INDUSTRIAL HEAT STRESS

SOUTHERN PHASE

Francis N. Dukes-Dobos, Austin Henschel, Clark Humphreys,
Kenneth J. Kronoveter, Marshall Benner and Walter S. Carlson

With the technical assistance of

Thomas E. Doyle, Leonard Margolies, Leonard L. Busch,
Paul L. Spenard, Ben A. Pearson, George W. Fischer,
Dennis McCarthy, David Quong, Stanley Kusnetz
and Alfred Mendenhall

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ABSTRACT

The problem of assessing the thermal impact of an industrial situation on the worker is complex because of the multiplicity of factors comprising the man-environment system. The definition of the system required, as a minimum, data on the actual climatic environment of the work site, the physiological and psychological demands of the job, the daily work-rest regimen, the heat exposure history, the health and nutritional status, the state of body hydration, the non-working physical environment with its seasonal variations, and the non-working activities of the workers studied. The Southern phase of the industrial heat stress study which is reported here, incorporated a simple standard laboratory type heat-work test along with an exhaustive study of the men at the work site. The physiological responses of the men to the standard test were significantly correlated with the responses elicited by the job and its environment and also reflected the climatic conditions of the living environment.

The amount of sweat evaporation required for maintaining body heat balance (E_{req}) was calculated for each observed job and was used for quantitative description of the combined heat and work stress. E_{req} values were calculated both for short term peak exposures and for average eight hour exposures, so they can be utilized for setting acceptable limits both for eight hour time weighted average levels and for peaks above base line.

FOREWORD

Thermal stress can adversely affect the workers' health in many industrial situations and can also diminish tolerance to other industrial hazards. The determination of the thermal stress of an industrial environment and the translation of the stress in terms of physiological and psychological strain is a complex problem. Yet for practical industrial situations, acceptable limits for thermal exposure must be established and methods for evaluating and predicting the thermal impact of an industrial environment must be available. Such limiting levels must take into account all of the factors that might affect heat exchange between the worker and his environment and all the factors that might influence the responses and tolerance of the worker to the total heat stress.

Several methods and indices have been proposed for assessing and predicting the thermal stress of a hot environment. However, most recent critical reviews emphasize the point that the indices are valid only for situations comparable to those upon which the indices were based. They are not, therefore, applicable to industrial situations in general (1-7). To further complicate the problem, the collection of the basic physiological and environmental data required to calculate an index of thermal stress is extremely difficult under conditions of routine plant operations. Many of the methods and instruments are designed primarily for use in the laboratory and are not adaptable to workshop conditions where the climate factors vary over short intervals both in space and in time.

Ideally, the determination of the heat stress in an industrial environment with regard to determining potential physiological and psychological strain requires data on factors referrable to the environment (e.g. air temperature, vapor pressure, air movement, long wave and solar radiation), to the worker (e.g. clothing, age, sex, nutritional and health status, body hydration, ethnic origin, acclimatization, physical and mental capacities), and the job (e.g. patterns of heat exposure, intensity of physical work, required job performance). Data on many of these factors are, of course, difficult to obtain because many cannot be controlled, reliably measured or faithfully described. Yet, in estimating thermal stress and the associated physiological and psychological strain we are concerned with the total man in his total working and living environment. The present study was designed to take into account as many as possible of these considerations and to evaluate their influence on the capacity of the workers to tolerate the heat and work stresses encountered in the working environment.

The interpretation of the data in terms of their combined effects on the health of the worker would require a time consuming epidemiological study. Because of the difficulties inherent in such an epidemiological study, an alternative approach, a single standardized test, was used to obtain immediate information concerning the effects of the interactions of the heat and work demands of the job and the general health and tolerance capabilities of the worker.

The authors express their appreciation to the workers, the union officials and the management of each of the three plants for their sincere and complete cooperation. Without their wholehearted support this study would not have been possible. Doctors David P. Discher, George M. Lawton and Robert L. Abrams provided essential medical supervision for the standard chamber test and assumed administrative responsibilities for the survey teams. Their contributions to the success of the study were great. A special acknowledgment is due Doctor Douglas H. K. Lee for his enthusiastic support of the project, assistance in the original contacts with the plant management and labor officials and guidance throughout the survey from its inception to the final report. Doctor Nicolas B. Strydom, while on a post-graduate PHS fellowship, provided invaluable guidance and stimulation during the design of the study and during the early phases of the data collection.

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INTRODUCTION

The selection of valid criteria which reflect the physiological strain imposed by many years of exposure to hot industrial processes presents major difficulties. It has been repeatedly demonstrated that sweat loss is significantly correlated with the total heat load, including both metabolic and environmental heat (8, 9 and 10). However, the sweat loss during a working day alone does not describe the sequence of heat exposures during the work-shift. The total day's heat exposure could occur at a constant moderate level or it could occur as a series of severe heat exposures of short duration. The effect of the pattern of daily exposure on the health and heat tolerance capacity of the worker is not clear; but it must be considered in any expression of permissible heat exposure limits.

Two other physiological responses which reflect the level of thermal stress are work and recovery pulse rates (11) and internal body temperatures (12). The pulse rate response can be used to assess the cardiovascular cost of meeting the combined load of the heat and the work. The internal body temperature will indicate how successful the body has been in meeting the thermoregulatory challenge.

Two sources of heat must be considered in calculating the total heat load of an industrial environment, the internally generated metabolic heat and the externally imposed environmental heat. During most types of physical work about 80 per cent of the energy released in the muscles is in the form of heat. The determination of the heat generated by work metabolism can be accomplished by respiratory gas analysis (13) or by the use of energy requirement tables (14). In the laboratory and in experimental field studies where gas collecting equipment can be used, direct measurement of metabolic heat from oxygen utilization is the procedure of choice. However, under industrial conditions where equipment would interfere with the normal work patterns of the men, the use of the energy requirement tables is sufficiently exact to provide realistic data. In this study the energy requirement tables prepared by the Purdue Farm Cardiac Project were used. The accuracy of estimating metabolism from the tables is considered to be ± 10 per cent (14), which is within the limits of expected day to day variability of an industrial job.

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To adequately describe the thermal load of an industrial environment, continuous monitoring of the four climatic factors (air temperature, humidity, air velocity and radiation) at the job sites is required. Since air temperature, air movement and radiation may vary within wide limits between closely adjacent points in a work area, measurements must be taken at all places where the worker spends significant amounts of time during a working day. The description of the work environment in terms of dry bulb and wet bulb temperatures presents no serious problem. However, wind velocity and radiant temperature measurements, which are also necessary to reasonably depict the actual exposure patterns of the worker, pose a real challenge.

Many attempts have been made to design instruments which would either simultaneously measure and record the several components of the climatic environment or would integrate two or more of the factors in such a way as to characterize the convective and radiative heat exchange potential of the environment (15, 16, 17 and 18). Of the many instruments or combination of instruments that are available only the katathermometer (19) and the recently developed miniature globe thermometer can be exposed in the same places and to the actual environmental conditions experienced by the worker while he is performing his normal job tasks. The katathermometer, which requires no power source, has a response time of from one-half to five minutes; the response time of the miniature globe thermometer may be as short as a few seconds.

The katathermometer was originally designed to measure comfort environments. However, it has been found to be a practical instrument for use in industrial heat studies (20). Theoretically, the katathermometer and the miniature globe thermometer, because of the small bulb, should overemphasize the convective cooling component when the air temperature is considerably lower than skin temperature (21). In the case of the katathermometer, however, this discrepancy in convective heat exchange diminishes at higher air temperatures and is practically eliminated at air temperatures of 30-40°C (22), temperatures which are common in hot industries. Sufficient experience with the miniature globe thermometer has not been accumulated under industrial conditions to fully determine its capabilities. The katathermometer as well as the conventional instruments (e.g., dry bulb, wet bulb and globe thermometer and hot wire anemometer) for measuring and recording the climatic factors were employed in this study.

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Standard heat-work tests such as the "Uniformity Test" used by the Royal Naval Tropical Research Unit (23) are suitable to assess the levels of heat acclimatization and performance capacity in the heat of men who were subjected to various levels of heat stress. This "Uniformity Test" was given before and at the end of the experimental program and the changes in responses to the test were used to evaluate the effects of the experimental conditions. In the present study a standard heat-work test was introduced to judge the capacities of the industrial workers to handle a thermal-work load of known intensity. As designed, the test was severe enough to adequately challenge the tolerance capabilities of each individual without producing physiological breakdown before the test was completed. By measuring the same physiological functions during the standard test that were monitored during the day of observations at the work site, the relative effects of the heat exposure on the different jobs and the level of heat tolerance of each worker could be estimated. The physiological responses that were considered to reflect the impact of the heat and work stress of the job and of the standard test were rate of sweating, total sweat production, heart rate and body temperature.

Psychosocial aspects were not analyzed because under regular conditions the observed jobs did not impose undue perceptual and intellectual demands, and in general there was a good cooperation between workers and supervisors.

METHODS

OVERALL DESIGN

In planning the Division of Occupational Health's Industrial Heat Stress Study it was decided that, as a minimum, data would be required on (1) the actual environmental conditions in which the men work, (2) the energy demands of the job, (3) the physiological responses during a typical workday, (4) the physiological responses to a standard heat-work stress and (5) the heat exposure history and health status of the individuals. Further, it was considered desirable to obtain the data on the same group of men in the same industrial plants during a winter and a summer season when the levels of heat exposure, both at the work site and during non-working hours might be vastly different. The plans also included studying similar hot industries located in the Southern and Northern parts of this country where the level of heat exposure particularly during the non-working part of the day would be grossly different. This report covers the Southern phase of the study; the Northern phase, which has not as yet been completed, will be reported later.

The three plants selected for the Southern phase of the study included a glass forming, a chemical and an aluminum reduction plant. The plants were chosen because they were representative of industries with hot manufacturing processes and because of the voluntary cooperation and participation by the management, the labor unions and the workers. Observations were made at each plant during the hottest months of two successive summers and during the coldest months of the intervening winter. Mean maximum and minimum temperatures obtained from the U.S. Weather Bureau for the hottest and coldest months for each are given in Table 1.

All three plants operated on a continuous 24-hour basis with three shifts per day changing at about 7 A.M., 3 P.M. and 11 P.M. The continuous operation required four crews of men, each crew worked five days followed by a 36 to a 56 hour break. The members of each crew were studied at the job site on days 2, 3, 4, and 5 when they were on the 3-11 P.M. shift.

SELECTION OF SUBJECTS

Only those workers who volunteered to participate in the study were considered. In the glass and sodium plants all volunteers who were exposed to hot manufacturing processes were studied. In the aluminum plant, where the number of workers employed in hot jobs exceeded the testing capacity of the team, a sample of the volunteers was selected on a random basis. Some workers in each plant who were not exposed to hot processes were used as control subjects. These men lived in the same general community as the heat-exposed workers and were, therefore, exposed to a similar social and physical environment during non-working hours. The relevant demographic data on the men in the three plants who participated in the study are discussed later in this report.

STANDARD HEAT-WORK TEST

Test Procedures

Each worker studied during a workday was also observed during a standard heat-work test conducted in a mobile climatic chamber. The conditions of the standard heat-work test are shown in Table 2. Each participant was instructed to avoid excessive alcohol intake the evening before and to have only a light breakfast before reporting for the standard heat-work test at 9:00 A. M.

Immediately preceding the standard heat-work test, each subject spent about 45 minutes in an air-conditioned examination trailer. During this time a physical examination, a 12 lead ECG, a blood pressure measurement, a pulse count and an oral temperature measurement were made by a medical officer. A questionnaire was filled in on the following items: medical history, occupational and heat exposure history, non-working hour activities, smoking habits and home living environment (air conditioning). Anyone with clinical evidence of acute illness or cardiovascular disease was excluded from further testing. To insure adequate hydration during the test each subject was offered 400 cc of water to drink before the test.

During the standard heat-work test conducted in the controlled environment trailer the subjects wore the clothing as indicated in Table 2. Nude and clothed body weights were measured before and after the one-hour walk. A towel, which was used to wipe sweat from the face to prevent dripping, was weighed with the clothed subject. Heart rates were recorded by the ECG with the subject standing at 5 minutes and 1 minute before the walk, and after at 5, 15, 45 and 60 minutes of walking and at 1, 2, 3, 5 and 10 minutes of seated recovery. Rectal temperatures were measured with a mercury thermometer before, at 45 and 60 minutes during the walk and 10 minutes after the walk. Symptoms and complaints were recorded during the walk.

After the exercise test each subject was questioned about how he felt. In only one instance was it necessary to terminate the exercise test because of high pulse rates, rectal temperatures or because of signs of impending heat exhaustion (pulse rate exceeded 170/min).

Forced Vital Capacity (FVC) was measured before the test in the examination trailer (temperature conditions) and 15 minutes after the exercise test in the climate chamber (hot conditions) using a Collins 6 liter recording vitalometer. The best of three trials was selected for calculating the various compartments of the FVC. About 20 minutes after the end of the exercise test the subjects returned to the examination trailer for a second clinical examination, including 12 lead ECG and questioning on reactions to the heat-work test. The entire procedure took about two and one-half hours.

Test Facilities

Plan and sectional views of the test chamber used in these studies are shown in Figures 1 and 2. The floors, walls and roof of the chamber were assembled from prefabricated panels four feet in width. The panels consisted of expanded polystyrene sandwiched between plywood facing sheets, the outer surfaces of which were covered with .015 inch thick aluminum. Locking devices mortised into the edges of the panels permitted rapid assembly of the chamber. The structure, when completed, was quite rigid. Instead of using gaskets between the panels, a plastic cover was placed over the room to make it weatherproof.

The air-conditioning equipment for the test chamber was installed in a 28-foot trailer, which was located adjacent to the chamber and connected to it by flexible ducts. As indicated in Figure 2, a fan located in the equipment trailer supplied conditioned air to the plenum space above the suspended ceiling. From the plenum, the air entered the test chamber through perforated ceiling panels and was then returned through floor gratings to the equipment trailer to be reconditioned. The air supply rate was 1200 cfm or approximately 100 air changes per hour. Fresh air was supplied through the damper shown in Figure 2. The air velocity in the occupied zone of the room varied from 20 to 30 feet per minute.

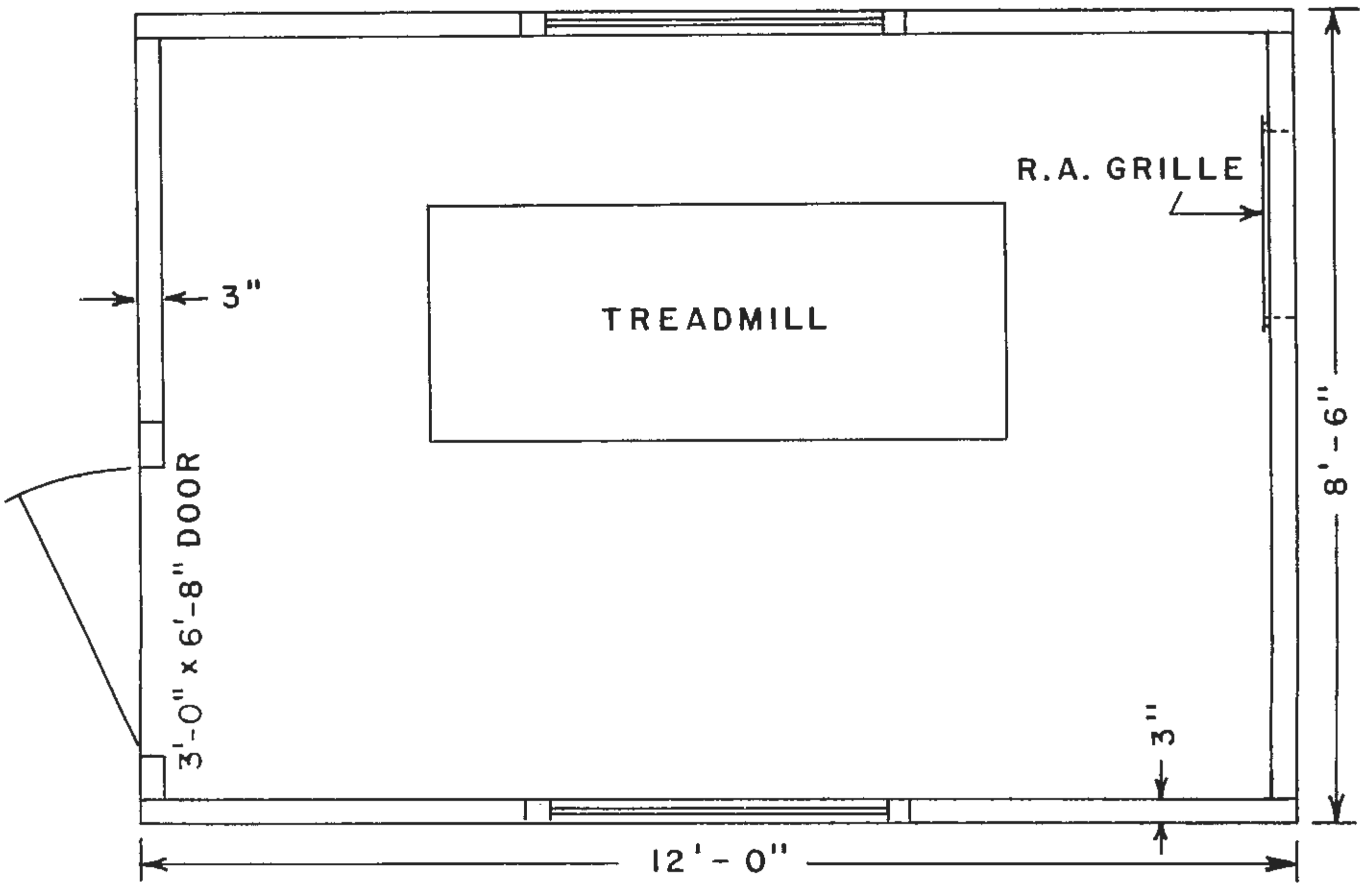

Fig. 1 Floor plan of Test Chamber

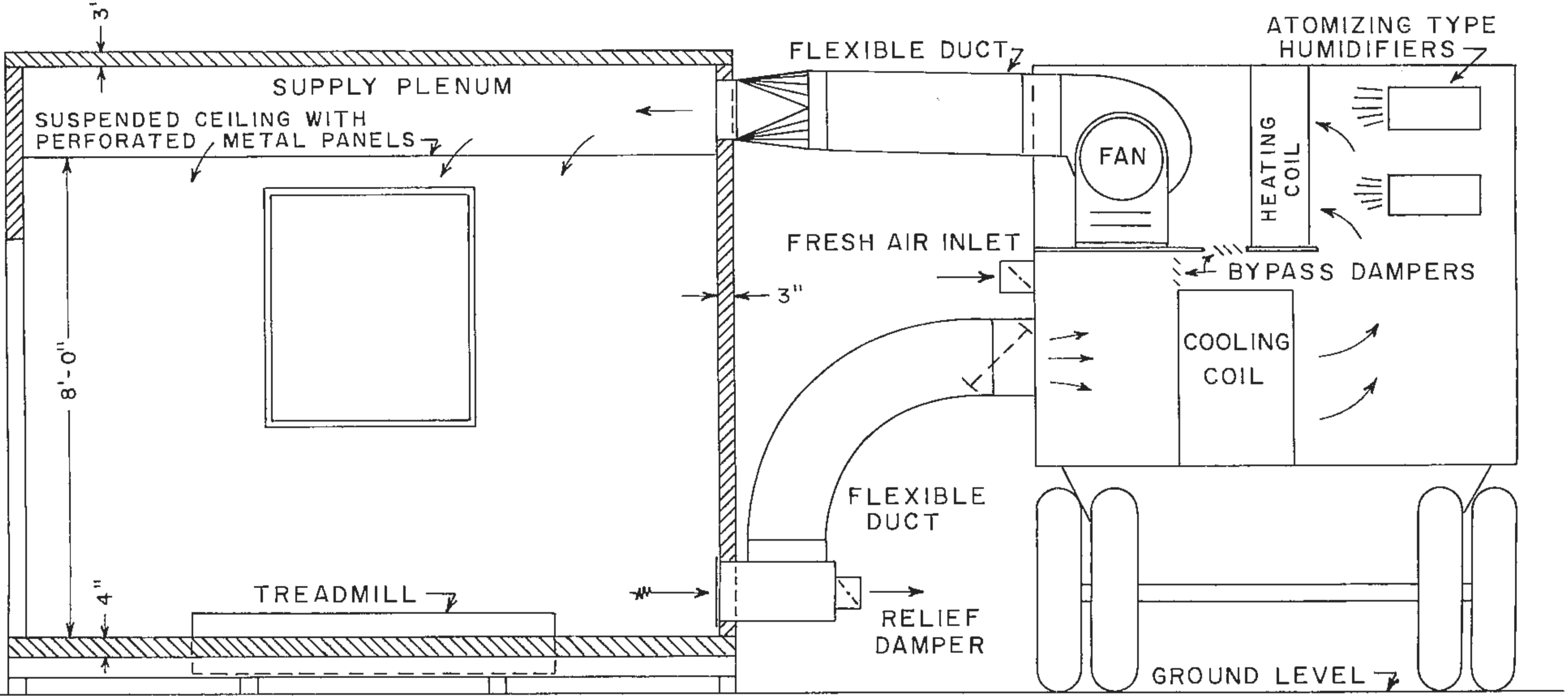

Fig. 2 Section through test chamber and equipment trailer

Environmental conditions in the test chamber were controlled by two Brown recorder-controllers. These instruments controlled the temperature of the liquid supplied to the heating and cooling coils by modulating pneumatically operated mixing valves in the supply lines. Aspirated wet- and dry-bulb thermocouples located at the return grille in the chamber served as sensing elements for the control system.

The test chamber, together with miscellaneous instrumentation and supplies needed for the field studies, were transported in a second 22 foot trailer. The chamber could be unloaded and completely assembled ready for testing in one day by a crew of four men. During the tests the trailer served as the office and the examination room. A window-type air-conditioner and thermostatically controlled electric heaters maintained comfortable conditions in the trailer at all times.

JOB SITE OBSERVATIONS

Physiological Measurements

Eight-hour total sweat productions were calculated from nude body weights taken at the beginning and end of a workshift. All fluids and food consumed and urine produced during the period were measured or weighed and accounted for in the sweat production calculations. One minute recovery heart rates (1RHR) were taken by palpation of the radial artery following the severest heat-work exposures during the shift. In addition, pulse rates were measured in some instances after every work round before the subjects entered the air-conditioned room for the rest period and before and at the end of each workshift. One minute recovery oral temperatures (1ROT) were taken at the same time the pulse rates were counted. Oral temperatures were measured with a thermistor probe placed under the tongue and a telethermometer indicator (Yellow Springs Instrument Company). The usual procedure was for one observer to constantly keep one subject under observation during an entire workshift.

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An estimate of the eight-hour shift metabolic heat production was obtained from detailed minute-by-minute observations on what the subject was doing, the duration of each task and the location within the plant where the task was performed. In some instances this information was put on tape using a portable constant speed tape recorder; the data were retrieved from the tape and analyzed after the study was completed. A plan of each work place was drawn and the exact site of each activity letter coded (Figs. 3-6). These same coded maps were used when the environmental data were obtained. After the daily activity pattern of a job and its variability were established, shorter time-activity analyses were conducted to refine the appraisal of the energy demands of the jobs. In some instances the observer performed some tasks himself in order to get a better estimate of the physical requirements. The calorie equivalent for the tasks was derived from the standard tables (14). Corrections were made for the energy conversion efficiency of mechanical work.

Environmental Measurements

A combination of recording and manually operated indicating instruments was used to measure environmental conditions. Four or five sets of recording instruments were used in each plant to secure continuous records of dry-bulb, wet-bulb, globe temperatures and air velocity. These instruments were centrally located in general work areas, but at points where they would not interfere with the workmen. Manual measurements of all four variables were also taken twice daily at various hours of the day at each recorder, at each of the work stations around the recorder and at other points of interest.

The locations at which recorded and manual measurements were taken at the glass, chemical and aluminum plants are shown in Figures 3, 4 and 5 respectively. The location of manual readings as related to a typical pot in the aluminum plant is shown at larger scale in Figure 6.

The recording instrument developed to meet the requirements was a redesign of the Envirec (24) instruments which were built several years ago at this Facility. Thermistors in bridge circuits were used as the sensing elements

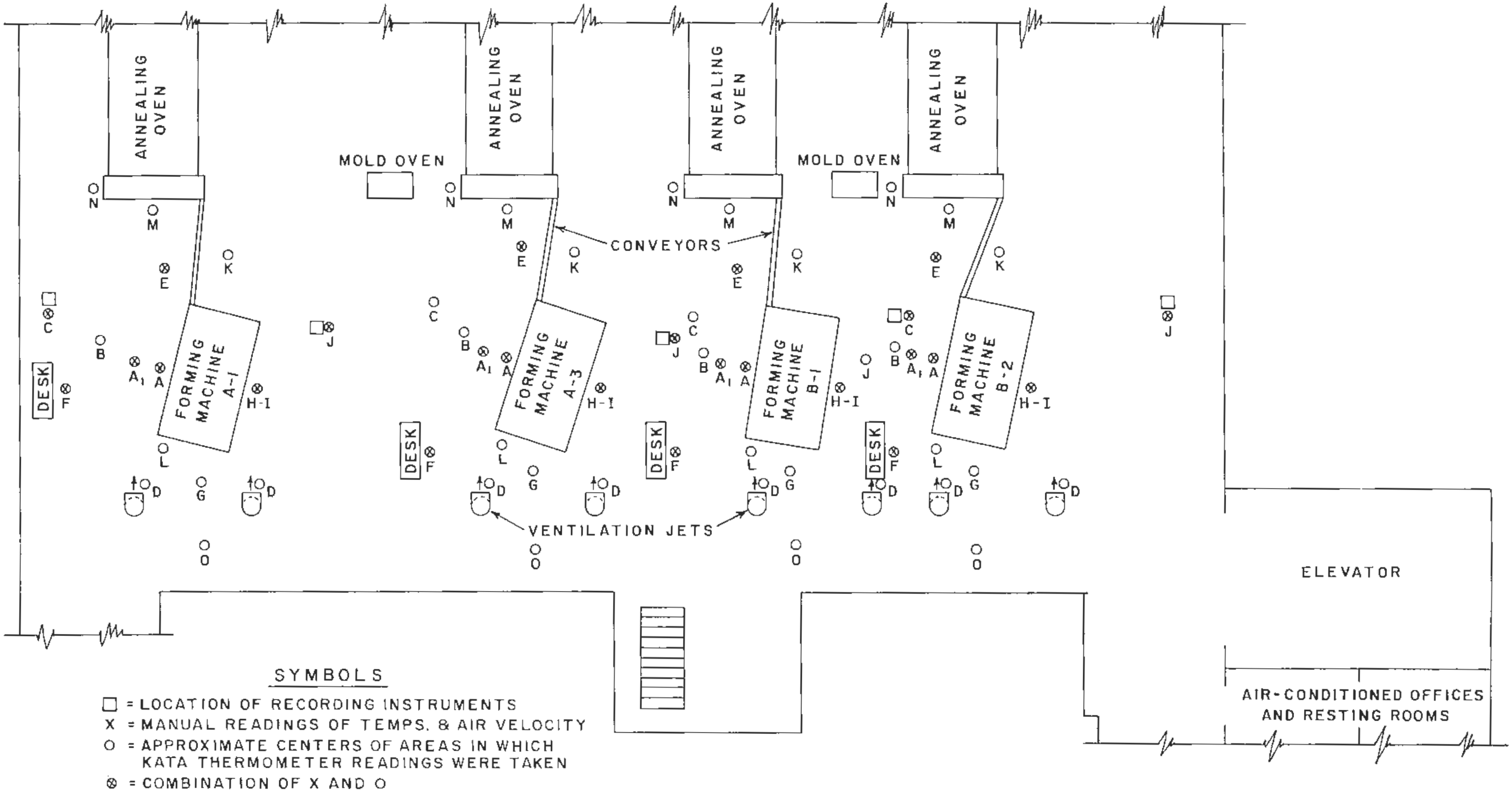


Fig. 3 Plan of Forming Department – Glass Plant

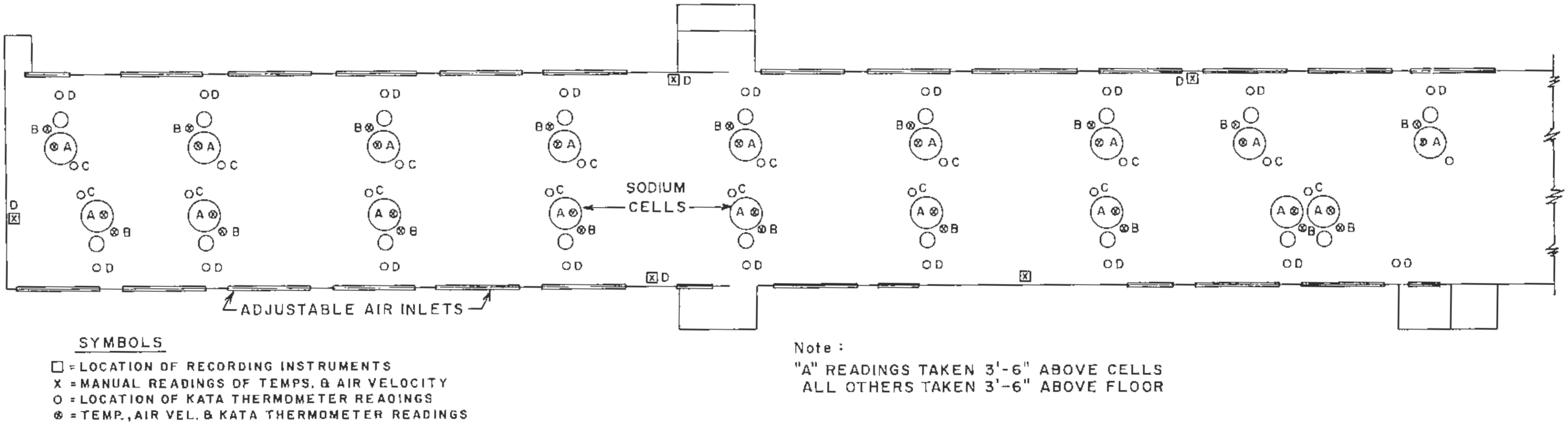


Fig. 4 Plan of Cell Room – Chemical Plant

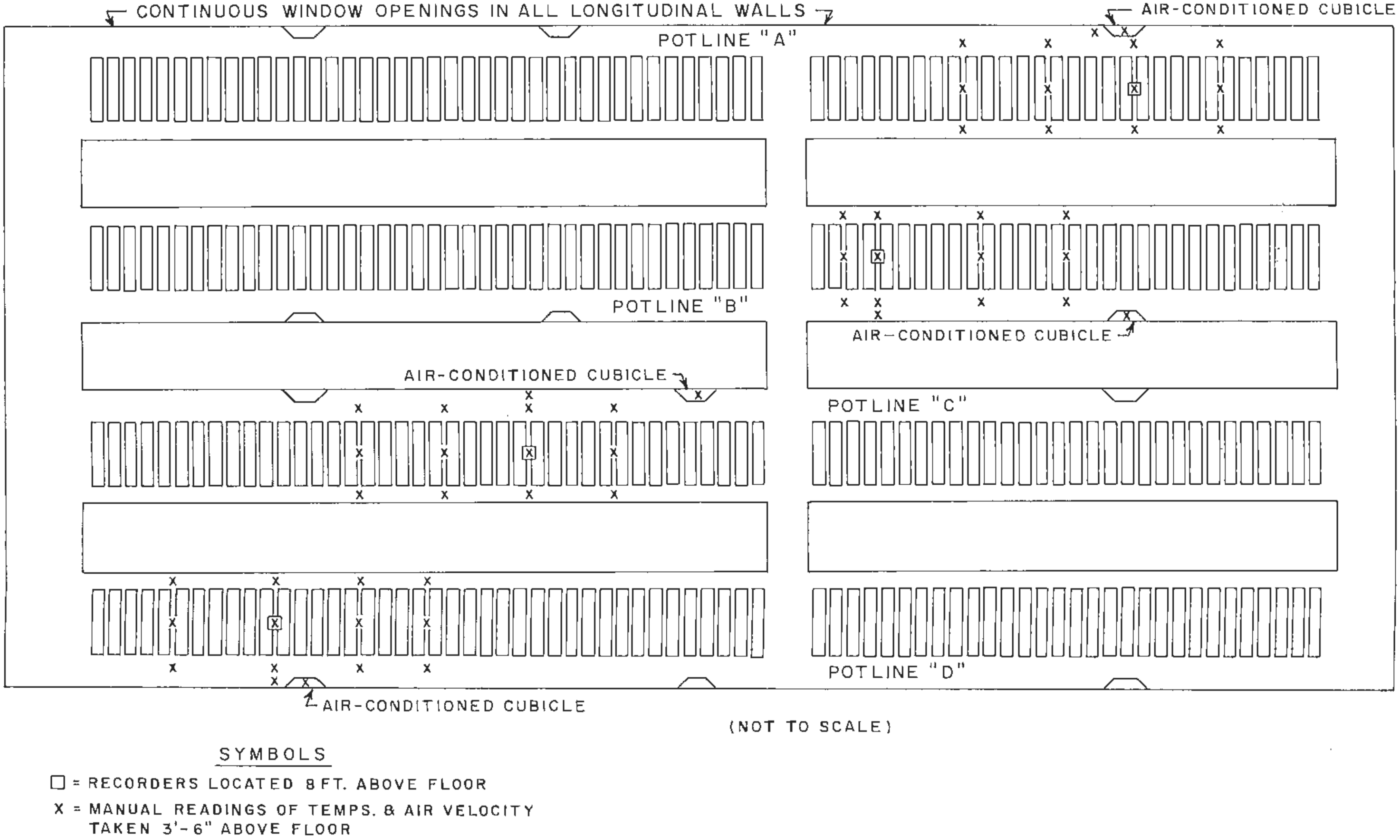
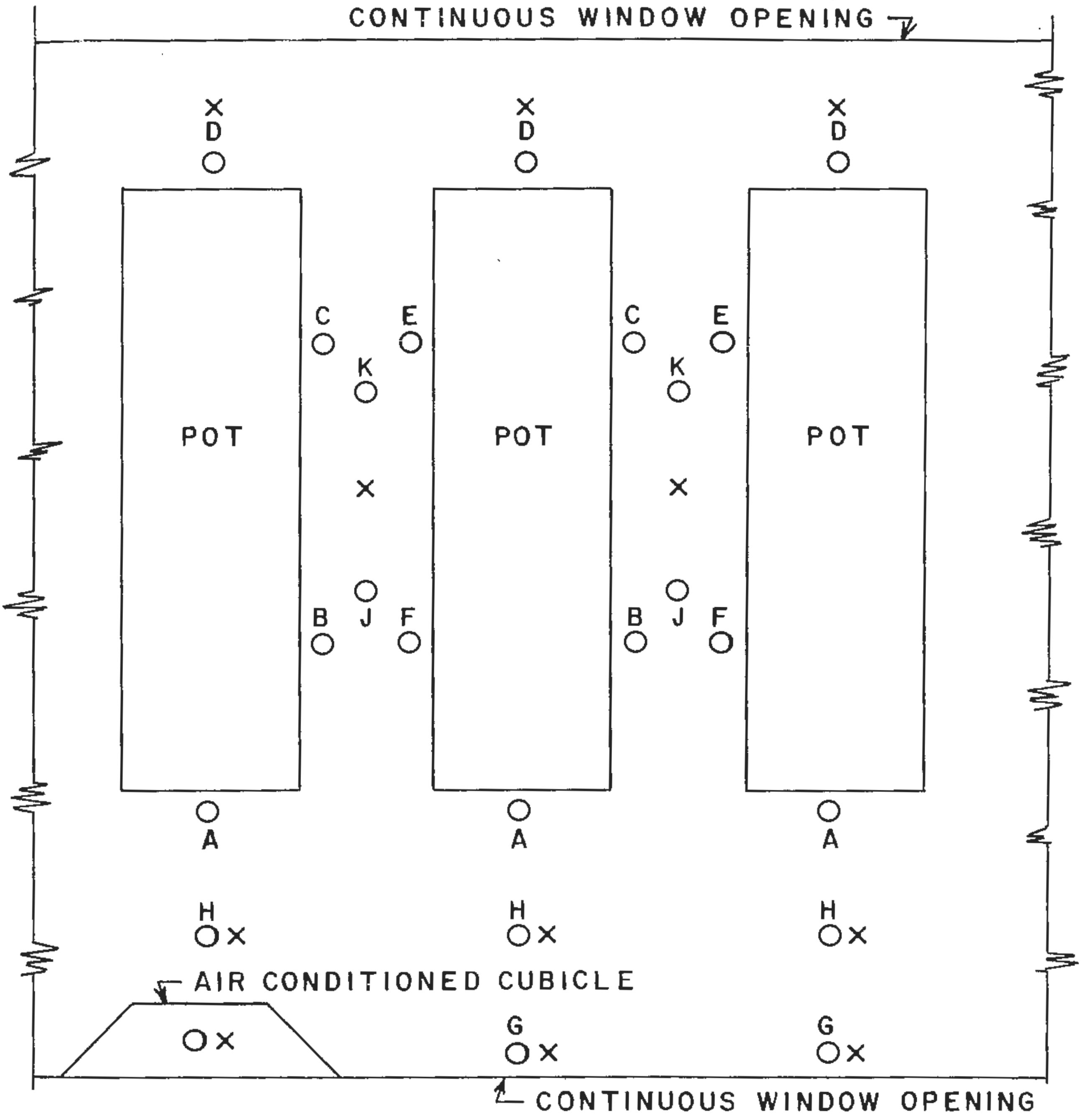


Fig. 5 Plan of Pot Room-Aluminum Plant



SYMBOLS

X – LOCATIONS OF TEMP. & AIR VEL. READINGS AS RELATED TO TYPICAL POT.

O – CENTERS OF AREA OF KATA THERMOMETER READINGS AS RELATED TO TYPICAL POT

Fig. 6 Typical pot arrangement – Aluminum Plant for dry-bulb, wet-bulb and globe temperatures. The outputs from all three thermistor bridges were fed into a Rustrak recording milliammeter (Rust Industrial Co., Inc., Manchester, New Hampshire) through a clock-operated program switch. A fan was used to provide air movement over the dry and wet-bulb thermistors. The globe thermometer, consisting of a six inch blackened copper sphere with the thermistor located at its center, was located at a sufficient distance from other parts of the instrumentation to eliminate serious interference. To record air velocity an Alnor heated-thermocouple type probe and power supply (Alnor Instrument Company, Chicago, Illinois) were used. The output from the probe was fed into a second Rustrak recorder through a suitable amplifier.

The arrangement of the recording instrumentation is shown in Figure 7. The air velocity probe and the globe thermometer are near the top of the standard. Dry and wet-bulb thermistors are in the box to which the water bottle is attached. Recorders, amplifiers and control boxes are on the shelf below. Typical sections of the temperature and the air velocity recorder charts are shown in Figures 8 and 9, respectively.

Indicating as well as recording instruments have presented problems in this study. In some areas thermal radiation was so intense that globe temperatures were as much as 100°F above the air temperature, and errors in sling psychrometer readings were suspected. A shielded, aspirated type psychrometer was constructed to check the sling psychrometer, and errors in dry- and wet-bulb temperatures of as much as 14 and 9 degrees F, respectively, were found. It was found that the Friez Psychron, a commercially available aspirated psychrometer, when fitted with a small radiation shield, showed no radiation pick-up. Such an instrument was used throughout the remainder of the tests.

Globe thermometers for manual measurements were made by inserting a mercury thermometer into a blackened copper sphere. The thermometer bulb was located at the center of the sphere. Approximately fifteen minutes were allowed for the globe to reach equilibrium before a reading was taken. Manual measurements of air velocity were taken with an Alnor Type 8500 Thermoanemometer.

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To provide an additional check on the radiant environment, the temperatures of readily accessible surfaces were measured with a surface type pyrometer (Pyrometer Instrument Company, Bergenfield, New Jersey). A Stoll-Hardy radiometer (Williamson Development Company, West Concord, Massachusetts) was used to measure the radiant temperature of inaccessible surfaces such as the roof. A few very high surface temperatures were measured with a Model TD-6B Thermodot radiometer made by Radiation Electronics, Division of Victor Electronic Systems Company, Chicago, Illinois.

The recorded temperatures for each hour of the day for the entire test period were averaged, and curves of the average daily dry-bulb, wet-bulb and glove temperature cycles at each recorder station were plotted. For each work station, the difference between the manually observed temperatures and the temperatures simultaneously recorded at the nearest recorder station were tabulated, and average differences between the recorded and manually observed dry-bulb, wet-bulb and globe temperatures were obtained. It was therefore possible to determine the approximate temperatures which prevailed at a given work station on a given day and hour by correcting the temperatures recorded at that time by the average differences. Similarly, it was possible to determine the average temperatures at a given work station at a given hour of the day by obtaining the average recorded temperatures from the curves, and correcting them by the average differences between the recorded and observed values.

When the average temperatures were tabulated for the various work stations, it was apparent that the temperature contours around the major heat sources in each plant (forming machines, reduction cells or aluminum pots) were quite similar (Figs. 10-15). This suggested a further condensation of data by averaging the temperatures for all stations similarly located with respect to the major heat sources.

Mean radiant temperatures for all work stations were calculated from the globe thermometer temperatures by the equation

$$MRT^4 = T_g^4 + 1.03 \times 10^8 \sqrt{V} \; (t_g - t_a)$$

where T_g = globe temperature, Deg. F absolute

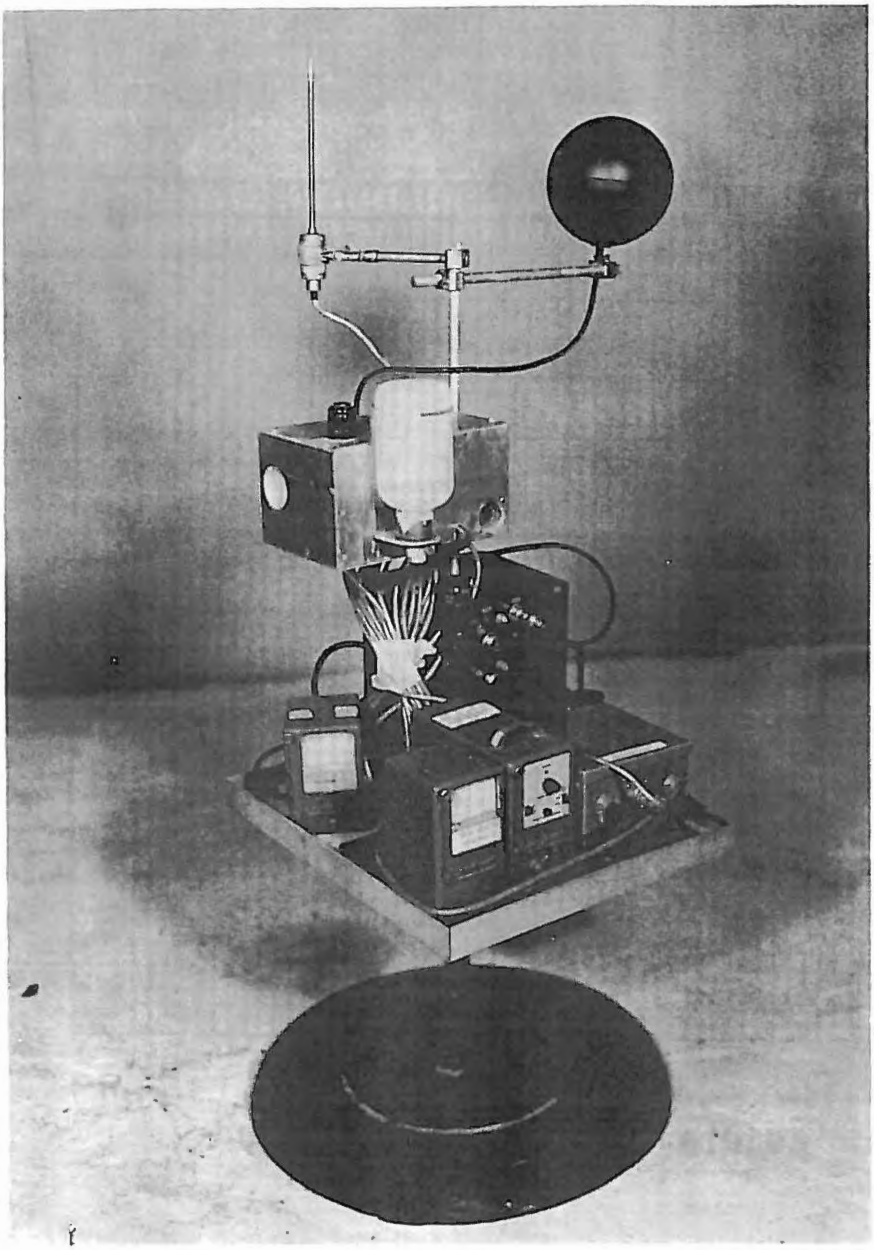

Fig. 7 General arrangement of Recording Instruments

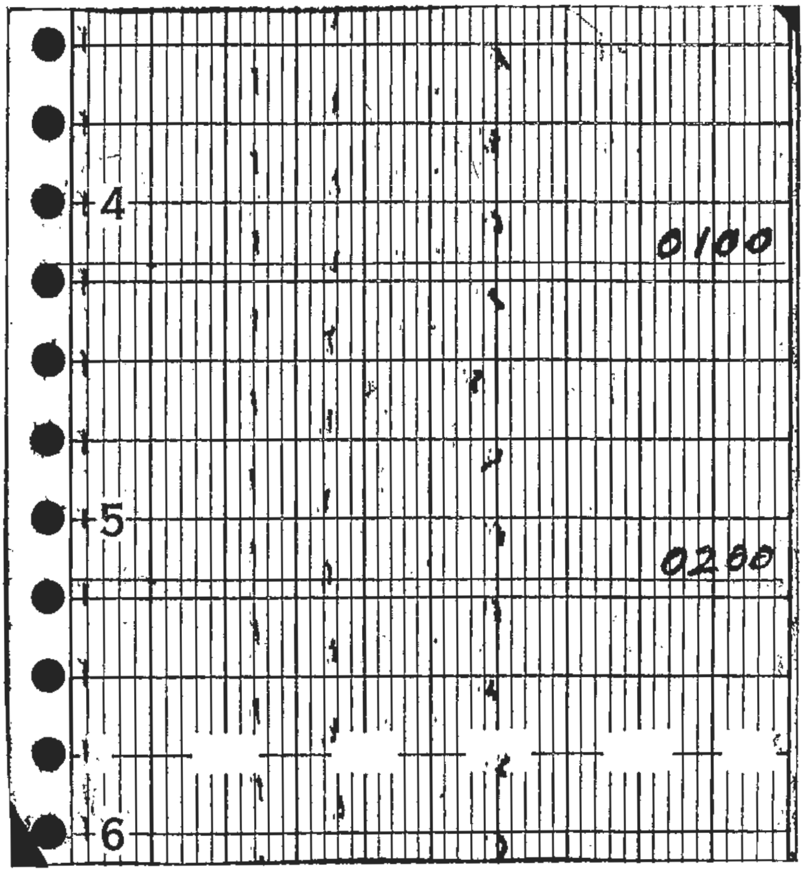

Fig. 8 Typical Record of dry-bulb, wet-bulb and globe Temperatures

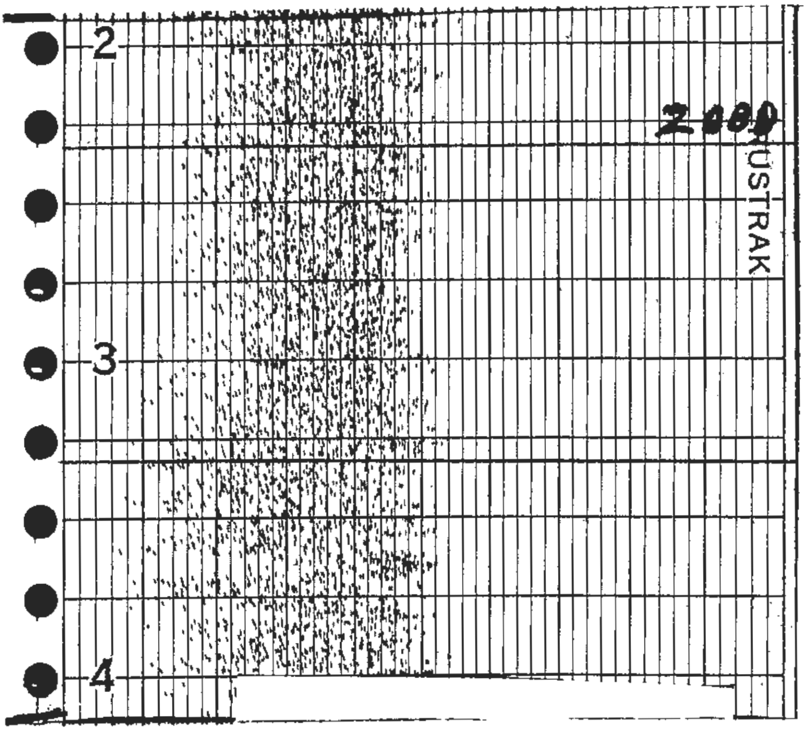

Fig. 9 Typical Record of Air Velocity

t_g = globe temperature, Deg. F

t_a = air temperature, Deg. F

V = air velocity, feet per minute

The mean radiant temperatures at several locations in one plant were also calculated from the observed surface temperatures and the geometry of the surroundings in accordance with reference 25.

The standard dry katathermometer calibrated for the 95-100°F range was also used to measure the cooling power of environments in the working areas and in the resting areas of all three plants. The cooling power of the environment (convective and radiative) as measured by the dry katathermometer is expressed in millicalories per square centimeter per second. In making measurements with the katathermometer, the observer held the instrument close to the worker in such a way that the katathermometer was exposed to approximately the same environmental conditions as the worker was at the time.

RESULTS AND DISCUSSION

DESCRIPTION OF JOBS

In the glass plant seven men in each shift monitored the four glass forming machines. Usually a machine was in continuous operation for several days or weeks until orders for a particular type bottle were completed. The machine was then stopped and the molds were changed. This required one to three hours and involved considerable heat exposure and physical effort. Otherwise most of the jobs involved light physical work and an extensive amount of walking, exposed intermittently to high heat. A high volume air jet was near each forming machine which could be adjusted and used by the men as a source of cooling at their discretion whenever the duties of the job permitted. Metal shielding panels could be raised on the sides of the forming machines to protect the workers against the radiant heat emanating from the freshly formed glowing hot bottles.

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The operations in the chemical plant required ten men for each shift. The level of physical effort varied considerably from light to moderately heavy work; the heat exposure varied from none in the air-conditioned rest and recovery rooms to high levels during the cell repair and change-over operations. The cell room was equipped with overhead exhaust fans which increased the air movement in the work area appreciably.

The operations in the aluminum plant also included a variety of tasks that differed in degree of heat exposure and level of physical exertion. The electro tenders worked in teams of two to three men who rotated the tasks among themselves. Each pot tender had to take care of the pots assigned to him by himself. Physical activity ranged from light to moderately heavy with some of the jobs being heavy work. The heat load was intense in some areas; particularly the radiant heat was high. However, in most instances the men had access to air-conditioned cubicles which could be used either for short cooling-off relief periods during operations or during scheduled rest periods. The electro tenders used portable fans and the pot tenders were supplied with helmets connected to compressed air. The hot surfaces of the pots were partially shielded with movable sheet metal panels.

ENVIRONMENTAL CONDITIONS AT THE JOB SITES

Single Climatic Factors (Conventional Instruments)

Representative mean daily cycles of environmental conditions in the three plants studied are shown in Figures 10 through 15. Figure 10 shows the mean daily cycle of dry-bulb, wet-bulb and globe temperatures at stations A_1 in the glass plant during the testing period in December 1963. Figure 11 shows similar data for the same station during July 1964. The average daily temperature cycles at station B at the chemical plant during January and August 1964, are given in Figures 12 and 13, respectively. Similar curves for station J-K at the aluminum plant during the winter and summer tests are presented in Figures 14 and 15. The daily cycles showed a maximum between 2:00 and 4:00 P. M. and a minimum between 6:00 and 8:00 A. M. in all plants in both summer and winter. The difference between the minimum and maximum was largest in the globe temperature values, amounting to about 10°F. The daily variations of the dry-bulb temperatures were slightly less, between 5 and 9°F, while the wet-bulb temperatures had a daily range of only 2 to 4°F.

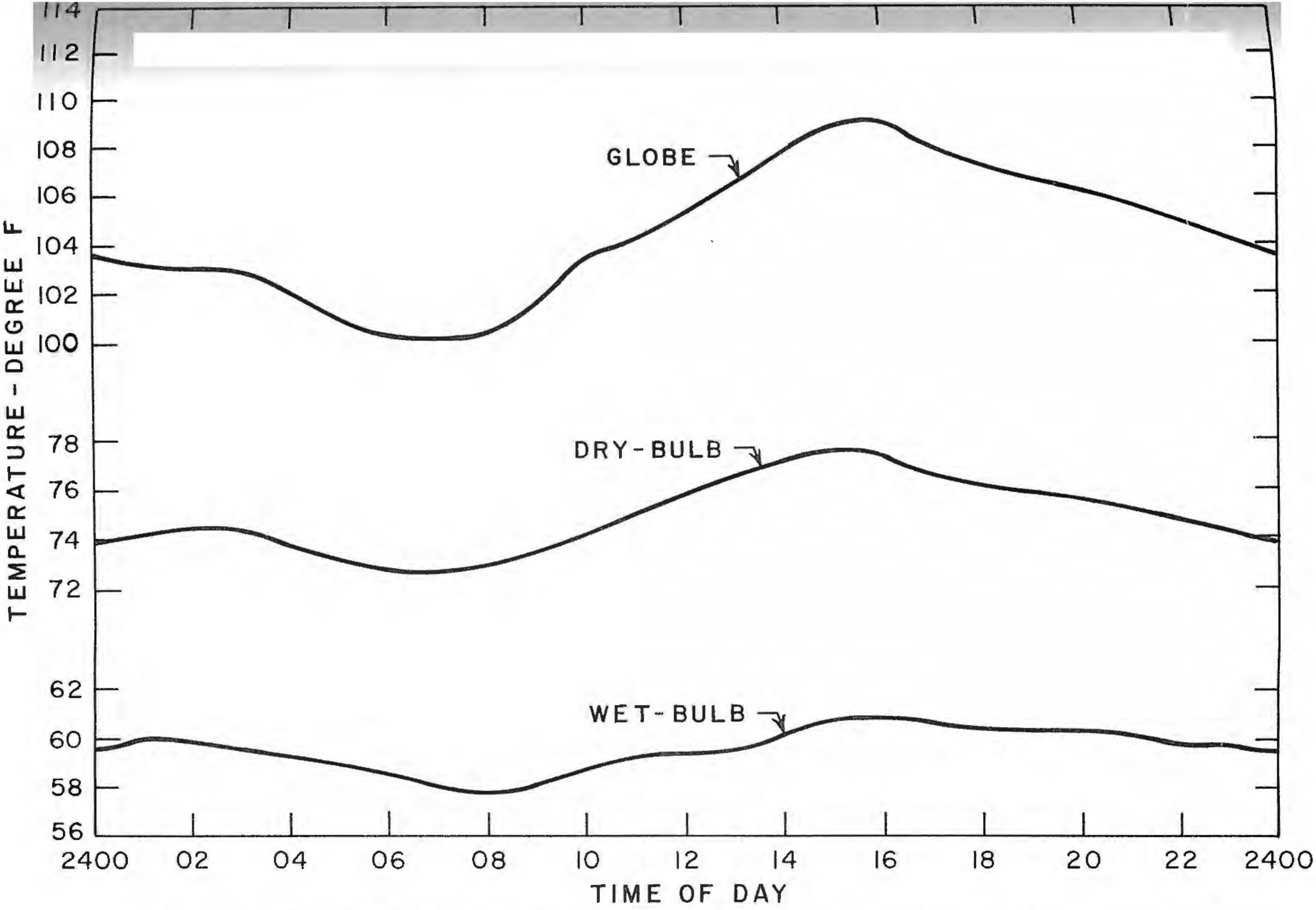

Fig. 10 Glass Plant - Average daily temperature cycles at points A_1
(December 3-19, 1963)

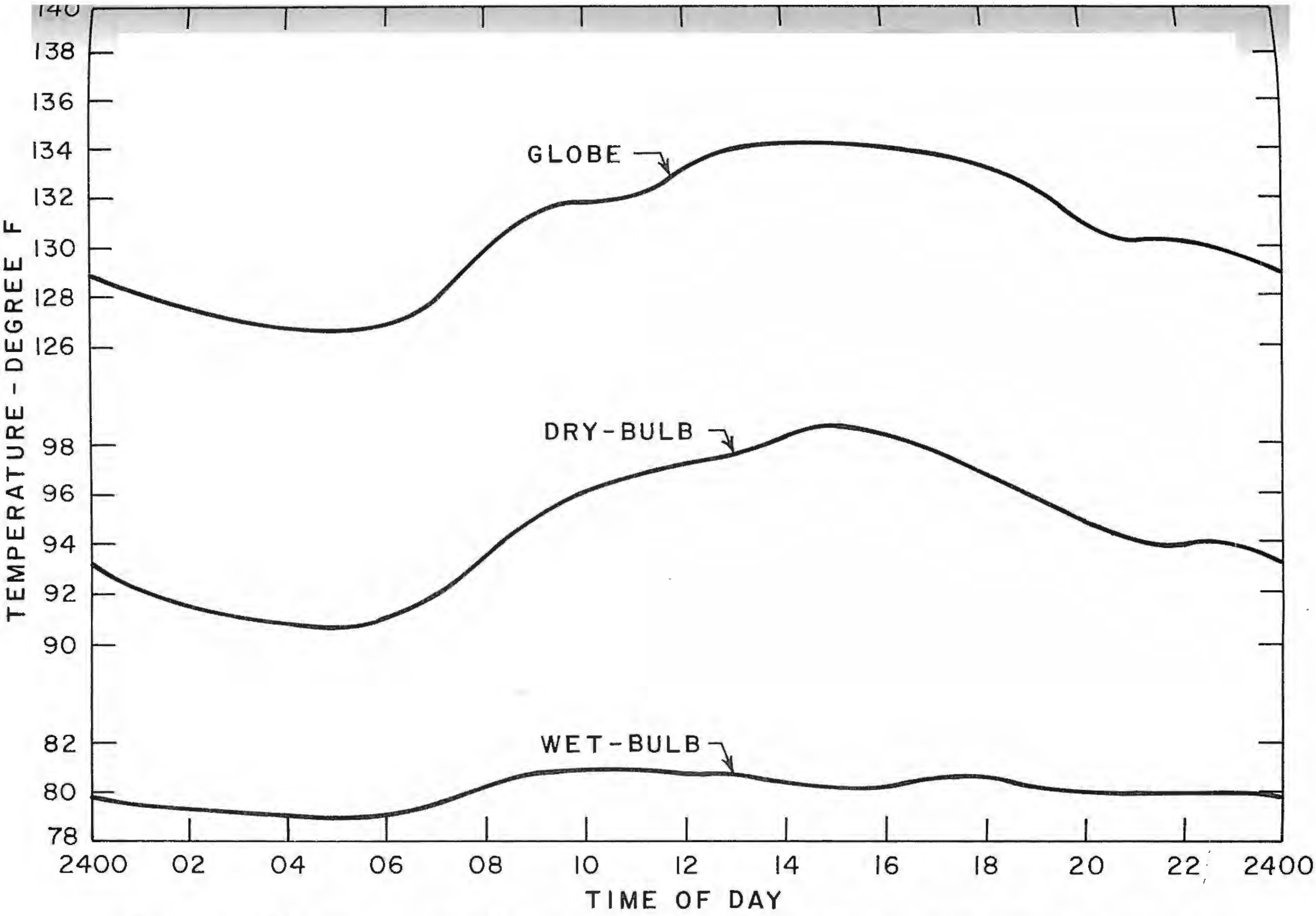

Fig. 11 Glass Plant - Average daily temperature cycles at points A_1

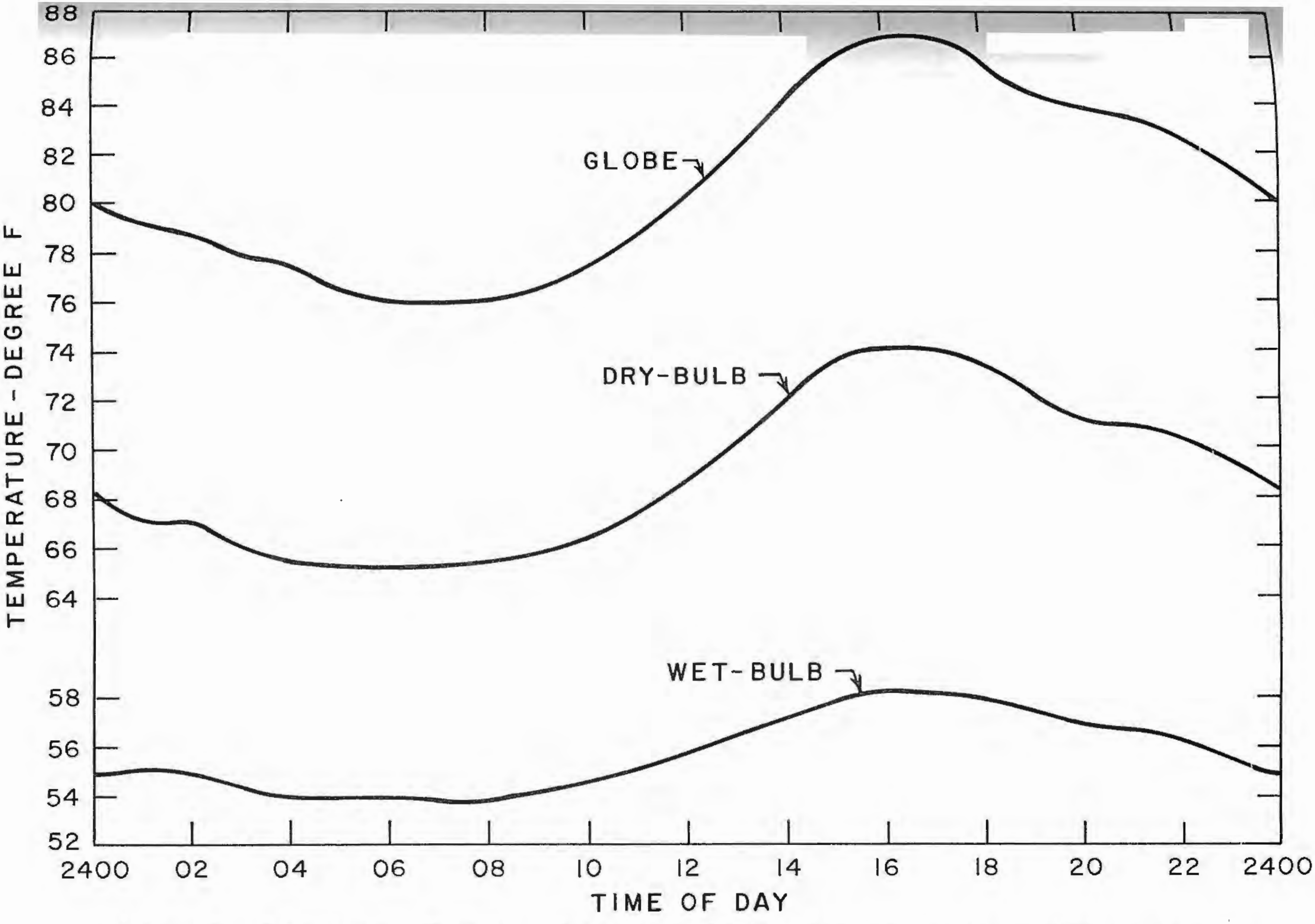

Fig. 12 Chemical Plant - Average daily temperature cycles at points B (January 22 - February 5, 1964)

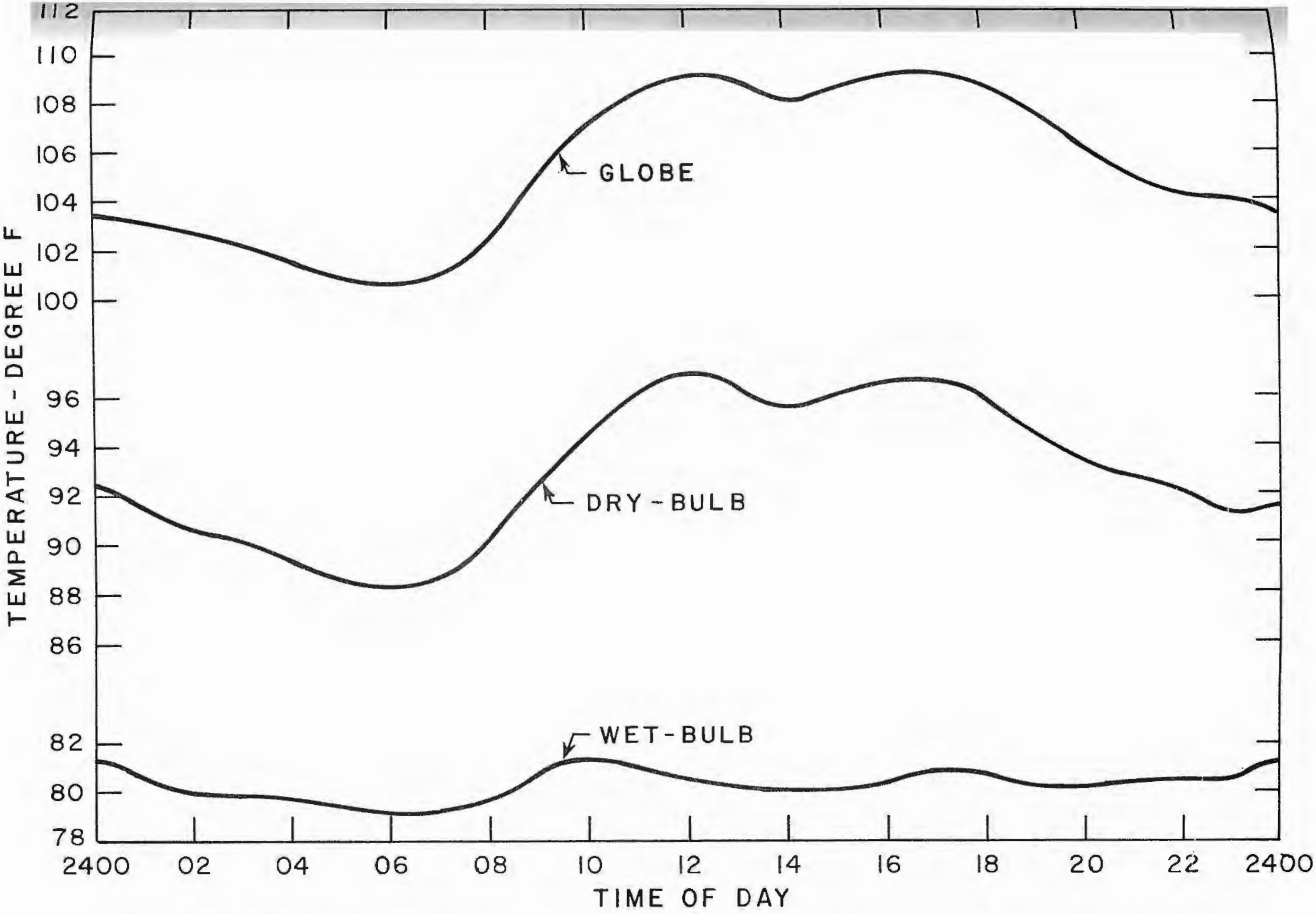

Fig. 13 Chemical Plant - Average daily temperature cycles at points B (August 6-17, 1964)

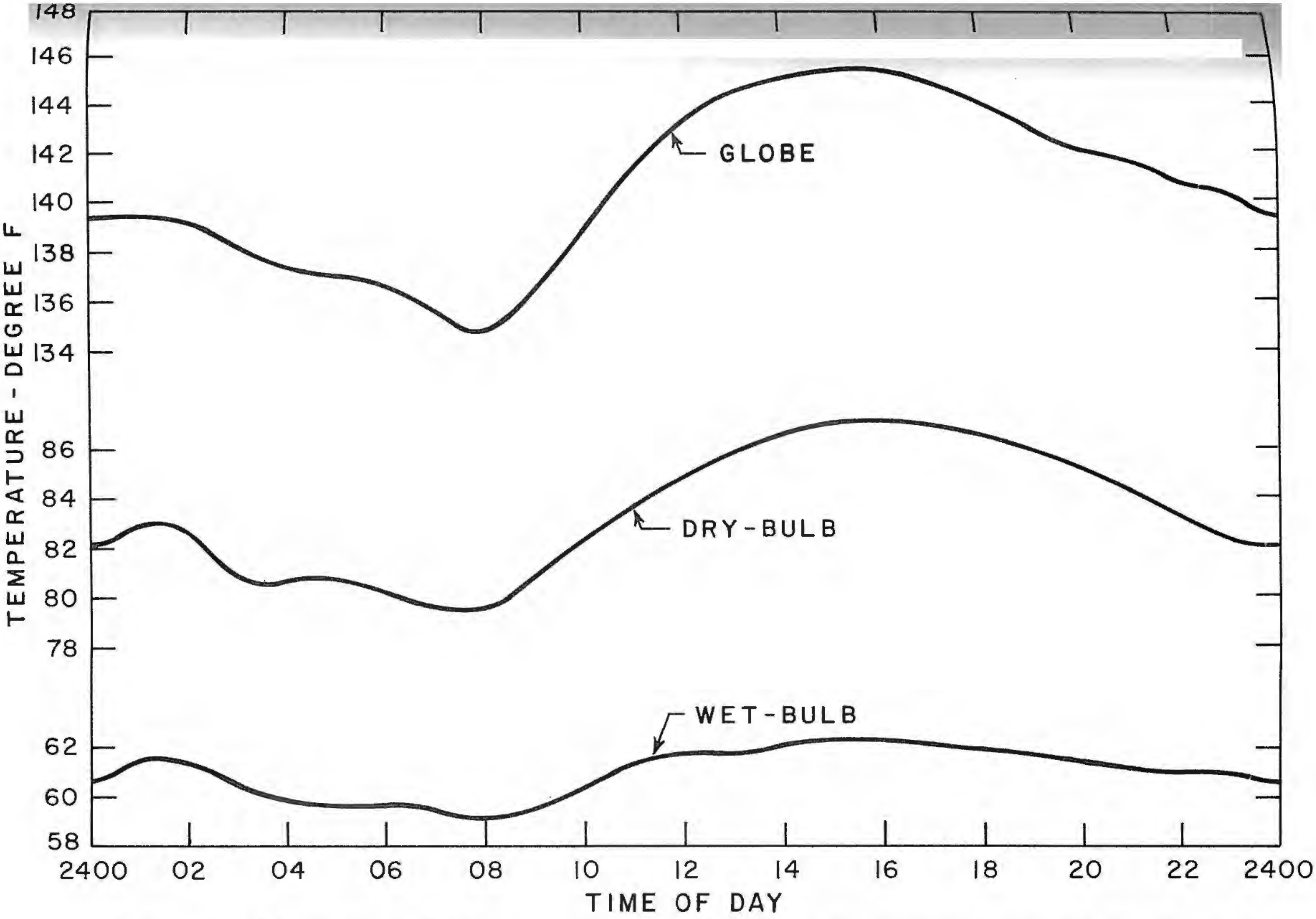

Fig. 14 Aluminum Plant - Average daily temperature cycles at points J — K (February 14 - March 5, 1965)

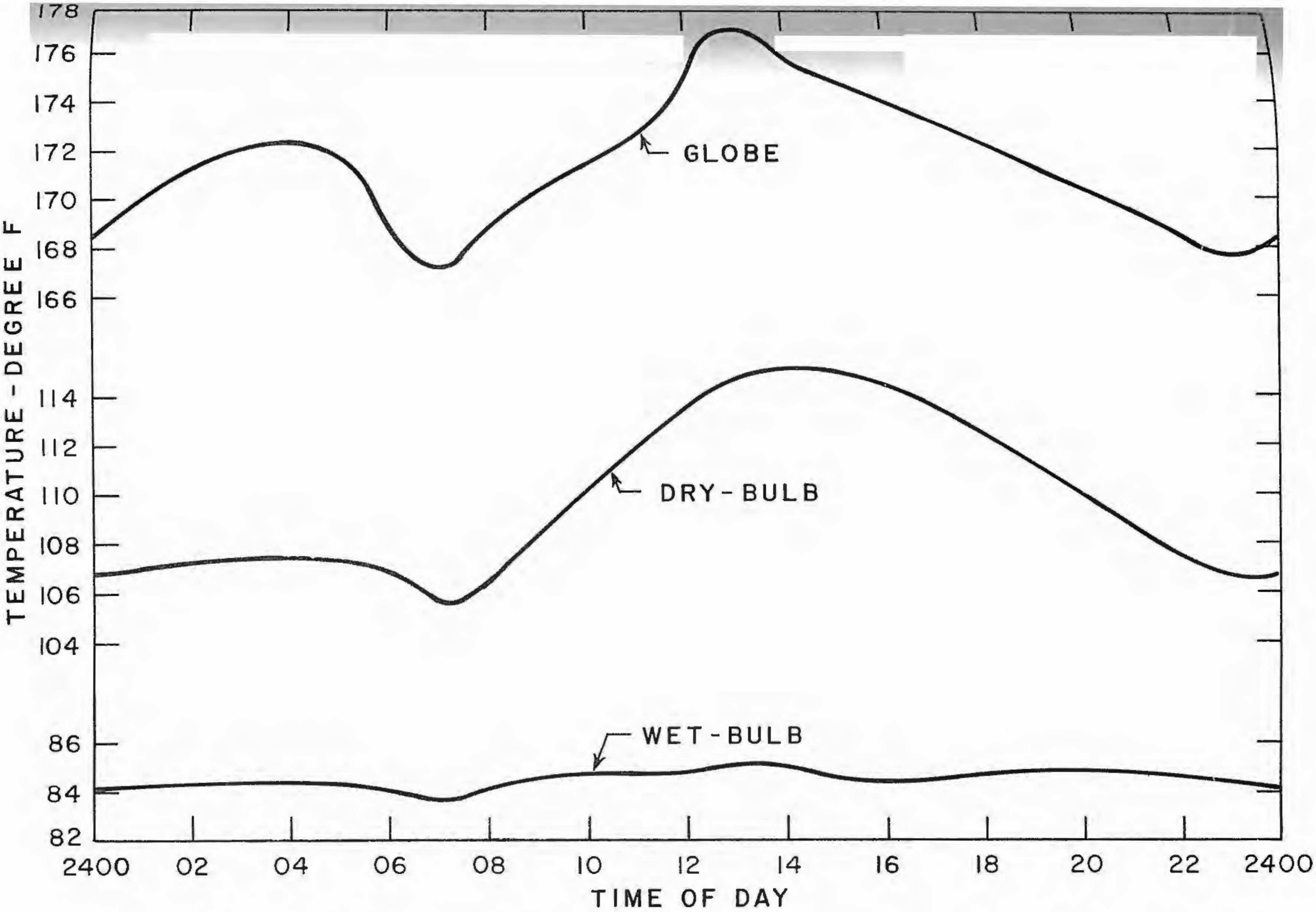

Fig. 15 Aluminum Plant – Average daily temperature cycles at points J — K (August 25 – September 10, 1964)

INDUSTRIAL HEAT STRESS

The hottest station where observations were made was around J-K measuring point of the aluminum plant where the mean globe temperatures reached a maximum of 177°F and even the minimum was as high as 167°F during the summer. The daily range of the mean dry-bulb temperatures at the same point was from 106 to 114°F and that of the wet-bulb from 84 to 86°F. During the winter the mean globe temperatures ranged between 133 and 145°F, the dry bulb temperatures between 80 and 87°F and the wet bulb temperatures between 59 and 62°F at the same measuring point. At the remainder of the observation stations the mean globe temperatures were mostly over 100°F, the mean dry bulb over 90°F and the mean wet bulb over 80°F during the summer. The mean winter temperatures were lower at every observed station by approximately 25°F for all the three observed climatic factors.

The warming up in the morning was somewhat faster than the cooling off in the afternoon. In the glass plant in both seasons and in the chemical plant in winter, the afternoon shift was the hottest, whereas in the aluminum plant during summer the average climatic conditions were hotter in the morning shift. In the aluminum plant in winter and in the chemical plant in summer the environmental conditions were approximately equal in the morning and afternoon shifts. During the night shift, of course, in each plant and in each season the conditions were coolest.

The average environmental conditions during the 3:00 to 11:00 P.M. or 4:00 P.M. to 12:00 Midnight shift at the various work stations in the three plants studied are given in Tables 3 through 9. Tables 3 and 4 are for stations in the glass plant for the winter of 1963 and the summer of 1964, respectively. Tables 5, 6 and 7 present results obtained at the chemical plant during the summer of 1963 and the winter and summer of 1964, respectively. Results for the winter and summer of 1964 at the aluminum plant are presented in Tables 8 and 9.

In all three plants, conditions at any given station were found to vary rather widely and erratically with time. These variations were due, in part, to changes in products manufactured and heat production by the manufacturing processes. The variability of air velocity was attributable primarily to changing air flow patterns from frequent readjustments by the workmen of the direction and volume of ventilation jets discharging into the work area. In spite of these variations, the daily temperature cycle graphs, which were derived from continuous recordings and manual measurements performed over a period of two to three weeks in each plant and in each season, are informative of the average climatic conditions at the observed job sites.

In the tabulated data for the aluminum plant (Tables 8 and 9) two different columns of mean radiant temperatures (MRT) are given. The first was calculated from black globe thermometer temperatures, the second from surface temperatures and solid angles. The values are in good agreement. It should be noted that the MRT values based on globe readings were calculated from average black globe and air temperatures, and air velocities during the 4 to 12 P. M. shift, while the surface temperatures used in the other calculation were measured at about noon on one day during the test period. The geometry of surfaces in the glass and the chemical plants was quite complex, and the calculation of MRT from surface temperatures would have been tedious and time consuming. It was therefore decided that for these two plants, MRT would be calculated only from black globe temperatures. The agreement between the results of the two methods for the aluminum plant seemed to justify this decision.

The data from the 1963 summer tests are given only for the chemical plant. Because of instrumentation difficulties, data taken at the other two plants during the first summer were not complete enough to justify analysis.

Cooling Power (Katathermometry)

Tables 10, 11 and 12 show the seasonal variations of the cooling power of the environment as calculated from katathermometer measurements at different working areas and for different activities in the same area. The letter symbols (column 1), indicating the working areas, correspond to those shown in the floor plans (Figures 3-6).

The numerical value of the cooling power was generally less during the winter than during the summer. However, the areas with a high cooling power value in the summer showed less seasonal change than those with a lower cooling power value. An explanation of this finding is the fact that the main source of heat at the observed plants is radiant heat emanating from hot surfaces. On the sites where the radiant heat was mild or moderate, a change in air temperature had a marked effect on the cooling power of the environment. At sites where the radiant heat was very intense, a change in air temperature had relatively less effect on the cooling power.

Conventional versus Katathermometric Measurements

A direct comparison between results of conventional climatic measurement and katathermometry cannot be made, because one is expressed in degrees F and feet per minute while the other is in millicalories/square centimeter/second. However, both the results of the conventional measurements and katathermometry can be utilized to calculate the amount of evaporation of sweat from the skin required (E_{req}) to eliminate the heat which the worker would gain by convective (C) and radiant (R) heat exchange from the environment and by metabolically generated heat (M)

$$E_{req} = M \pm C \pm R$$

From the conventional measurements, E_{req} was calculated by Burton's formula (26) as modified by Lee and Henschel (2) and corrected to obtain the total E_{req} for an average 70 kg man and for the total exposure time.

$$E_{req} = \frac{M + \left[\dfrac{5.55\,(t_a - 35) + RI_a}{I_a + I_c}\right] \times 1.7 \times WT}{580}$$

where E_{req} = Required evaporation in liter*/70 kg** man/WT
M = Metabolic heat production in kcal***/70 kg man/WT = (0.8 x work metabolism) + basal metabolism

---

* 1 liter ≅ i quart

** 70 kg = 154 lbs., the body weight of an average sized man

*** 1 kcal = 4 BTU

t_a = Air temperature in °C
R = Radiant heat exchange between the worker and the surrounding surfaces in kcal/m^2/hr as calculated by the Stefan-Boltzman equation
I_a = Insulation of air in clo units as calculated by Burton (27) (See Figure 16)
I_c = Insulation of clothing in clo units (for wet, light summer clothing the value is 0.4 and for dry clothing 1.0)
1.7 = The average of the estimate of effective convective and radiant body surface areas in m^2 of an average 70 kg clothed man in semi-erect position (28)
WT = The work time in hours, i.e., the time spent in a given area during the workshift
580 = The latent heat of vaporization of 1 liter water, in kcal.

The estimate of the effective body surface area (1.7 m^2) would be about 11 per cent less if heat exchange would occur completely by radiation and about 11 per cent more if heat exchange would occur completely by convection. However, the variations in effective surface area due to individual differences in clothing and body build and to differences in body posture during work are larger than the ± 11 per cent maximal possible deviation in surface area due to the changing proportions between convective and radiant heat exchange. For practical purposes 1.7 m^2 was taken as a "best" estimate.

The E_{req} can be calculated directly from the cooling power of the environment as determined by the katathermometer, because by coincidence

$$1 \text{ millical/cm}^2\text{/sec} = 0.6 \text{ kcal/m}^2\text{/min} = 1 \text{ kcal/1.7m}^2\text{/min}$$

and 1.7 m^2 corresponds with the average estimate of the effective convective and radiant surface of a 70 kg clothed man in semi-erect position, as indicated above. Thus the cooling power (H) provides without further calculations an estimate of the combined convective and radiant heat exchange. Therefore, E_{req} can be calculated from the katathermometric measurement by the following equation

$$E_{req} = \frac{M \pm (60 \text{ H x WT})}{580}$$

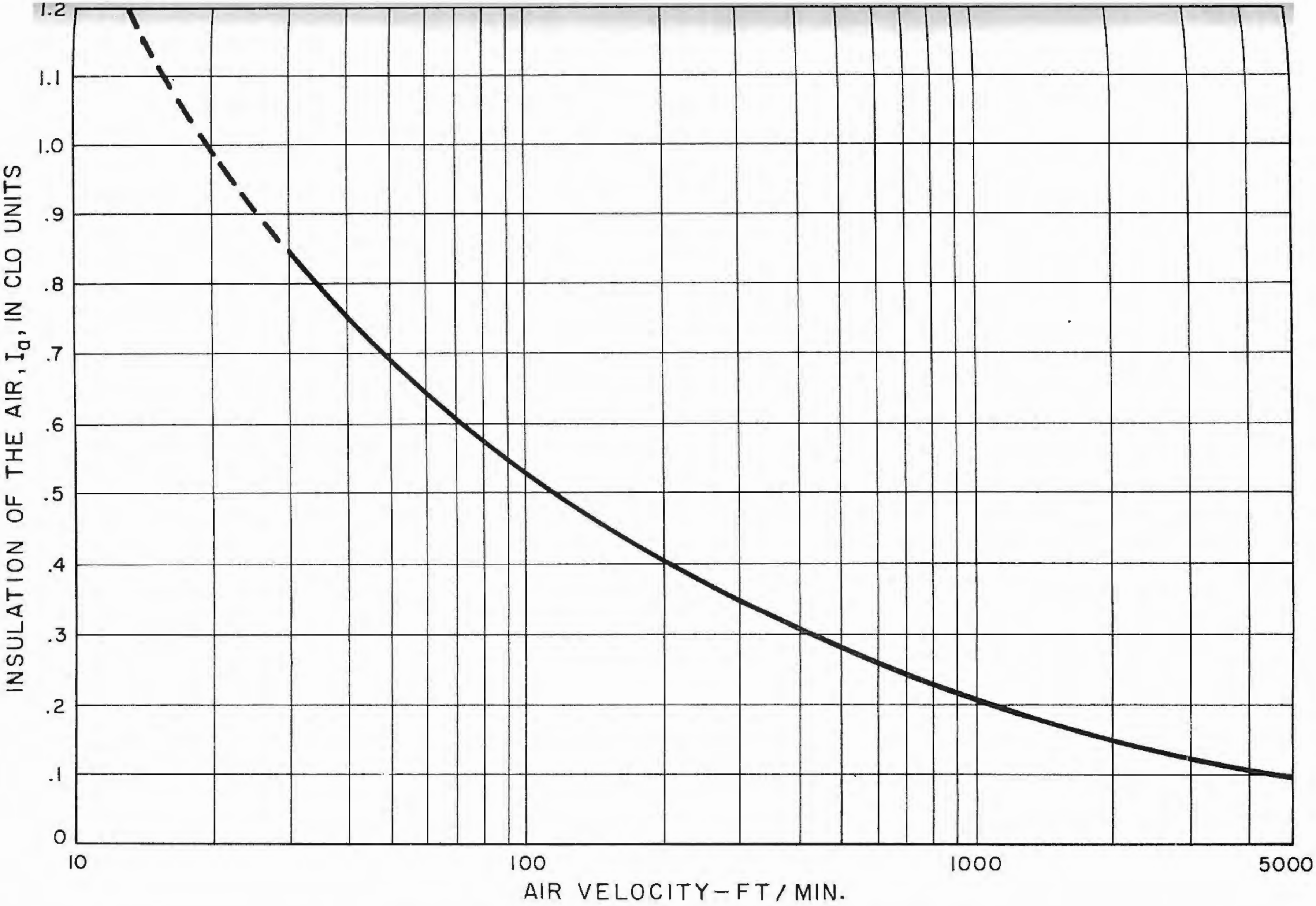

Figure 16. Insulation of Air, I_a vs. Air Velocity

where E_{req} is obtained in the same units as in the modified Burton formula, i.e. liter/70 kg man/WT.

Tables 13, 14 and 15 show the mean values of WT and M for each working area and activity which were substituted in the above equations. In the same tables are shown the calculated E_{req} values based on conventional and katathermometer measurements for both summer and winter. The E_{req} values for the several activities making up each job during a working day were added to give the eight-hour total E_{req} values for each job. E_{req} calculations were not made for the filter operators, truck drivers and salt and temperature men because the data were incomplete.

An important question arises here when adding the E_{req} values to obtain the total eight hour E_{req} value: is it necessary to subtract the negative values from the positive values? In other words will the evaporation requirement accrued at the hot work areas be diminished by the convective and radiant heat loss occurring in the cooler work and recovery areas?

To answer this question one has to consider the fact that at the observed job sites the general work pattern was such that the workers moved back and forth between hot work and cooler recovery areas. When the workers entered a hot area, they first stored heat in their garments, their skin and the outer layers of their body. Evaporative heat loss became necessary only after the skin temperature exceeded a critical temperature. Thus the actual E_{req} was reduced by the amount of heat which could be stored in the clothing and surface layer of the body before the critical skin temperature was reached. When the workers left the hot area and entered the cool area again, the stored heat would be partially or completely eliminated by convection and radiation without the need for evaporation. If the time spent at a hot area were short, the cooling effect in the recovery area would significantly diminish the required evaporation, and, therefore, the negative E_{req} value of the recovery area should be subtracted from the sum of the positive E_{req} values of the hot work areas. However, under conditions where the hot cycles are longer than a few minutes the relative significance of the outer layers' heat capacity in diminishing E_{req} becomes small. After working a few minutes, the workers sweated profusely and this could not be undone, no matter how cool the recovery areas were. Therefore, subtraction of the negative E_{req} values under these conditions would give a false estimate of the total eight hour E_{req}. Similarly if the worker spent a longer time continuously under conditions yielding a negative E_{req} value, it would not diminish the required evaporation of hot cycles occurring not immediately before or after this period. Thus, negative E_{req} values, which belong to continuous exposures for more than a few minutes, should not be subtracted.

Analysis of the observed jobs from this point of view revealed that in the jobs of the glass plant the hot and cool work cycles were generally short, seldom exceeding two minutes either in summer or in winter. An exception was the floor boy's long work cycle in area J when cleaning up the workshop. In the jobs of the chemical plant the hot work cycles were longer, with the exception of the cell repair men's work during the summer, which consisted of cycles lasting only one to three minutes. In the aluminum plant both the pot tenders and the electro tenders had longer work cycles in the hot areas during the winter. However, during the summer the electro tenders' work pattern remained practically the same. The work patterns of three of the observed jobs are graphically demonstrated in Figures 18-20 and will be discussed later in the text.

The negative E_{req} values were subtracted from the positives only when calculating the total eight hour E_{req} for jobs consisting of short hot work cycles alternating with short cool cycles. The criteria to distinguish between short and long work cycles were based on rudimentary observations of average time for saturation of clothing and superficial layers of the body with heat. More accurate estimates for saturation time at the different levels of heat exposure should be established in the future by controlled laboratory experiments. When calculating the E_{req} values for the total eight hour workshift, E_{req} values were not included for the longer rest periods and breaks spent in air-conditioned areas, because no evaporation would be required to maintain the worker's heat balance under these conditions.

The summer values of E_{req} calculated from katathermometric measurements were positive at the working areas where the actual heat-work was performed but were negative in some of the cooler recovery areas. In winter the kata E_{req} values were negative in all recovery areas and became negative in some of the work areas (e.g. area H-I in the glass plant, area E in the chemical plant). The E_{req} values calculated from conventional environmental measurements were all positive during the summer, and all were positive also in the winter except for two areas (area E in the chemical plant and area G in the aluminum plant).

In the areas where the heat exposure was intense, the kata E_{req} values were higher than the conventional values both during summer and winter. In areas where heat exposure was slight or absent, the conventional E_{req} values were the higher ones. This discrepancy can be partially due to the difference in the application of the two kinds of instruments. The katathermometer was moved during the measurement along with the worker, while the dry-bulb, wet-bulb and globe thermometers were exposed at a fixed point at the center of the worker's moving area, usually at a time when the worker was not there anymore, thus avoiding interference with his activities. Another factor which can cause the discrepancy between the results obtained by the two methods is the difference between the globe thermometer's and katathermometer's physical characteristics, which influence their heat exchange with the environment. Bognar, et al (29) compared estimates of man's heat exchange, based on conventional and katathermometric measurements, under a broad range of climatic conditions in laboratory experiments. They found that when the heat exchange corresponded to an eight hour E_{req} value of about 1.7 liters per man, the conventional and katathermometric method yielded the same estimate. However, warming or cooling the environment caused approximately twice as much increase or decrease respectively in the estimated heat exchange when based on katathermometric measurements as when based on conventional ones.

The above differences between calculated conventional and kata E_{req} values are reflected also in our estimates of eight hour total E_{req}. For the summer all kata eight hour total E_{req} values were higher than the conventional values but for winter the values of the kata and conventional values were distributed in the same range. This is shown in Table 16 and also demonstrated in Figure 17, where the total eight hour conventional and kata E_{req} values corrected for the average weight of the observed workers are plotted against the total eight hour observed sweat losses. The regression line of the conventional E_{req} values runs well below the kata E_{req} regression line at the higher summer values, but the two lines converge towards the lower winter values and intersect at the point corresponding to 1 liter sweat loss, i.e. 1.3 liter E_{req}.

Observed Sweat Loss and E_{req}

As shown in Fig. 17, there is a high correlation between the observed sweat loss and E_{req}, as indicated by the correlation coefficients (for kata E_{req} $r = 0.81$, level of significance 1 per cent; for conventional E_{req} $r = 0.66$, level of significance 5 per cent). It is also shown in Fig. 17 that, over the point corresponding to approximately 1.5 liters, both E_{req} regression lines run below the 1 to 1 ideal regression line, indicating that most of the E_{req} values are lower than the observed sweat losses. This is in accord with the well established fact that in order to evaporate a certain amount of sweat a somewhat larger amount has to be secreted, because part of the sweat remains soaked in the material of the garments and another part drips off before it can evaporate.

At the level of approximately 1.5 liters both regression lines intersect the ideal regression line. This suggests that the E_{req} values would become higher than the observed sweat losses under conditions where the workers' average sweat loss would be below 1.5 liter in eight hours. However, so far we have not observed any job in this low category. It is quite doubtful that a worker engaged in physical work would have a sweat loss of less than 1.5 liters in eight hours, even in a cool work environment (30).

Bognar, et al (31) performed a similar comparison between observed sweat loss and kata E_{req} values of industrial jobs in Hungary. Their correlation graph encompasses kata E_{req} values from -2 to +15 liters corresponding to observed sweat rates from 0.5 to 8.0 liters for eight hour workshifts. Their regression line is an S curve, which is above our regression lines at the upper end but below our line at the lower values (See Fig. 17). This difference may be accounted for by the manner in which Bognar et al. estimated the E_{req} value, because they: (1) subtracted all negative values from the positive ones; (2) included the E_{req} values of break periods; and (3) did not include basal metabolism and did not correct the value of M for the mechanical efficiency of metabolism.

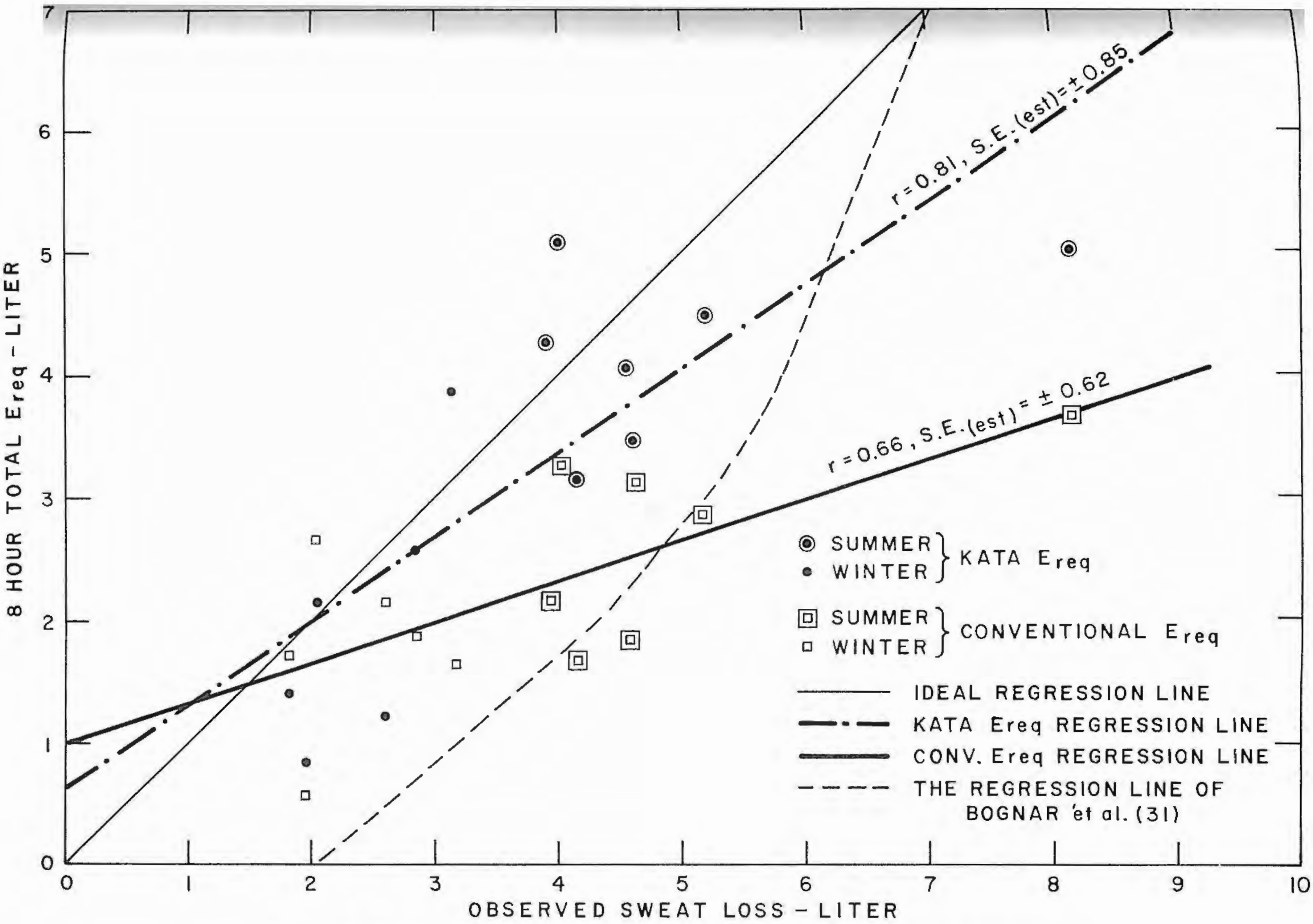

Fig. 17 Relationship between Ereq and observed sweat loss

Bognar, et al.'s regression line turns upward over the E_{req} value of 3, corresponding to an observed sweat loss of 5.2 liters, suggesting that in jobs with higher eight hour total E_{req} value the workers' actual sweat loss did not increase in the same ratio as it did up to that point. They suggest that this is so because in jobs with higher than 5.0 liters per eight hour sweat loss the sweat secretory apparatus becomes inadequate. Since we observed only one job in which the average eight hour sweat loss was over 5.2 liters, we can neither confirm nor disprove this theory.

Our results suggested that conventional and katathermometric measurements were equally useful for calculating E_{req}. The katathermometer could be substituted for dry-bulb and globe thermometer measurements. Its use simplifies not only the measuring procedure but the calculation of E_{req} as well, since the cooling power value can replace R + C in the thermal balance equation. The conventional climatic measurements have the advantage of yielding separate values of air temperature and radiant temperature. However, the conventional globe thermometer has a long equilibration time (10-20 minutes) which renders it inapplicable to follow fast changes of radiant heat, or to obtain an average value for operations shorter than ten minutes. Hellon and Crockford's globe thermometer is an improvement (32) but does not solve the problem completely, because its equilibration time is still too long.

In the E_{req} values as calculated, one calorie of metabolic heat produced was considered to be equal to one calorie of heat gained from the environment. From the point of view of physiological strain, however, these two sources of heat may have different significance. In order to strengthen the reliability of E_{req} for predicting physiological strain, the relative impact of metabolic and environmental heat must be established. Furthermore, the relationship between F_{req} and actual sweat loss will be altered if the vapor pressure and wind velocity in the working environment is changed. Givoni (5) determined quantitatively this function in steady state laboratory experiments. However, for the variable conditions of a workshop this function has yet to be established, in order that E_{req} can be used with complete confidence. Despite these uncertainties, the estimated E_{req} is reasonably satisfactory to predict the average sweat loss of workers. The accuracy of this prediction is defined by the standard error of estimate ($SE_{(est)}$) which is ± 0.85 for E_{req} based on katathermometer measurements and ± 0.62 for E_{req} based on measurements with conventional instruments. Considering the broad inter-individual and day to day variations of actual sweat loss (standard deviations of sweat losses in the observed jobs range between ± 0.42 and ± 2.0 liters per eight hours of work) the accuracy of prediction defined by the above $SE_{(est)}$ is sufficient for use in the design of necessary preventive measures for protecting workers employed in hot jobs.

The Relative Strain Index

Tables 13, 14 and 15 also contain the values of RSI (relative strain index) for each working area. RSI was calculated according to Lee and Henschel (2) by the following equations:

$$RSI = \frac{E_{req}}{E_{max}}$$

The equation used to calculate E_{req} was described earlier in this report. The formula for obtaining E_{max} was modified so that E_{max} and E_{req} were in the same units:

$$E_{max} = \frac{7.5\ (42 - P_a)}{I_a + I_c} \times \frac{1.7 \times WT}{580}$$

where P_a is vapor pressure of air in mm Hg and the other terms are the same as those used for the equation on page 15 - 16.

The RSI, as its name suggests, gives an indication of the severity of physiological strain connected with any work-environment situation. Its value increases not only with the increase of metabolic, convective and radiative heat load but, also, with the conditions which alter evaporative heat loss, i.e., changes in vapor pressure, in windspeed and in the insulation value of the worker's clothing.

During the summer, the RSI values at the work places ranged between 0.3 and 2.6 and the recovery areas between 0.1 and 0.6. During the winter the work area's RSI values ranged between -0.1 and 1.4 and the recovery areas between -0.3 and +0.3. The upper limit for daily work for heat acclimatized young men is considered to be between 0.7 and 1.0 (33). Work can be tolerated under hotter environmental conditions for shorter periods, e.g., distress will occur after about two hours of work under conditions corresponding to an RSI between 1.0 and 2.0 (34, 35) ; even hotter environmental conditions can be tolerated for shorter periods of time. These values, however, are suggested for continuous work under constant environmental conditions. Since the workers in all of the observed jobs in the plants were not exposed continuously for hours or even for many minutes to the same environmental conditions, the RSI of the single work areas would not yield a value which would characterize the entire job according to the severity of the imposed physiological strain.

The "Heat-Work Profile"

In all the observed jobs the workers moved at short time intervals back and forth from hot work places to nearby cooler recovery areas. Therefore, the characterization of a job from the point of view of the involved physiological strain by a thermal strain value alone would not be satisfactory unless the frequency and length of the heat exposures and recovery periods were considered in calculating the index values. As previously discussed, the length of heat work exposure cycles plays a decisive role in determining the overall heat stress. If the worker moves back and forth from the heat to a cooler area in short time intervals, the heat exchange may be almost completely limited to between the environment and the worker's clothing with little or no exchange between the worker and the environment being involved. The length of heat work cycles is also important when heat exposure is so high as to approach the tolerance limit for even short exposures. The length of the recovery period between two heat work cycles must be known; because if the recovery period is not long enough for recovery to occur, a residual physiological strain may be transferred from one heat work cycle to the succeeding one, causing an accumulative effect.

The "Heat-Work Profiles" (Fig. 18, 19 and 20) were constructed as an attempt to satisfy the requirement delineated above. The variations of the workers' heat exposure are shown as bar graphs, with E_{req} values on the ordinate and time on the abscissa. Each bar represents a "work cycle" consisting of a single task performed under a well defined heat stress and physical work load. The E_{req} values in the profiles were based on katathermometer measurements rather than on the conventional measurements of the working climate, because the latter were taken independently of the ongoing operations and because the katathermometric measurements were taken during every single operation in each area. Thus applying the kata E_{req} values in the Profiles made it possible to present a more detailed picture of the variations of the worker's heat exposure.

In Fig. 18, 19 and 20 are shown the average Heat-Work Profiles for one job at each plant. A full work phase (work bout) is shown for the cell repair man in the chemical plant (Fig. 18), the electro tender in the aluminum plant (Fig. 19) and a 30 minute work period of the machine operator in the glass plant (Fig. 20). The E_{req} values are calculated for a standard man weighing 70 kilograms.

In the Profile graphs the shaded parts of the bars indicate the portion of the E_{req} which was due to the heat generated by work metabolism. In the work phases with higher E_{req} values the metabolic heat furnished a small increment, as compared to the environmental heat, to the total heat load. However, from the point of view of physiological strain, physical work may constitute an additional stress, besides its heating effect. The study conducted by Kraining et al. (36) suggests that a certain amount of sweat loss brought about by heat gain due to work metabolism may be associated with about twice as much increase in heart rate as is the same amount of sweat loss when the heat is gained from the environment.

The Profiles were analyzed to identify and determine the frequency of the peak exposures which were responsible for most of the physiological strain. The maximal 1RHR's (1 minute recovery heart rates) and 1ROT's (1 minute recovery oral temperatures) occurred in connection with these peak exposures. The means of the daily maxima of these parameters are also shown in the Profile graphs. The work cycles for the machine operator were the hottest in areas A and E; they were exposed in areas A and E 12 times during the summer and 7 times during the winter within a 30 minute interval. Since the effective exposure time (EET) of this job was seven hours, A and E work cycles occurred 168 times

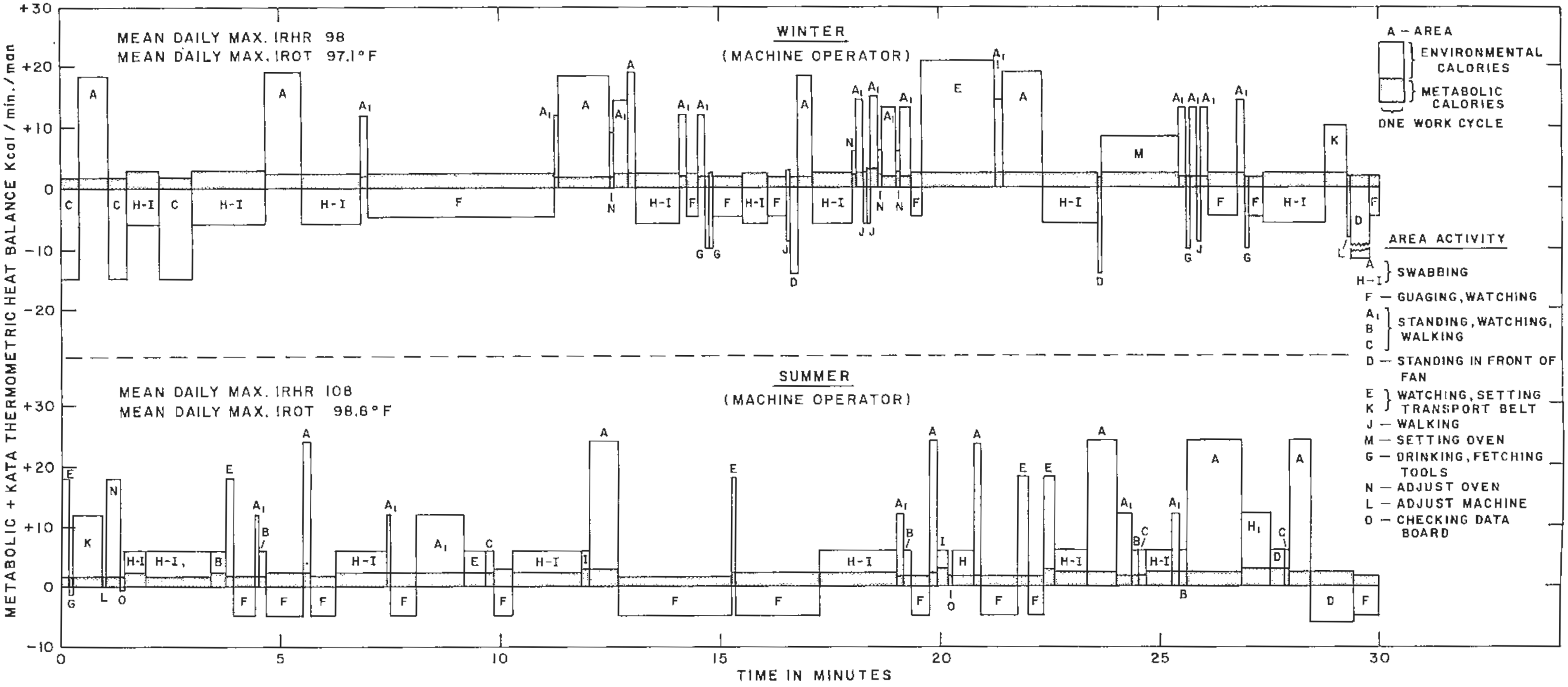

Fig. 18 Heat-Work Profile (Calculated for a 70 Kg man, for a period of 30 minutes)

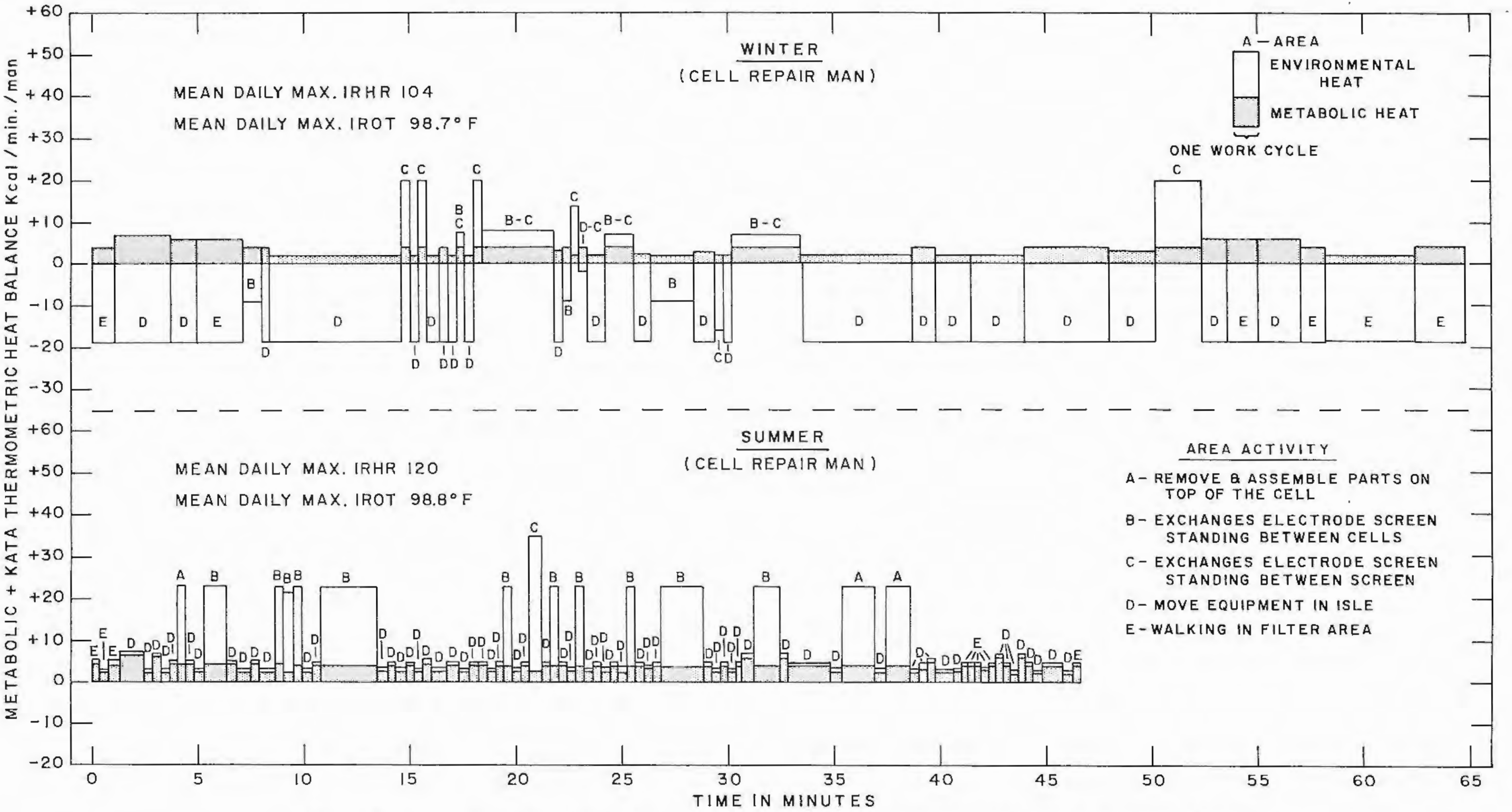

Fig. 19 Heat-Work Profile (Calculated for a 70 Kg man, for one complete work bout)

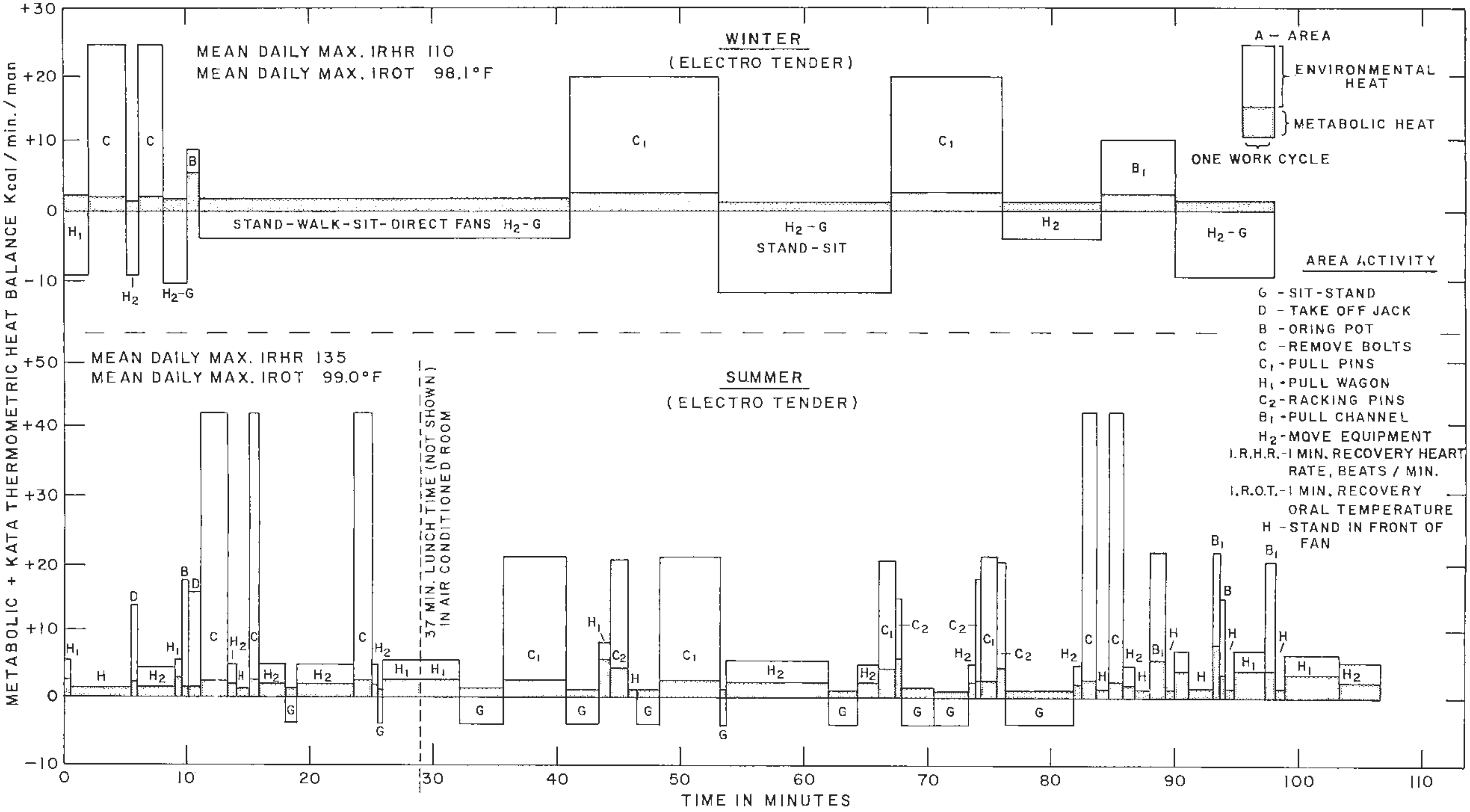

Fig. 20 Heat-Work Profile (Calculated for a 70 Kg man, for one complete work bout)

in summer and 98 times in winter in a workshift. The cell repair man had the highest heat exposures in the work cycles at areas A, B and C. Within a work bout these cycles occurred 13 times in the summer and 11 times in winter; the duration of a work bout was 45 minutes in the summer and 66 minutes in the winter. Since there were seven bouts in summer and six in winter, exposure in areas A, B and C occurred 91 times in summer and 66 times in winter in a workshift. For the electro tender the highest E_{req} values were in the work cycles at areas B and C. These cycles occurred 14 times during the summer and 5 times during the winter in a bout. Since there were on the average three bouts in a workshift, the critical work cycles occurred 42 times in summer but only 15 times in winter. It is emphasized, however, that the profiles show average conditions. Deviations from the average work pattern are frequent and sometimes quite substantial, e.g., the sequence of work cycles was different during summer and winter, although basically the same manufacturing operations were performed by the workers in both seasons.

The length of a work cycle was generally longer in winter than in summer because the lower heat exposure during the winter at the work places permitted the workers to stay longer in the work area and at times to complete the operation in one cycle. As a result, during the winter most operations could be accomplished within less total elapsed time than during the summer. This was the reason why the electro tender's total work phase lasted longer in summer than in winter (Fig. 18). The cell repair men worked in bouts, which they cut somewhat shorter in the summer than in winter as shown in the Profiles (Fig. 19). To accomplish the same amount of work they had seven work bouts per shift in the summer but only six bouts in winter. The work of the machine operators was continuous, interrupted only by regular breaks which were the same all year around. Thus we show equal length of work time both in the summer and winter Profiles, i.e., 30 minutes (Fig. 20). However, it can be seen on these graphs that the machine operators spent also slightly more time at each cycle in the hot working areas during the winter, while the number of cycles was less, as mentioned above. (pp. 35-36).

PHYSIOLOGICAL RESPONSES TO THE JOB

Sweat Loss, Heart Rates and Oral Temperatures

The averages and standard deviations (S.D.) of the eight hour total sweat losses, and the averages and the S.D.'s of the observed daily maximal one minute recovery heart rates (1RHR) and daily maximal one minute recovery oral temperatures (1ROT) for each observed job are shown in Figures 21, 22 and 23, respectively.

The jobs are arranged on the graphs in the sequence of diminishing eight hour sweat losses. The average values of each of the three observation periods (two summers and one winter) are shown next to each other for each job. There are no significant differences between the average responses for the summers of 1963 and 1964. During the winter, however, the eight hour sweat loss was diminished by approximately 50 per cent in each job. The maximum of the 1RHR and 1ROT were also lower in the winter than in the summer.

In none of the observed jobs did the workers have an average sweat loss of more than 1 liter per hour, which is within the maximum recommended limit for sustained work (6). However, sweat production must be related to body weight when workers with significantly different average body weights are compared on different jobs. Under equal heat and work conditions a heavier subject must evaporate more and, therefore, secrete more sweat in order to keep his thermal balance. His metabolic heat production will be higher and having a larger surface he will also gain more heat by convection and radiation in hot environments. Acceptable levels of sweat production would, therefore, be higher for the larger workers than for the smaller ones.

Furthermore, the eight hour sweat loss was not produced at an even rate during the workshift. Most of the sweat was secreted during the heat-work cycles, while in the recovery areas sweating continued at a much lower rate or ceased completely. In the observed jobs the effective exposure time (EET) varied between 3.3 and 7 hours in the hot jobs and between 7.2 and 8 hours in the control jobs. As a consequence, if on two jobs the eight hour total sweat productions are the same, it does not necessarily mean that the worker will

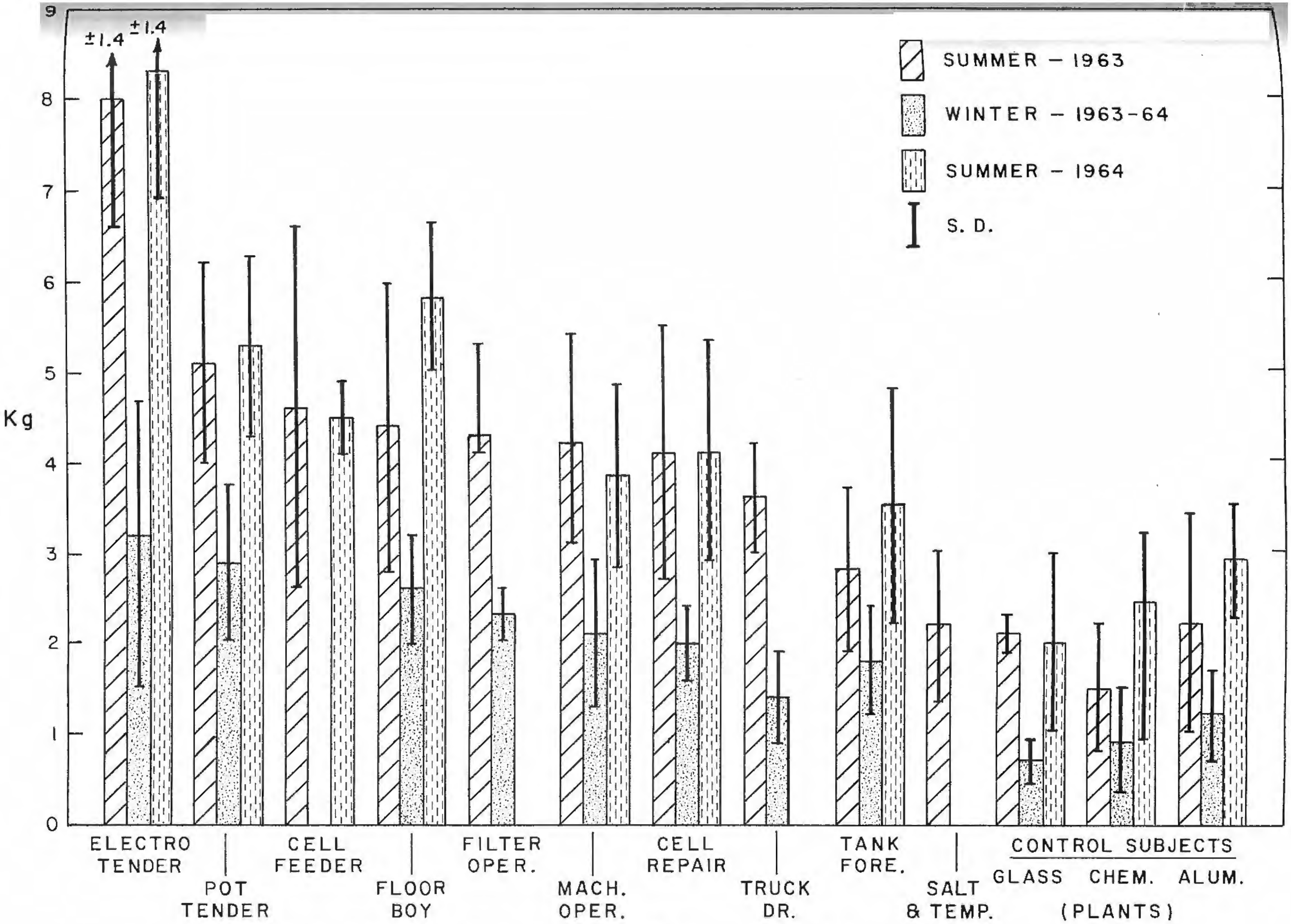

Fig. 21 Means of total 8 hour sweat losses on the job

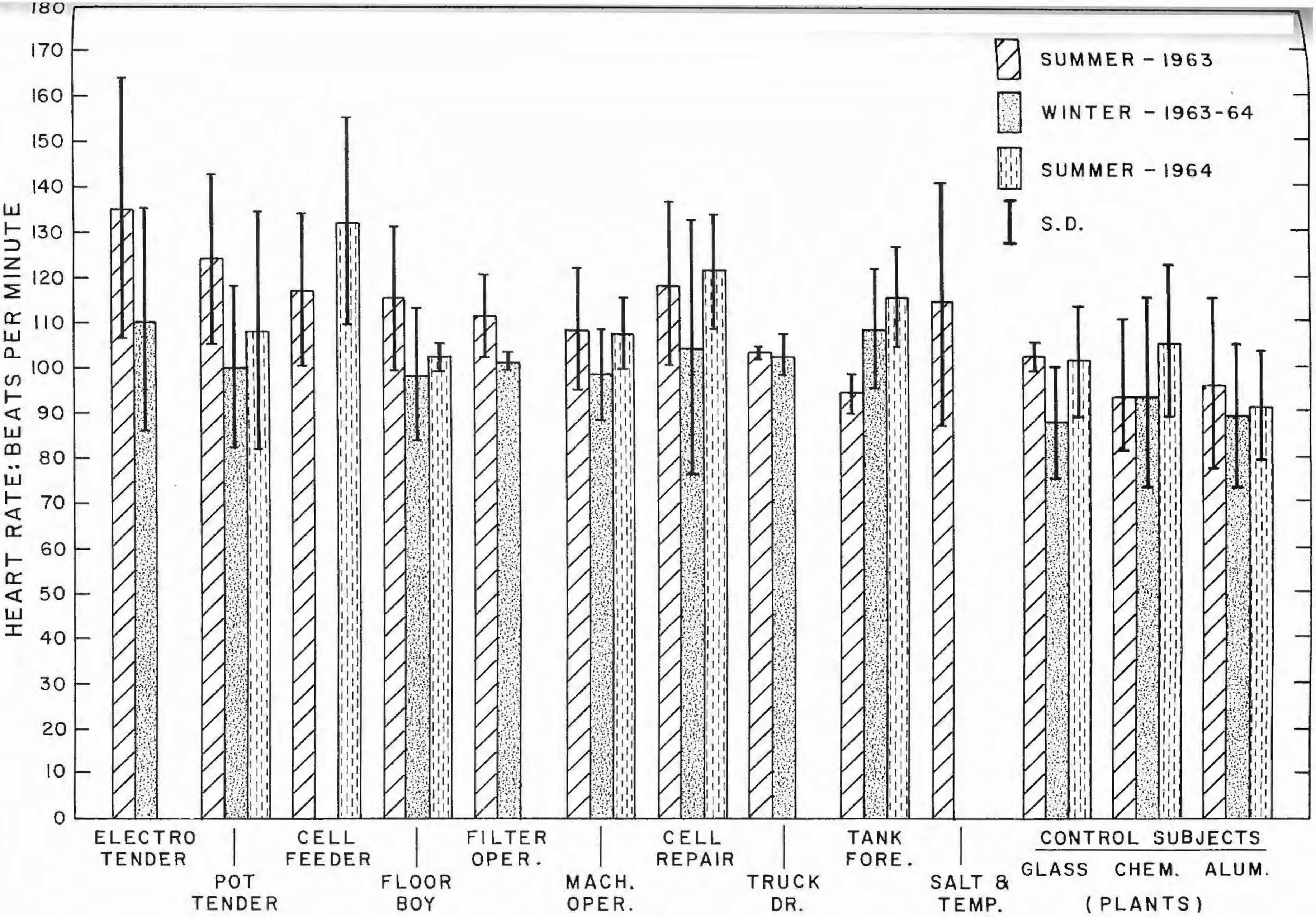

Fig. 22 Means of daily maximal 1 minute recovery heart rates on the job

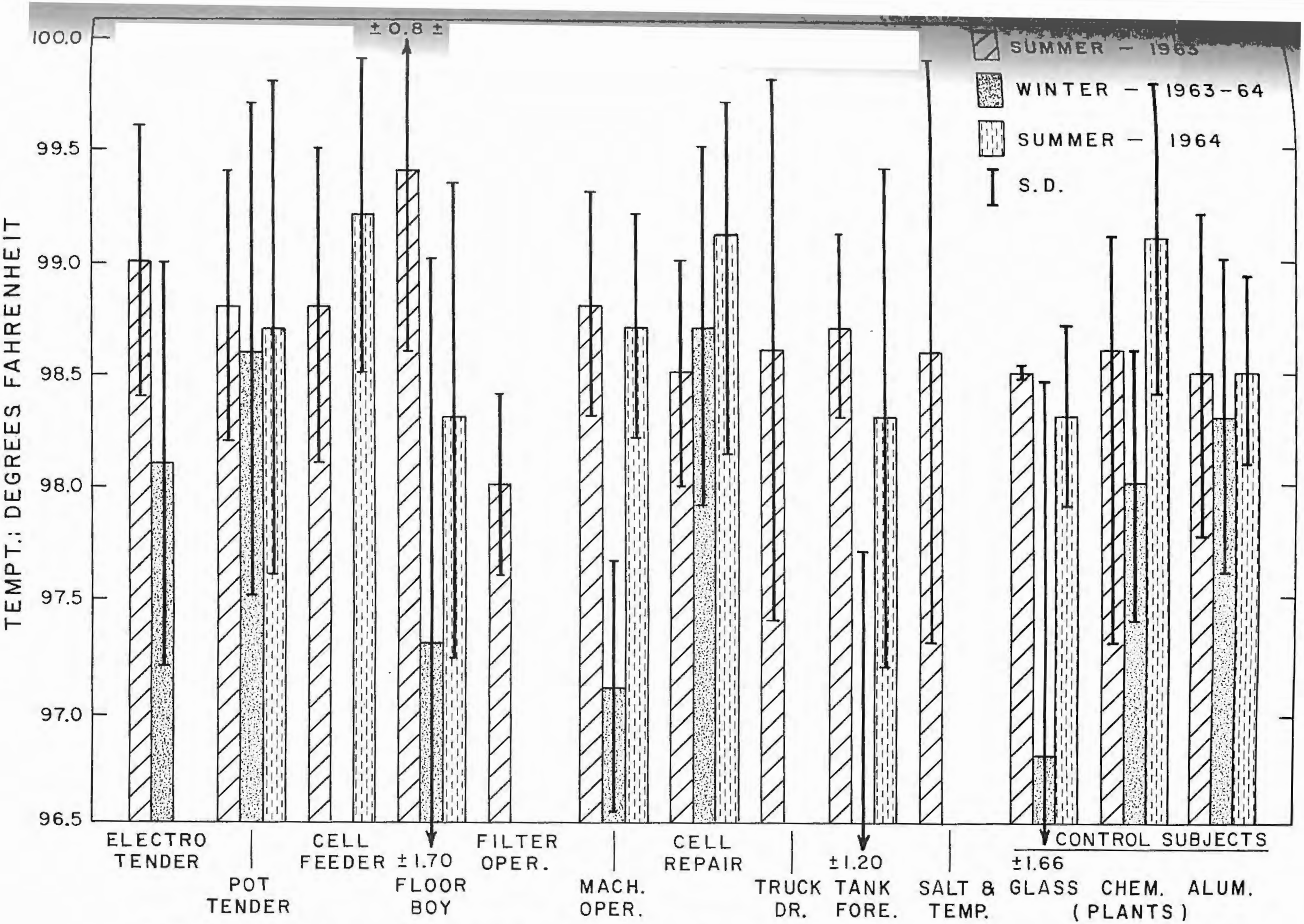

Fig. 23 Means of daily maximal 1 minute recovery oral temperature on the job

secrete sweat at the same rate during the entire workshift; e.g., a worker whose eight hour sweat production is six liters and his recovery and break time at air-conditioned locations is four hours, actually has twice as high a sweat rate during the four hours of his effective exposure time than does the worker whose sweat production is also six liters in eight hours but does not have a cool recovery area at all.

In Fig. 24 are shown the average sweat rates on the observed jobs for one hour EET calculated for the standard man weighing 70 kilograms. The data were obtained during the summer 1963 phase of this study. The results indicate that in three of the observed jobs the average sweat rates during the actual heat exposure periods exceed the 1 liter per hour level, even though the average total eight hour sweat loss did not exceed 8 liters. The permissible sweat rate for shorter periods than one hour has not been established, but it must be well beyond the rate of 1 liter an hour, thus the observed rates cannot be considered as excessive for acclimatized men.

The mean daily maximal 1RHR's for the different jobs did not show a diminishing tendency similar to that observed for the eight hour sweat losses. There were some phases in almost every hot job where during the summer the mean daily maximal 1RHR exceeded 110 beats per minute which according to Brouha (12) is the safety limit for continuous type of heat work. For intermittent type of heat work the safety limit of the 1RHR is probably well over 110. It requires further studies to establish such a limit.

The mean daily maximal 1ROT values were well below 100°F, indicating that the workers did not accumulate heat to an extent that would endanger health. They interrupted their work and retreated to cooler areas when under circumstances of severe heat exposure they felt a high degree of discomfort.

From the point of view of physiologic strain it is important to know how often in a workshift work cycles are encountered which lead to maximal 1RHR's or 1ROT's. One advantage of the "Heat-Work Profiles" (Figures 18, 19 and 20) is that they show how often work cycles having the highest E_{req} values occur.

For all the three observed physiological parameters the control subjects showed lower values than those working in hot environments. This difference was most pronounced for sweat losses, less for the 1RHR's and least for the 1ROT's. This could be expected, because under the observed conditions sweat production was caused mainly by heat exposure but high heart rates and oral temperatures can be brought about by intensive physical work alone.

The mean before- and after-workshift heart rates and oral temperatures are shown according to jobs in Tables 17 and 18. There were no consistent increases in heart rates or oral temperatures at the end of the workshift either in the winter or summer. The greatest increase was observed in the glass plant among the floor boys during the summer. The floor boy's work pattern was such that he was engaged in a cleaning up job which involved intense physical work during the last half hour of the shift. On the other hand, the electro tenders and pot tenders had relatively low heart rates and oral temperatures at the end of the shift, despite the fact that their heat exposure was the highest, because they were usually not involved in vigorous activities in the last half hour of the shift. These data lead to the conclusion that in jobs where the work is not continuous and evenly distributed during the workday, the heart rates and oral temperatures observed at the end of the shift are not informative concerning the overall cardiovascular load of the job unless the stress is sufficiently severe to delay recovery beyond the end of the working day.

Dehydration

In view of the large sweat losses of the workers in some of the observed jobs, dehydration could play an important role in the overall strain caused by the job. Men exposed to hot environmental conditions usually do not completely replace the water lost by perspiration during the work time, thus a decrease in the water content of their body may occur. A slight dehydration may have a beneficial effect (37); but if it reaches an excessive level (2-2 1/2 liters), it may have a detrimental effect on health and performance (38). Table 19 shows the mean weight losses of the workers in each observed job during a workshift. In most jobs the workers, including the controls, were slightly dehydrated at the end of the workday, particularly in summer. The electro

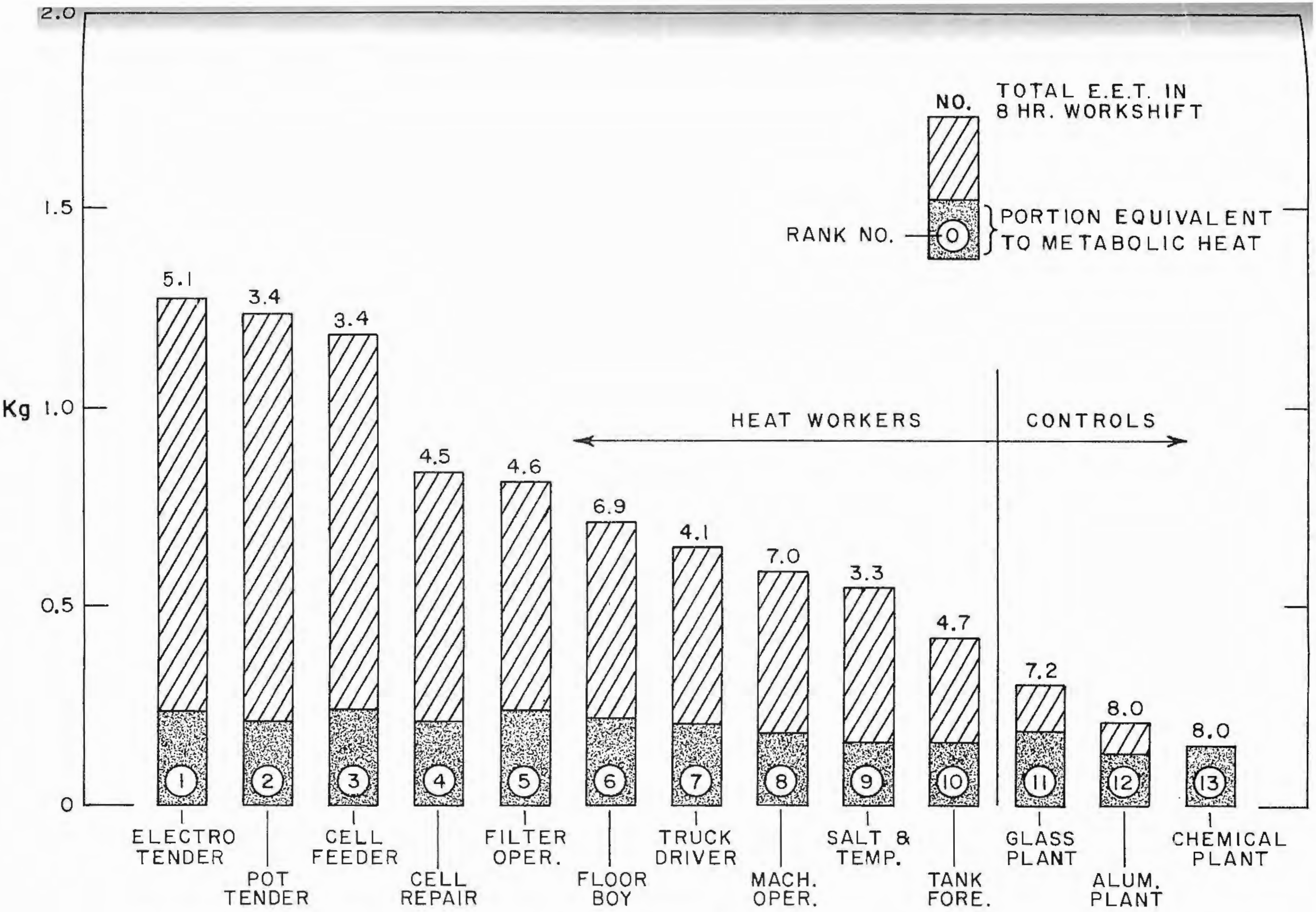

Fig. 24 Mean Sweat Rates in Kg / 70 Kg body weight for one hour effective exposure time (Summer 1963)

tenders, whose eight hour sweat loss was the highest, also showed the highest degree of dehydration during the summer (0.94 ± 0.57 liters). This remained far below the 2-2.5 liters which according to Ladell (39) can be lost without any serious alterations in physiological functions.

The workers' dehydration observed in this study was definitely voluntary, because cooled water was available close to each work place and the workers were encouraged to drink often and more than their thirst dictated. Coffee, chilled milk and soft drinks were in easy access. Salt tablets were available in containers near the water fountains. In the aluminum plant a 0.1 per cent salt (NaCl) solution was furnished in most of the drinking fountains. The workers were conscious of their higher water requirements but some were afraid of gastrointestinal disturbances if they drank more than usual. This caution may be partially justified since Strydom et al. (40) report that their subjects vomited or experienced nausea if they tried to drink enough at one time to completely restore the water which they lost during one hour of heat exposure. This could be prevented if the subjects started to drink small amounts of water at frequent intervals from the beginning of the heat exposure.

STANDARD HEAT-WORK TEST

Subject Participation

The experimental design called for repeated observations on the same subjects in the three phases of the study. Because of vacations, sick leaves, refusals and rejections, 36 per cent of the workers who participated both on the hot job and in the standard test during the first summer did not come under repeated observation during the winter and only 30 per cent came under repeated observation in all the three stages of the study. Among the controls the repeat rate was worse with only 50 per cent remaining in winter and 10 per cent by the second summer. Details of subject participation are shown in Table 20. In evaluating differences between the summer and winter responses of the workers we used only data obtained on subjects observed in both summer and winter.

INDUSTRIAL HEAT STRESS

Seasonal Variations in Physiological Responses

Table 21 shows the mean sweat losses, heart rates and rectal temperatures of the heat workers observed during the standard heat and work test. The subjects of each plant had significantly higher sweat losses and rectal temperatures in the summer than in the winter. These seasonal differences correspond with the higher degree of heat acclimatization (41, 42) which must have followed the higher heat exposures during the summer, both in the plant and in the outside environment. In fact the increased outside heat by itself could produce such an effect, as indicated by the test results of the glass plant's control subjects, who were not exposed to industrial heat sources (Table 22).

There were no significant seasonal differences between summer and winter heart rates of the observed workers, including the control subjects, during the standard test. This was considered evidence of maintained cardiovascular performance capacity even during the hottest part of the summer season.

The seasonal variation of FVC's[+] and FEV1%'s[++] is shown in Tables 23 and 24. There was no significant difference between the summer and winter means of the FVC's in the three age groups (Table 23). The FVC's were generally higher after the test exposure. The increase was slight and similar in magnitude in summer and winter. This was probably only a virtual increase because the body and room temperatures were higher after the test than before (43). Exact evaluation of this was not possible because the Collins vitalometer was not equipped with a thermometer.

[+] FVC = Forced Vital Capacity. It differs from vital capacity (VC) only inasmuch as the test expiration is performed with the maximal speed the subject is capable of.

[++] FEV1% = the volume of air expired during the first second of the timed forced expiratory volume test, divided by the FVC and multiplied by 100.

The $FEV_1\%$, however, showed a definite seasonal variation, as seen in Table 24. During the winter the $FEV_1\%$ diminished significantly in all age groups after the standard test, while during the summer it increased slightly. A change in $FEV_1\%$ can be caused by organic or functional cardio-pulmonary factors but can be brought about also by differences in motivation to perform the test. Data necessary to identify the causal relationships in this phenomenon were not obtained in the study.

Heat Workers versus Control Subjects

Table 25 shows that those working in the hot shops (heat workers) consistently sweated more than the control subjects both during the winter and the summer. The higher summer rectal temperatures before the standard test were also more pronounced among the heat workers (Table 21). As far as heart rates are concerned, the only difference between heat workers and controls was that the heat workers had lower heart rates before the test. All these differences probably reflect the higher level of heat acclimatization and cardiovascular fitness of the heat workers.

The mean FVC's of both heat workers and control subjects in each of the three age groups were less than the predicted VC which was calculated according to Kory et al. (44) (Table 23). This would be expected because there is a methodological difference between the FVC and VC tests (44). The control subjects had a larger average FVC than the heat workers by approximately 5 per cent in all age groups. In the age group 31-40 this difference was proportional to the difference in height between heat workers and controls. In the other age groups, i.e. 21-30 and 41-50, the difference in FVC was real. However, because of the broad individual variation of the VC, (S.D. ± 0.5 lit.) no conclusion can be drawn.

Effects of Age, Weight, Height and Job Experience

A comparison of the workers in the three plants showed differences in average age, weight, height and employment time. Table 26 shows the data of the three groups observed in the summer of 1963. The oldest group was the one at the chemical plant; they also had the highest body weight and were employed longest in jobs with hot working environments. The youngest and tallest group was the glass plant workers and their employment in hot jobs was also the shortest. The group in the aluminum plant occupied a middle place in all the above variables. This distribution remained essentially the same during the winter and 1964 summer observations.

The significant differences existing between the relevant personal data of the observed workers in the three different plants offered an opportunity to examine whether age, weight, and height influenced the workers' physiological adaptation capacity to heat and work, as reflected in their responses during the standard test. Table 27 shows the mean increases in rectal temperature, heart rate and the sweat loss of the heat workers observed in the three different plants during the summer of 1963. There were significant differences between their responses; however, the magnitude of responses did not seem to be related to the relevant demographic data. The sodium plant workers who were the oldest, heaviest and had the longest employment in heat work, took the middle position in increase of heart rate and sweat loss, and they showed less increase in rectal temperature than did the workers of the other two plants. No correlation was found between these relevant personal data and the physiological responses as indicated by the low correlation coefficients as shown in Table 28.

The only function which showed a significant age effect was FEV1%. Table 29 presents the means of the FEV1%'s in age groups 21-30, 31-40, 41-50 and 51-60. There was a decrease in FEV1% with age similar to that found by other investigators in other populations (45).

The 1963 summer standard test data were analyzed to determine whether the length of time employed in hot jobs had an effect on the physiological responses of the heat workers. The results are shown in Table 30. There was no significant differences between the average responses of workers employed 1-5, 6-10 and over 10 years. It may be noted that the average Δ heart rate (i.e. the difference between the heart rates before and at the end of the standard test) was higher in the two groups with longer employment time. This may raise the question whether the trend of increasing Δ heart rates can be considered as a sign of diminishing cardiac performance capacity. However, the increased Δ heart rates are not the result of higher heart rates at the end of the test but by lower rates before the test. This is suggestive of an improving physical condition rather than a diminishing one. In Table 27, where the workers of the three plants are compared as to their physiological responses during the standard test, similar phenomenon was observed. The workers in the aluminum plant, who were exposed to the highest heat stress, had significantly higher Δ heart rates. This too was due to the lower heart rates before the test. These results suggest that work sustained for many years under the conditions prevailing in any of the observed jobs does not cause an accelerated deterioration in the physiological functions.

National Background of the Heat Workers

In the aluminum plant there was a sufficient number of workers with similar national backgrounds to permit statistical comparison of their physiological responses to the standard heat-work test. The majority of heat workers was of Spanish-Mexican descent, the rest being American with diverse ancestry. Table 31 shows the mean sweat loss and increase in rectal temperature and heart rate during the standard test. There was no significant difference in any of these responses between the Spanish-Mexicans and the rest of the workers.

Reproducibility of Experimental Results

In Table 21 the results obtained during the two summer stages of the study are compared. No significant differences were observed with the exception of the recovery heart rates in the glass plant which were significantly lower during the summer of 1964. This difference resulted from a slight change in the experimental procedure. During the beginning of the study in the summer of 1963 at the glass plant the workers stood during the early part of the recovery period, but they were seated immediately after the end of the treadmill walk and remained seated during the recovery period in all treadmill tests thereafter.

The fact that there was otherwise no significant differences between the data of the two summer observations may be considered as an indication of the reproducibility of the data and the reliability of the experimental procedures. Therefore, not all analyses which were performed on our data obtained in summer 1963 were repeated on the second summer's data.

INDUSTRIAL HEAT STRESS

HEAT STRESS ON THE JOB AND ADAPTIVE CAPACITY

Among the physiological responses measured at the job site, the sweat loss was the only one which reflected the total eight hour heat stress imposed on the workers by their jobs. The mean eight hour total sweat losses on the job (gram/kg body weight) were plotted against the mean sweat losses during the standard test (Fig. 25). Each point in the graph represents the average sweat loss of workers employed in the same job. The correlation coefficient for the summer of 0.80 is significant at the 1 per cent level, the $SE_{est} = \pm 2.4$. The corresponding values for winter are $r = 0.57$, significant at the 5 per cent level, $SE_{est} = \pm 0.8$.

These correlations indicate that the workers who had higher sweat losses on the jobs because of larger heat and work loads also had higher sweat losses during the standard test. Since increased sweat loss under given hot conditions is considered a sign of improved heat acclimatization (42), the correlation shown in Figure 25 suggests that the workers successfully increased their level of heat acclimatization in accordance with the heat-work stress of the job. The linear regression lines indicate that the heat exposures on the job did not exceed the upper limit of the workers adaptation capacity. If it had, the upper end of the regression lines would tend to level off.

In Fig. 26 the sweat losses during the standard test were plotted against the on-the-job sweat rates calculated for one hour effective exposure time (EET). The correlation coefficients in Fig. 26 are similar to those in Fig. 25. However, the points representing jobs with long EET's (jobs 6 and 8) fit closer to the summer regression line in Fig. 26. This difference in fit of points was the result of the fact that while total eight hour sweat losses in these two jobs were high, the hourly sweat rates during the EET were relatively low. Thus in the case of jobs with long EET's the amount of sweat produced during the standard test correlated better with the on the job sweat loss when the latter was expressed for one hour EET than when expressed for total eight hour work time. This agrees with the findings of Lind and Bass (46) who showed that to achieve a certain level of acclimatization a 100 minute per day heat exposure was sufficient and no additional acclimatization was acquired by extending the daily exposure time.

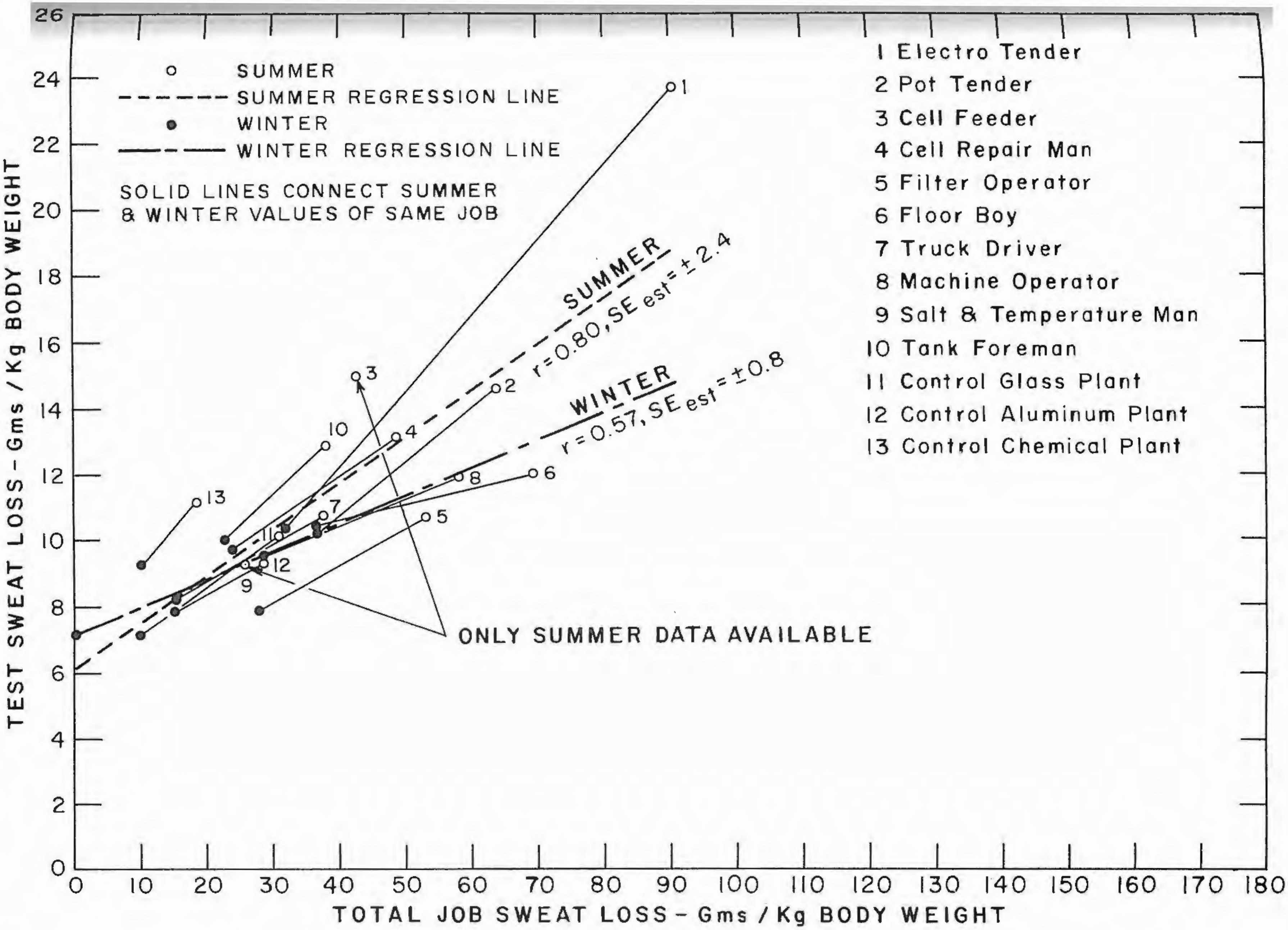

Fig. 25 Relationship between job site and test sweat losses

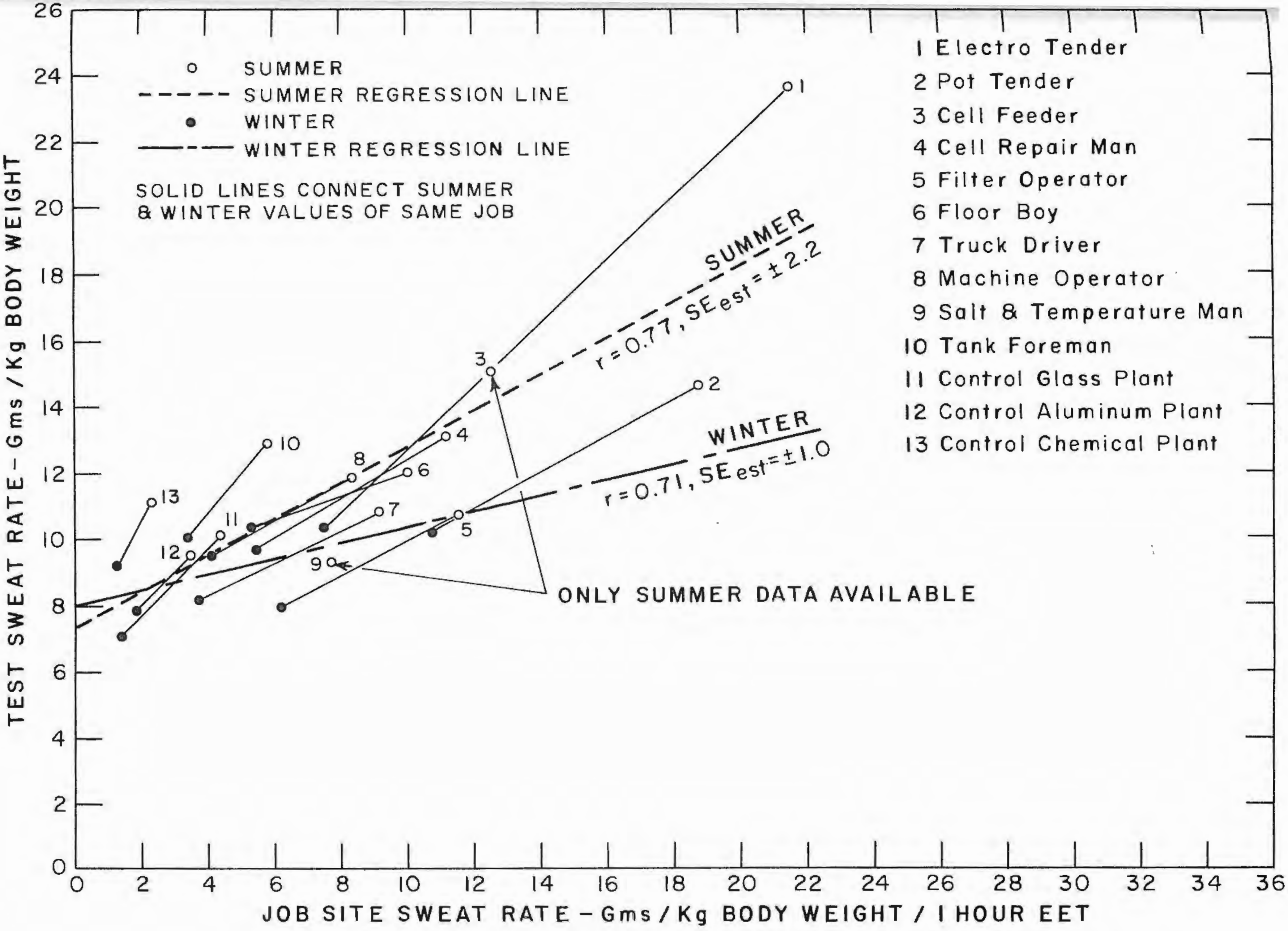

Fig. 26 Relationship between job site and test sweat rates

INDUSTRIAL HEAT STRESS

The increased sweat rates observed by Lind and Bass in laboratory experiments paralleled a decrease of heart rate and rectal temperature as acclimatization progressed. We could not observe this trend, perhaps because in a field study such as ours there are too many uncontrollable circumstances to which heart rate and rectal temperature are more sensitive than sweat rate. One of these circumstances is that in the subtropical climate people have more outdoor physical activites in winter than during the summer. Thus, the loss in heat acclimatization during winter may be counterbalanced by increased physical fitness, as far as heart rates are concerned. It also could be that even though sweat rates showed a diminishing in heat acclimatization during the winter, the workers may have still been sufficiently acclimatized, so cardiovascular demands were not excessive in the test.

The regression lines of the summer values in Fig. 25 and 26 are steeper than those of the winter values. Thus, during the summer a given increase in on-the-job sweat loss was accompanied by more rise in the standard test sweat rate, i.e., in the level of the workers' heat acclimatization, than during the winter. This phenomenon leads to the assumption that the level of heat acclimatization of the heat workers in the summer was enhanced not only by the job heat but also by the off job heat exposure which was quite substantial during the summer in the subtropical area of the Southern U.S. The lines connecting the summer and winter values of the control subjects are much steeper than those of the heat workers. This reflects the fact that the control subject's heat acclimatization was much more dependent on the outside climate than on the working environment.

HOME ENVIRONMENT AND OFF JOB ACTIVITIES

The answers obtained on the questionnaires concerning the home environment and off job activities are summarized in Table 32. One-half of the observed heat workers had either air-conditioned homes or at least an air conditioner in the bedrooms. A higher percentage of control subjects had air conditioning in their homes. The physiological responses of the workers who had air conditioning did not differ significantly from those who did not have air conditioning. Apparently home air conditioning did not affect the worker's state of heat acclimatization. However, it is possible that the workers who did not have air conditioning in their homes resided in areas where the need for air conditioning was not as impelling.

There was no difference in the average hours of sleep between heat workers and controls. Five per cent of the observed heat workers pursued a second occupation regularly besides their job in the plant but none of the controls did. As far as hobbies are concerned, 72 per cent of the heat workers and 75 per cent of the controls participated in some kind of free time activity involving physical exercise. On the average the workers who were exposed to hot environments on their jobs spent their free time very similarly to those whose job did not include hot manufacturing processes.

HEALTH EFFECTS OF INDUSTRIAL HEAT STRESS

According to the physiological responses observed in the standard heat and work test, there was no demonstrable accelerated deterioration in the state of health and adaptation capacity of the workers, regardless of the intensity of heat exposure on the jobs, the number of years employed in hot jobs or age. On the contrary, the higher the heat exposure on a job, the more acclimatized the workers became.

This conclusion was corroborated by the ECG records taken before, during and after the standard test. No abnormal alterations in these ECG records were found. Furthermore, the data from the questionnaire concerning the off-job activities of the workers showed (Table 32) that the heat workers conducted a normal family and social life, comparable to that of the controls.

There were no heat casualties during the time of the study in any of the observed jobs. However, information was obtained that in the past, when these plants were new and the operations had just started or when new processes were started in existing plants, the number of heat casualties and also the turnover rate of workers was high. These circumstances induced an improvement in working conditions at the hot jobs. At the same time a natural selection may have taken place among the workers and only the workers who could acclimatize to the prevailing working conditions stayed in these hot jobs. Thus, the results indicating no harmful health effects are valid only for workers who have already proved to be able to acclimatized to high heat exposures and for jobs in which certain measures were already established to prevent heat casualties.

Some of the measures which were instituted to reduce heat casualties were:

1. Preemployment and periodical medical examination of the heat workers.

2. When a new worker was employed for a hot job, his full assignment was not enforced during the first week to allow time for heat acclimatization. An alternative towards the same goal was the seniority system in employing workers for hot jobs. One result of this system was that only those workers were assigned to jobs with intense heat stress who previously had some experience in similar jobs under less heat stress. This gave the workers time to acclimatize to the working conditions.

3. The operations requiring heavy physical effort in hot working environment were mechanized.

4. Hot radiant surfaces were shielded and ventilation was increased. The workers were supplied with personal protective devices such as helmets, aprons and gloves, where necessary.

5. The assigned work schedule permitted the workers to interrupt their work and take a rest when under circumstances of severe heat exposure they felt a high degree of discomfort. This was accomplished either by scheduling the work with frequent rest periods or by assigning more workers to the job, so they could work alternately. The performance required from an individual worker was not enforced rigidly when extraordinary hot conditions were encountered at a job.

6. There were air-conditioned resting rooms available where the workers could spend their breaks.

7. Cooled water was supplied near each job site from drinking fountains. The workers were instructed to drink water frequently during the workshift, more than what would be desired just to satisfy their thirst. Vending machines with chilled fruit juices and soft drinks were placed not far from the work places. Entero-coated salt tablets were made available to the workers and were placed near the drinking fountains. An alternate method used for salt supplementation was NaCl dissolved at no more than 0.1 per cent concentration in the drinking water. Workers were encouraged to eat food rich in salt.

INDUSTRIAL HEAT STRESS

It is not known whether workers who quit their jobs before the study started suffered any health damage due to heat stress. Neither could the upper age limit be established at which workers may be employed in jobs with hot working environment. This was because there were only a few older heat workers participating in the study. Six men were over 50 years of age in the sodium plant, four in the aluminum plant and none in the glass plant. The oldest observed worker was 56. Most of the older workers were employed in their jobs since these plants started operation (20-25 years in the chemical plant and around 10 years in the aluminum plant). How much longer the men will stay on the job cannot be predicted. The reasons why other workers quit their hot jobs at an earlier age or how many workers stayed on to an older age is not known.

On the basis of the observations made in this study it is concluded that the heat stress levels prevailing at the observed jobs are within the permissible limits, provided that all the preventive measures mentioned above are made available. However, it should be reemphasized that all the observed workers alternated weekly in the morning, afternoon and night shifts. Since during the summer in the glass plant the average climatic conditions were hottest during the afternoon shift, the workers of this plant were exposed only in one-third of the summer season to the heat stress delineated in Table 13. In the chemical plant the working climate was equal in the morning and in the afternoon during the summer, but the night shift was cooler here too.

In the aluminum plant during the summer the climatic conditions were hotter in the morning shift than in the afternoon. The average values of the working climate in the morning shift are shown in Table 33. From these values E_{req}, E_{max} and the R.S.I. were calculated (Table 34), assuming that the work sequence and demands were the same in the morning and in the afternoon. The E_{req} for the morning shift was 52 per cent higher than for the afternoon shift, suggesting that the electro tenders' heat load during the summer was approximately one-half greater in the morning than in the afternoon shift. The RSI's in the morning shift showed an increase of similar magnitude as that of the E_{req} in all the working areas. The E_{max} remained practically unchanged. Thus in the aluminum plant during summer the relief of heat stress obtained on the night shift was offset by the increased heat exposure during the morning shift.

CONCLUSIONS AND RECOMMENDATIONS

1. The diurnal variations of the dry-, wet-bulb and globe temperature in the work environment can be satisfactorily traced (Figures 10 through 15) by stationary continuous recorders, placed close to the actual work site at locations where they do not interfere with the workers' activities. The relationship between the actual working climate and the recorded climate must be established by manual temperature measurements taken at the work site, evenly distributed in time.

The globe thermometer has a long equilibration time, which renders it inapplicable to measure the peak exposures lasting only a few minutes. The development of an omnidirectional radiometer with short equilibration time would greatly improve the capability to measure industrial heat exposure where radiant heat is high.

2. The dirunal variations of wind velocity of the working environment in hot plants where the direction of air jets and fans is often and randomly changed, cannot be established by stationary continuous recorders. However, the average of manual measurements taken at the work site, evenly distributed in time, will satisfactorily complement the continuous temperature records to produce a full picture of the working climate.

3. Katathermometric measurements, following the worker close with the instrument throughout the measurement, yield data of the combined effect of air temperature, mean radiant temperature and wind velocity prevailing in hot workshops. If the katathermometric measurements are taken of each work cycle, the obtained data can be utilized to demonstrate graphically the short term variations of the workers' heat exposure, in the form of "Heat-Work Profiles" (Figures 18, 19 and 20). From the Profiles seasonal changes in work patterns and the frequency and duration of peak heat exposures can be evaluated.

4. Vapor pressure varies little within different work and rest areas of the observed plants, shows little 24 hour fluctuation and closely approximates the outside vapor pressure. Thus, only a few wet-bulb temperature measurements are sufficient to establish the diurnal variation of this climatic factor in plants where the manufacturing process does not add significant amounts of water vapor to the air.

INDUSTRIAL HEAT STRESS

5. A significant correlation was found between observed sweat loss on the job and required sweat evaporation (E_{req}) as calculated from both conventional and katathermometric measurements of the working climate. This correlation is of significance from three important aspects: it validates the use of both conventional and katathermometric methods for measuring the working climate; it validates the use of estimated E_{req} for prediction of the combined climatic and metabolic heat load prevailing in an industrial job; and it shows that, within the limits of the data, sweat loss is a linear function of E_{req}, i.e., of the combined environmental and metabolic heat gain. However, further studies are necessary to establish in what proportions the environmental and metabolic heat factors contribute to the physiological strain present at different levels of E_{req}. Furthermore, the effect of vapor pressure on the above correlations has yet to be established.

6. The Relative Strain Index (RSI) (2) includes the vapor pressure factor by giving proper emphasis to those variables of the environment and clothing which counteract sweat evaporation. However, the RSI in its present form can be applied only for the characterization of single work cycles within a job. To confirm the validity of calculating an average eight hour on the job RSI must await more relevant data.

7. The observed daily maximal one minute recovery heart rates (1RHR's) indicated that almost all observed jobs have some work phases in which the workers have to use their circulatory capacity to a high degree. However, this is not specific to environmental heat exposure, because physical work has a relatively larger effect on heart rate than would be expected from the heat gain due to work metabolism. Further studies are necessary to determine more exactly the proportions of cardiovascular strain that are due to heat and to physical work in these conditions. The daily maximal 1RHR's do not give information about the maximal heart rates occurring during the heat-work bouts, which is an important factor in assessing the cardiovascular strain connected with a job. This information could be obtained only by radiotelemetric registration of the worker's heart rate. However, the 1 RHR's are useful in establishing whether there is an unduly prolonged recovery time or residual strain.

8. The daily maximal one minute recovery oral temperatures (1ROT) indicated that none of the observed workers accumulated body heat during the work to an extent that it could endanger health.

9. The standard heat-work test yielded useful information concerning the status of the workers' physiological adptive capacity to heat and work. The physiological responses on the standard heat-work test suggest that the workers' state of health and adaptation capacity had not deteriorated even after working as many as 25 years in the hot jobs and up to the age of 56. On the contrary, as shown by the high correlation between the on the job sweat loss and the standard test sweat loss, the higher the heat exposure on a job, the more acclimatized the workers became. This conclusion was confirmed by the ECG records taken before, during and after the standard test and by the data on the heat workers' off-job activities. The observed heat workers conducted a normal family and social life, comparable to that of the controls, who were not exposed to hot working environments.

10. The validity of our results is limited to a worker population which already has gone through the process of natural selection and heat acclimatization and which proved to be able to adapt to the work conditions of hot industries.

11. Although the high heat exposures during the summer in the observed jobs caused the feeling of marked discomfort to most of the workers, no signs were found which would suggest that these heat stress levels exceed the permissible limits, provided that all of the preventive measures which were secured on these jobs and listed in this report are satisfied. In all the observed jobs the heat workers alternated weekly in the morning, afternoon and night shifts. since the working climate was cooler during the night shift in all jobs, this also has to be taken in account when sustained overall heat stress levels are considered. In the case of the electro tender, however, the mitigating effect of the cooler night shifts was upset to some extent by the hotter morning shift during the summer.

12. The average voluntary dehydration did not exceed the safety limit of 2.5 liters per eight hour workshift. However, it would be of advantage to diminish dehydration even more by educating the workers thoroughly to improve their drinking habits. It would be helpful to this end if the workers would weigh themselves before and after workshifts. This would help them to keep their drinking habits in step with their sweat losses.

13. The validity of the conclusions is limited to the Southern hot and humid regions of the country. Additional observations are necessary in the Northern temperate and cold regions of the country, where summers are shorter but extreme hot weather may occur periodically for days. As a consequence, working conditions with a severe heat stress may find the workers unacclimatized, and before they would become acclimatized the weather cools off. Such a situation would necessitate either lower exposure limits or additional preventive measures or both. The Northern phase of the heat study is designed to provide the facts necessary to substantiate this hypothesis.

14. In all the jobs observed in this study the workers' heat exposure was intermittent. There are, however, hot jobs in other industries where the workers' climatic environment is steady or changes little during the workshift. Furthermore, the main heat source in all of the observed jobs was radiant heat, while there are many hot jobs where a high air temperature is the only cause of heat stress. Finally, the physical work load in all of the observed jobs belongs to the medium work category, whereas many hot jobs exist where the physical work requirement falls in the sedentary or standing category (light work), or in the heavy work category. It remains to be examined whether or not heat loads of the same magnitude but consisting of different combinations of the above three factors have the same physiological effect on the workers.

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APPENDIX

Table 1

U. S. Weather Bureau Average Monthly Maximum and
Minimum Air Temperatures in ^{o}F During the Summer and Winter Months

DEC.	JAN.	FEB.	MARCH		JULY	AUG.	SEPT.
65-49	63-48	67-50	71-55	GLASS PLANT	90-76	90-76	87-73
63-45	61-43	64-47	70-51	CHEMICAL PLANT	90-72	90-72	87-68
69-50	67-47	70-51	74-56	ALUMINUM PLANT	94-75	94-75	90-71

Table 2

The Standard Heat and Work Test

LEVEL OF EXERCISE

TREADMILL SPEED : 2.8 MILES PER HOUR

SLOPE : 0% (ON LEVEL)

DURATION : 1 HOUR

CLIMATIC CONDITIONS

AIR TEMPERATURE: 91.5 ± 0.5 °F DRY BULB

VAPOR PRESSURE : 24.5 mm Hg.

WIND VELOCITY : LESS THAN 30 FEET PER MINUTE, NON-DIRECTIONAL

CLOTHING OF SUBJECTS

STANDARD WORKER UNIFORM: PAIR OF PANTS
LONG SLEEVE SHIRTS
SOCKS AND WORK SHOES

Table 3

Average Environmental Conditions at Various Work Stations in Glass Plant
3:00 to 11:00 P.M. December 3-19, 1963

Location	Dry-Bulb °F	Dry-Bulb °C	Wet-Bulb °F	Wet-Bulb °C	Vapor Pressure mm Hg	Globe Temperature °F	Globe Temperature °C	M.R.T.* °F	M.R.T.* °C	Air Velocity FPM
A	80	26.7	61	16.1	8.7	132	55.5	188	86.7	100
A_1	74	23.4	59	15.0	8.7	107	41.7	151	66.2	110
C	69	20.6	57	13.3	8.7	84	28.9	110	43.4	140
F	65	18.4	55	12.8	8.3	81	27.2	104	40.0	90
H&I	69	20.6	57	13.9	8.7	86	30.0	111	43.9	100
J	67	19.4	56	13.4	8.5	82	27.8	103	39.4	80

*M.R.T. - Mean radiant temperature calculated from surface temperature and solid angle readings or from black globe temperatures.

Table 4

Average Environmental Conditions at Various Work Stations at the Glass Plant
3:00 to 11:00 P.M. July 14-29, 1964

Location	Dry-Bulb		Wet-Bulb		Vapor Pressure	Globe Temperature		M.R.T.*		Air Velocity
	°F	°C	°F	°C	mm Hg	°F	°C	°F	°C	FPM
A	102	38.9	81	27.2	24.4	153	67.2	220	104.5	190
A_1	96	35.6	80	26.7	21.8	130	54.4	188	87.0	255
C	90	32.2	79	26.1	22.3	104	40.0	135	57.3	275
D	79[a]	26.1	76[a]	24.4	22.1	85[b]	28.9	113	45.0	1500[b]
E	96	35.6	80	26.7	21.8	144	62.3	211	99.5	185
F	89	31.6	78	25.6	22.6	96	35.6	125	51.7	920
H&I	90	32.2	78	25.6	21.3	101	38.3	137	58.4	620
J	89	31.6	78	25.6	22.6	102	38.9	135	57.3	375

[a] Assumed same as outdoor air

[b] Estimated

*MRT = Mean radiant temperature calculated from surface temperature and solid angle readings or from black globe temperatures.

Table 5

Average Environmental Conditions at Various Work Stations at the Chemical Plant
3:00 to 11:00 P.M. August 8-21, 1963

Location	Dry-Bulb		Wet-Bulb		Vapor Pressure	Globe Temperature		MRT**		Air Velocity
	°F	°C	°F	°C	mm Hg	°F	°C	°F	°C	FPM
Center of Aisle (D)	97.0	36.1	79.3	26.3	21.0	102.5	39.1	119	48.4	500
Near Cells (B)	97.5	36.4	79.5*	26.4*	21.0	109.5	43.1	137	58.3	290
Over Cells (A)	118.3	47.9	84.3*	29.1*	21.0	128.5	53.6	146	63.4	200

*These wet-bulb temperatures determined from dry-bulb measurements and dew points at aisle stations (D).

**MRT = Mean radiant temperature calculated from surface temperature and solid angle readings or from black globe temperatures.

Table 6

Average Environmental Conditions at Various Work Stations at the Chemical Plant
3:00 to 11:00 P.M.   January 22 - February 5, 1964

Location	Dry-Bulb		Wet-Bulb		Vapor Pressure	Globe Temperature		MRT**		Air Velocity
	°F	°C	°F	°C	mm Hg	°F	°C	°F	°C	FPM
Center of Aisle (D)	72.2	22.3	57.5	14.2	8.1	79	26.1	96	35.9	270
Near Cells (B)	71.6	22.0	57.0*	13.9*	8.0	84	28.9	120	49.2	410
Over Cells (A)	94.3	34.6	65.0*	18.3*	8.0	112	44.5	141	60.6	160
Filter Area (E)	69.0	20.6	56.5	13.6	8.3	69	20.6	69	20.6	335
Lunchroom	76.0	24.4	60.0	15.6	8.9	-	-	-	-	-

*These wet-bulb temperatures determined from dry-bulb measurements and dew points at aisle stations (D).

**MRT - Mean radiant temperature calculated from surface temperature and solid angle readings or from black globe temperatures.

Table 7

Average Environmental Conditions at Various Work Stations at the Chemical Plant
3:00 to 11:00 P.M. August 6-17, 1964

Location	Dry-Bulb °F	Dry-Bulb °C	Wet-Bulb °F	Wet-Bulb °C	Vapor Pressure mm Hg	Globe Temperature °F	Globe Temperature °C	MRT** °F	MRT** °C	Air Velocity FPM
Center of Aisle (D)	90	32.2	79	26.1	22.4	96	35.6	121	55.0	1045
Near Cells (B)	94	34.5	80*	26.7*	22.4	107	41.7	148	64.5	620
Over Cells (A)	113	45.0	82*	27.8*	22.4	129	53.4	158	70.0	225
Filter Area (E)	93	33.9	80	26.7	22.4	-	-	-	-	440
Lunchroom	75.5	24.2	67.3	19.6	15.0	-	-	-	-	-
Cell Assembly	90	32.2	79	26.1	22.4	-	-	-	-	800
Tool Clean-up	88	31.1	78.5	25.8	22.4	-	-	-	-	175
Control Area	88	31.1	78.5	25.8	22.4	-	-	-	-	110

*These wet-bulb temperatures determined from dry-bulb measurements and dew points at aisle stations (D).

**MRT = Mean radiant temperature calculated from surface temperature and solid angle readings or from black globe temperatures.

Table 8

Average Environmental Conditions at Various Work Stations at the Aluminum Plant
4:00 P.M. to 12:00 Midnight February 14 - March 5, 1964

Location	Dry-Bulb		Wet-Bulb		Vapor Pressure	Globe Temperature		MRT[a]		MRT[b]		Air Velocity
	°F	°C	°F	°C	mm Hg	°F	°C	°F	°C	°F	°C	FPM
Wide Aisle (H)	69.5	20.8	55.4	13.0	7.4	82.3	27.9	120.0	42.3	96.5	35.8	170
Narrow Aisle (D)	75.6	24.2	57.0	13.9	6.9	91.1	32.8	105.5	48.1	105	40.5	154
Between Pots (J&K)	84.2	29.0	61.5	16.4	7.8	142.0	61.1	206.5	97.0	193	89.5	123
Along Window (G)	63.6	17.6	53.4	11.9	7.7	-	-	-	-	88.5	31.4	565
Air-Conditioned Cubicles	74.0	23.3	59.0	15.0	8.7	-	-	-	-	-	-	-

[a] MRT calculated from globe readings
[b] MRT calculated from surface temperatures and solid angles

Table 9

Average Environmental Conditions at Various Work Stations at the Aluminum Plant
4:00 P.M. to 12:00 Midnight August 25 - September 10, 1964

Location	Dry-Bulb		Wet-Bulb		Vapor Pressure	Globe Temperature		MRT[a]		MRT[b]		Air Velocity
	°F	°C	°F	°C	mm Hg	°F	°C	°F	°C	°F	°C	FPM
Wide Aisle (H)	94	34.4	81	27.2	23.7	102	38.9	120	49.0	131	55.0	260
Narrow Aisle (D)	100	37.8	82.5	28.1	23.8	115	46.1	141	60.6	135	57.3	190
Between Pots (J&K)	109	42.8	84	28.9	23.2	168	75.6	236	113.3	212	100.0	175
Along Window (G)	90	32.2	79.5	26.4	23.0	-	-	-	-	117	47.2	845
Air-Conditioned Cubicles	70.5	21.4	62.0	16.7	11.9	-	-	-	-	-	-	-
Crust Breaking[c]	103	39.4	82	27.8	22.3	177	80.6	257	125	-	-	175[d]
Pin Pushing[e]	105	40.6	83	28.3	23.0	138	58.9	232	111.1	-	-	870
Controls[f]	91	32.8	77	25.0	20.0	-	-	-	-	-	-	-

[a] MRT calculated from globe readings

[b] MRT calculated from surface temperatures and solid angles

[c] Averages of data taken on 9/4 during crust breaking operation in seven aisles. Readings taken after crust was broken and before additional alumina was added.

[d] Velocity assumed same as (J&K) above

[e] Averages of data taken on 9/7 during simulated pin pushing operation in three aisles

[f] Averages of data taken on 9/4 and 9/5 in machine, welding and copper shops

Table 10

Mean Cooling Power Values of the Environment Calculated from Katathermometric Measurements in the Glass Plant

Positive values indicate heat gain by convection and radiation from the environment, negative values heat loss, expressed in millical/cm^2/sec. (1 millical/cm^2/sec. = 0.004 BTU/ft^2/sec.).

Area	Work Phase	Summer 1963-64 Average	Winter 1964
A	Swabbing	21.5	16.8
A_1	Checking operation	12.1	11.7
B	Weighing bottles	5.8	-13.2
C	Picking up new molds	5.1	-15.3
D	Recovering, resting	-6.2	-14.8
E	Checking bottles	18.2	18.3
F	Gauging bottles	-4.9	-5.3
G	Walking	-1.7	-10.6
H-I	Swabbing	4.5	-6.2
J	Mixing mold lubricant	-3.2	-9.5
K	Adjusting conveyor belt	15.2	8.0
L	Adjusting machine	0.0	-8.5
M	Checking oven	-	6.0
N	Checking oven	17.2	7.1
O	Picking up tools	-1.0	-26.3
Between ovens	Checking rejected bottles	-1.8	-
Top of machine	Adjusting machine	9.5	-

Table 11

Mean Cooling Power Values of the Environment Calculated from Katathermometric Measurements in the Chemical Plant

Positive values indicate heat gain by convection and radiation from the environment, negative values heat loss, expressed in millical/cm^2/sec. (1 millical/cm^2/sec. = 0.004 BTU/ft^2/sec.).

Area	Work Phase	Summer 1963-64 Average	Winter 1964
A	Working on top of the cell	11.8	6.9
B	Working between cells	11.5	-5.8
C	Working in behind the cell	19.8	10.0
D	Working in the aisle	0.6	-11.6
E	Walking to and from cell	0.5	-11.6
Air conditioned lunch room	Sitting	3.3	-

Table 12

Mean Cooling Power Values of the Environment Calculated from Katathermometric Measurements in the Aluminum Plant

Positive values indicate heat gain by convection and radiation from the environment, negative values heat loss, expressed in millical/cm^2/sec. (1 millical/cm^2/sec. = 0.004 BTU/cm^2/sec.).

Area	Work Phase	Summer 1963-64 Average	Winter 1964
A + D	Jack raising	11.3	4.3
A + D	Standing in readiness	9.0	-
A + D	Oreing	12.4	-
BC + EF	Operating pin pulling machine	15.9	13.0
BC + EF	Plugging holes	-	3.5
BC + EF	Pulling pins	18.3	17.0
BC + EF	Loosening bolts	25.4	22.6
BC + EF	Racking pins	17.4	12.6
BC + EF	Removing bolts	39.7	33.9
B-C + E-F	Crust breaking	21.0	3.7
B-C + E-F	Sweeping floor	22.2	16.3
B-C + E-F	Sweeping ore	-	10.5
B-C + E-F	Gas holing	21.6	14.3
G	Recovering, resting	-3.5	-14.3
H	Adjusting fans	3.0	-9.4
H	Standing in front of fan	0.0	-
H	Moving equipment	-	-9.1
J-K	Rolling off channels	6.1	8.1
J-K	Crust breaking	12.5	7.5
J-K	Crust breaking at a hot pot	-	17.7
Air conditioned cubicle	Sitting	-5.2	-5.5

Table 13/a

Average values of effective exposure time (EET), total time spent at each location during one shift (WT), metabolic heat production (M), required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] and katathermometric measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Glass Plant - Foreman

Location of measurement Conv.	 Kata	Work time hours	M kcal[b]/70 kg[c]/WT	E_{req} l.[d]/70 kg/WT Conv.	 Kata	E_{max} l./70 kg/WT	RSI
Summer 1963-64							
A	A	0.56	79	0.61	1.38	0.23	2.6
A_1	A_1-N-M	0.43	53	0.31	0.75	0.22	1.4
C	C-B-L	0.33	42	0.12	0.20	0.17	0.7
E	E-K	0.23	24	0.21	0.44	0.11	1.9
F	F	1.49	167	0.34	0.47	0.85	0.4
H-I	H-I	1.36	169	0.43	0.92	0.80	0.5
J	J-G-O	0.11	16	0.04	0.00	0.06	0.7
D	D	0.15	20	0.01	-0.06	0.10	0.1
Total for EET		4.66	570	+2.07	+4.16 -0.06	-	-
Rest Period		3.34	266	-	-	-	-
Total for Shift		8.00	836	+2.07	+4.10	-	-
Winter							
A	A	0.65	91	0.52	1.29	0.37	1.4
A_1	A_1,N,M, E,K	1.05	162	0.52	1.39	0.61	0.9
C	C,B,L	0.27	32	0.03	-0.29	0.17	0.2
F	F	1.06	165	0.20	-0.30	0.61	0.3
H-I	H-I	1.41	248	0.39	-0.48	0.80	0.5
J	J,G,O,D	0.20	27	0.03	-0.27	0.11	0.3
Total for EET		4.64	725	+1.69	+2.68 -1.34	-	-
Rest Period		3.36	269	-	-	-	-
Total for Shift		8.00	994	+1.69	+1.34	-	-

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[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 kcal = 4 BTU

[c] 70 kg = 154 lbs, the body weight of an average sized man

[d] 1 liter = 1 quart

Table 13/b

Average values of effective exposure time (EET), total time spent at each location during one shift (WT), metabolic heat production (M), required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] and katathermometric measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Glass Plant - Machine Operator

Location of measurement		Work time	M	E_{req} 1.[d]/70 kg/WT		E_{max}	
Conv.	Kata	hours	kcal[b]/70 kg[c]/WT	Conv.	Kata	1./70 kg/WT	RSI
Summer 1963-64							
A	A	0.85	118	0.93	2.19	0.44	2.1
A_1	A_1,N,M	0.65	81	0.47	1.13	0.43	1.1
C	C,B,L	0.49	63	0.18	0.29	0.32	0.6
E	E,K	0.34	35	0.31	0.65	0.20	1.6
F	F	2.24	251	0.52	-0.70	1.70	0.3
H-I	H-I	2.05	254	0.65	1.39	1.60	0.4
J	J,G,O	0.17	24	0.06	0.01	0.11	0.6
D	D	0.23	30	0.01	-0.09	0.20	0.1
Total for EET		7.02	856	+3.13	+5.66 0.79	-	-
Rest Period		0.98	78	-	-	-	-
Total for Shift		8.00	934	+3.13	+4.87	-	-
Winter							
A	A	0.98	137	0.79	1.94	0.79	1.0
A_1	A_1,N,M, E,K	1.58	243	0.79	2.09	1.32	0.6
C	C,B,L	0.40	47	0.05	-0.43	0.36	0.1
F	F	1.60	250	0.30	-0.45	1.30	0.2
H-I	H-I	2.12	373	0.58	-0.72	1.72	0.3
J	J,G,O,D	0.30	40	0.04	-0.41	0.24	0.2
Total for EET		6.98	1090	+2.55	+4.03 -2.01	-	-
Rest Period		1.02	81	-	-	-	-
Total for Shift		8.00	1171	+2.55	+2.02	-	-

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[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 kcal = 4 BTU

[c] 70 kg = 154 lbs, the body weight of an average sized man

[d] 1 liter ≅ 1 quart

Table 13/c

Average values of effective exposure time (EET), total time spent at each location during one shift (WT), metabolic heat production (M), required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] and katathermometric measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Glass Plant - Floorboy

Location of measurement		Work time hours	M kcal[b]/70 kg[c]/WT	E_{req} [d] l./70 kg/WT		E_{max} l./70 kg/WT	RSI
Conv.	Kata			Conv.	Kata		
Summer 1963-64							
A	A	0.52	72	0.57	1.28	0.27	2.1
A_1	A_1,N,M	0.40	52	0.29	0.69	0.26	1.1
C	C,B,L	0.30	38	0.11	0.18	0.20	0.6
E	E,K	0.21	22	0.19	0.40	0.12	1.6
F	F	1.37	153	0.32	-0.43	1.04	0.3
H-I	H-I	1.25	155	0.40	0.85	0.97	0.4
J	J,G,O	0.10	14	0.04	0.00	0.07	0.6
J	J,G,O	2.60	374	1.05	0.38	1.69	0.6
D	D	0.14	19	0.01	-0.06	0.12	0.1
Total for EET		6.89	899	+2.98	+3.78 -0.49	-	-
Rest Period		1.11	88	-	-	-	-
Total for Shift		8.00	987	+2.98	+3.29	-	-
Winter							
A	A	0.60	84	0.48	1.19	0.49	1.0
A_1	A_1,N,M E,K	0.97	149	0.48	1.28	0.81	0.6
C	C,B,L	0.24	28	0.03	-0.26	0.22	0.1
F	F	0.98	153	0.18	-0.38	0.80	0.2
H-I	H-I	1.30	229	0.36	-0.44	1.05	0.3
J	J,G,O,D	0.18	24	0.03	-0.24	0.15	0.2
J	J,G,O,D	2.93	598	0.54	-3.61	2.39	0.2
Total for EET		7.20	1265	+2.10	+2.47 -1.32 -3.61*	-	-
Rest Period		0.80	64	-	-	-	-
Total for Shift		8.00	1329	+2.10	+1.15	-	-

*Not subtracted when calculating eight hour total E_{req} (see text)

[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 kcal = 4 BTU

[c] 70 kg = 154 lbs, the body weight of an average sized man

[d] 1 liter = 1 quart

Table 14/a

Average values of effective exposure time (EET), total time spent at each location during one shift (WT), metabolic heat production (M), required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] and katathermometric measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Chemical Plant - Cell Feeder

Location of measurement		Work time	M	E_{req} 1.[d]/70 kg/WT		E_{max}	
Conv.	Kata	hours	kcal[b]/70 kg[c]/WT	Conv.	Kata	1./70 kg/WT	RSI
Summer 1963-64							
A	A	1.77	230	1.13	2.56	1.09	1.0
B	B	0.57	89	0.28	0.83	0.38	0.7
D	D	0.09	11	0.03	0.02	0.07	0.4
E	E	0.97	134	0.21	0.28	0.65	0.3
Total for EET		3.40	464	+1.65	+3.69	-	-
Rest Period		4.60	444	-	-	-	-
Total for Shift		8.00	908	+1.65	+3.69	-	-
Winter							
A	A,C	1.77	230	0.84	1.66	1.62	0.5
B	B	0.57	89	0.10	-0.19	0.49	0.2
D	D	0.09	11	0.00	-0.08	0.06	0.1
E	E	0.97	145	-0.07	-0.09	0.56	-0.1
Total for EET		3.40	475	+0.94 -0.07*	+1.66 -0.36*	-	-
Rest Period		4.60	383	-	-	-	-
Total for Shift		8.00	858	0.94	+1.66	-	-

*Not subtracted when calculating eight hour total E_{req} (see text)

[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 kcal = 4 BTU

[c] 70 kg = 154 lbs, the body weight of an average sized man

[d] 1 liter = 1 quart

Table 14/b

Average values of effective exposure time (EET), total time spent at each location during one shift (WT), metabolic heat production (M), required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] and katathermometric measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Chemical Plant - Cell Repair Man

Location of measurement		Work time	M	E_{req} 1[d]./70 kg/WT		E_{max}	
Conv.	Kata	hours	kcal[b]/70 kg[c]/WT	Conv.	Kata	1./70 kg/WT	RSI
Summer 1963-64							
A	A	0.33	42	0.21	0.48	0.20	1.0
B	B	1.06	133	0.46	1.49	0.70	0.7
D	D	2.76	259	0.77	0.62	2.02	0.4
E	E	0.26	33	0.05	0.07	0.17	0.3
C	C	0.08	7	0.05	0.18	0.05	0.9
Total for EET		4.49	474	+1.54	+2.84	-	-
Rest Period		3.51	279	-	-	-	-
Total for Shift		8.00	753	+1.54	+2.84	-	-
Winter							
B	B	0.55	76	0.08	-0.20	0.48	0.2
C	C	0.57	87	0.29	0.74	0.52	0.6
D	D	2.55	339	0.15	-2.48	1.72	0.1
E	E	0.89	133	-0.05	-0.84	0.51	-0.1
Total for EET		4.56	635	+0.52 -0.05*	+0.74 -3.52*	-	-
Rest Period		3.44	274	-	-	-	-
Total for Shift		8.00	909	+0.52	+0.74	-	-

*Not subtracted when calculating eight hour total E_{req} (see text)

[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 kcal = 4 BTU

[c] 70 kg = 154 lbs. the body weight of an average sized man

[d] 1 liter ≅ 1 quart

Table 15/a

Average values of effective exposure time (EET), total time spent at each location during one shift (WT), metabolic heat production (M), required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] and katathermometric measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Aluminum Plant - Electro Tender

Location of measurement Conv.	Location of measurement Kata	Work time hours	M kcal[b]/70 kg[c]/WT	E_{req} l.[d]/70 kg/WT Conv.	E_{req} l.[d]/70 kg/WT Kata	E_{max} l/70 kg/WT	RSI
Summer 1963-64							
H	H	3.45	455	1.18	1.32	1.94	0.6
D	A & D	0.21	47	0.14	0.30	0.11	1.2
J-K	J-K, BC-EF	1.44	261	2.00	3.50	0.77	2.6
G	G	1.44**	112	0.09	-0.40	1.07	0.1
Total for EET		5.10	875	+3.41	+5.12 -0.40	-	-
Rest Period		2.90	117	-	-	-	-
Total for Shift		8.00	992	+3.41	+4.72	-	-
Winter							
H	H	1.85	226	0.23	-1.41	1.72	0.1
D	A & D	0.57	86	0.13	0.40	0.60	0.2
J-K	J-K, BC-EF	1.73	256	1.68	3.27	1.50	1.1
G	G	0.78	64	-0.13	-0.85	0.49	-0.3
Total for EET		4.93	632	+2.04 -0.13*	+3.67 -2.26*	-	-
Rest Period		3.07	245	-	-	-	-
Total for Shift		8.00	877	+2.04	+3.67	-	-

* Not subtracted when calculating eight hour total E_{req} (see text).

** Not considered as part of EET, therefore added to rest period time.

[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 Kcal = 4 BTU

[c] 70 kg = 154 lbs., the body weight of an average sized man

[d] 1 liter ≅ 1 quart

Table 15/b

Average values of effective exposure time (EET), total time spent at each location during one shift (WT), metabolic heat production (M), required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] and katathermometric measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Aluminum Plant - Pot Tender

Location of measurement Conv.	Kata	Work time hours	M kcal[b]/70 kg[c]/WT	E_{req} l.[d]/70 kg/WT Conv.	Kata	E_{max} l./70 kg/WT	RSI
Summer 1963-64							
H	H	1.30	156	0.42	0.47	0.73	0.6
J-K	J-K, BC-EF	1.66	246	2.21	3.74	0.89	2.5
G	G	0.44	33	0.02	-0.08	0.33	0.1
Total for EET		3.40	435	+2.65	+4.21 -0.08*	-	-
Rest Period		4.60	367	-	-	-	-
Total for Shift		8.00	802	+2.65	+4.21	-	-
Winter							
H	H	1.30	156	0.16	-0.95	0.82	0.2
J-K	J-K, BC-EF	1.66	246	1.61	2.44	1.18	1.4
G	G	0.44	33	-0.08	-0.70	0.27	-0.3
Total for EET		3.40	435	+1.77 -0.08*	+2.44 -1.65*	-	-
Rest Period		4.60	367	-	-	-	-
Total for Shift		8.00	802	+1.77	+2.44	-	-

*Not subtracted when calculating eight hour total E_{req} (see text).

[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 kcal = 4 BTU

[c] 70 kg = 154 lbs, the body weight of an average sized man

[d] 1 liter ≘ 1 quart

Table 16

Average observed eight hour total sweat losses of the workers in each job as compared to their eight hour total E_{req} values[a] calculated from conventional[b] and katathermometric measurements of the work environment. The E_{req} values are changed from liter/70 kg to liter/mean surface area of observed workers. The summer values are averages of the 1963 and 1964 observations.

			E_{req} in liter[c]		Observed Sweat Loss in liter
Plant	Job	Season	Conv.	Kata	Ave. ± S.D.
Glass	Foreman	Summer	2.16	4.28	3.92 ± 1.51
		Winter	1.76	1.40	1.82 ± 0.42
	Machine Operator	Summer	3.26	5.08	4.01 ± 1.10
		Winter	2.66	2.11	2.07 ± 0.79
	Floor Boy	Summer	3.11	3.43	4.63 ± 1.80
		Winter	2.19	1.20	2.60 ± 0.55
Chemical	Cell Feeder	Summer	1.81	4.05	4.55 ± 2.00
		Winter	1.03	1.82	- -
	Cell Repair Man	Summer	1.69	3.12	4.11 ± 1.40
		Winter	0.57	0.81	1.96 ± 0.44
Aluminum	Electro Tender	Summer	3.61	5.00	8.13 ± 1.41
		Winter	2.16	3.89	3.18 ± 1.53
	Pot Tender	Summer	2.81	4.46	5.19 ± 1.10
		Winter	1.88	2.59	2.86 ± 0.87

[a] Required sweat evaporation to maintain thermal balance

[b] Dry- and wet-bulb temperatures, wind speed and globe temperature measured separately

[c] 1 liter ≅ 1 quart

Table 17

Mean Heart Rates at the Beginning and End of Workshift (in beats per minute)

	Summer 1963-1964			Winter		
	Glass Plant			Glass Plant		
Job	Beginning	End	Difference	Beginning	End	Difference
Foreman	80	91	+11	86	82	-4
Machine Operator	92	94	+2	92	91	-1
Floorboy	84	103	+19	82	83	+1
Control Subjects	85	90	+5	90	87	-3
	Chemical Plant			Chemical Plant		
Job	Beginning	End	Difference	Beginning	End	Difference
Cell Repair Man	80	93	+13	86	85	-1
Cell Feeder	82	94	+12	96	84	-12
Filter Operator	95	91	-4	85	95	+10
Truck Driver	87	94	+7	93	91	-2
Salt and Temperature Man	95	83	-12	76	62	-14
Control Subjects	95	89	-6	87	86	-1
	Aluminum Plant			Aluminum Plant		
Job	Beginning	End	Difference	Beginning	End	Difference
Electro Tender	80	78	-2	87	79	-8
Pot Tender	86	79	-7	83	85	+2
Control Subjects	92	88	-4	91	90	-1

Table 18

Mean Oral Temperatures at the Beginning and End of Workshift (in $^{\circ}F$)

	Mean Summer 1963-1964			Winter		
	Glass Plant			Glass Plant		
Job	Beginning	End	Difference	Beginning	End	Difference
Foreman	98.0	98.3	+0.3	97.2	96.5	-0.7
Machine Operator	97.7	98.2	+0.5	97.1	97.1	0.0
Floorboy	97.4	98.4	+1.0	96.7	97.3	+0.6
Control Subjects	97.8	98.2	+0.4	96.9	95.7	-1.2
	Chemical Plant			Chemical Plant		
Job	Beginning	End	Difference	Beginning	End	Difference
Cell Repair Man	97.8	97.9	+0.1	97.8	97.1	-0.7
Cell Feeder	97.9	98.2	+0.3	98.0	97.4	-0.6
Filter Operator	97.4	97.4	0.0	98.7	96.2	-2.5
Truck Driver	98.9	98.3	-0.6	98.1	97.9	-0.2
Salt and Temperature Man	98.2	96.9	-1.3	99.0	96.0	-3.0
Control Subjects	98.6	98.3	-0.3	97.3	98.2	-0.9
	Aluminum Plant			Aluminum Plant		
Job	Beginning	End	Difference	Beginning	End	Difference
Electro Tender	98.0	98.0	0.0	98.3	97.9	-0.4
Pot Tender	97.8	97.8	0.0	98.0	97.9	-0.1
Control Subjects	97.4	98.0	+0.6	97.9	98.1	+0.2

Table 19

The Workers' Body Weight Change During a Workshift in Kilograms
(1 kg = 2.2 lbs)

	Summer 1963			Winter		
Job	Mean kg	S.D. + -	Maximal Weight Loss kg	Mean kg	S.D. + -	Maximal Weight Loss kg
Heat Workers						
Electro Tender	-0.94	0.57	2.04	-0.18	0.48	0.94
Pot Tender	+0.06	0.91	1.70	-0.34	0.61	1.82
Cell Feeder	-0.53	0.49	0.96	-0.07	(1 subject)	-
Cell Repair Man	-0.21	0.82	1.89	+0.02	0.56	0.97
Filter Operator	-0.41	0.49	0.84	-0.36	0.52	0.87
Floorboy	-0.45	0.23	0.71	-0.62	0.45	1.25
Truck Driver	-0.49	0.50	0.97	+0.02	0.46	0.47
Machine Operator	-0.43	0.66	2.02	-0.33	0.45	1.14
Salt & Temperature Man	-0.41	0.24	0.58	-0.69	(1 subject)	-
Tank Foreman	-0.14	0.50	0.80	-0.13	0.90	0.97
Control Subjects						
Glass Plant	-0.18	0.36	0.43	-0.21	0.19	0.45
Aluminum Plant	-0.59	0.60	1.25	+0.31	0.62	0.74
Chemical Plant	+0.07	0.69	0.76	+0.44	0.86	0.56

Table 20

Number of Subjects Observed in Different Seasons, at the Job Site in the Standard Test

	Summer and Winter	Summer only	Winter only
Both in standard heat and on the job site	52	28	17
Job site only	20	5	0
Standard test only	11	10	11

Table 21

Means of Physiological Responses of Heat Workers in the Standard Test

Test Period	Sweat loss grams[a] per kg body weight	Heart Rates-beats per minute						Rectal Temperature-^{o}F		
		At start	30 min	45 min	At end	+3 min	+5 min	At start	45 min	+10 min
				Glass Plant						
Summer 1963	11.8**	94	111	113	114	107	107	99.6**		100.7*
Winter	9.8**	87	109	112	114	106	105	98.8**		100.1*
Summer 1963	12.0	94	111	113	114	107*	106**	99.7	100.7	100.8
Summer 1964	13.0	90	112	115	114	94*	91**	99.3	100.3	100.4
				Chemical Plant						
Summer 1963	11.4**	89	105	108	110	107	105	99.5**		100.5
Winter	9.3**	86	109	113	115	112	111	98.6**		100.3
Summer 1963	13.5	93	107	108	111	105	110	99.6	100.5	100.3
Summer 1964	14.5	86	113	112	119	102	94	99.1	100.1	100.2
				Aluminum Plant						
Summer 1963	13.8**	83	106	108	108	99	97	99.5**		100.7**
Winter	10.4**	82	106	113	115	99	95	98.7**		100.1**
Summer 1963	14.2	82	107	110	109	99	97	99.5	100.7	100.7
Summer 1964	14.7	81	100	105	108	88	85	99.4	100.2	100.3

*Means significantly different from each other at the 0.05 level

**Means significantly different from each other at the 0.01 level

[a] Sweat loss is expressed for 1 kg (2.2 lbs) body mass in grams (1 gram = 0.035 oz)

Table 22

Means of Physiological Responses of Control Subjects Observed in the Standard Test

Glass Plant

		Heart Rates beats per minute						Rectal Temperature °F		
Test Period	Sweat loss grams[a] per kg body weight	At start	30 min	45 min	At end	+3 min	+5 min	At start	45 min	+10 min
Summer 1963	9.3*	101	110	113	113	107	107	99.1	100.5	100.2
Winter	6.8*	93	110	111	116	110	105	98.8	100.2	100.2

*Means are significantly different from each other at the 0.05 level

[a] Sweat loss is expressed for 1 kg (2.2 lbs) body mass in grams (1 gram = 0.035 oz)

Table 23

Predicted Vital Capacities (VC)[a] and Observed Mean Forced Vital Capacities (FVC)[b] Before and After the Standard Test

Season	Age Group	N	Mean age years	Mean height[c] centimeters	Predicted VC in liters[d]	Observed FVC in liters Before	Observed FVC in liters After
Heat Workers							
Summer 1963	21-30	11	25	174	4.96	4.08	4.33
	31-40	24	36	173	4.67	3.94	4.21
	41-50	28	46	175	4.55	4.00	3.99
Winter	21-30	9	25	177	5.12	4.22	4.26
	31-40	13	35	173	4.69	4.07	4.26
	41-50	16	46	175	4.55	3.79	3.93
Control Subjects							
Summer 1963	21-30	3	26	176	5.04	4.83	5.13
	31-40	4	36	180	5.03	4.21	4.44
	41-50	4	45	183	4.99	4.49	4.82
Winter	21-30	3	26	176	5.04	5.05	5.12
	31-40	3	37	178	4.91	4.29	4.33
	41-50	2	45	184	5.04	4.70	4.93

[a] VC is the volume of air which one can expire after a maximal deep inspiration

[b] FVC is the same as VC except the expiration is performed with maximal speed

[c] 1 centimeter = 0.39 inches

[d] 1 liter ≅ 1 quart

Table 24

Mean FEV$_1$%'s[a] of Heat Workers Before and After the Standard Test During Summer and Winter

	Age Groups					
	21-30 years		31-40 years		41-50 years	
Test Period	Before	After	Before	After	Before	After
Summer 1963	80	90	72	78	73	78
Winter	90**	72**	90**	80**	77*	63*

*Means are significantly different from each other at the 0.05 level

**Means are significantly different from each other at the 0.01 level

[a] FEV$_1$% = The volume of the air expired during the first second of the forced expiratory volume (FEV) test, expressed as a percentage of the total expired air.

Table 25

Mean Physiological Responses of Heat Workers and Control Subjects in the Standard Test

				Heart Rate beats per minute		Rectal Temperature °F	
Test Period	Plant	Job	Sweat loss[a] grams per kg body weight	At start	At End	At start	At end
Summer 1963	Glass	Heat workers	11.8*	94.0	113.5	99.6	100.7
		Control subjects	9.3*	100.8	113.4	99.1	100.2
	Chemical	Heat workers	12.3	88.7	110.1	99.4	100.4
		Control subjects	11.1	92.7	119.0	99.9	100.9
	Aluminum	Heat workers	14.8**	84.0	111.7	99.5	100.7
		Control subjects	9.6**	92.6	108.6	99.2	100.4
Winter	Glass	Heat workers	9.8**	87.7	110.0	98.9	100.3
		Control subjects	6.8**	93.4	115.8	98.8	100.2
	Chemical	Heat workers	10.0	85.5	114.5	98.6	100.3
		Control subjects[b]	-	-	-	-	-
	Aluminum	Heat Workers	10.4	82.3	115.1	98.7	100.1
		Control subjects	7.6	98.7	129.3	99.2	100.7

*Means are significantly different from each other at the 0.05 level

**Means are significantly different from each other at the 0.01 level

[a] Sweat loss is expressed for 1 kg (2.2 lbs) body mass in grams (1 gram = 0.035 oz)

[b] None of the summer control subjects were available for repeat observation in winter.

Table 26

Personal Data of the Observed Heat Workers in the Three Plants. Means and Standard Deviations of Summer 1963 Data

Plant	Age	Height (cm)[a]	Nude Weight (kg)[b]	Surface Area in m^2[c]	Years Employed in Hot Industry
Glass	31 ± 6**	176 ± 6*	74 ± 15*	1.91	5 ± 5**++
Chemical	46 ± 5**	176 ± 5+	84 ± 13*	2.02	12 ± 9**
Aluminum	40 ± 6**	172 ± 5*+	81 ± 12	1.95	10 ± 2++

Means marked * or + are significantly different from each other at the 0.05 level
Means marked ** or ++ are significantly different from each other at the 0.01 level

[a] 1 cm = 0.39 inches

[b] 1 kg = 2.2 lbs

[c] 1 m^2 = 10.76 ft^2

Table 27

Standard Test Sweat Losses and Increases (Δ) in Heart Rate and Rectal Temperature of Heat Workers Grouped According to the Plant in Which they Worked. Means and Standard Deviations of Summer 1963 Data.

Plant	Sweat Loss grams[a] per kg body weight	Δ Heart Rate beats per minute	Δ Rectal Temperature °F
Glass	12.1 ± 2.2*	19 ± 13*	1.1 ± 0.7
Chemical	12.3 ± 3.9+	22 ± 10	1.0 ± 0.4*
Aluminum	14.8 ± 5.2*+	27 ± 12*	1.2 ± 0.4*

Means marked * or + are significantly different from each other at the 0.05 level.

[a] Sweat loss is expressed for 1 kg (2.2 lbs) body mass in grams (1 gram = 0.035 oz)

Table 28

Coefficients of Correlations Between Personal Data and Physiological Responses in the Standard Test (Summer 1963)

	Sweat Rate	Increase in Heart Rate	Increase in Rectal Temperature
Age	0.1	0.1	-0.1
Height	0.0	-0.1	-0.1
Weight	0.1	0.3	0.0

Table 29

Mean Before Standard Test $FEV_1\%$ Values[a] of Heat Workers According to Age Groups

	Age Group 21-30	 31-40	 41-50	 51-60
Summer 1963	78	74	72	61
Winter	89	82	77	-
Summer 1964	74	71	63	-

[a] $FEV_1\%$ = The volume of the air expired during the first second of the forced expiratory volume (FEV) test, expressed as a percentage of the total expired air.

Table 30

Standard Test Sweat Losses and Increases (Δ) in Heart Rate and Rectal Temperature of Heat Workers Grouped According to Length of Employment in Hot Jobs. Means and Standard Deviations of Summer 1963 Data.

Years Employed	N	Sweat Loss grams[a] per kg body weight	Δ Heart Rate beats per minute	Δ Rectal Temperature °F
1-5	25	12.3 ± 3.6	20 ± 13	1.0 ± 0.6
6-10	18	13.5 ± 3.5	25 ± 9	1.4 ± 0.3
10<	36	13.7 ± 4.9	25 ± 13	1.1 ± 0.5

[a] Sweat loss is expressed for 1 kg (2.2 lbs) body mass in grams (1 gram = 0.035 oz).

Table 31

Standard Test Sweat Losses and Increase (Δ) in Heart Rate and Rectal Temperature of Heat Workers at the Aluminum Plant Grouped According to their National Background. Means and Standard Deviations of Summer 1963 Data.

	N	Sweat Loss grams[a] per kg body weight	Δ Heart Rate beats per minute	Δ Rectal Temperature °F
Mexican descent	25	14.7 ± 5.4	27 ± 13	1.3 ± 0.4
Non-Mexican descent	7	15.3 ± 4.4	29 ± 8	1.2 ± 0.4

[a] Sweat loss is expressed for 1 kg (2.2 lbs) body mass in grams (1 gram = 0.035 oz).

Table 32

Home Environment and Off Job Activities

	Air Conditioning					Hobbies			
Plant	None %	Home %	Bedroom %	Average hours of sleep	Free Time Jobs %	None %	Yard Work Fishing Hunting %	Sports %	Farming Ranching %
				Heat Workers					
Glass	40	47	13	7.7	0	37	40	23	0
Chemical	33	48	19	7.2	14	24	56	10	10
Aluminum	71	3	26	7.6	4	21	71	8	0
Overall	51	29	20	7.4	5	28	55	15	2
				Controls					
Glass	50	33	17	7.3	0	33	17	50	0
Chemical	0	100	0	7.3	0	33	33	0	34
Aluminum	40	0	60	6.8	0	0	66	34	0
Overall	36	36	28	7.4	0	25	33	33	9

Table 33

Average Environmental Conditions at Various Work Stations
8:00 A.M.-4:00 P.M. August 25-September 10, 1964

Aluminum Plant

Location	Dry-Bulb		Wet-Bulb		Vapor Pressure	Globe Temperature		MRT		Air Velocity
	°F	°C	°F	°C	mm Hg	°F	°C	°F	°C	FPM
Wide Aisle (H)	98	36.7	81	27.2	22.5	124	51.1	172	77.8	260
Narrow Aisle (D)	103	39.5	83	28.3	23.6	136	57.8	185	85.0	190
Between Pots (J&K)	113	45.0	85	29.4	23.1	189	87.2	268	131.1	175
Along Window (G)	93	33.9	80	26.7	22.8	98	36.7	-	-	845

Table 34

The estimated required sweat evaporation to maintain thermal balance (E_{req}) as calculated from conventional[a] measurements of the work environment, the maximum vapor uptake capacity of the environmental air (E_{max}) and the Relative Strain Index (RSI).

Location of measurement	E_{req} l.[b]/70 kg[c]/WT[d]		E_{max} l./70 kg/WT		RSI	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
H	2.21	1.18	2.19	1.94	1.0	0.6
D	0.22	0.14	0.13	0.11	1.7	1.2
J-K	2.46	2.00	0.80	0.77	3.1	2.6
G	0.28	0.09	1.08	1.07	0.3	0.1
Total	5.17	3.41	-	-	-	-

[a] Dry- and wet-bulb temperatures, globe temperature and wind speed measured separately.

[b] 1 liter ≅ 1 quart

[c] 70 kg = 154 lbs, the body weight of an average sized man

[d] Total time spent at a location during one workshift