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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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HEATING, AIR-CONDITIONING AND VENTILATION; FACILITIES; AND LIGHTING

Addendum

ENVIRONMENTAL CONTROLS AND RELATED CONSIDERATIONS FOR CALIBRATION AND TESTING LABORATORIES 1/

H.L. Daneman*

* Specialist, Leeds & Northrup Co., North Wales, Pennsylvania, U.S.A.

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SUMMARY

The purpose of control of laboratory environment is to subdue whatever disturbences may seriously affect the intended work.

The elements of the environment which require some degree of control and typical constraints are:

Temperature Level..............	usually 20°C, 23°C or 25°C
Temperature Constancy..........	from ±0.01°C to ± 2°C
Temperature Uniformity.........	from 0.02°C to 2oC
Relative Humidity..............	35% to 55% R.H.
Pressure.......................	5 to 10 mm W.C. gage
Lighting.......................	75 to 100 foot candles
Electrical fields..............	avoid radio-frequency interference and magnetic masses
Vibration......................	less than 50 nM displacement below 200 Hz at instrument base
Noise..........................	35 on Noise Criteria curve from 20 to 9,600 Hz
Cleanliness....................	less than one-half million particles over one micron in size per cubic meter of air

The selection of building site, location of laboratory space within the building, segregation of work by degree of precision, the use of modular laboratories, proper location of office space, storage areas and passageways and careful apparatus design all influence ability to control the laboratory environment.

There are many important decisions affecting the design of the control systems. For example, centralised versus local refrigeration, size of controlled zones, choice of detector type and location, type of filtration and the use of digital monitoring facilities.

Since environmental control can amount to as much as 40% of the total cost of the building and its interior construction, it is important to pay careful attention, at the beginning of the project, to all factors which influence controllability.

INTRODUCTION

Better work is possible when disturbing influences are minimized. The purpose of control of the laboratory environment is to subdue whatever disturbances may seriously affect the intended work. The proper time to consider these influences is when project approvals are first requested - simply because environmental controls have an appreciable effect on cost. Other occasions are during site selection, building design, materials choice, laboratory layouts, facility definition and equipment selection. Since it is possible to decide on environmental control needs right after assumption of laboratory functions, this decision can precede the other elements of laboratory design. In fact, since these other elements of laboratory design are dependent on aspects of environmental control, its definition should be completed early in the design process.

Conversely, if left for later, costly constraints are included in the control problem. In fact, the most difficult and expensive possibility is to add controls to an existing structure.

The environmental elements which require control are shown in Table 1 along with some typical values.

Various factors which influence the laboratory environmental control problem are given in Table 2.

Finally, from the point of view of the control equipment itself, a number of decisions vitally affect the resulting system with respect to complexity, versatility and security.

The designation of environmental controls is, therefore, a process of choosing from alternative locations and degrees of specialization required for the laboratories in a manner which will adequately limit disturbing elements by means of acceptable systems of control.

Table 1. Controlled Elements of the Laboratory Environment

1. ATMOSPHERICS

1.1 Temperature

1.11 Level..................20, 23 or 25°C

1.12 Uniformity.............0.01°C to 2°C

1.13 Rate of Change.........0.5°C per hour

1.2 Relative Humidity...........35% to 50% R.H.

1.3 Cleanliness.................less than 50,000 particles per cubic foot over 0.5 micron

1.4 Pressure....................5 to 10 mm W.C.

2. LIGHTING

2.1 level.........................75 foot candles at 1 meter elevation

2.2 Spectrum......................low infra-red

3. ELECTRICAL FIELDS

3.1 ..............................R.F.I.

3.2 ....Magnetic Mass

4. VIBRATION

4.1 Seismic.......................0.001 to 0.003 G, or, 50 nm below 200 Hz

4.2 Noise

Table 2. Factors Which Influence Laboratory Environmental Control

1. LOCATION

   1.1 Building site....terrain, traffic, electrical fields.

   1.2 Laboratory Area..interior or not.

2. DEGREE OF SPECIALIZATION

   2.1 Type of work..........calibration, test or general product evaluation.

   2.2 Size of laboratories..modular or specialized.

   2.3 Logistics.............designation of office space, storage areas and passageways.

3. APPARATUS DESIGN.............console, rack mounted or bench.

I. CONTROLLED ELEMENTS OF THE LABORATORY ENVIRONMENT

The type of test work to be done (mechanical, electrical, chemical) and the precision specified determine which elements require control and the degree of control needed. In general; temperature, lighting, noise and cleanliness are often considered from the point of view of human occupancy, so the additional justification of adequate test results is not, at first, assumed to be a burdensome imposition on the laboratory designer. For the precise measurements demanded by modern standards of product performance, control of environmental disturbances has now become an important limitation to achieving acceptable results. The precision of available test apparatus exceeds performance specifications of the tested objects. The capability to obtain meaningful and reproducible test data is, therefore, a function of adherence to certain test conditions. For this reason, environmental controls are selected according to measurement accuracy requirements and have now surpassed the demands imposed by human comfort.

A. Atmospheric Disturbances

Due to the fact that many standards instruments change value with temperature, it is necessary that temperature be known if the properties of these devices are also to be known. In particular, where highest precision is required, historical trends are used to estimate instantaneous values. In such cases the reproducibility of temperature levels spanning long periods of time is important.

(a) A suitable temperature level is selected according to optimum conditions for the measuring instruments and devices to be tested - as compromised by practices in associated laboratories. More than one temperature level is needed in an extensive laboratory facility to achieve adequate results for the various technologies involved.

The section of the ISA report of Committee F-6 [1] pertaining to temperature levels was prepared by government investigators anticipating the design of NBS, Boulder, Colorado, and by a representative of an industrial laboratory. From discussions with these authors, it is concluded that the primary basis for the selection of 23°C was the assumption of a most comfortable temperature level for personnel. It is the author's observation that the most comfortable ambient temperature is subjective. It is not intended to debate physiological and psychological effects of the ambient temperature on the human, however. It is generally conceded that changes in relative humidity, outside temperature and the activity of an individual outshadows the effect of the difference between 23°C and 25°C in one's attitude about the comfort of an ambient temperature level.

The VDE/VDI on the subject of resistance standards maintains 20°C as a recommended temperature for usual standard resistors while choosing 25°C for resistors of the highest precision. European-made resistance standards have traditionally been referenced to 20°C. These are now of secondary standard grade. Presently, with respect to primary resistance standards, precise work requires the use of a controlled temperature oil bath. These are generally maintained at 25°C.

For technical reasons of minimizing resistor temperature coefficient, heat transfer from humans to instruments and frequently transfer error from reports of calibration (given at a reference temperature of 25°C) to test results, the temperature level of 25°C is suggested for electrical laboratories in preference to either 23°C or 20°C.[2]

For mechanical and optical laboratories, the gages and test devices are invariably specified for use at 20°C.[3] This is, therefore, the recommended temperature level for these laboratories. Choices for other laboratories can be similarly made.

(b) A practical spacification is ±0.5°C for temperature uniformity of tha alectrical and heat laboratories. While closer control over uniformity is dasirable, it is the writer's experience that most laboratories do not consistently achiave better results. As a practical matter, the simplification of the design of cooling and control apparatus resulting from the adoption of a reasonable specification, such as $\pm 0.5^{\circ}$C, can actually lead to improved performance if more attention is paid to the factors of heat and mass transfer.

For general testing laboratories, a specification of $\pm 1^{\circ}$C is acceptable. In the case of chemical and acoustic laboratories, $\pm 2^{\circ}$C would be a normal variation.

Mechanical laboratories for dimensional measurement and calibration, on the other hand, have special demands on uniformity and constancy. It is not rare to find ambient temperature levels specified to be within $\pm 0.02^{\circ}$C for length measurement by interferometry.[4]

(c) Deviations with respect to amplitude and rate are significant. It is suggested that the amplitude of temperature changes from the desired set point be limited to $\pm 0.5^{\circ}$C. The effect on most instruments should be negligible. This applies to instruments which are essentially comparison or ratio devices in which all parts are exposed to the same temperature and in which some care is taken to assure that these parts have proportional changes due to temperature (thereby maintaining ratio). Other devices which are to be measured in air such as air capacitors, do have a significant coefficient, (e.g., 20 ppm for a 0.5°C change of temperature of air capacitors). When the accuracy limit of measurements of air capacitors is ± 50 ppm, a change of 0.5°C from designated temperature can obviously result in a contribution of approximately 40% of total allowable limits from this source alone.[5] Where the introduction of temperature variations becomes a significant part of error tolerance, special precautions for temperature monitoring can be undertaken to achieve desired results. Accordingly, it is the writer's judgment that the specification of precision of temperature control of $\pm 0.5^{\circ}$C will be adequate for the majority of circumstances and not an insurmountable impediment for the special occasions when more careful attention to stability is required.

With respect to rate of change of temperature, a period of one hour should be acceptable for the maximum amplitude mentioned above. A good control result is illustrated in the chart of Figure 1.

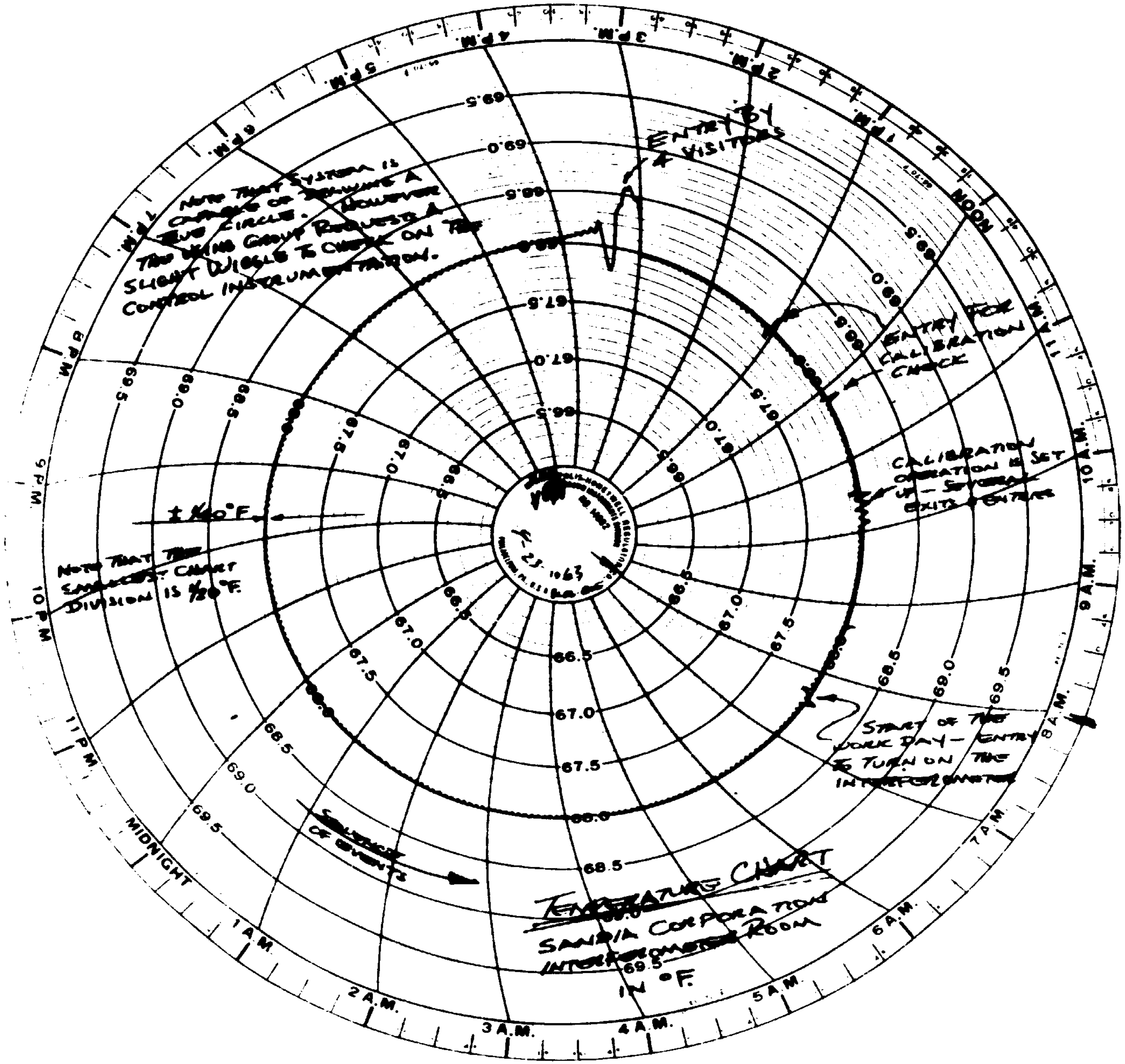


Figure 1. Temperature Chart - Interferometer Room

(Reprinted with permission Mr. H. H. Baxter, Jr., Sandia Corp., Albuquerque, N. M.)

Reference is made to the work of J. R. Miller, III, on "Time Constants of Laboratory Instruments,"[6] which shows that most instrumentation has a relatively high thermal inertia to rapid changes in ambient. This work further suggests the requirement for preconditioning of instruments prior to making measurements. The rate of change of temperature of typical electrical standards is shown in Figure 2 below.

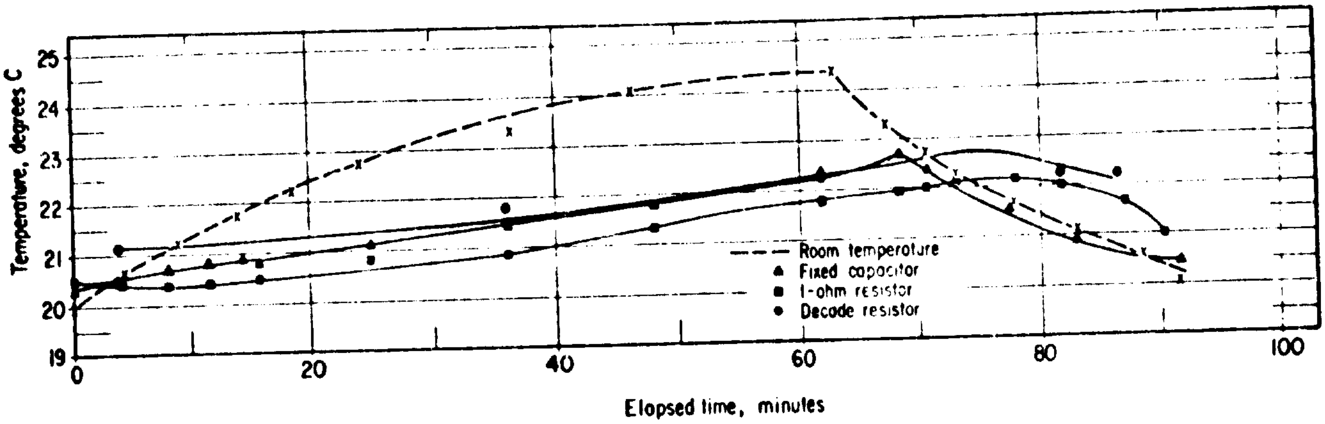


Figure 2. Thermal Lag of Certain Electrical Standards (reprinted with permission of Mr. J.R. Miller of U.S. Army Metrology and Calibration Center)

(d) Electrical and certain mechanical tests are influenced by relative humidity and this is normally controlled as an auxiliary function of temperature regulation. A value of 35% - 50% relative humidity is generally acceptable and recommended.

(e) The measurement of mass to high levels of precision, as well as protection of exposed internals of instruments, requires certain standards of cleanliness with respect to gaseous and solid atmospheric impurities. This affects the design of traffic patterns with the laboratories. Materials of construction should necessarily be selected to avoid their creating problems of dust. Acoustical materials are particularly dangerous in this respect. Likewise, common floor materials create substantial air-borne particulate matter. Vinyl floor surfaces are recommended for general use plastic coated materials should be used where possible.[7]

The recommendations of ISA-F6 Report in this regard are acceptable for solid matter (less than one-half million particles per cubic meter over one micron - less than two million particles per cubic meter over one-half micron). These results are obtainable as a consequence of filtration and due care in the handling of equipment before it comes to the laboratory. Figure 3 will illustrate the effectiveness of H.E.P.A. filters. Electrical and heat laboratories are not particularly critical with respect to this factor. Good operating practices reduce contaminants brought in by humans.[8] Physical layout of the laboratory can help with removal of larger particles of dirt. The maintenance of instruments in console constructions can also minimize the consequences of this problem. Finally, the use of separate cleaning and storage areas will aid further to achieve an acceptable result.

A fact which is important, but not often recognized, is the desireability of clean air with respect to gaseous components. Small concentrations of hydrocarbon in the atmosphere can cause poor reliability of electrical contacts used in low level circuits. While most low-level switching devices are hermetically sealed, it is still recommended that care be taken to ensure reasonable levels of freedom from gaseous contamination by attention to fresh air intake and fume hood design.[9] [10]

(f) General recommendations call for the maintenance of a slight positive pressure for laboratory atmospheres. Recommendations range from 5 mm to 10 mm of water column gage pressure within the laboratory proper. This results in leakage of air to the exterior of the laboratory instead of infiltration of dusty air or drafts. There is no need for precise regulation of this positive pressure. It is recommended that a minimum positive pressure is perhaps the more desirable to make it easier to open the doors of the building.

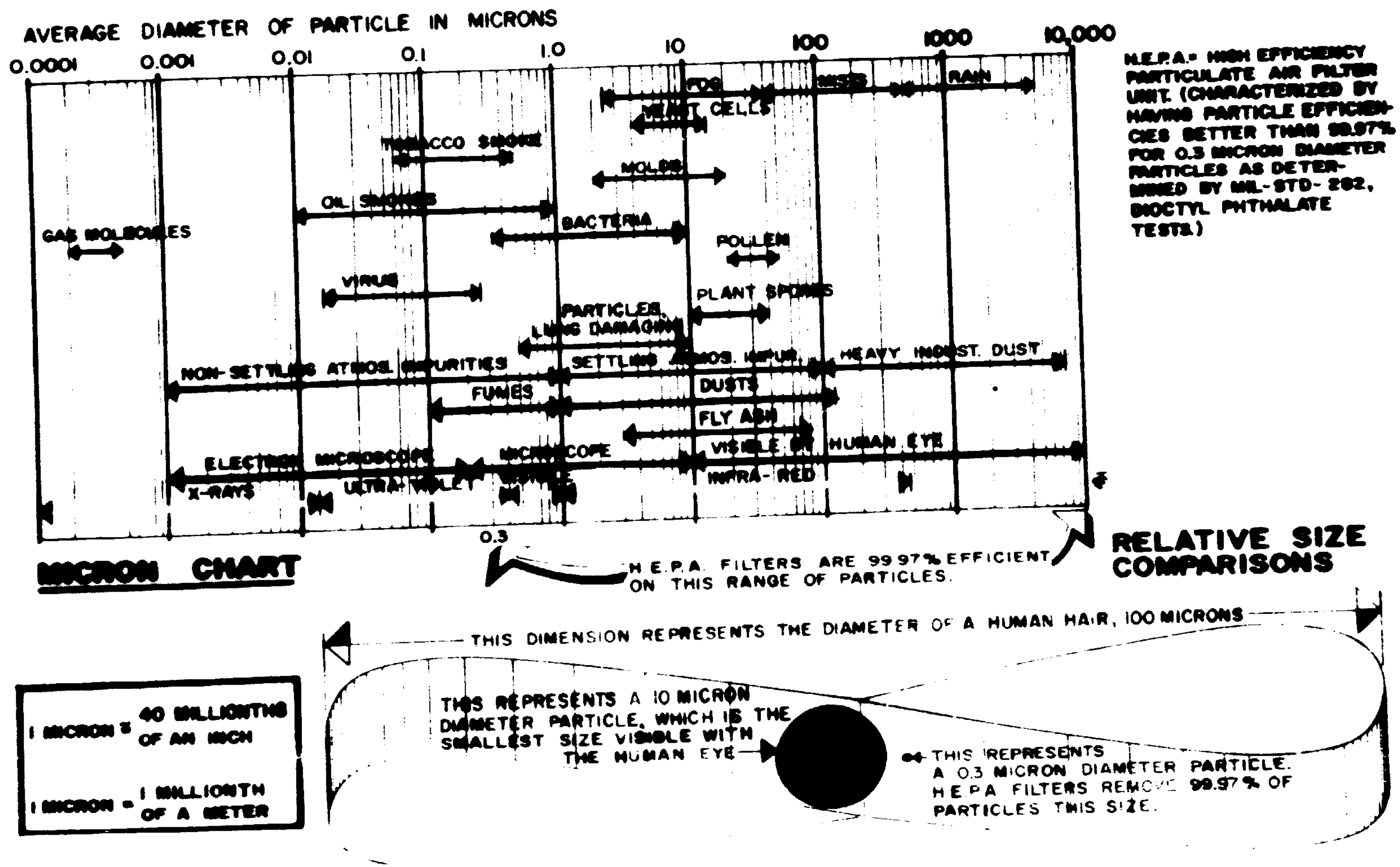


Figure 3. Efficiency Range of H.E.P.A. Filters

(Reprinted with permission Mr. H. H. Baxter, Jr., Sandia Corp., Albuquerque, N.M.)

B. Illumination

(a) Adequate levels and contrast contribute to reduction of human error. In some cases, light must be excluded. (Photography, optics, pyrometry).

Lighting specifications are referred to bench level. Most commonly specified is a level of 100 foot candles. It is recommended instead, that an average value of 75 foot candles at a height of one meter above the floor be maintained.

It is also prudent to achieve a comfortable level of brightness contrast and a ratio of one to three is suggested between surroundings and task. There have been attempts to provide extremely uniform lighting patterns to avoid glare and the psychological aspects of objectionable reflections. In such places, shadowless lighting is a disadvantage and results in lower visual acuity.[11]

It should be an important requirement to avoid the use of localized light sources as these are also significant sources of heat and, therefore, temperature distortion.

Attention should be given to the finish and color of walls and ceilings to enhance general illumination levels. Where lamps are enclosed, it is helpful to include some type of diffuser lens with transmission cut-off characteristics in the near-infrared region.

(b) Removal of infra-red energy may be needed where temperature is extremely important. A 0.5^{o}C elevation of bench temperature has been traced to IR energy from lamps.[7] Certain wavelengths affect the output of saturated standard cells. Fluorescent light contains spectral energy responsible for darkening of saturated cell chemicals and a consequent change in EMF output. While incandescent light has frequently been recommended where saturated standard cells are used, it is also to be noted that such saturated standard cells are invariably enclosed in constant temperature baths. For this reason, it is not essential to use incandescent lamps. Furthermore, any slight effect on the EMF output of saturated standard cells as a consequence of temporary exposure is temporary and not permanently harmful.

C. Electrical

Electromagnetic interference depends on communication and energy transfer both inside and outside the laboratories. Attention required to cable and room shielding depends on the pattern of spectral and sensitivity requirements for measurements during the useful life of the laboratory.

Shielding requirements are local, in general. The exceptions relate to proper grounding. A ground net or grid should be designed and installed during building construction. The arrangement for the introduction of ground potential conductors throughout the laboratory should not encourage multiple grounds for the same measuring system.

(a) Sources of radio-frequency energy should not create interference for further measurements. This includes machinery which can create sparks such as certain types of generators and motors as well as fluorescent fixtures. These devices should be shielded at the source.[12] Some apparatus, such as refrigeration machinery or other equipment should be mounted outside the laboratory (preferably outside the building) and these services brought in through conductors. Attenuation levels of 16 dB are generally specified. It is proposed that special areas devoted to sensitive measurements of AC energy including microwave energy be especially shielded to avoid interference.[8]

(b) Very weak field measurements should be conducted in an area relatively free of magnetic masses in the structure. Materials chosen include non-reinforced, cast concrete, hollow concrete bricks, wood beams such as from solid oak or glued sheets, copper angle pieces, brass bolts and bronze nails.[12]

D. Vibration

(a) Vibration maxima of 0.001G to 0.003G are acceptable for dimensional and electrical laboratories, respectively. Another specification for vibration limits is 50 nanometers below 200 Hz at an instrument base.

(b) Limitations of 40 decibels, or, 35 on the Noise Criteria curve from 20 to 9600 Hz have been suggested in general. Acoustic laboratories are exceptional installations which have other requirements.

II. FACTORS WHICH INFLUENCE LABORATORY ENVIRONMENT CONTROL

A. Location

From the macro viewpoint, the first consideration for environmental control of a laboratory is geographical. Ordinary judgment suggests isolation as a means of obtaining freedom from disturbance. With regard to environmental protection, some attention should be drawn to the possible advantages of a hillside or underground location.[4]

The following four laboratories have taken advantage of the greater temperature and position stability afforded by underground installation. The Instituto Galileo Ferraris in Italy has its primary voltage calibration facilities some meters underground. This affords temperature stability which, together with other precautions, has resulted in an excellent history of standard cell calibration with the BIPM. This is notwithstanding the absence of automatic temperature control equipment.

The LCIE at Fontanay Aux Roses used two basement levels for laboratory facilities.[12]

The U.S. Air Force main laboratories at Heath, Ohio, has four levels underground to a depth of 65 feet.[3]

The new dimensional laboratory of the Instituto G. Colonetti at Turin, Italy, will have twenty primary laboratories underground. The temperature will be controlled to $\pm 0.01^{\circ}C$. These results should be approximated with a minimum of control effort as a result of careful attention to heat transfer concepts.[13]

Special attention is drawn, however, to the Westinghouse Electric Corporation primary calibration laboratories at their Aerospace Division near Baltimore, Maryland. This laboratory is partially buried in the side of a hill. The primary laboratory rooms are located within the deepest part of the structure leaving offices and access for personnel and instrument transfer for the exposed front of the building. It is known that the results exceeded the anticipated performance by a comfortable margin, and also that costs were minimized.

It is recommended that advantage be taken of available terrain to locate laboratories where the stabilizing effect of sub-surface conditions can be used to advantage, and, further, where wind and sunlight changes introduce the least disturbance to the refrigeration load of the laboratory building.

For reduction of exposure and prevention of gradients due to outside temperature changes, it is suggested that all primary laboratories be located internal to the building structure.[14] This means there will be no walls of any primary laboratory adjacent to an exposed building exterior nor any windows which face on the outside.

It is acceptable that the laboratories face other primary laboratories, offices, corridors, antechambers or facility passageways.

Windows to let people see inside the laboratory without entering are desireable. A widely used material for observation room windows is 1/4 inch polished plate glass on which a very thin chromium alloy surface coating is deposited on one side.[15] This would protect against heat transmission from the outside and disturbance to workers inside (from noticing people looking in).

B. Degree of Specielisetion

It is essumed thet there will be two generel types of leboratories, differentieted in design end location eccording to function. One type would be occupied with routine repetitive meesurements while the second would involve sophisticeted, eperiodic tests of the highest order. The basis for this concept is to minimize confusion between the different classes of equipment required, to reduce treffic in areas requiring greater care, to reserve expensive control apparatus to those sections requiring such complicated systems, es well es to provide the most edventageous physical locetion for eech function.

It is e further essumption thet the higher order laboratories will usually operete with e full time steff of two men per laboratory.(16)

The grouping of specielized celibration leboratories seperately from the routine testing leboretories is recommended to maintein respective environmentel requirements.

Leboratories renge from enterooms used for single instruments (such as micro-belence rooms) to huge erees for complete product tests (hengers). The usual renge is 10' x 15' to 75' x 100'. Unless crowded, the smaller room is eesier to control. This is not to sey thet the lerger rooms cannot be controlled. In the lerge leboretory et McClellen AFB, for example, two distinct arees of tempereture ere echieved with no visible demarcetion.

For control purposes, a small leboratory is better. The sise end shape must elso allow for epparetus and services.

Mr. Jesse C. Norman has enelysad the laboratory from the point of view of efficient utilisation of floor end bench space and determined thet 3.35 x 6.1 meters represents optimum.(16) He also presents e good case against the use of movable partitions and other then multiples of the basic module. Considerations of environmental control confirm Mr. Norman's recommendations to avoid partitions and non-moduler erees.

Exceptional areas are high voltage and acoustics laboratories. Environmental controls may be localized by placing detectors and air outlets at appropriate places within these rooms.(17)

The equipment to enter the laboratory should be stored in some other area, notwithstanding the necessities for conditioning to arrive at the proper temperature. One reason for this is the requirement for cleanliness. This means that the instruments should be cleaned elsewhere (on receipt) and also pre-checked for condition and previous history. The passage of equipment (as well as people into the laboratory) should be through an air-lock, or intermediary room, which can provide some protection against temperature disturbance and dirt. That air-lock may be utilized for storage of instruments which have already been cleaned and to provide a means for temperature conditioning of these instruments. The storage can be arranged so equipment is accessible from either side of the air-lock (the air-lock side or the laboratory side).

Another useful function for the air-lock can be that of an office area for computation, secretarial work, maintenance of reference manuals, records, etc. This concept permits best use of space and at the same time avoids upset. The average person generates dust, heat (about 125 watts),(4) disturbance to air flow patterns, electrical fields and sound levels and is best left outside the laboratory when not needed for conducting tests.

Storage area is a most underestimated requirement, in general. From the point of view of environmental conditions, do not store unused apparatus, equipment to be tested or records within the laboratory.

C. Apparatus Design

The attenuation of disturbance to the measuring instrumentation and their standards can be achieved by means of console construction. Such consoles (usually of metal) provide screening and a protective layer of air. This also shields electrical connections and terminations from drafts.

Included in the concept of consoles, would be special chambers such as oil baths, air baths or specialized groups of apparatus.

This concept isolates sensitive measuring apparatus and also maintains the aspect of devices which produce heat or electrical fields, thereby yielding more consistent measurements.

III. ENVIRONMENTAL CONTROL SYSTEMS

The previous chapters described the elements of the environment to be controlled and factors of laboratory design which influence our ability to control disturbance. These design considerations are an important part of the environmental control problem and their cost and purpose can be charged to the environmental control function. For example, they should not only be considered in the architectural context of suitability for use by inhabitants or flexibility of function. It is most important to design the facility so it can be controlled.

A number of important decisions are involved in selecting the control system (see Table 3). These will be considered in the following discussion. It is not intended to substitute for a design study.

A. Airflow

A typical airflow system is described in Figure 4.

The airflow pattern frequently recommended is that from ceiling to floor. (See Figure 5). Various inlets along the ceiling can be arranged in a pattern which will provide distribution as well as adjustment. Openings of various types in the floor can permit exit for exhaust gases. One possibility is a removable floor panel which can also facilitate changes in sub-floor cable layout. Such an installation can be found at the Matsushita Electric Company, Tokyo, Japan.

Table 3. Control System Decisions

1. Pneumatic or Electric Control
2. Centralized or Individual Systems
3. Analog or Digital Execution
4. Degree of Computer Intervention
5. Additional Computer Functions
6. Sequence of Dehumidification, Cooling and Heating
7. Air Inlets and Outlets
8. Air Velocity
9. Detector Choice and Location
10. Leadwire and Shielding Considerations
11. Monitoring Recorders
12. Types of Actuators
13. Filtration Measurements
14. Resetting of Control Points
15. Safety Considerations

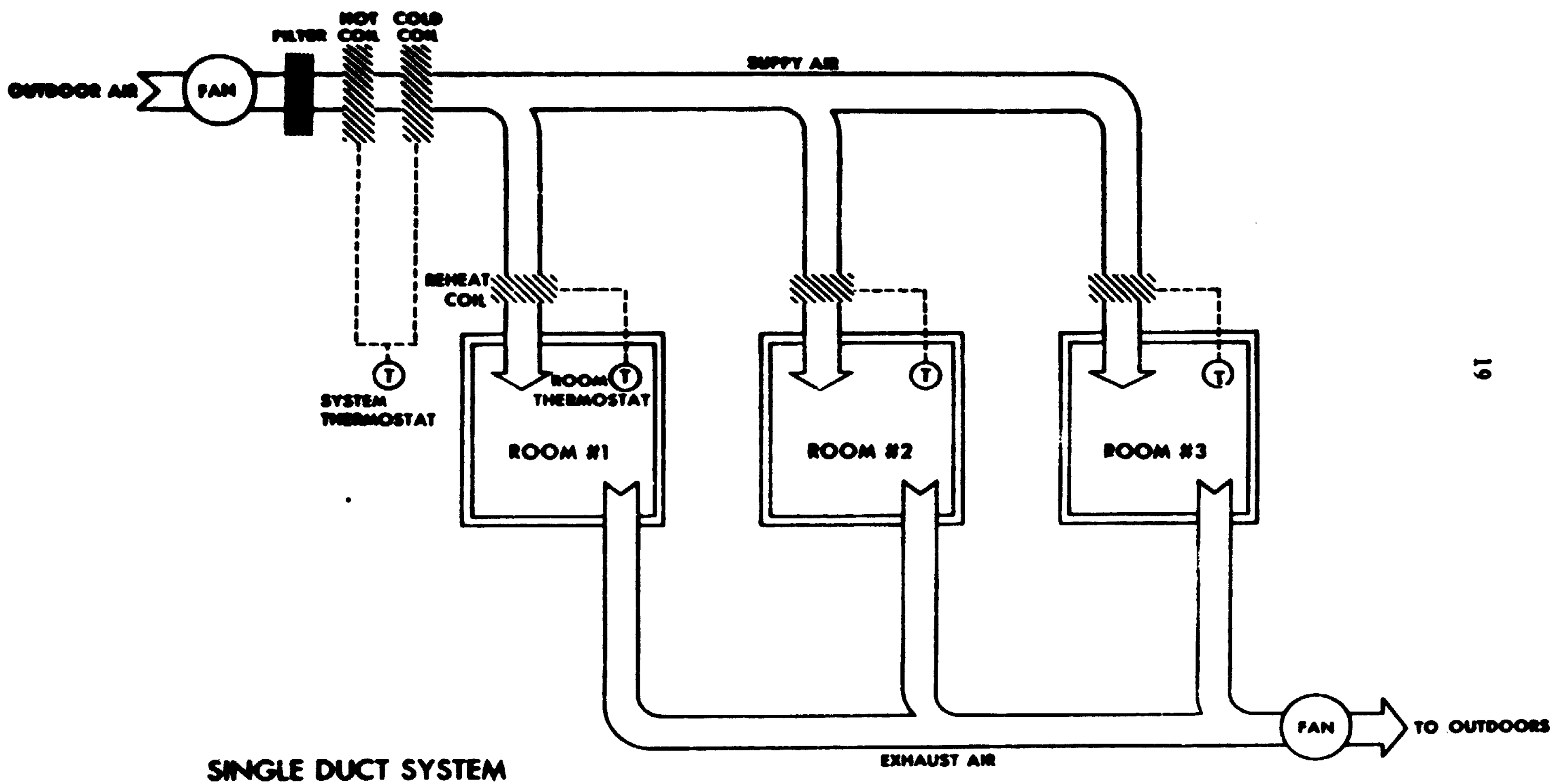
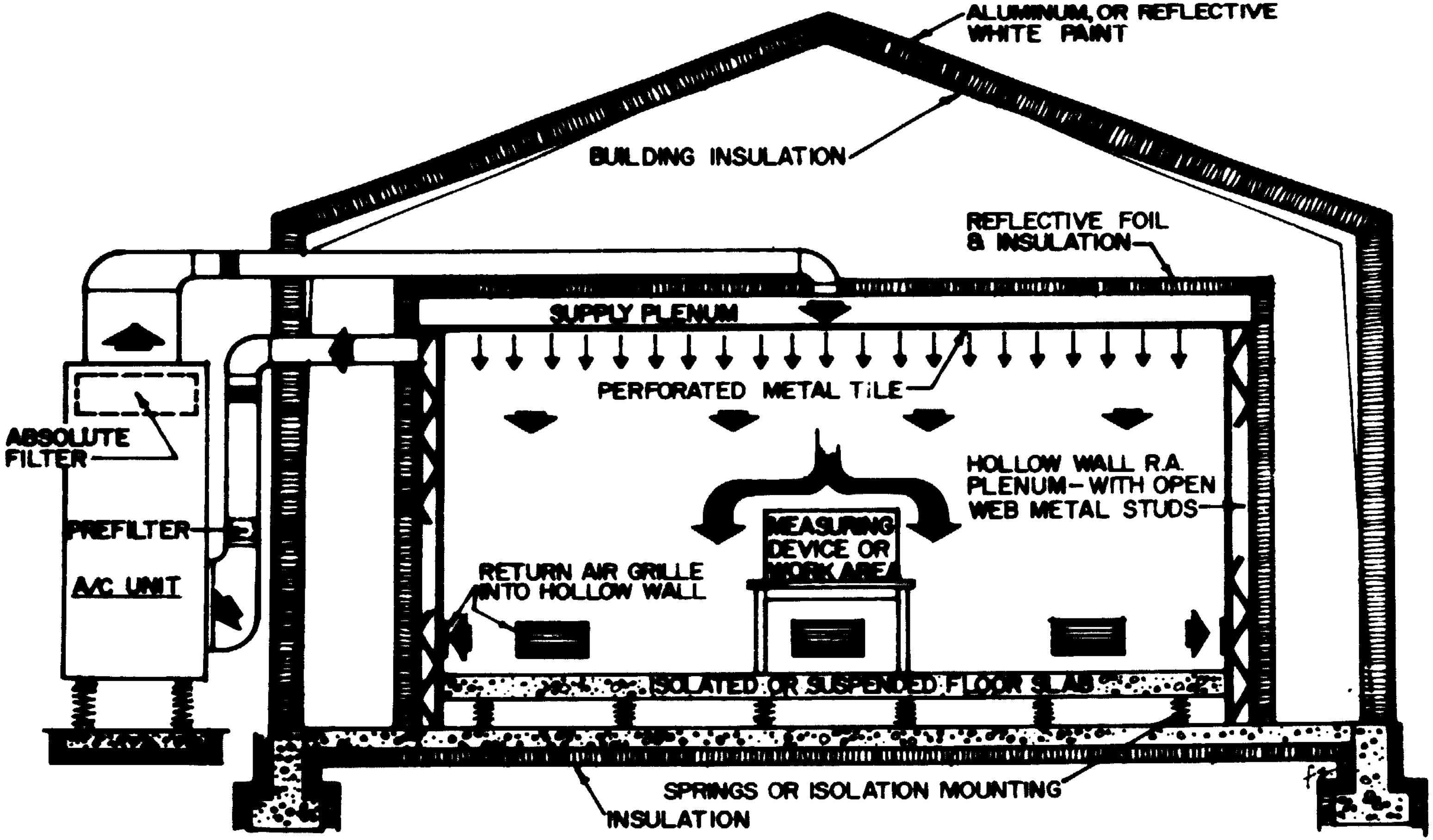


Figure 4. Reheat Scheme for Individual Room Controls[22]



APPLICATION of LAMINAR AIR FLOW to STANDARDS LABORATORY AREA

Figure 5. Return Air Flow Through Walls

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Return ducts within the walls are especially recommended as a means of removing the heat generated within consoles or other apparatus mounted adjacent to these walls.[18] Make-up air ranges from 20% to 100% of circulation depending upon outside air temperature and interior activities. Chemical laboratories, for example, use 100% fresh air. About 10 changes of air per hour with room velocities limited to about seven meters per minute are suggested.[7]

B. Control Apparatus

For extremely precise control ($\pm 0.01^{\circ}C$), a mini computer regulating a series of hot and cold water mixtures provides controlled wall temperatures at the IMGC at Turin, Italy.[13]

More typical are refrigeration machines for air cooling and dehumidification with electric heaters, hot water or steam coils for final temperature control. Cooling can be regulated by means of bypass of refrigerant or chilled water around cooling coils in the filtered air inlet duct.

Electric heat can be precisely regulated by devices such as saturable reactors. A "zero-firing" type of power regulator is recommended to avoid generation of electrical interference.

Examples of dust removal by electrostatic and mechanical filtering can both be found in standards laboratories. Stationary as well as moving belt types of mechanical filters are employed. For clean rooms very special arrangements for air flow are necessary.[19]

C. Zoning

Calculations of dynamic response of temperature distribution resulting from changes in heat load, air flow and cooling medium will define limits of controllability. This, in turn, will establish the area of each controlled zone.

Efforts should also be made to analyze and prevent possibilities of interaction between zones resulting from the use of common air flow paths. A damper position change made to control air distribution in one laboratory should not induce an airflow disturbance in another laboratory.

D. Detectors

A humidity detector can be located in a central air supply for control of refrigeration of primary air. Both wet and dry bulb (using thermocouples or resistance thermometers) and conductivity types are used.

Temperature detectors should have a stable calibration. Many instances have been observed where typical electrical thermometers show readings in greater variance than control tolerances claimed for the individual laboratory. Useful are resistance thermometers of the 100 ohm Copper type in a Caliendar four-lead configuration. The speed of response is slower than for thermistors, for example, but still faster than the laboratory control response.

Peripheral location near benches is preferred to a central location near the ceiling. Pairs can be connected for temperature level or uniformity control by adding or subtracting transmitter outputs.

E. Monitoring

A multi point trend recorder in an ante-chamber or in the laboratory proper can be used for startup and also monitoring baths, chambers, power supplies or long term functions related to experiments.

There is some benefit to considering the use of a small computer for control of the various rooms throughout the laboratory building. It can also provide for security functions such as the measurement and monitoring of service facilities as well as to permit calculations.

In this case a centralized facility can be used for pump, chiller, mechanical equipment "start-stop" functions, change-of-state scanner for critical switch position monitoring, programmer for start-stop timed functions, high-speed scanning with digital readout for alarm functions, alarm status summary, system shut-down programs, security monitoring, graphic projection system, emergency situation display. In one instance, a centralized monitoring facility for 12 buildings cost $150,000 including wiring but resulted in annual savings in electric power valued at $85,000.[20]

C. Costs

Various references can be found to suggest the cost of controlled environment. In view of subsequent price changes, it may be more useful to compare the cost ratios, for example:

Table 4. Cost of Laboratory Construction

Design	7%
Building	27%
Inside Construction	25%
Air Conditioning	22%
Electrical	16%
Plumbing	3%

Accordingly, the cost of environmental protection amounts to perhaps 40% of the total.

Selection of a suitable site can reduce the requirements of environmental control, and correspondingly, reduce the cost of the facility. It is, therefore, recommended that a laboratory site survey pay particular attention to questions of electro-magnetic interference, vibration, acoustic noise and temperature range. In conclusion, substantial benefit can be had by careful attention, at all stages, to minimizing disturbances to the operating environment of any new testing or calibration laboratory, but it is most important at the outset.

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