven airflows can rid the roofing assembly of internal heat. In this regard, the double

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2 Moore, Fuller. 1993. Environmental Control Systems. New York: MacGraw-Hill, Inc.

3 Givoni, Baruch. 1976. *Man, Climate, and Architecture*. London: Applied Science Publishers.

roof system acts as a very efficient vented attic, offering some thermal buffering to the occupied space below. Vented double roofs can reduce the solar load by over 95%[4].
Double roofs should be designed so the outer skin (the topmost roof deck) is highly reflective to solar radiation, yet has a low emittance, as high-emittance materials can readily reradiate the heat that they do absorb. A reflective white membrane would work well for such a surface.
The cavity of the double roof should have a low average emittance value to intercept radiant heat flow from the upper roof to the lower roof. A radiant barrier applied to the underside of the upper roof deck will fulfill this requirement.
The outer surface of the lower roof (facing the cavity), can be left untreated, allowing free flowing of heat from inside out. A conductive, non-metal, material would help to rid the occupied space of its internal heat more efficiently than a low-conductivity material (due to the double roof, that material would not absorb heat from solar radiation). Such conductive materials, however, are usually dense (concrete) compared to the low-conductivity property of plywood.

Concrete elements, such as roof and slabs can be advantageous due to their high conductivity and density. Although high conductivity might seem undesirable in a hot climate (heat flows more readily from outside to the indoor space), it can be used effectively to conduct the internal heat gain out of a portable classroom. As the internal temperature rises with the occupancy, the thermal differential between outside and inside can become negative (hotter inside than outside), allowing heat to flow toward the exterior of the building's fabric. Under this condition, a conductive material will facilitate this heat exchange.
In addition, concrete has a high heat capacity (ability to hold heat), which, when combined with high conductivity, makes the material act as a thermal mass. This property increases the energy needed to heat up (and cool) the material, in effect slowing down its rise in surface temperature and overall MRT. While the indoor temperature of P-26 (wood construction) reaches its maximum about 2 hours after the outdoor maximum temperature, the maximum indoor temperature of the concrete portables at Koko Head Elementary School reaches its maximum up to 4 hours after the maximum outdoor temperature. Since the portables are not occupied during the evening hours (time at which the concrete would start radiating the absorbed heat from the day), thermal mass can thus be used to absorb exterior heat (from solar radiation and air temperatures) as well as internal heat from occupancy and equipment.
This strategy is widely used in arid areas, where daily temperature fluctuations are large (hot day, cold night). In climates with little daily temperature fluctuations, like Hawaii, the surfaces of the thermal mass will tend towards the average daily temperature[5], which, in the case of Hawaii, is quite comfortable all year around (between 71°F and 80°F) [Fig. 32]. Modeling shows that thermal mass effect can be beneficial under some hot and arid conditions that occur on the leeward side of the islands. Fig. 33 shows by how much the comfort zone can be increased through thermal mass in portable P-02, in Waianae. The data points plotted on the psychrometric chart represent the occupied time (weekdays, 0800 – 1400) of portable P-02 during the month of March. The data are seen as cumulative frequencies, i.e., the darker olive hues represent higher occurrence. The blue parallelogram is the comfort zone without thermal mass. The red parallelogram is the extended comfort zone with thermal mass.

[4] Brown, G. and DeKay, M. 2001. Sun, Wind & Light. New York: John Wiley & Sons, Inc.
[5] SQUARE ONE research PTY LTD. 2003. [www.squ1.com]

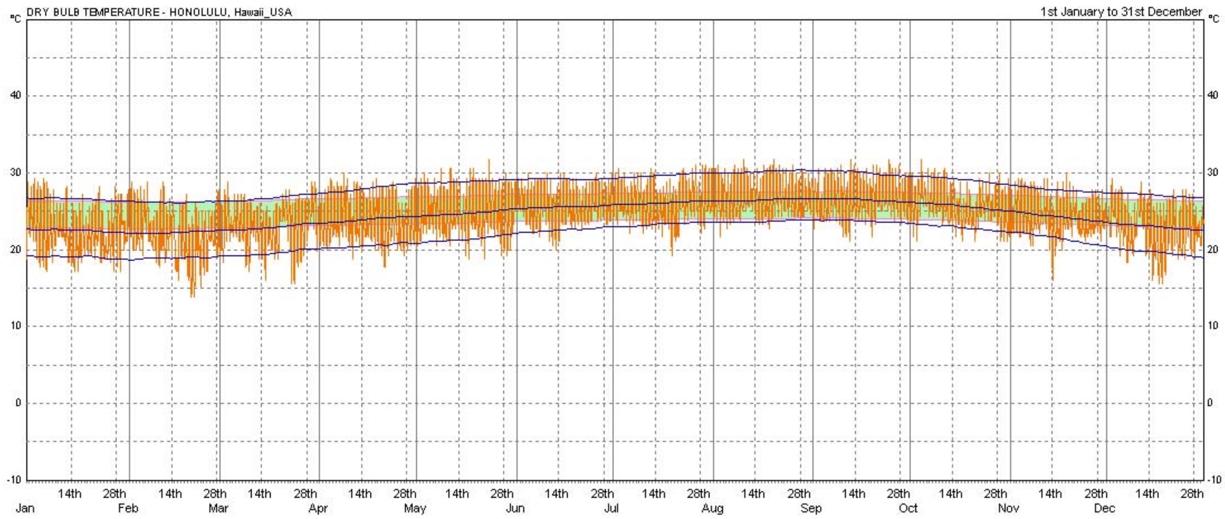

Fig. 32 – Annual Temperature in Honolulu, Hi.

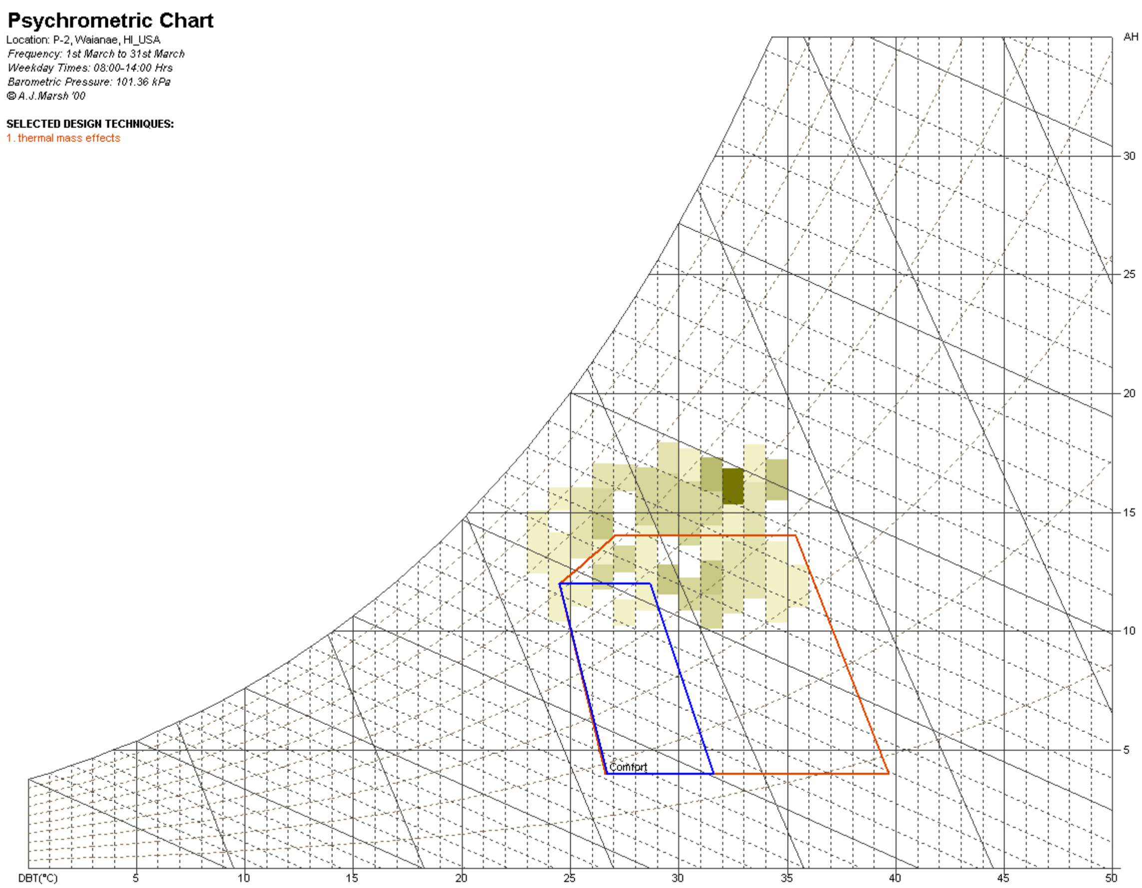

Fig. 33 – Increased Comfort Zone in P-2 through Thermal Mass Effect.

Another strategy is the use of night flushing, or night ventilation. Such strategy implies cooling any thermal mass located within the interior space during the night. Since thermal mass re-radiate the absorbed heat during the night (because of the thermal lag), ventilation in direct contact with the thermal mass will rid the space of the accumulating heat while cooling off the radiant element.

Night flushing can also be very effective when the building's fabric has a high insulating (thermal resistance) value, such as with fiberglass batt. In this case, the night ventilation helps flushing the internal heat that accumulated during the day and was unable to flow out through the insulated building's fabric.

Portable P-01 is equipped with floor vents that may allow enough convective airflow during nighttime to flush out undesirable internal heat.

Security issues with open venting systems at night need to be assessed and resolved during the pre-design stage.

Traditional natural ventilation strategies should also be considered. These design strategies have been studied in detail in various publications. The *Field Guide for Energy Performance, Comfort, and Value in Hawaii Homes*, published by the Hawaii Department of Business, Economic Development, and Tourism in association with the AIA Committee on the Environment, provides indoor ventilation strategies[6].

Fig. 34 shows by how much the comfort zone can be increased through natural ventilation in portable P-26. The data points plotted on the psychrometric chart represent the occupied time (weekdays, 0800 – 1400) of portable P-26 during the month of November. The blue parallelogram is the comfort zone without ventilation. The teal parallelogram is the extended comfort zone through natural ventilation, with an airflow velocity of 100 ft/m (0.5 m/s).

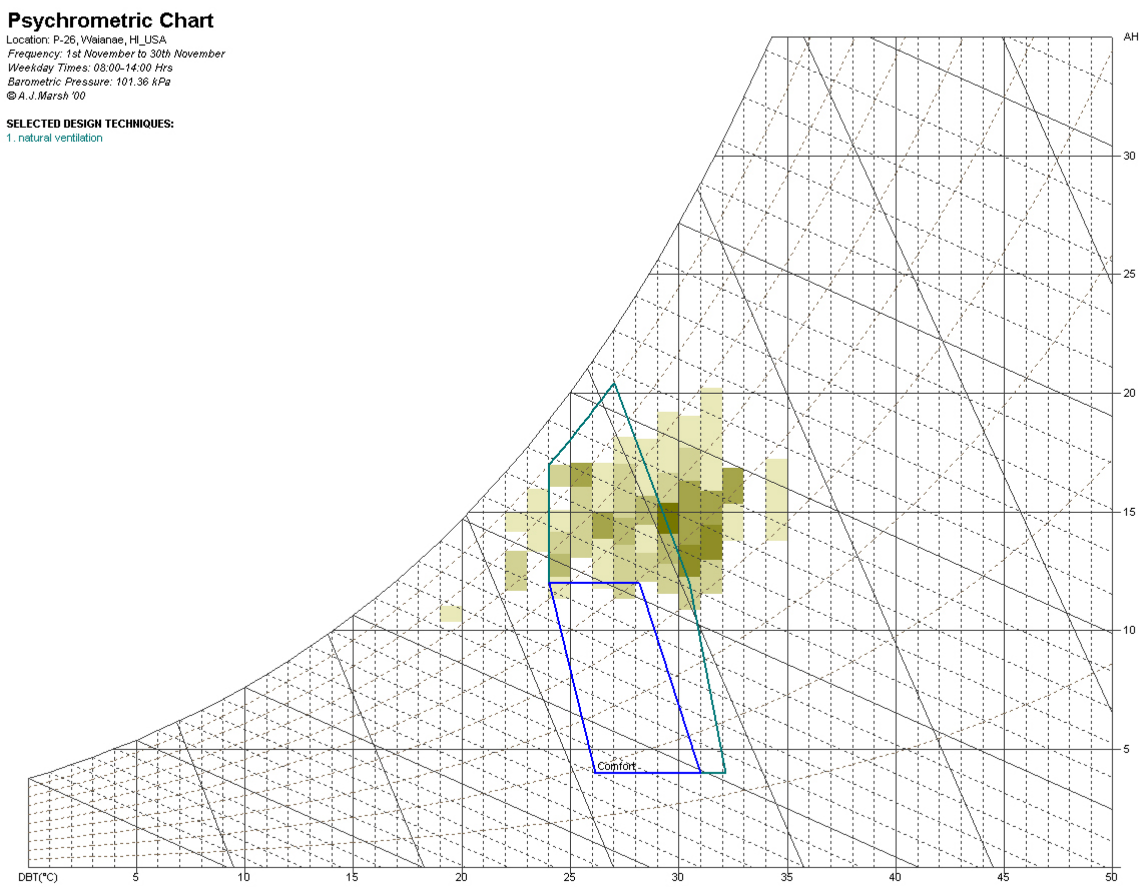

Fig. 34 – Increased Comfort Zone in P-26 through Natural Ventilation.

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[6] State of Hawaii DEBEDT & AIA COTE. 2001. *Field Guide for Energy Performance, Comfort, and Value in Hawaii Homes*. Honolulu.

Fig. 35 is an annual wind rose from the Honolulu airport. This chart shows the frequency of the wind for a particular direction and speed; it can be used to orient the building appropriately. Note that this wind chart was compiled from weather data recorded at the airport and might not be relevant in other part of the islands. Always refer to local wind data, where available, to ensure an appropriate building orientation.

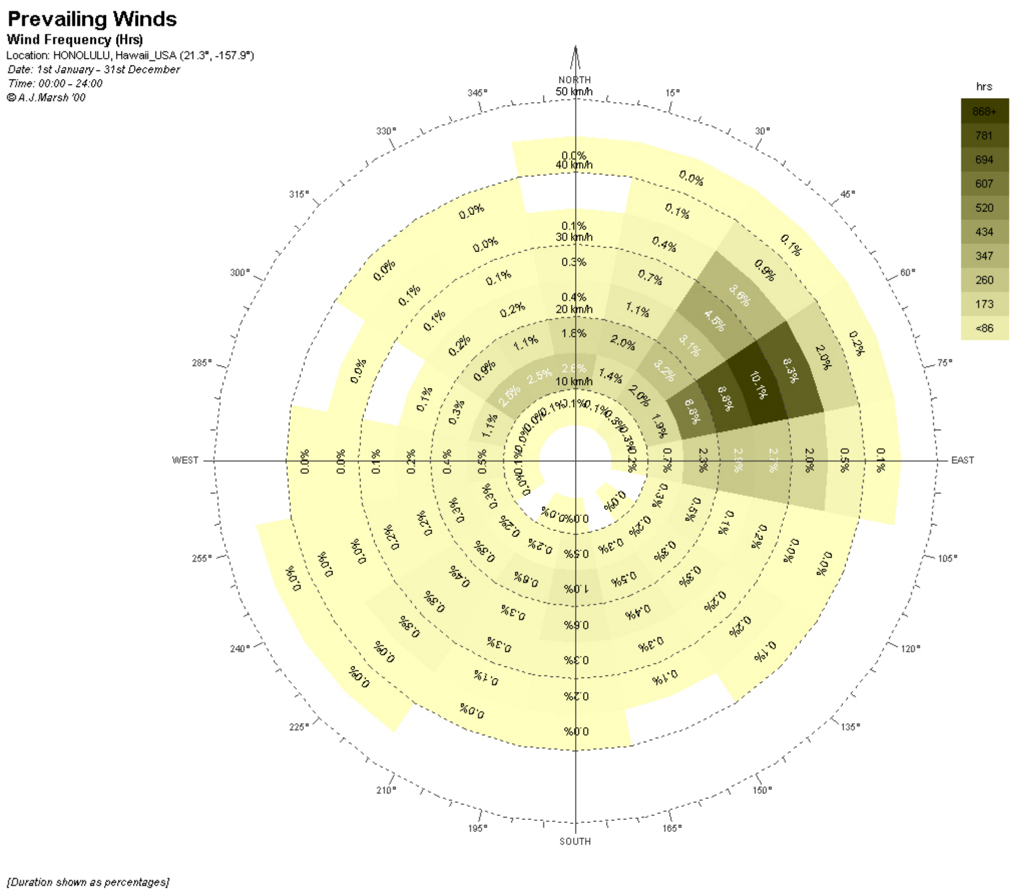

Fig. 35 – Annual Wind Rose for Honolulu, Hi.

Orientation of the structure is an important component of any heat-mitigating design scheme. Proper orientation will allow prevailing winds to enter the building and provide for natural cross ventilation.

Orientation of the building to minimize solar heat gains should also be combined with the best ventilation orientation. On an annual basis, the southern and northern façade of a structure receives a combined 25% of the total incident radiation - 10% less than what is received on the combined eastern and western elevations. It is thus important to orient the longer side of the structure on an east-west axis. Under a climate similar to Honolulu (where the meteorological data used in this study were recorded), the optimum building orientation to reduce solar radiations is 17.5° west of south. This was calculated assuming overheated period throughout the year. This westerly shift occurs due to the increase of cloud cover during the afternoons [Fig. 36].

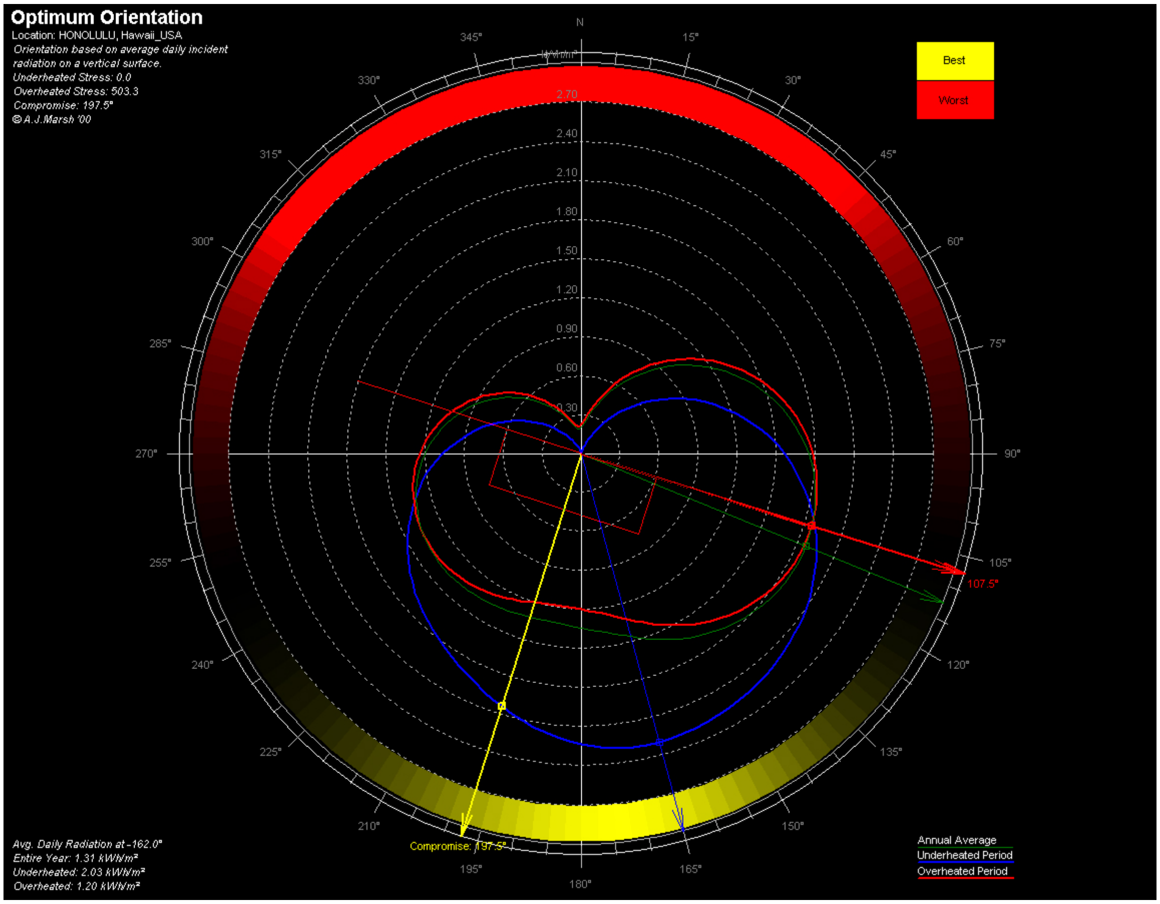

Fig. 36 – Optimum Building Orientation for Honolulu, Hi, for Solar Gains Mitigation.

The proportion of the building (the ratio of the long side to the short side) can also have an influence on the overall thermal gain of the structure[7]. Under a climate similar to Honolulu's, with the building long side orientation ± 30° from due south, a ratio of 1:1.5 offers a good balance of design proportions and thermal mitigation [Fig. 37]. Thus, a portable 30 feet in width by 45 feet in length and oriented on an east-west axis would receive less thermal stress that a portable of similar floor area, but different length/width ratio.

[7] Olgyay, Victor. 1963. *Design with Climate*. Princeton, N.J: Princeton University Press.

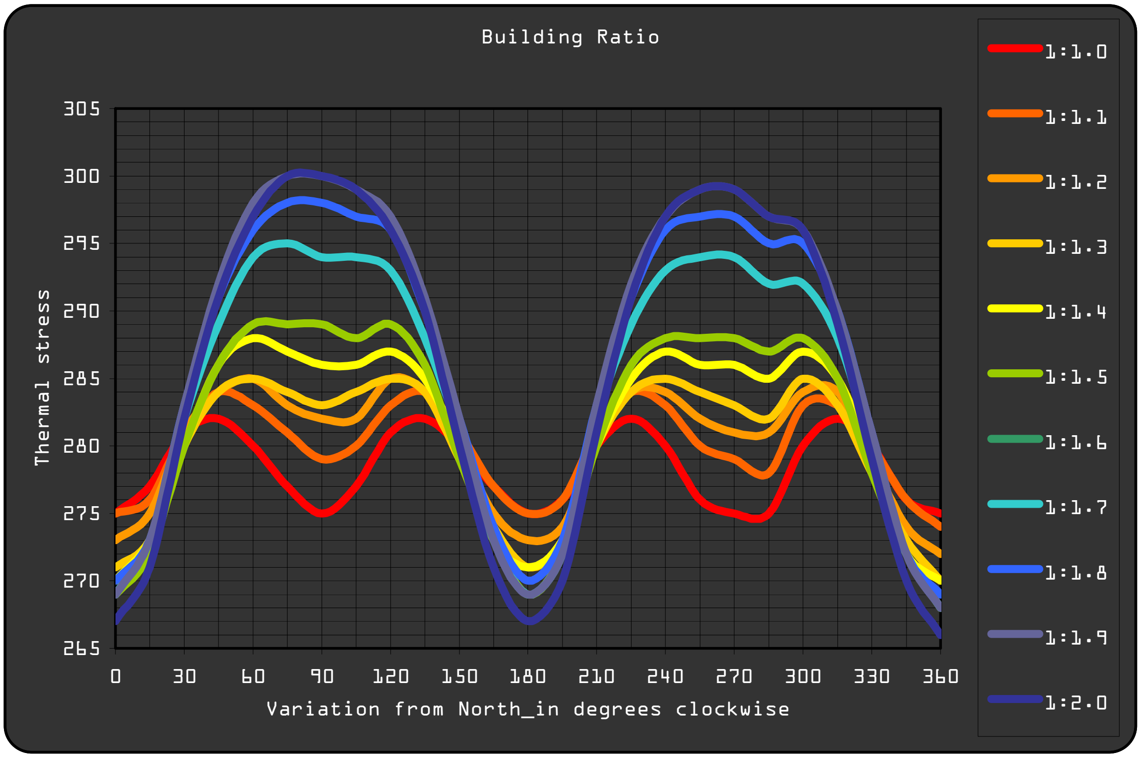

Fig. 37 – Solar Stress versus Building Proportion Ratios.

Overhangs should also be considered to minimize the incident radiation on the structure's facades. During the winter months, the southern elevation receives up to 28% of the overall incident radiations, while temperatures are only slightly lower than during summer time (< 10°F). Consequently, it is important to protect the southern walls from solar radiations as practically as possible.

Because the lowest winter sun-angle facing the southern elevation is still relatively high (~45°), a fully protective overhang would have to be as deep as the building's height. Due to this design impracticality, designers need to compromise the extent of the overhang with the wall assembly construction that will receive solar radiations. Strategies such as reflective paint and/or radiant barrier must then be used to mitigate heat gains.

Eastern and western facades receive a combined 35% of the total annual incident radiations. It is, however, difficult to intercept the low sun-angles incident on these surfaces with horizontal overhangs. These surfaces also need to be fitted with heat-mitigating features.

3.3 – Physical Modeling & Testing

In addition to computerized thermal simulation, the Environmental Research & Design Laboratory continuously monitors large-scale structures fitted with various heat-mitigating strategies [Fig. 38]. An evaluation of the strategies' efficiency under the Hawaiian climate can thus be studied.

Fig. 38 – Thermal Monitoring on Large-Scale Models – UH School of Architecture.

Note that these structures are uninhabited therefore, no internal gains are generated. The following heat-mitigating strategies have been studied for over 15 weeks:

- Radiant Barrier
- Cellulose Blown insulation [R 20]
- Vented Attic
- Cellulose insulation + Radiant Barrier
- Dark Roofing Material
- Grey Roofing Shingle

The performance of the thick (R 20) cellulose insulation is marginally superior to the radiant barrier. Test results show that a radiant barrier or an R 20 ceiling insulation can reduce the indoor temperatures by an average of 4.5°F from the exterior temperature. Attic temperatures are however very different: Since the insulation stops the heat from getting into the living space, it builds up in the attic, reaching temperatures in the 120°F, compared to a maximum temperature of 92°F in the attic fitted with a radiant barrier.

Venting an attic can also be an effective heat-mitigating approach. Test results show that a vented attic could lower occupied space temperatures by an average of 2°F from a non-vented attic. The cooling efficiency is directly related to the outdoor temperatures. Consequently, as exterior temperatures rises, the cooling efficiency decreases. Vented attic does not mitigate radiant heat from the roof deck. It however rids the attic space of the heat gained via convective thermal flow accumulating in the attic.

Interestingly, preliminary test results (2 weeks of data) show that a combination of radiant barrier and blown cellulose insulation (R 20) does not have the combined performance of its separated constituents. This combination of strategies resulted in an average indoor temperature increase of 1.5°F from the outdoor temperature, compared to the sole use of insulation. This can perhaps be attributed to a lack of heat flow conduction from the building outwards. Nonetheless, the attic temperatures decreased by 2.5°F from outdoors temperatures, due to the radiant barrier.

4.0 – Design Guidelines

4.1 – Improving Existing Portables

The environmental conditions in certain portables on the island are far from adequate. It is obvious from the recorded data, field surveys, and personal interviews, that learning, as well as teaching, is extremely impaired by the uncomfortable conditions experienced in the classrooms. It is difficult to teach children, advocate, and promote the benefits of education in environments that demonstrate disregard to their well-being and intellectual performance of its occupants.

Portable classrooms as old as 37 years old have been monitored in this study.
While newer portables are being built, the effectiveness of their design's heat-mitigating strategies and their overall energy efficiency is dubious. Some of the new portables have greater heat mitigating ability but, portables designed in 2000, 34 years after the oldest monitored portables, still performed poorly under hot weather conditions.
The "quick fix" of fitting air-conditioning units to old portable classrooms is too often considered. The existing portables were not designed to be air-conditioned. Their fabrics, as well as their windows, are far too permeable to make air-conditioning an efficient solution, thermally and economically speaking.
Instead, a more appropriate approach is to design portable classrooms that could keep their occupants comfortable for most of the year. An air-conditioning unit could be used during times were passive heat-mitigating strategies are not sufficient to keep the occupied space within a comfort range. Passive cooling strategies are functional throughout the year: during moderate weather, they provide a comfortable learning environment; during hot weather, they increase the efficiency of any air-conditioning units.
Where air-conditioning units are installed, it is important to have individual thermostat in each classroom. These allow for a more precise control of the classroom's thermal environment as experienced by its occupants. This individual control saves energy by eliminating unwanted and unnecessary space conditioning[8]. It is important to educate the occupants, such as the instructors, on the proper functioning of the system control.

Other design concerns raised by portable classroom instructors during interviews were also recorded to complement the thermal comfort issues.
Dust blowing into the classrooms was a concern that was mentioned a few times by different instructors. Since the simplest way to deal with this problem is to close the windows, the classrooms become either too hot or too dusty.
Privacy, interestingly, was also a raised issue. Distractions from the outdoors oblige instructors to close the windows to maximize student's attention. In other cases, students themselves close the windows to avoid their peers to see them in certain courses, i.e. special education.
These various concerns should be addressed when designing portable classrooms.

The research team noted that the light levels in most portables were generally appropriate to classroom tasks. A good natural lighting scheme can, nevertheless, reduce internal load by minimizing the use of electric lighting, as would efficient lighting fixtures (compact fluorescents bulbs, T-8 etc).

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[8] Paladino Consulting LLC. 2001. LEED reference Guide 2.0. USGBC. [www.usgbc.org]

4.2 – Design Guidelines for Hawaii's Portable Classrooms

The Environmental Research & Design Laboratory team tested the design recommendations of section 3 and developed the following guidelines from those results, in order to improve portable classroom conditions in Hawaii.

The heat-mitigating strategies described in the preceding chapter should all be considered and evaluated for the design of any newer portables.
To achieve acceptable thermal comfort inside portables, multiple cooling strategies will have to be used. Protecting the roof and walls from solar radiation, increasing natural ventilation flows, and minimizing internal heat gains are the three major recommendations. Once these passive strategies are in place, only then should an active cooling system be incorporated into the design. This approach will ensure the best energy-efficiency, economic feasibility, and human comfort inside the portables.

As seen in the previous chapter, solar control can be achieved in various ways, but the designer should prioritize the protection of the roof area:

- Double roofs are the most effective way to reduce the solar gains on the structure's roof (95-100% reduction). Modeling results show that the internal temperature of portable P-26 could be reduced by approximately 4°F* and the occupant comfort increase by over 30%* with an efficient double roof (reflective roof, radiant barrier, untreated plywood lower level).
- Reflective roofing is the first step to any heat mitigating design strategies. It can reduce the solar heat gains by 70% to 85%, reducing the temperature of portable p-26 by a little more than 2°F* and increasing the occupant comfort by over 15%*.

* During the occupied hours of 0800-1400 on weekdays.

Heat-mitigating strategies to reduce solar load on the structure's facades are important, although not nearly as effective as the roof-applied strategies because most structures are equipped with some kind of overhangs, limiting incident insolation on the wall surfaces. Because overhang cannot be practically long enough to shade the entire facade, it is highly recommended to apply radiant barrier or insulation within the walls and a reflective paint to the surface.

- Overhang / Shading devices will protect the upper portion of the facades, mostly the south and north (in summer) façade. Overhangs have little effect on the east and west façade. These walls must be treated with other strategies.
- Reflective paints, radiant barrier, or insulation in walls will reduce the indirect solar gains to enter the structure. Radiant barrier in walls, as well as reflective paints could reduce the indirect solar gains in P-26 by 3 to 4% (p-26 already features a light-color paint). Because insulation and radiant barrier also keep the heat in, care should be taken to reduce internal gains (efficient lighting scheme) and increase ventilation as much as possible.

Natural ventilation of the structure should be a major aspect of the design. "*At the site scale, admitting a desired resource is more important than blocking an undesirable force.*"[9] Indeed, while design strategies can be applied to block incident insolation, little can be done to naturally ventilate the structure if wind access is denied. Thus,

[9] Brown, G. and DeKay, M. 2001. Sun, Wind & Light. New York: John Wiley & Sons, Inc.

orientation of the building to take advantage of the airflow, the *limiting factor*, should be the shaping force behind any design in Hawaii.
Fortunately, the wind direction in Hawaii is quite predictable. The trade winds flowing in a northeast - southwest direction can be efficiently captured by a structure facing (long side) a slight southwestern direction, as discussed in the previous chapter. This orientation would not only reduce thermal gain from incident radiation, it would also allow the perpendicular of the openings on the north and south sides to be within 40° of the prevailing winds. "Variations *in orientation up to 40° from perpendicular to the prevailing wind do not significantly reduce ventilation*."[10]

Internal heat gains, from occupants and equipment (lighting, computers, etc...) presently account for most of the overall portable P-26's thermal heat gains. This assumes occupancy of 22 students doing sedentary activity (seating) from 0800 to 1400 during the year's weekdays, and a sensible heat gain from equipments of 10 watts per m^2 (conservative). Computer simulations show that in August, internal heat gains are equal to 73% of the total fabric gains (conduction + indirect solar), while they amount to over 18 times the total fabric gains in February. It is thus important to assess the efficiency of the lighting equipment and the daylighting strategies in the classrooms to reduce internal gains as much as possible.
A well-designed daylighting scheme will reduce the amount of electrical light usage and can thus reduce the heating load of the building.
Increasing the efficiency of the light fixture will also minimize the amount of heat generated. Modern T8 fluorescent lamps, coupled with a rapid-start electronic ballast, can produce 87 lm/W and last over 20,000 hours[11]. This compares to 59 lm/W for T12 fluorescent bulbs working on electromagnetic ballasts.

4.3 – Cost Estimates

The research team took on the task to estimate the costs associated with the retrofitting of existing portable classrooms, to achieve adequate comfort levels.
Portable P-26, one of the least comfortable structures in the study, was chosen as the baseline model on which to estimate construction costs.
The portable has the following measurements:

- Floor area = 895 square feet
- Walls area = 1011 square feet
- Roof area with overhangs = 1326 square feet

The labor costs were calculated with a $75/hour contractor wage.
Some estimates were calculated with the *Sweet's Unit Cost Guide 2002*[12].

- Double roof = no less than $9,500
- Reflective roof coating = no less than $1,600
- Reflective wall painting = no less than $1,600
- Reflective modified bitumen on roof = no less than $3,000
- Radiant barrier on ceiling (includes second ceiling) = no less than $4,000
- 3½ inches fiberglass insulation (includes second ceiling) = no less than $4,000
- Radiant barrier in walls = no less than $2,800

[10] Givoni, Baruch. 1976. *Man, Climate, and Architecture*. London: Applied Science Publishers.
[11] Egan, M. and Olgyay, V. 2002. Architectural Lighting. Boston: McGraw-Hill Companies, Inc.
[12] Marshall & Swift. 2002. Sweet's Unit Cost Guide 2002. New York: McGraw-Hill Companies, Inc.

These various heat mitigating strategies retrofitting costs reflect an estimate, including only labor and material costs.

4.4 – Economic Feasibility of Portable Retrofit

The research team unanimously feels that the retrofitting of existing portable classrooms is economically prohibitive. While the sole construction of a double roof could decrease the internal temperatures by a few degrees and extent the comfort level of the occupants, it will not by itself, provide a comfortable learning environment during the hottest months of the year. To achieve such challenging goal, multiple strategies ought to be implemented, including solar radiation mitigation, natural ventilation, and efficient lighting. This can hardly be achieved with the existing portables, of which the orientation is determined by the overall campus master plans rater than the direction of the prevailing winds.

The addition of air-conditioning units to existing portable would certainly be the least cost-effective option, due to the lack of airtight construction.

5.0 – Conclusions

The monitoring of a few portables confirms the intolerable thermal conditions the students and instructors experience during a majority of the year.
Indoor temperatures reaching the low nineties during many months, even as late as November, are unacceptable. Mental capacities are highly impaired, irritability is increased, and learning becomes as challenging a task - and so does teaching.

The construction type of the monitored portables varies.
Wood-type construction allows far too much heat in during the days, but cools off quite rapidly over night.
Insulated portables reduce solar heat gains, but also keep internal gains, which can be higher than solar gains. These portables do not cool off as much during the night. Natural ventilation scheme is thus extremely important in this type of construction, to flush the accumulated internal gains.
The demonstration cool portable of Virginia McDonald has the coolest temperatures of all portables. Its insulation reduces heat gains during the day, while forced ventilation from floor vents provides relief during the daytime and flushes out accumulated internal gains during the night via convective flow. Attention should be focused on the source of air intake, as indoor air quality could be fouled by potential pathogens.
The concrete portables show very little daily variations in temperature. Peak indoor temperatures occur quite late in the day, offering certain advantages. The concrete mass seems to absorb some of the internal and solar gains, and release it during the night. Natural ventilation is also important in these portables, especially during the coolest times of the night, in order to help the mass riding itself of the stored heat.
The on-slab portable features high R-value insulation, which helps reduce its solar gains considerably. The concrete slab might help a bit in providing cooler radiant temperatures to the occupants and absorbing internal gains. Again, ventilation needs to be implemented to rid the building of the stored and accumulated heat.

A combination of heat-mitigating strategies such as efficient double roof, reflective coating, shading devices and radiant barrier can provide thermal relief and comfort IF AND ONLY IF coupled with natural ventilation design strategies and reduces internal load. Air conditioning units should be installed after the passive strategies are in place. Only then will the portable indoor environment be within acceptable comfort levels and highly energy efficient.

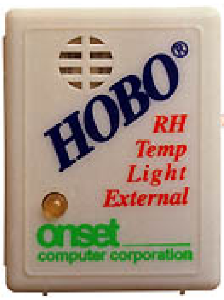
Retrofitting existing portables to achieve acceptable comfort levels is not an economically viable solution. Instead, existing portable classrooms should be catalogued and put on a priority list for replacement by new portables featuring the recommendations of this report.

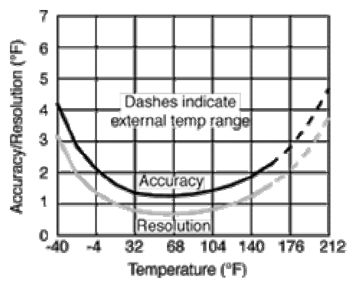
Designing comfortable portable classrooms should not be limited to experimenting with the least costly way to minimize solar gains. The conditions that these students are enduring are conditions that most adults would not tolerate in their work place. These conditions are beyond acceptable standards. [Appendix B]. Hawaii is now approaching nearly three full K-12 cycles of uncomfortable portable use. This represents an untold number of lost educational opportunities. Our teachers, our children and Hawaii’s future deserves better. It is the UH School of Architecture research team’s hope that this report and subsequent activities will help to improve the portable classrooms conditions and the future educational opportunities for the children of Hawaii.

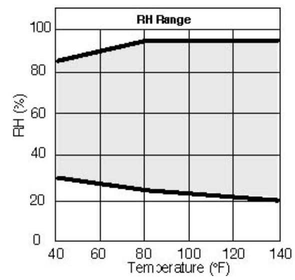
Appendices

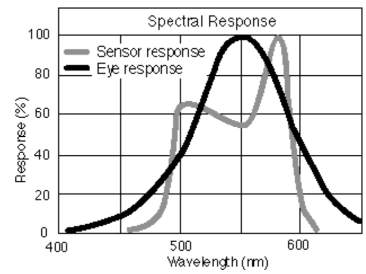
A - Instruments

Data Loggers HOBO H8 (Temperature – Relative Humidity – Light Intensity):

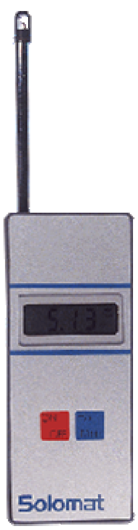








Solomat anemometer (airflow velocity):



B – Thermal Standards

Board of Education **Policy 6700**
Air-conditioning of classrooms and administrative spaces is now permitted by the Board of Education¹s Policy 6700. Air-conditioning may be installed if the Effective Temperature exceeds 80 degrees for 18 school days in the classroom and 25 weekdays in the administrative spaces during any 12-month period.

Jeff Ekard at DOH said that DOH recommends that the DOE design for AC if temperatures are above 78 degrees (the comfort range being 72-78 degrees/ RH at 40-60%, target of 50%)

ASHRAE 55-1992: Thermal Environmental Conditions for Human Occupancy
[from LEED Reference Guide 2.0[13]]

This standard identifies the range of the design values for temperature, humidity, and air movement that provide satisfactory thermal comfort for a minimum of 80% of building occupants. The acceptable range of operative temperatures for the winter and summer, for people performing light, primarily sedentary activities, at 50% relative humidity and a mean air speed of 30 fpm (0.15m/s), are summarized in Table 11 below.

The standard includes specific details for occupant thermal comfort and provisions for building occupants at various activity levels and non-uniformity in air temperatures. It also describes appropriate instruments and procedures for measurement of thermal environment conditions.

Table – 11: Operative temperatures.

Room	Temperature Range [°F]	Optimum Temperature [°F]
Winter	68 - 74	71
Summer	73 - 79	76

[13] Paladino Consulting LLC. 2001. LEED reference Guide 2.0. USGBC. [www.usgbc.org]

References

- Givoni, Baruch. 1976. *Man, Climate, and Architecture*. London: Applied Science Publishers. 483 p.
- SQUARE ONE research PTY LTD. 2003. [www.squ1.com]
- Moore, Fuller. 1993. *Environmental Control Systems*. New York: MacGraw-Hill, Inc. 427 p.
- State of Hawaii DEBEDT & AIA COTE. 2001. *Field Guide for Energy Performance, Comfort, and Value in Hawaii Homes*. Honolulu.
- Olgyay, Victor. 1963. *Design with Climate*. Princeton, N.J: Princeton University Press. 190 p.
- Paladino Consulting LLC. 2001. LEED reference Guide 2.0. USGBC. [www.usgbc.org] 280 p.
- Brown, G. and DeKay, M. 2001. Sun, Wind & Light. New York: John Wiley & Sons, Inc. 382 p.
- Egan, M. and Olgyay, V. 2002. Architectural Lighting. Boston: McGraw-Hill Companies, Inc. 436p.
- Marshall & Swift. 2002. Sweet's Unit Cost Guide 2002. New York: McGraw-Hill Companies, Inc. 640 p.