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BUILDING 381 HI BAY AIR CONDITIONING SYSTEM

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INTRODUCTION

Building 381 was completed in early 1975. This building features the best commercially available air conditioning systems. C. Meier made some preliminary temperature measurements that indicated that the six temperature control zones of the empty Hi Bay just barely met or exceeded the specification of $\pm 2^{\circ}\text{F}$, with 7°F to 8°F temperature swings noted.⁽¹⁾ A request was made to ESED to evaluate the Argus laser system location and to determine the potential of the building Hi Bay for temperature control. In addition, building the flexibility to optimize the temperature control for various internal configurations was desired.

The first phase of the study was made in March 1975. Control of temperature to $\pm 1/2^{\circ}\text{F}$ with cycling periods of 1-5 minutes was demonstrated using a bread board electronic thermistor system.⁽²⁾ Recommendations were made to replace the bi-metallic thermostats with the electronic units. Electronic thermistor units have been installed in the Building 381 Hi Bay.

Recently a request was made to complete the evaluation of B381 Hi Bay. This has been completed. To facilitate future studies of this kind, a step by step procedure will be described

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- 1 C. Meier to R. McCardle, "Bldg. 381-HVAC Systems," Feb. 3, 1975.
 - 2 P. Johnson to Distribution, "Building 381 Hi-Bay Temperature Control," April 9, 1975.

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in this report followed by the results of the study for Building 381 Hi Bay. Lastly, recommendations are made so optimum performance of the air conditioning system can be realized and maintained.

STEP-BY-STEP SYSTEM EVALUATION PROCEDURE

In an evaluation of this type it is important to closely follow the suggested procedures. It usually takes several hours to get a trend response for a large air conditioning system and about 24 hours for a complete temperature stabilization. Short cuts will invariably lead to uncertainty in the results. The following step-by-step procedure will yield optimum results.

Step 1: Measure What You Have

Before making any changes to the system it is important to determine the performance of the existing system. First set up monitoring stations to measure and record the temperature for at least 24 hours. If feasible, it is preferable to monitor the temperature at both the control point (thermostat-controller) and the critical points where the temperature control is needed. It is also desirable to monitor the temperature over a weekend (when the activity level is low) and through one or two work cycles. This gives a record of both unloaded and loaded performance (heat loading).

Instrumentation

The key to success in measuring, diagnosing, and curing thermal effects is the availability of certain types of measuring

equipment and their proper use.⁽³⁾ The temperature measuring devices used in this evaluation were developed through the efforts of the Metrology Group at LLL. The result of this effort was the LLL thermograph.⁽⁴⁾ For this study the following features were necessary:

1. 10°F range;
2. Adjustable zero from 66°F to 86°F in 1°F increments;
3. Continuous recording and indication of temperature;
4. Thermistor sensor with interchangeability;
5. Resolution and accuracy better than 0.1°F;
6. Chart speed of one inch per hour; and
7. Ability to record continuously for at least seven days.

For the tests described in this report, a recording station was established for each of the six temperature control zones. These recorded air temperature constantly for the entire duration of the study. One additional thermograph was used for miscellaneous measurements such as local variations, etc.

System Power Test

Next determine if the system has adequate "muscle", or heating and cooling capacity. Set the thermostat so the heat is full on (set point adjusted to a temperature above room temperature)

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- 3 Eldon R. McClure, Manufacturing Accuracy Through Control of Thermal Effects, D. Eng. Thesis, UCRL-50636, Lawrence Radiation Laboratory, Livermore, CA., April 30, 1969, p. 73.
 - 4 P. M. Johnson, M. O. Phillips, Thermograph Manual, LRL internal document LE 13606-2, Lawrence Radiation Laboratory, Livermore, CA., Dec. 19, 1969.

and record the room temperature rise ($^{\circ}\text{F}$ per minute, say, for a $3\text{--}5^{\circ}\text{F}$ change). Then set the thermostat so the cooling is full on. Record the room air temperature drop ($^{\circ}\text{F}$ per minute). (A reasonably good rate is 1°F per minute and it is also desirable to have them approximately equal.) If the system is sluggish in either the heating or cooling rate (say less than 0.1°F per minute), the cycling time will be undesirably large. If the system does not pass this test, it may be necessary to "trim" the system (i.e., add additional heating or cooling capacity).

Measure Air Flow Rates and Pattern

Now map the room air currents with a device such as a hot wire anemometer. Miscellaneous drafts will be zero to a few feet per minute. These are two important reasons to map the room air currents. The first is to find an optimal temperature control probe location and the second is to locate dead spots.

Note: Do not make any system changes until Step 1 is completed.

Step 2: Determine Heating and Cooling Loads and Capacities

While the temperature is being monitored, walk through the system. Is the air conditioning operating according to specification? What are the building heat loads both from external (e.g., solar) and internal (e.g., machinery) sources? If possible, check the air flow and temperature in the ducts. Measure cooling and re-heat water temperatures and flows. Check for dirty or plugged filters, etc. Also check for other obvious problems such

as heat sources in front of thermostats, improper connections, location, etc.

Step 3: Substitute Electronic Controllers

This step consists of replacing bi-metal controllers with electronic on-off controllers. While this step may seem arbitrary, it eliminates the hysteresis inherent in the bi-metal thermostats (giving a switching sensitivity of typically $\pm 0.1^{\circ}\text{F}$) and permits flexibility in locating the control probe.

Step 4: Adjust System for Optimal Control

This step is to determine the best location of the thermistor temperature control probes. The probe should be positioned somewhere between the air inlet and the exhaust air outlet. The closer to the inlet, the shorter the control loop lag and the higher the cycling frequency. However, it must be recognized that room air temperature control is insensitive to heat loads imposed between the control probe and the HVAC exhaust. At the exhaust, the lag is longest, cycling longest, and produces a large load-induced ΔT at the inlet. In any case, the room ΔT is proportional to the heat loading. This can be very difficult if there are intermittent heat sources in the room. If the control probe is downwind of the heat source, a negative zero shift will occur as the air conditioning tries to compensate for the heat source. If the probe is upwind of the heat source, the air downwind of the heat source will be warmed. An excellent example of this effect was detected

with the Cyclops laser in Building 174 in October 1975.⁽⁵⁾ An alignment laser power supply and two oscilloscopes were located next to the wall thermostat controlling the area next to the master oscillator. These devices were turned on at 8 a.m. and off about 5 p.m. This resulted in a 2°F negative offset and drafts during running hours. This effect is clearly shown in Figure 3 of the referenced memorandum.

Usually a best location can be found by trial and error methods and will usually be closest to the most sensitive piece of equipment. It should be noted that changes in room contents and changes of season suggest a reevaluation of the temperature control system.

Step 5: Install Monitoring System

A continuous temperature monitoring system is very important in achieving reliable temperature control. This warns the user in the case of a malfunction in the temperature control or other air conditioning system components.

Step 6: Set Up Regular Maintenance Program

A program of regular maintenance includes scheduled system monitoring and the recording of key control data. It is also important to have a stock of spare parts available.

5 P. Johnson to C. Hurley, "Temperature Control Problem in Building 174 -- "Cyclops" and Target Room," October 30, 1975.

RESULTS FOR BUILDING 381 HI BAY

In this section the results for B381 Hi Bay will be discussed. The initial evaluation was made in March 1975, and the final evaluation was completed in June 1976. These results will be discussed in the context of the procedure of the preceeding section.

March 1975

Step 1: Measure What You Have

Building 381 Hi Bay was instrumented as shown in Figure 1. One monitoring station was set up for each thermostat controller. Figure 2 is a typical recording of temperature vs. time for that test. The typical excursion was $\pm 2^{\circ}\text{F}$ with a period of 25 minutes. The capacity test indicated a heating rate of 1°F per minute and a cooling rate of $1/2^{\circ}\text{F}$ per minute.

Step 2: Determine Heating and Cooling Loads and Capacities

A walk through the system disclosed everything was working per design specification. The contractor had just completed the acceptance testing, so further testing on our part was unnecessary. The only heat sources in the Hi Bay area were the clean room facilities in Bays 1 and 2. The air conditioning system is a sub cool - re-heat configuration as shown in Figure 3. The temperature of the cool air can be adjusted as well as the temperature of the re-heat water. This permits load balancing. The capacity tests had indicated adequate heating and cooling capacity so it was assumed the plant was operating properly. The air flow

patterns of the room were also roughly mapped using a hot wire anemometer.

The air flow from the ceiling of each of the eight 30 foot by 55 foot segments is 12,500 cfm. The average air velocity in the room is 7.6 feet per minute with actual measured velocities varying from 0 to 50 feet per minute. If the control probes were located near the exhaust (which they were) the minimum time lag would be about $3\frac{1}{2}$ minutes. Added to this, of course, would be the response of the thermostat and the hot water control valve.

Step 3: Substitute Electronic Controllers

The bi-metal wall thermostats were replaced with electronic thermistor controllers as shown in Figure 4.

Step 4: Adjust the System for Optimal Control

The air flow patterns from Step 2 were used to determine the best control probe locations. The control probes were located in the center of each Bay opposite the wall thermostat location and located 10 feet from the floor. Figure 5 is a typical result. The excursion was $\pm 1^{\circ}\text{F}$ with a period of eight minutes. A helium-filled balloon was used to position the control probe for Bays 5 and 6. The probe was located as shown in Figure 6. The result is shown in Figure 7. The excursion is approximately $\pm 1/2^{\circ}\text{F}$ with a period of five minutes. This is probably the best performance the building air conditioning system is capable of doing under optimal conditions.

Step 5: Monitor System Performance

The permanent installation of temperature monitoring equipment was recommended. The best solution would be to incorporate the thermistor-type recorders into the Argus laser operating console. Suitable units are available.

Step 6: Regular Maintenance

A schedule of regular maintenance was also recommended.

June 1976

Electronic controllers had been installed as recommended in the earlier study. The thermistor control probes were located on the wall with a location similar to the bi-metal thermostats. Partitions had also been constructed in the Hi Bay area as shown in Figure 8. There is also a large raisable curtain between the target room (Bays 7 and 8) and the Argus laser (Bays 3, 4, 5 and 6). The purpose for this second study was to evaluate the performance of the system and determine the best control probe location for the present configuration.

Step 1: Measure What You Have

Temperature monitoring devices were set up as previously shown in Figure 1. Figure 9 shows some typical cool weather temperature vs. time recordings. The excursion is $\pm 1\frac{1}{2}^{\circ}\text{F}$ or less with a period of 10 minutes. There were some anomalous results and these will be discussed below.

Bays 1 and 2

The heat loads and drafts caused by the clean room equipment causes some localized perturbations. On warm days (91°F) there was evidence of either severe load imbalance or exceeding cooling capacity of the air conditioning. This is similar to the results shown in Figure 10.

Bays 3 and 4

The partitions interrupt the air flow causing some drafts and a slightly longer period and cycle as shown in Figure 11.

Bays 5 and 6

The construction of an observation deck disrupted an already marginal circulation pattern on the South wall. In addition, a curtain for optical shielding was added such that when closed, the control thermistor was in a closet. This resulted in a 1°F offset and the behavior shown in Figure 12.

Bays 7 and 8

Bays 7 and 8 are isolated from the rest of the room by a large curtain. The bays demonstrated fairly good cool weather control when the curtain was closed. However, when the curtain was raised the air flow changed resulting in an increase in amplitude and period.

A hot wire anemometer was used to map the air currents. This information was used in the determination of the best control probe locations. A capacity test was not performed because of

possible interference with experiments being conducted with the Argus laser system. Bays 7 and 8 also exhibited a cooling capacity problem as shown in Figure 10.

Step 2: Determine Heating and Cooling Loads and Capacities

The primary internal heating load is the clean room equipment. The rest of the room has relatively minor heating loads imposed on it by the laser system. There is also a machine shop and energy storage capacitors and power supplies in the Hi Bay basement. The main heating loads will be from the building exterior on hot days. The cooling system can be adjusted by maintenance machinists to lower the temperature of the cold air supply. If the building heat load exceeds available capacity it may be necessary to raise the Hi Bay operating temperature.

Step 3: Substitute Electronic Controllers

Permanent electronic controllers had been installed as recommended in the earlier study. The thermistor control probes were located on the wall with a location similar to the bi-metal thermostats.

Step 4: Adjust System for Optimal Control

The inlet air comes from the ceiling and returns through the base of the false walls. The location of the original bi-metal thermostats and the initial location of the thermistor probes was essentially in the return air duct. This was particularly true of Bays 1, 2, 3, 4, 7 and 8 where the air flow around obstructions

produced a steady flow of return air across the control probes. The exception was Bays 5 and 6 where the control probe was in a closet part of the time.

It was initially hoped that adequate control ($\pm 1^{\circ}\text{F}$ with a period of 10 minutes) could be achieved by standing the probe off the wall or partitions with flagpoles as this would be simpler to do. Studies of air flow with the hot wire anemometer indicated these areas had unsteady, drafty air circulation. This was verified by actual tests. In general, locating the control probes off the wall on stand-offs results in the same or poorer results than their initial locations. However, locating the probe in the center of the room, 15 feet off the floor produced a substantial improvement as shown in Figure 13. This results in $\pm 1/2^{\circ}\text{F}$ with a seven minute period. This is the recommended location of the probes.

Step 5: Monitor System Performance

This step is vital and should be incorporated into the regular laser operating procedures with the monitors incorporated in the control consoles.

Step 6: Regular Maintenance

Regular maintenance is the responsibility of several groups. First, it is the responsibility of the maintenance machinists to keep the machinery operating properly. Secondly, the experimental areas have to be monitored by the laser facilities people for changes that would disrupt existing air flow patterns and control

probe locations. Lastly, Plant Engineering should consider temperature control problems caused by major facilities changes such as adding partitions.

SUMMARY AND CONCLUSIONS

1. The 381 Hi Bay has a superior air conditioning system and is capable of $\pm 1/2^{\circ}\text{F}$ with five minute cycle periods with suitable electronic control and proper control probe location.
2. Thus far the system performance has been improved from $\pm 3^{\circ}\text{F}$ and 25 minute cycles to $\pm 1^{\circ}\text{F}$ and 10 minute cycle.
3. There is an immediate need for continuous monitoring equipment and a regular maintenance and inspection cycle should be established to insure reliable temperature control.
4. Electronic load control should be investigated. With the 50°F temperature swings common in the summer, substantial load imbalance between the heating and cooling muscle of the air conditioning system can occur. This results in a zero shift of the average temperature.

RECOMMENDATIONS

1. Locate thermistor control probes for Argus laser (Bays 3, 4, 5 and 6) and target room (Bays 7 and 8) in center of Hi Bay 15 feet from the floor. Combine Bays 3 and 4 on one control probe.
2. Install temperature monitors at the control probe locations. The existing two channel temperature recorder could be used

for the Argus laser room and a single channel for the target room. It is advisable to have the temperature amplitude and frequency response offered by these units.

The monitoring referred to here is actually the responsibility of the Argus laser operating personnel. They in turn would alert the facilities people if problems are detected. A failure in a mechanical component this spring resulted in a 3°F per hour temperature rise. The Argus laser/target system rapidly drifted out of alignment.⁽⁶⁾ However, the problem was not immediately identified as a temperature control problem and significant time and effort was expended before the source of the problem was discovered. The existence of a built-in monitoring system would have saved both time and effort.

3. A maintenance schedule should be established. The temperature records, controllers, etc., should be checked at least once a week to be sure everything is working.
4. The base of the wall is the return air duct. Equipment should not be stored there. Signs should be placed to prohibit blocking of air-flow passages.
5. The capacity of the air conditioning system must be carefully monitored. It may be necessary to raise the Hi Bay set point (now approximately 73°F) to assure control on the warm days. Heating and cooling capacities (muscle) are relative. When

6 Personal communication, P. Johnson with W. Simmonds, June 16, 1976.

the requirement for maintaining a stable (or relatively constant) temperature is important, but maintenance of an absolute temperature within fixed limits is not, heating and cooling balances can be achieved by changing the set-point to accommodate seasonal or, at least, long-term variations in heat load. The most difficult situation is where a fixed absolute temperature must be maintained (such as 68°F/20°C) for a precision gaging laboratory. This, fortunately, is not the case with the laser systems.

□ Temperature Recorder

○ B-Metal Wall Thermostat

Figure 1 - Schematic of 381 Hi Bay Instrumentation

Figure 2 - Typical Temperature Recording

Figure 3 - Schematic - Subcool Reheat System

Figure 4 - Thermistor Controller

Figure 5 - Typical Result with Bread Board

Figure 6 - Location of He Weather Balloon

Figure 7 - Typical Result - Probe 5' From Ceiling

⊗ Temperature Control Probe

Figure 8 - Schematic Showing Partitions, Etc. B381 Hi Bay

Figure 9 - Typical Mild Weather Temperature vs. Time
B381 Hi Bay Bays 7 and 8 (Target Room)

Figure 10 - Typical Hot Day Heat Overload Temperature vs. Time
B381 Hi Bay Bays 7 and 8

Figure 11 - Typical Temperature vs. Time Control Probe
On Wall Behind Partition

Figure 12 - Typical Mild Weather Temperature vs. Time
 B381 Bays 5 and 6 Control Probe in Closet

Figure 13 - Typical Mild Weather Temperature vs. Time Bldg. 381
Hi Bay Bays 5 and 6 Control Probe in Center
of Area 15 Feet From Floor (Also Showing Effect of
Moving Probe)

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