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A Study of Factors Involved in Establishing a Satisfactory Thermal Environment in the Classroom

Homer Franklin Mincy Jr.
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Homer Franklin Mincy Jr. entitled "A Study of Factors Involved in Establishing a Satisfactory Thermal Environment in the Classroom." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Education, with a major in Educational Administration.

John W. Gilliland, Major Professor

We have read this dissertation and recommend its acceptance:

Howard F. Aldmon, Edward S. Christenbury, Lawrence M. DeRidder, Ralph B. Kimborough

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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August 1, 1961

To the Graduate Council:

I am submitting herewith a thesis written by Homer Franklin Mincy, Jr., entitled "A Study of Factors Involved in Establishing a Satisfactory Thermal Environment in the Classroom." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Education, with a major in Educational Administration and Supervision.

John W. Gilliland
Major Professor

We have read this thesis and recommend its acceptance:

Ralph B Kimbrough

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Accepted for the Council:

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Dean of the Graduate School

A STUDY OF FACTORS INVOLVED IN ESTABLISHING A SATISFACTORY THERMAL ENVIRONMENT IN THE CLASSROOM

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Education

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by

Homer Franklin Mincy, Jr.

August 1961

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Appreciation is expressed to the other members of the committee, Dr. Orin B. Graff, Dr. Howard F. Aldmon, Dr. Edward S. Christenbury, and Dr. Lawrence M. DeRidder. Each, in his own way, contributed immeasurably to the study.

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INTRODUCTION

A. GENERAL INTRODUCTION

Since the dawn of civilization, man has wrestled with the weighty problems of government, war, science, philosophy, and religion. Perhaps no problem has taxed man's ingenuity as much, however, as that of determining and maintaining the proper thermal environment for the various activities in which he has engaged. Indeed, some sociologists believe that the satisfactory solution of this problem has often aided man in the solution of his other problems.

Although the term "thermal environment" is a comparatively recent addition to the vocabulary of school administrators and teachers, the control of temperature, humidity, cleanliness, and movement of air, aspects of our environment which the word "thermal" implies, has long been of concern to man. Primitive man was not able to control his thermal environment in any way, however, and was forced to adapt himself to the environment. From our ancestors' crude attempts to adapt to the thermal environment evolved our present forms of shelter and clothing. Only after the discovery of fire did man begin to progress in his quest for some type of positive control over various elements of his thermal

environment.[1] From the early control of external cold by positive heating of the air, thermal control has now evolved to such a state that air can be treated so as to control simultaneously its temperature, humidity, cleanliness, and distribution within a given building so that the comfort, health, and efficiency of its occupants are kept at the optimum.

Since thermal control has now reached such an advanced state, to what extent is the thermal environment being controlled in the thousands of classrooms in the United States? Indeed, what is an adequate thermal environment for optimum working and learning efficiency? What type of school buildings and heating and ventilating equipment best provide an adequate thermal environment? Are public school educators cognizant of the many factors involved in determining and maintaining an adequate thermal environment? This study was concerned with investigating the problem area suggested by the preceding questions.

B. STATEMENT OF THE PROBLEM

The problem of this study was to analyze and appraise conditions relating to thermal environment in the classroom that existed in selected schools.

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[1]C.-E. A. Winslow and L. P. Herrington, Temperature and Human Life (Princeton, New Jersey: Princeton University Press, 1949), p. 163.

Sub-problems

The following sub-problems were identified in order to accomplish more adequately a satisfactory treatment of the problem:

1. To identify criteria related to thermal factors affecting classroom environment.

2. To apply criteria identified to a varied selection of classrooms as a means of determining existing conditions relating to thermal environment in the classroom.

3. To analyze the findings in the light of the criteria in order to draw conclusions relating to the present situation regarding thermal environment in the selected classrooms.

C. BASIC ASSUMPTIONS

The following basic assumptions were advanced prior to the undertaking of the study:

1. A child grows, develops, and functions as an integrated whole. The "whole child" is constantly solving new problems and learning through activity. Environmental factors affect the child's learning experiences, either beneficially or detrimentally.

2. The thermal environment of a school is one of the environmental factors which affects, to a certain extent, the teaching-learning process.

3. Educators, particularly school administrators, need information regarding thermal environment.

4. Research in the field of thermal environment is justified because of (a) the increased public clamor for quality education; (b) the effect that thermal environment may have upon quality education; and (c) the increased competition and remarkable claims made to school administrators by rival heating and ventilating equipment manufacturers on behalf of their equipment's ability to provide an adequate classroom thermal environment.

5. Information concerning the thermal environment within the classroom will be of value to school administrators in the United States.

6. The best available criteria relating to thermal factors in the classroom environment may be found by examining literature and interviewing authorities in the fields of engineering, physiology, and education.

7. The selected schools will give a general picture of thermal conditions that exist in classrooms, particularly those to be found in the same geographical region.

D. LIMITATIONS

1. In planning a completely co-ordinated classroom, one finds that the visual, thermal, and acoustical environments are all interrelated. This study dealt only with the thermal environment inasmuch as it was possible to divorce the thermal environment from other areas of the physical environment.

2. Research in the area of the effect of the thermal environment upon learning has been rather limited. Criteria identified for the purpose of analyzing classroom conditions were drawn from what was considered to be the best information available concerning thermal environment at the time this study was conducted.

3. It is an accepted fact that children must occupy classrooms where the temperature rises above 100°F. during the early school months of July, August, and September and the late school months of May and June. Effective learning is always at a minimum under these conditions. This study was limited, however, to a study of the classroom thermal conditions which existed during the winter heating season of 1960-61.

4. Although control of thermal environment poses a universal problem, this study was concerned primarily with thermal conditions within classrooms as determined by applying the identified criteria to classrooms selected for this study.

5. The selected classrooms were drawn from schools which represented various forms of design and building materials and which housed various types of heating and ventilating equipment. These schools were selected from within as near a proximity of the University of Tennessee as it was possible to locate schools which met the requirements for the buildings desired for this study.

6. Although this study included an investigation of various types of heating and ventilating equipment utilized in school buildings, no attempt was made to identify the cost of various items; nor was there

any consideration given to technical differences between similar units produced by different manufacturers.

E. DEFINITIONS

Air-conditioning. The term "air-conditioning" refers to the process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space.[2]

Air movement. "Air movement" refers to the motion of air within a given area. The velocity of the motion is usually expressed in feet per minute.

Air temperature. The "air temperature" is determined by thermometers or thermocouples shielded from radiation effects from walls or other objects at temperatures above or below air temperature.[3]

Air velocity. "Air velocity" refers to the average air movement in feet per minute or centimeters per second, as determined by an anemometer or kata thermometer.[4]

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[2]American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1957, Vol. 35 (New York: American Society of Heating and Air-Conditioning Engineers, Inc.), p. 1.

[3]Winslow and Herrington, op. cit., p. 258.

[4]Ibid., p. 259.

Anemometer. An "anemometer" is an instrument for measuring the velocity of air.[5]

British Thermal Unit (B.T.U.). The term "B.T.U." represents the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Calorie. A "calorie" is the amount of heat energy required to raise the temperature of one kilogram of water one degree Centigrade.[6]

Central fan system. A "central fan system" is a mechanical indirect system of heating, ventilating, or air conditioning, in which the air is treated or handled by equipment located outside the rooms served, usually at a central location, and is conveyed to and from the rooms by means of a fan and a system of distributing ducts.[7]

Comfort. "Comfort" is a state of being characterized by the absence of effort or strain.

Conduction. "Conduction" is the flow of heat through an unequally heated substance from places of higher to places of lower temperature. It is the main process by which heat is transmitted through solids, but it also occurs in liquids and gases.[8]

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[5]American Society of Heating and Air-Conditioning Engineers, Inc., *loc. cit.*

[6]Winslow and Herrington, *op. cit.*, p. 257.

[7]American Society of Heating and Air-Conditioning Engineers, Inc., *op. cit.*, p. 2.

[8]Thomas Bedford, *Basic Principles of Ventilation and Heating* (London: H. K. Lewis and Company, Ltd., 1948), p. 7.

Convection. "Convection" is the process by which the diffusion of heat is facilitated by the motion of the warmed fluid.[9]

Effective temperature. "Effective temperature" refers to the temperature of air with 100 per cent relative humidity and minimal air movement which would exert the same influence upon heat sensation as any given combination of air temperature, air movement, and relative humidity.[10]

Evaporation. "Evaporation" as used in this study represents the amount of heat loss due to evaporation from skin and oral surfaces in a given time (expressed in calories per square meter of body surfaces or in calories per individual).[11]

Fatigue. "Fatigue" is a term used to cover all those determinable changes in the expression of an activity which can be traced to the continuing exercise of that activity under its normal operational conditions, and which can be shown to lead either immediately or after delay, to deterioration in the expression of that activity, or, more simply to results within the activity that are not wanted.[12]

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[9] Ibid.

[10] Winslow and Herrington, loc. cit.

[11] Ibid.

[12] Frederick Bartlett, "Psychological Criteria of Fatigue," Fatigue, The Ergonomics Research Society (London: H. K. Lewis and Company, Ltd., 1955), p. 1.

Globe thermometer. The "globe thermometer" is an instrument consisting of a six-inch diameter hollow copper sphere coated with flat black paint and having a thermocouple or thermometer bulb at its center. The globe thermometer is commonly used to indirectly measure mean radiant temperature as the temperature assumed by the globe at equilibrium is the result of the balance between the heat gained or lost by radiation and loss or gain by convection.[13]

Kata thermometer. The "kata thermometer" is an alcohol thermometer with a very large stem, and with only two scale divisions etched on its stem, used for measuring air currents.[14]

Mean radiant temperature. "Mean radiant temperature" refers to the temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing nonuniform environment. Perhaps more simply expressed, "mean radiant temperature" measures radiation from the surroundings.[15]

Metabolism. The term "metabolism" refers to heat produced in the human body through the combustion of food; expressed as calories per square meter of body surface or per individual.[16]

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[13]American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959, Vol. 37 (New York: American Society of Heating and Air-Conditioning Engineers, Inc.), p. 634.

[14]Ibid., p. 632.

[15]American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1957, Vol. 35 (New York: American Society of Heating and Air-Conditioning Engineers, Inc.), p. 9.

[16]Winslow and Herrington, op. cit., p. 258.

Operative temperature. "Operative temperature" is the temperature representing the combined effect of an environment exerting various influences upon heat interchanges by convection and radiation, weighted to take account of air temperature and mean radiant temperature. (If air and walls are at the same temperature, operative temperature equals air temperature.)[17]

Plenum ventilation. "Plenum ventilation" refers to the forcing of air into a room or building so that the result is slightly denser air than the surrounding air of equal temperature. The air is forced by means of a fan either through ducts from a central compartment or by means of a unit ventilator located within each room.[18]

Psychrometer. A "psychrometer" is an instrument for ascertaining the humidity or hygrometric state of the atmosphere.[19]

Radiant panel heating. The term "radiant panel heating" represents (1) heating by means of hot water circulating through pipes embedded in concrete slabs in floors, ceilings, or walls; (2) heating by means of electric wires so embedded.[20]

Radiation. "Radiation" refers to heat exchange between the body and its environment due to radiative interchanges with surrounding

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[17] Ibid.

[18] Carter V. Good (ed.), Dictionary of Education (second edition; New York: McGraw-Hill Book Company, Inc., 1959), p. 598.

[19] American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1957, Vol. 35, op. cit., p. 7.

[20] Good, op. cit., p. 265.

surfaces (expressed in calories per square meter of body surface or per individual).[21]

Radiator. A "radiator" is a heating unit exposed to view within the room or space to be heated. A radiator transfers heat by radiation to objects within visible range, and by conduction to the surrounding air, which in turn is circulated by natural convection; a so-called radiator is also a convector, but the term radiator has been established by long usage.[22]

Relative humidity. The term "relative humidity" refers to the ratio of the amount of water vapor present in a volume of air at a given temperature to the maximum amount of water vapor that could be contained in that volume of air at that temperature.[23]

Temperature. "Temperature" refers to the thermal state of matter with reference to its tendency to communicate heat in contact with it. If no heat flows upon contact, there is no difference in temperature.[24]

Thermocouple. A "thermocouple" is an electrical device used to measure differences in temperature. A thermocouple is formed when two wires of dissimilar metals are joined by soldering, welding, or twisting.[25]

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[21] Winslow and Herrington, loc. cit.

[22] American Society of Heating and Air-Conditioning Engineers, Inc., loc. cit.

[23] Good, op. cit., p. 275.

[24] American Society of Heating and Air-Conditioning Engineers, Inc., op. cit., p. 9.

[25] Ibid., p. 1,220.

Thermometer. A "thermometer" is an instrument used for determining the temperature of a body or space.

Thermostat. A "thermostat" is an instrument which responds to changes in temperature, and which directly or indirectly controls temperature.[26]

Unit ventilator. The term "unit ventilator" represents equipment by means of which air is drawn into each room separately, passed over heating or cooling coils and distributed through the room.[27]

Ventilation. "Ventilation" is the process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned.[28]

Vitiated air. The term "vitiated air" refers to air that is contaminated or polluted.

F. SIGNIFICANCE OF THE STUDY

Readers of this study whose memories go back a generation or so may well be reminded of the long and pungent debates over questions of school room ventilation which took place during the second and third decades of this century. Professional journals were filled with articles which were concerned with methods of securing proper classroom

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[26] Ibid., p. 9.

[27] Good, op. cit., p. 598.

[28] American Society of Heating and Air-Conditioning Engineers, Inc., op. cit., p. 10.

heating and ventilation. Quite often, these debates centered around the relative merits of mechanical ventilation as opposed to window-gravity ventilation.

The beginning of interest in the thermal environment did not begin in this century. Man has long realized that human beings are affected by the climate in which they live. The writer of "Ecclesiasticus" referred to the effect of heat on the workman in his writings. Even prior to the writing of "Ecclesiasticus," Hippocrates was interested in the thermal environment and wrote describing the effects of climate on the physique, temperament, and energy of peoples. Modern climatologists have followed the leadership of Hippocrates and the writer of "Ecclesiasticus" and have also written about the effects of climate on civilization.[29]

An awareness of the need for proper ventilation in the classroom was evidenced in this country as early as 1838 when Samuel Lewis, the first State Superintendent of the Common Schools of Ohio, wrote regarding the necessity of proper school site selection, ". . . If the house is dark and ill ventilated, the children may be expected to be dull, and careless and disorderly and perhaps unhealthy."[30]

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[29]Thomas Bedford, "Thermal Factors in the Environment Which Influence Fatigue," Fatigue (Report of The Ergonomics Research Society, W. F. Floyd and A. T. Welford, editors; London: H. K. Lewis and Company, Ltd.), p. 7.

[30]T. C. Holy, "Location, Construction, and Equipment of Schoolhouses for Health," The American School Board Journal, 104:1 (January, 1942), 19-20.

Various innovations brought about by architects, engineers, and physiologists, made much improvement in the area of thermal control in the century following 1838; yet misconceptions, misunderstandings, and open disagreement on the part of educators often failed to bring these improvements into the classroom. Neutra quite adequately describes one effect of poor thermal control in the classrooms of a generation ago:

> . . . The interior of the little red schoolhouse, with its cast-iron stove glowing in an unventilated room and the classrooms of its great successor, the monumental brick box of a metropolitan school district, with its wood-trimmed blackboards and oiled or waxed floors, all had a peculiar sour smell. Generations of boys and girls have been thoroughly familiar with the schoolroom odor which attaches itself to that wooden chalk rail with a wet sponge on it, the lockers loaded with rain-drenched overcoats, and the lunch kit scented by cheese sandwiches.[31]

Yaglou[32] reported that the basic requirements for providing the proper thermal control in the classroom are simple and have changed very little in the past thirty years. These requirements consist of providing a comfortable temperature with natural or moderate humidity and supplying a sufficient quantity of outside air in order to avoid accumulation of unpleasant odors and to prevent overheating of rooms exposed to the sun. Objectionable drafts and sharp vertical temperature gradients must also be avoided.

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[31] Richard Neutra, Survival Through Design (New York: Oxford University Press, 1954), p. 145.

[32] C. P. Yaglou, "Present Status of School Health Ventilation," American Journal of Public Health, 46 (February, 1956), 183.

Methods of meeting the basic requirements outlined by Yaglou run the gamut from designing buildings for thermal comfort through orientation, natural ventilation, sun control, and roof insulation to the installation of air conditioning in the schools. What method best provides the proper thermal environment in today's schools? This study attempted to explore this question.

As school administrators are faced with the growing clamor for quality education for all American youth, and at the same time are faced with the task of providing economically new school structures which can be utilized by the exploding American population for the next twenty-five to fifty years, they must make decisions both of an educational and technical nature that may have an effect on the school's thermal environment. This study was planned to aid school administrators in their decisions.

All future thermal conditions of the schools of tomorrow are not the total responsibility of school administrators, however. Although teachers have too often been called upon to become human thermostats because they have been responsible for the thermal environment of the classroom by raising and lowering of windows, it is still vitally necessary that the classroom teacher understand the basic factors necessary in providing the proper thermal environment. And, what of the custodian? How often can poor thermal conditions be prevented or corrected by a simple correction which can be made by the building custodian? This study was designed to be of value to all people who

have a share in the educational process as it explores thermal conditions that exist in today's classrooms.

Another important value of this study is the possibility that the information gained will be used as the basis for additional basic research. It is hoped that this study will be used as a basis for further research in the area that would deal more specifically with the effect of thermal factors upon learning. Specific recommendations for subsequent research are made.

G. RELATED STUDIES

A voluminous amount of work has been done in the production of literature relating to the thermal environment. A large portion of the literature is filled with individual opinions, however, and there seems to be a lack of agreement among the various fields which have an interest in control of the thermal environment.

Some research has been done regarding the influence of the classroom environment on learning, but that research has quite often been characterized by the use of adult-aged subjects with the data obtained being applied to children of school age. At the present time many manufacturers of heating and ventilating equipment are conducting experimental studies concerned with the effect of various types of heating and ventilating equipment on the classroom environment.

One of the first organizations in the United States to conduct studies in the area of classroom thermal control was the New York

Commission on Ventilation[33] which was originally constituted as the New York State Commission on Ventilation in 1913. After a reorganization of the State Government in the mid-1920's, the Commission was reconstituted as the New York Commission on Ventilation with substantial financial aid being received from the Milbank Memorial Fund.

During both phases of the work of the Commission, the Commission from time to time published a series of technical reports regarding the Commission's investigations. The experimental work of the original Commission was conducted between 1913 and 1917 but was not published until 1923. Two types of studies were conducted during this period with one type involving studies of physiological and psychological reactions to various atmospheric conditions which were produced in the experimental chambers at the City College and the other type involving observation of the effect of various atmospheric conditions on school children in actual classroom situations.

Some of the results of the City College studies are as follows:

1. The conclusion that overheating is the primary factor in bad ventilation was confirmed.

2. With a given thermal condition, the presence of chemical vitiation produced no physiological or psychological reaction except a slight decrease in physical work and in appetite.

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[33]New York Commission on Ventilation, School Ventilation Principles and Practices, Final Contribution of the New York Commission on Ventilation (New York: Teachers College, Columbia University, 1931), pp. v-vi.

3. Overheating produced (a) fundamental physiological changes, (b) marked decrease in physical work performed, and (c) abnormal reactions of the mucous membranes of the nose and throat which interfered with their adaptation to outdoor atmospheres.

4. High moisture content aggravated the effect of high atmospheric temperatures, but low humidities had no noticeable influence and could not be subjectively detected by the subjects exposed to them.[34]

The studies conducted in actual classroom situations produced the following conclusions:

1. The ventilation of classrooms by windows alone was found to be highly unsatisfactory.

2. A system of window-gravity ventilation with air admitted over slanted window boards and tempered by radiation below the windows and with gravity exhaust ducts for removing vitiated air from near the ceiling proved highly satisfactory.

3. The conditions necessary for satisfactory utilization of the window-gravity system of ventilation were considered to be as follows:

a) Radiators should be located beneath the windows and should extend the full width of the windows.

b) Deflecting boards should be placed at the bottom of windows which open from the bottom.

c) Two window shades should be attached to each window frame, one to be pulled upward and the other downward.

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[34] *Ibid.*, pp. 16-17.

d) Exhaust ducts should be placed on the wall opposite the windows.

e) The classroom should not be overcrowded.

f) A large thermometer with 68°F. clearly marked should be displayed in a prominent position on the teacher's desk.

4. Careful observations in the classroom showed no difference whatever in the health, physical condition, or mental performance of pupils in unhumidified as compared with humidified rooms.

5. Recirculation of classroom air had no harmful effect upon the health of the pupils, but elimination of objectionable odors was difficult.

6. The choice for a suitable school ventilation method seemed to lie between plenum ventilation and window-gravity ventilation. The atmosphere, as measured by subjective impressions, was more agreeable in a room ventilated by the window-gravity system. Respiratory illnesses were also less pronounced in rooms employing window-gravity ventilation.[35]

During the years 1926-1929, the Commission investigated, under actual classroom conditions, such areas as body radiation and drafts, rural school ventilation, relation of atmospheric temperature to health and efficiency, and the hygienic values of various systems of school ventilation. Some of the conclusions derived from the latter series of studies were:

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[35] Ibid., pp. 17-22.

1. The major objective of classroom ventilation is the provision of such atmospheric conditions as will facilitate the elimination of heat from the body surface without the production of objectionable drafts. An objective of a minor nature should be the elimination of unwanted body odors by sufficient air change.

2. Comfort, efficiency, and resistance against disease are maintained by avoiding overheating.

3. Desirable thermal conditions may be obtained by (a) plenum ventilation, (b) by local unit ventilation, or (c) window-gravity ventilation with window-gravity ventilation found to be the most comfortable and economical.

4. The physiological effects of radiation and convection of heat and of vertical variation in temperature need further investigation.

5. Laws requiring a supply of thirty cubic feet of air per minute per pupil have no justification and should be replaced by laws which outline the major objectives of schoolhouse ventilation.[36]

Although not investigating the area of thermal environment specifically, Harmon's concept of the co-ordinated classroom[37] contributed much to the consideration of environmental factors as being statistically related to the health and performance of children. Beginning in 1938, Harmon and his research team began their study of the health

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[36]Ibid., pp. 65-67.

[37]Darell Boyd Harmon, The Co-ordinated Classroom (Grand Rapids, Michigan: The American Seating Company, 1949).

problems of 160,000 Texas elementary school children. By comparing itinerant children who did not attend school with children with regular attendance, Harmon was able to point out the effects produced by the stress of a child's environment. A remark attributed to some of Harmon's research team as they analyzed the data was, "If you want to keep your child healthy, don't send him to school." Harmon has since become interested in the thermal environment as an important factor in the co-ordinated classroom and has done some research in this area.

In 1957, Shupp[38] set up a proposed study on the effects of air-conditioning on classroom learning activities. Shupp was concerned primarily with reviewing related literature and outlining a plan for actually determining the effects of air-conditioning on learning. After reviewing related literature, Shupp set up a study which included the description of the equipment needed, the method of selecting subjects, the selection of school tasks, the method, and the testing procedure to be utilized in the study. The proposed study has never been carried out.

Of particular interest are the unpublished Master's theses by Stewart[39] and Bays.[40] Stewart, in 1959, observed and recorded the

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[38]David Eugene Shupp, "A Proposed Research Study on the Effects of Air Conditioning on Learning Activities Within a Classroom" (unpublished project report, Leland Stanford Junior University, Palo Alto, 1957).

[39]Claude York Stewart, "A Study of Thermal Environment in the Harrison-Chilhowee Baptist Academy, Seymour, Tennessee" (unpublished Master's thesis, The University of Tennessee, Knoxville, 1960).

[40]Crofton McVeigh Bays, "A Study of the Thermal Environment in the Flatwoods Elementary School, Jonesville, Virginia" (unpublished Master's thesis, The University of Tennessee, Knoxville, 1960).

conditions of temperature which existed in the Harrison-Chilhowee Baptist Academy, Seymour, Tennessee, during a forty-school-day interval from January to March. Readings were made with mercurial thermometers and a Bacharach tempscribe recorder. Even though the outside temperature during the test period ranged from 18°F. to only 67°F., the inside temperature ranged from 54°F. to 93°F. Of the 5,120 readings, 69.64 per cent were above 72°F., thus indicating the need for cooling. The study indicated that heat gain was increased by arrival of the students and the southern exposure of some of the rooms. Stewart concluded that maximum learning could not take place because of a thermal environment that was not conducive to learning.

Bays conducted a similar study in the Flatwoods Elementary School, Jonesville, Virginia, during the unusually snowy heating season which prevailed during the thirty-school-day testing period from January to March, 1960. Similar recording instruments were utilized and these instruments showed that 77.98 per cent of the readings were above the optimum of 72°F. Slightly better than 81 per cent of the 3:30 p.m. readings were above 72°F.

Bays concluded that fatigue and less effective learning resulted from the poor thermal environment that prevailed at the Flatwoods Elementary School. The poor thermal environment was found to be partially due to the inadequacy of the gravity ventilation system and the improper zoning method used to control classroom heat.

While some of the studies mentioned above are more pertinent to this study than others, all of these studies and others were used as a

partial basis for identifying criteria relating to thermal factors in the classroom.

H. PROCEDURES

The purpose of this study was to analyze and appraise conditions relating to thermal environment in the classroom that existed in selected schools. An assumption underlying this study was that research findings as revealed in literature and interviews with leaders in the field of thermal control would reveal the best available criteria for analyzing and appraising classroom conditions relating to thermal environment. These criteria were applied to the selected classrooms in order that the present status of thermal environment could be determined.

Sub-problem 1

To identify criteria related to thermal factors affecting classroom environment.

One of the primary sources utilized for collecting background information relating to thermal factors from which criteria were drawn was literature related to classroom heating and ventilating. This literature included graduate studies that related to thermal environment, publications of professional societies such as the American Society of Heating and Air-Conditioning Engineers, books by authorities in the field, reports on conferences, state heating and ventilating codes for schools, periodicals, reports from manufacturers of heating

and ventilating equipment, and other literature that was related to the problem in any way.

In order to identify criteria, special emphasis was given to literature that emphasized (1) the physiological and psychological effects of various thermal conditions upon human behavior; (2) various physical factors which affect the thermal environment in the classroom; (3) school heating and ventilating codes in various states; and (4) information regarding the various types of heating and ventilating equipment utilized in the schools included in this study.

Authorities in the fields of engineering, architecture, physiology, and education were contacted for the purpose of securing assistance in locating certain types of information that were related to the study. Effort was made to locate every possible source of background information in order to develop or identify a complete set of criteria to be used in analyzing and appraising thermal conditions in the selected schools. Chapters II and III are utilized as a background for identification of criteria in Chapter IV.

After tentative criteria were identified by the investigator from the background sources that were utilized, practitioners from the fields of architecture, engineering, and education were enlisted to serve as a sounding board to determine the working practicality of the criteria. The judgments of these professional people served as a refining process in the final identification of the criteria as stated in Chapter IV.

Sub-problem 2

To apply criteria identified to a varied selection of classrooms as a means of determining existing conditions relating to thermal environment in the classroom.

Using the criteria as a guide, a total of twenty-seven classrooms located in nine different schools were examined in order to determine existing thermal conditions. Permission of six school superintendents, nine principals, and twenty-seven teachers was secured for the investigator to examine classrooms that represented a number of varied physical conditions contributing to the thermal environment. The selected classrooms were in schools that were located within a radius of one hundred miles from the University of Tennessee.

The schools to be investigated were selected carefully, keeping in mind the type of educational program offered, size of school, organization of school, building construction materials, heating and ventilating equipment utilized in the building, directional orientation of the classrooms, and all other factors that would aid the investigator in including a representative cross section in the selection.

Instruments that were capable of measuring such phenomena as temperature, humidity, mean radiant temperature, and air movement were utilized in collecting data in the selected schools. These instruments were highly valid and reliable instruments for purposes of this nature. A thermal environment data sheet was devised for recording data that could not be recorded automatically by the various instruments.

The investigation of classroom conditions was conducted during the normal heating season months of February and March, 1961, in keeping with the limitations of the study. Outside weather conditions during February and March in the East Tennessee region are normally quite varied, thus creating a variety of problems with which heating and ventilating equipment must cope.

Sub-problem 3

To analyze the findings in the light of the criteria in order to draw conclusions relating to the present situation regarding thermal environment in classrooms in the area investigated.

Analysis of the data and presentation in some meaningful form became a critical task of this study. After the data were collected in the selected schools, the investigator had in his possession readings and observations concerning temperature, relative humidity, mean radiant temperature, odor, and air movement. The problem then was to arrange these data so that they were meaningful in light of the criteria.

From a numerical standpoint, the most imposing problem centered around analysis of temperature data secured through utilization of a twelve-point thermocouple recorder, an instrument that automatically recorded a temperature per minute for each of twelve locations within a classroom. Approximately 140,000 temperature readings were recorded during the investigation period. A systematic random sampling of the total number was taken giving the investigator one out of ten of the original recordings.

Ranges, means, and standard deviations were computed for most of the data. These computations were then arranged in tables and graphs for the purpose of simple inspection analysis in terms of applying the criteria to the data.

Through the analysis of the data gathered in light of the criteria, strengths and weaknesses of the existing thermal conditions were set forth. The analysis and presentation of the data were used as a basis for a set of conclusions of the present situation.

A more complete description of procedures utilized in the solution of Sub-problems 2 and 3 is found in Chapter V.

I. ORGANIZATION OF THE STUDY

Chapter I of the study presents an introduction to the study, the statement of the problem and sub-problems, basic assumptions, limitations, and definitions of terms used in the study. The chapter also contains the significance of the study, a review of related studies and a brief description of procedures used in gathering data.

The development of a physiological and psychological understanding concerning effects of the thermal environment on human activity is the concern of Chapter II. Discussion centers around the historical background of the thermal concept, physiological aspects of heat production and heat loss, and the effect of the thermal environment on health, comfort, and efficiency.

Chapter III concludes the development of a thermal background essential for the identification of criteria. The chapter identifies

four elements of the thermal environment and discusses physical factors that affect the control of these elements. One of the more important of these factors is the heating and ventilating equipment used in a school building. The concluding portion of the chapter deals with heating and ventilating systems and their control.

Chapter IV identifies five criteria related to thermal factors affecting the classroom environment. The criteria were used for the analysis and appraisal of the thermal environment found in the selected schools. The criteria were identified partially from the background presented in Chapters II and III.

Specific procedure techniques are dealt with in Chapter V. Included in the chapter are: method of selecting schools, discussion of selected schools and classrooms, and description of equipment used and method of collecting thermal data.

Chapter VI presents and analyzes thermal data pertaining to air temperature and mean radiant temperature collected in selected schools and utilizes criteria developed in Chapter IV. Numerous graphs and tables are used in presenting the data.

Chapter VII continues the presentation of thermal data collected in selected schools. Data presented pertains to relative humidity, ventilation and air movement.

Chapter VIII contains the summary, conclusions, and recommendations.

CHAPTER II

THE PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF THE THERMAL ENVIRONMENT UPON HUMAN ACTIVITY

A. INTRODUCTION

The purpose of this chapter is to establish the importance of maintaining an adequate thermal environment because of the effect which the thermal environment has on health, comfort, and efficiency. Before beginning the writing of this chapter, the investigator made an exhaustive analysis of all available literature which related in any way to the study under consideration. The investigator also received much valuable assistance from C. M. Humphreys, Assistant Director of Research, American Society of Heating, Refrigerating and Air-Conditioning Engineers; Henry Wright, former managing editor of Architectural Forum and now a technical consultant for the Herman Nelson Division of American Air Filter Company; Dr. John W. Gilliland, Professor of Educational Administration and Supervision at the University of Tennessee; and other educators and professional people with whom the investigator discussed the problem.

A brief historical treatment of the development of the thermal concept of ventilation is given as a foundation for the point of view to be developed in this chapter. Consideration is then given to the physiological aspects involved in maintaining an equilibrium between heat production and heat loss in the human body. The effects of the

absence of such an equilibrium are then treated in the remainder of the chapter.

B. DEVELOPMENT OF THE THERMAL CONCEPT OF VENTILATION

Although man has long recognized the effect of the atmosphere upon human health, comfort, and efficiency, it was only in the latter half of the eighteenth century that the first scientific hypothesis, the carbon dioxide theory, was advanced that would explain why such an influence existed. Since that time two other hypotheses, the organic effluvia theory and the thermal concept of ventilation, have been given as explanations.[1] These explanations have centered around the changes which Winslow and Herrington pointed out that occur in a poorly ventilated space as a result of human occupancy: (1) a reduction in the oxygen content of the air; (2) an increase in the carbon dioxide content of the air; (3) an increase in the amount of partially oxidized organic matter to be found in the air; (4) an increase in the air temperature due to heat liberation of the human body; and (5) an increase in the humidity of the air caused by the moisture given off by the body.[2]

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[1]New York Commission on Ventilation, School Ventilation Principles and Practices, Final Contribution of the New York Commission on Ventilation (New York: Teachers College, Columbia University, 1931), p. 1.

[2]C.-E. A. Winslow and L. P. Herrington, Temperature and Human Life (Princeton, New Jersey: Princeton University Press, 1949), pp. 166-167.

<u>The Carbon Dioxide Theory</u>

Although early physiologists believed that a decrease in the oxygen supply in an inadequately ventilated room led to the sensations of discomfort which were produced, the French chemist, Lavoisier, in 1777, presented the view that the presence of carbon dioxide, rather than the lack of oxygen, was the chief factor which led to deleterious effects. Lavoisier's views were substantiated by Claude Bernard and Lewes. The conclusion reached by these scientists was based on their observation of animals which were confined within a small enclosed area.

The carbon dioxide theory of ventilation was exploded by Pettenkofer, a nineteenth century experimental hygienist, as he demonstrated that the increase of carbon dioxide even in the worst ventilated rooms was not enough to bring about the toxic results of poorly ventilated rooms which had been observed. Harmful physiological effects due either to an oxygen decrease or a carbon dioxide increase were found to be impossible in the worst ventilated rooms because the oxygen content was not found to decrease below 20 per cent of the total content and the carbon dioxide content was not found to increase above 0.5 per cent of the total content. These limits are far below those which have been proven to produce harmful physiological effects.[3]

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[3]*Ibid.*, pp. 167-68; and New York Commission on Ventilation, *op. cit.*, pp. 1-2.

The Organic Effluvia Theory

As well as helping to disprove the carbon dioxide theory, Pettenkofer, in 1863, advanced the belief that the harmful effects of poor ventilation were due to the presence of hypothetical organic effluvia given off by the lungs and surfaces of the body. The organic substances which Pettenkofer maintained were responsible for harmful physiological effects were not easily identified, so Pettenkofer's theory, which was supported by the French physiologist, Brown-Séquard, was not easily substantiated or rejected.

Even though Pettenkofer did not believe the presence of carbon dioxide in the air to be an important factor in poor ventilation, he proposed that carbon dioxide be utilized as an index to measure the unknown poisons, since the poisons and carbon dioxide were both waste products of the body and would be expected to vary together in amount produced. By using the known facts that the human individual produces about 0.6 cubic feet of carbon dioxide per hour and that the normal outdoor air contains 0.03 per cent of carbon dioxide, advocates of the organic effluvia theory assumed that 0.06 per cent of carbon dioxide in the atmosphere represented a permissible maximum figure and came up with the figure of thirty cubic feet of outside air per minute per person as being necessary for proper ventilation. A minimum outside air figure as well as minimum space allowances per person for schools and other crowded places of assembly became the object of legislation in many states in the country. Some states still have laws based on the thirty cubic feet formula which was intended to rid enclosed areas of the

volatile substances emanating from human bodies, thus eliminating unpleasant odors and harmful effects at the same time.[4]

Several proponents of the organic effluvia theory discussed and investigated their theory for several years, but none were ever able to prove that human beings emanate any organic poisons into the air. Even though the theory was disproved, Winslow and Harrington reported that the resulting "well-meant but misguided standards cost millions of dollars in the aggregate and greatly retarded the development of adequate and efficient methods of air conditioning."[5] Meredith also stated that "as relics of that generation, we still have a few fresh air fiends who believe they should live in a gale."[6]

<u>The Thermal Concept of Ventilation</u>

Some doubt as to the validity of the theory of organic effluvia was established by Hermans of Amsterdam in 1883 when he was able to demonstrate that the air of a chamber containing only 15 per cent of oxygen and 2 to 4 per cent of carbon dioxide was not toxic and the ill effects experienced in crowded, inadequately ventilated rooms were not due to any chemical poisons but to heat and humidity. Acceptance of a new theory was reached very slowly, however.[7]

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[4]New York Commission on Ventilation, <u>op</u>. <u>cit</u>., p. 2; and Winslow and Herrington, <u>op</u>. <u>cit</u>., pp. 168-169.

[5]Winslow and Herrington, <u>op</u>. <u>cit</u>., p. 169.

[6]Florence L. Meredith, <u>Hygiene</u> (third edition; Philadelphia: The Blakiston Company, 1941), p. 551.

[7]Winslow and Herrington, <u>op</u>. <u>cit</u>., p. 170.

Impetus to the thermal concept of ventilation was given by Flügge at Breslau in 1905 when he and his pupils performed the following experiments:

1. A subject was kept in a poorly ventilated room until the carbon dioxide content of the air became quite high and symptoms of discomfort became very great. Fresh, outside air was then piped to the subject's nostrils so that he was breathing fresh air while being surrounded by bad air. There was no relief from the symptoms of discomfort. Neither did any relief come when air of the same temperature and humidity as the room air, but with the correct oxygen and carbon dioxide content, was allowed to enter the room. Immediate relief came when an electric fan was started in the "bad air."[8]

2. Air with a low oxygen and high carbon dioxide content but of low temperature and low humidity was blown into a room containing foul air. The uncomfortable subject immediately began to experience greater comfort even though the oxygen and carbon dioxide content remained the same. Flügge concluded that cool, dry, moving air was needed rather than air containing an increased amount of oxygen and a decreased amount of carbon dioxide. He also concluded that the subject needed the air around his body.[9]

3. A subject was placed in a chamber with a content of 1.1 per cent carbon dioxide, a temperature of 86°F., and a relative humidity of

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[8] Meredith, loc. cit.

[9] Ibid.

87 per cent. Symptoms of discomfort were recorded and these symptoms were not relieved by breathing fresh air from outside the chamber through a tube. Complete relief came when the chamber was cooled to 63°F. although the carbon dioxide content had risen to 1.6 per cent.[10]

4. As a final experiment, the subject was taken into fresh air and asked to breathe bad air with a low oxygen and high carbon dioxide content through a tube. As long as the subject's body was in good air, he was able to breathe the air which contained a low percentage of oxygen and a high percentage of carbon dioxide without any ill effects.[11]

Winslow and Herrington pointed out that the following conclusions reached by Flügge and his associates have been proven correct for several years:

1. Experiments have demonstrated that chemical changes in the air produced by any type of gaseous excreta of human beings do not exercise any deleterious effect on the health of the occupants of the space involved.

2. When detrimental health conditions such as fatigue, headache, dizziness, and nausea are observed in closed or crowded rooms, these conditions are to be attributed entirely to a deficient heat loss.

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[10] Winslow and Herrington, loc. cit.

[11] Meredith, loc. cit.

3. The thermal properties of the atmospheric environment, temperature, moisture, and air movement, are far more significant for human well-being than any supposed chemical properties of the air.[12]

Flügge's work was soon confirmed by Haldane and Hill in England and Benedict and the New York State Commission on Ventilation in the United States.[13] As a result of the establishment of the thermal theory of ventilation, the New York Commission on Ventilation stated very adequately that "the major objective of ventilation, is, therefore, to remove the excess of heat given off by the human body so as to maintain an atmosphere which will be comfortably cool but not too cold."[14]

In helping to establish the thermal concept of ventilation, the New York State Commission on Ventilation also experimented extensively in the area of chemical vitiation and its effect upon appetite. Temperature conditions were kept constant in an experimental room, but fresh air was supplied some days while on other days body odors were permitted to accumulate. Comfort votes indicated no preference for fresh air days, but there was a significant increase in the amount of calories consumed by the subjects from a standard meal on days when the air was fresh. The experiments showed that slowly accummlating odors are not easily perceived by room occupants.

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[12]Winslow and Herrington, op. cit., pp. 170-171.

[13]Meredith, loc. cit.; New York Commission on Ventilation, op. cit., p. 3; and Winslow and Herrington, op. cit., p. 170.

[14]New York Commission on Ventilation, loc. cit.

Other experiments by Greenburg and Winslow with guinea pigs that were exposed to odors from dog feces showed that temporary loss of appetite was the only ill effect to be produced by accumulated odors. Total experiments seemed to indicate that unless subjects were excessively crowded together that ten cubic feet of outside air per person per minute would be sufficient to eliminate all odors, provided that a space allotment of four hundred cubic feet per person was provided. In rooms occupied by only a few people, normal leakage would take care of such an air change. These findings did not completely eliminate the need for a larger amount of fresh air than ten cubic feet per person per minute, but rather made the amount needed dependent upon the need for thermal control in removing heat rather than control of organic effluvia.[15]

C. THE HUMAN BODY AS A HEAT PRODUCING MACHINE

Comparing the human body with a machine is perhaps an analogy that is difficult for some to accept. Even though the human body is extremely complex, it is subject to some of the same laws that govern the operation of simple machines. Real progress in the field of physiology did not come until scientists recognized that complete combustion of a foodstuff in a bomb calorimeter and in the human body produced the same amount of heat. This simple analogy assumes a role of importance in dealing with the complete picture of thermal control.

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[15]Winslow and Herrington, op. cit., pp. 171-72.

<u>The Role of Metabolism</u>

In order that the energy needs of the body might be met, the basic physiological process called "metabolism" provides for the needs by the combustion of foods. All movement of living organisms along with the growth and repair of the various tissues require energy. Food serves as a source of the energy and is converted into energy by a union with the oxygen taken into the body through the breathing process. This process is analogous to the liberation of energy by burning fuel in a machine. The process of metabolism, as other forms of combustion, liberates the energy contained in food, thus permitting work to be done and heat to be produced. There is a definite quantitative relationship between the intake of fuel, or food, and oxygen on the one hand and work done and heat liberated on the other, but the human body is slightly more efficient than the steam engine by comparison, being able to convert 20 per cent of the energy value of food into physical work as compared with 14 per cent efficiency for the steam engine.[16]

Best and Taylor, in discussing the effects of various factors upon the metabolism rate for an individual, enumerated the following physiological conditions which stimulate metabolism: (1) muscular work; (2) food; (3) a fall in environmental temperature; or (4) a rise in body temperature.[17] Table I illustrates the effect of one of the factors,

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[16] <u>Ibid.</u>, pp. 6-8.

[17] Charles Herbert Best and Norman Burke Taylor, <u>The Physiological Basis of Medical Practice</u> (Baltimore: The Williams and Wilkins Company, 1950), p. 611.

TABLE I

EXTRA CALORIES OF METABOLISM PER HOUR ATTRIBUTABLE TO OCCUPATION

Occupations	Extra calories per hour
Men	
Tailor	44
Bookbinder	81
Shoemaker	90
Metal worker, filing and hammering	141
Painter of furniture	145
Carpenter making a table	164
Stonemason chiselling a tombstone	300
Man sawing wood	378
Women	
Seamstress, needlework	6
Typist, 50 words per minute	24
Seamstress, using sewing machine	57
Bookbinder	63
Housemaid (moderate work)	81
Laundress (moderate work)	124
Housemaid (hard work)	157
Laundress (hard work)	214

Source: Charles Herbert Best and Norman Burke Taylor, The Physiological Basis of Medical Practice (Baltimore: The Williams and Wilkins Company, 1950), p. 621. Used by permission.

muscular work, upon metabolism. The data presented here show that additional calories produced per hour by various occupations range from 6 for needlework done by a seamstress to 378 for sawing wood by a man.

Because of the sweeping effect of variables upon metabolism rate, physiologists have utilized the basic metabolism concept. Basic metabolism applies to the heat production of an individual who is awake but is as nearly as possible at complete muscular and physical rest. The rate for the individual is determined in a room where the air temperature is 70°F. and at a time when the digestive processes are at their lowest ebb. Basic metabolism cannot be determined immediately after meals because metabolism may increase as much as 5 to 30 per cent due to the oxidation of food. Winslow and Herrington reported that the basic metabolism value is quite constant. The rate for an individual of average weight and body build is roughly sixty calories per hour.[18] In spite of the term, "basic" metabolism, however, there are many other variables which cause a deviation from the mean metabolic rate.

A determining factor in the amount of heat produced by the individual at rest is the total surface area of the body. Best and Taylor gave an interesting analogy of a fasting adult man and a starving dog. The total surface area and the total heat production of each are different, but each produces remarkably similar amounts of heat per square meter of body surface. They pointed out that a small animal's surface area is always greater in proportion to its mass, so small

[18]Winslow and Herrington, op. cit., p. 16.

animals generate more heat per unit of body weight than larger animals.[19] Basal metabolism is usually expressed in terms of square units of surface area.

Expressed in terms of body surface, the average basal metabolism rate of normal men who are between the ages of twenty and fifty years is from 38 to 40 calories per square meter of body surface per hour. This rate is constant for most normal men. The average surface area for most American and Canadian adult males is about 1.8 square meters and for most American and Canadian adult females is 1.6 square meters. The total basal heat production for the average adult ranges from 1,400 to 1,800 calories per day.[20]

Best and Taylor listed the following seven physiological conditions which influence the basal metabolic rate:

Age and sex.[21] Perhaps the metabolism differences between children and adults present the greatest problem in providing simultaneously an adequate thermal environment for adult teachers and children in the classroom. Heat production of humans per square meter of body surface definitely decreases progressively from infancy to old age. Rising from a low of about 25 calories at infancy, human heat production rises above 50 calories per square meter per hour during childhood and gradually reduces to a metabolism rate of about 32 calories at

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[19] Best and Taylor, *op. cit.*, pp. 610-611.

[20] *Ibid.*, p. 619.

[21] *Ibid.*, p. 620.

ninety years. The metabolic rate for females is slightly lower than that for males at all age levels.

DuBois discussed the difficulty in establishing metabolism norms for children because of the wide variance in metabolism rates to be found among children of the same age.[22] This difficulty is illustrated by the differences to be found among the various children's basal metabolism charts which are found in physiological literature. Table II is representative of metabolism charts for children. This chart was compiled from different sources by Herrington to show the basal metabolic rate of school age children, kindergarten age through high school age, as compared with adults who are resting in the same environment. The heat production of the kindergarten child as compared with the teacher in his sixties presents a contrast of nearly 20 calories per square meter per hour. While all differences are not as great as this contrast, a substantial difference in heat loss requirement exists between most school children and teachers. This contrast becomes even more apparent when one considers the increase in metabolism which is due to the livelier activity of the child.

Harmon emphasized the importance of considering the basal metabolism of the child in planning for the thermal environment by stating:

> The incompleteness of growth and development of the school child, differences of metabolic rate, and the mass-skin-area ratio of that child as compared to the adult, necessitate a

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[22] E. F. DuBois, Basal Metabolism in Health and Disease (Philadelphia: Lea and Febiger, 1936), pp. 210-11.

TABLE II

BASAL METABOLISM OF SCHOOL PERSONNEL

	Age	Male	Female
Kindergarten	4.5	54.9	51.7
Grade 1	6.0	53.7	50.1
Grade 4	10.5	48.0	45.7
Grade 8	14.0	46.2	41.2
Senior High School	18.0	44.4	37.9
Personnel	22.5	40.9	35.8
Personnel	32.5	39.3	35.8
Personnel	42.5	38.0	35.5
Personnel	52.5	36.7	34.0
Personnel	62.5	35.5	32.7

Source: L. P. Herrington, "Effect of Thermal Environment on Human Action," American School and University, XXIV (1952-53), 369.

different set of standards for controlling the thermal environment of the school child than those used for controlling the work environment of the adult.[23]

Race and climate.[24] The metabolism rate of some oriental races is from 10 to 15 per cent higher than that of occidentals living in the same climate. Conversely, some orientals have a higher rate than whites. The basic metabolism of white persons in a tropical climate is usually lower than in a cooler climate.

Habits.[25] Persons who engage in some type of occupation that requires a considerable degree of muscular tissue development usually have higher basal metabolism rates than those leading a sedentary life. Athletes are included in this group.

Pregnancy.[26] Normal pregnancy exerts little specific influence upon the basal metabolism rate of women until the sixth or seventh month when an appreciable increase of weight occurs. This increase, however, equals the metabolism of the new-born infant and the metabolism of the mother returns to normal after giving birth.

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[23]Darell Boyd Harmon, Controlling the Thermal Environment of the Co-ordinated Classroom (Minneapolis: Minneapolis-Honeywell Regulator Company, 1953), p. 32.

[24]Best and Taylor, loc. cit.

[25]Ibid., p. 621.

[26]Ibid.

Diet.[27] The total diet pattern seems to have little influence upon the basal metabolism rate. Strict vegetable eaters are said to have an 11 per cent lower rate than meat eaters, however.

Variations in barometric pressures.[28] Breathing excessive or reduced amounts of oxygen do not seem to have any effect upon the basal metabolism. A change does occur, however, when the barometric pressure falls to a certain point. The metabolic rate decreases in varying amounts depending upon the individual. The reduction may range from 5 to 25 per cent.

Chemical substances.[29] Several chemical substances, including adrenaline, caffeine, and benzedrine, raise the basal metabolism rate. Of particular concern in considering the optimum thermal environment of older school children is the fact that smoking a cigarette increases the metabolism of most subjects at an average of 9 per cent.

The physiological concept of metabolism or heat production is of great concern to engineers who plan heating and ventilating systems for classroom use. The engineer must convert human heat production into a term which is compatible with his heat measurements. For such a measurement engineers use the term, British Thermal Unit (B.T.U.). One B.T.U. is roughly equal to the amount of heat released in burning a kitchen match.

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[27]Ibid. [28]Ibid. [29]Ibid.

In terms that are applicable to creating an optimum thermal environment in the classroom, what does human metabolism mean to the heating and ventilating engineer? It is interesting to note that the average sedentary adult or active school child generates as much heat as a 100 watt electric light bulb. Expressed in terms of B.T.U.'s a school child will produce from 260 to 650 B.T.U.'s per hour during normal classroom activities, depending on age, sex, and the specific activity. Simple arithmetic enables one to estimate the heat production of twenty-five to thirty-five school children. A teacher walking slowly will dissipate from 400 to 500 B.T.U.'s per hour. Light factory work or work in a shop class will raise the B.T.U. output to around 750 B.T.U.'s per hour and heavier factory work will cause a heat production of 1,000 to 1,450 B.T.U.'s per hour.[30]

Body Temperature and Its Control

Most school children know that the temperature of the healthy human body as determined by placing a thermometer in the mouth is around 98.6°F. This temperature refers to the temperature of the interior of the body as most skin temperatures are lower than 98.6°F. The body temperature figure of 98.6°F. represents a mean figure, however, as there is a slight variation from 98.6°F. in the body temperature of some people and measurement proves that variations in temperature also occur

[30]"Thermal Comfort Affects Learning," from "Thermal Environment," portfolio on heating, ventilating and air conditioning for today's schools, The Nation's Schools, LXIII (May, 1959), 88.

in the same individual throughout the day. Body temperatures also vary among the very young and the very old. As opposed to body temperature, the temperature of the bare skin varies widely with the environmental temperature.

Even though the body temperature is capable of rising or falling due to environmental conditions, man cannot survive a prolonged variation of more than a few degrees either way. Man is regarded as homoiothermic or warm-blooded. Body temperature remains fairly constant regardless of the environment. On the other hand, the human is able to adjust to extreme limits of outside temperatures. The ability to adjust is partly due to the fact that man is capable of intelligently making use of temperature regulation aids.

Homoiothermic body temperatures are able to maintain a high degree of constancy because of the continuous balancing of body heat production and body heat loss in respect to each other, and balancing of both against external heat applications. When heat production and heat loss stop, life of the human organism will also stop. When production and loss are not adequately balanced, previously mentioned variations in body temperature occur.

Heat production, or metabolism, has previously been discussed in light of conditions which influence metabolism. Heat production will be further discussed in relation to its interaction with heat loss in maintaining a constant body temperature.

From the discussion of metabolism, the conclusion might be reached that the body is capable of overheating itself. This would be

true if it were not also capable of cooling itself in a way so that a compensating effect for the overheating may be reached. Here again the analogy between man and machine is appropriate as this balance of heating versus cooling is similar to the energy production, heating, and need for cooling of a gasoline engine.

A large per cent of bodily heat is lost through the skin, while most of the remainder is given off through the lungs. Specifically, heat is lost from the body through: "(1) radiation, convection, and conduction; (2) evaporation of water from the lungs and skin; (3) raising the inspired air to body temperature; and (4) urine and feces."[31]

Since over 95 per cent of the total body heat loss occurs through radiation, convection, conduction, and evaporation, the discussion of heat loss will be centered around these means of heat regulation.

Radiation. Heat from the body is given off by radiation as is heat from all heated objects such as a hot motor, a hot stove, or the sun. Normally, radiation will account for about 55 per cent of the total heat loss of the body. Loss of heat by this source, as well as by the other sources discussed here, will vary with (1) conditions of the "thermal environment," (2) type and amount of clothing worn, and (3) rate of metabolism.

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[31]Best and Taylor, op. cit., p. 720.

Physicists have named the human skin, regardless of color, a "black body radiator." The "black body," as the term implies, is capable of radiating or absorbing infra-red rays. Largely through loss of body heat through the process of radiation, the temperature of a room increases when human occupants are enclosed therein. Since radiation is concerned with exchange of heat between the body and surrounding surfaces, the primary factor influencing radiative heat loss is the temperature of surrounding objects relative to that of the skin. If the mean temperature of surrounding surfaces is below that of body temperature, the body is able to radiate heat to the surface. Conversely, as the mean temperature of surrounding surfaces approaches or surpasses that of the body, heat loss by radiation comes to a stop and the body begins to absorb heat from the environment. Because air with a high relative humidity content is somewhat opaque to radiant heat, heat loss through radiation is slightly reduced in situations where the relative humidity is high.

Convection. Approximately 15 per cent of total heat loss is blown away on currents of air, a process known as convection. Just as heat loss by radiation depends on the mean temperature of surrounding surfaces in relation to body temperature, heat loss by convection depends on the temperature of the atmosphere as related to body temperature. Since clothing tends to trap a large portion of the moist air which comes in contact with the skin, loss by convection is impossible unless the atmosphere is cooler than the surface of the skin, or

unless enough air movement to cause mixing is present. Air movement is actually the most important factor affecting heat loss by convection.

Conduction. Heat is given off by conduction when the body comes in contact with a cool object. The body when in contact with a cube of ice is cooled to the same degree that the ice is heated and melted. Obviously, not too many ice cubes are to be found within the confines of a classroom; therefore, heat loss by conduction assumes a role of lesser importance than that of radiation and convection.

Evaporation of water from the lungs and skin. Under normal conditions, slightly more than 25 per cent of total heat loss is effected through evaporation from skin and lungs. As the environmental temperature approaches that of the body, heat loss by radiation and convection becomes less and less possible. When air and surface temperature reach 98.6°F., heat loss by these two methods becomes impossible. Above 98.6°F., the body would gain heat, if it were not for the process of secretion and evaporation of sweat and the exhalation of water vapor. At a temperature above 95.0°F., evaporation accounts for practically all the heat lost from the body. The ability of the body to maintain a constant temperature by means of evaporation in an extremely high temperature, depends on the relative humidity of the air and air movement. These factors will be discussed in Chapter III.

In order for the preceding four means of heat loss to become effective, three heat regulating functions of the body must be in operation to bring heat to the skin's surface. The functions are:

(1) vasomotion in the skin; (2) sweat secretion; and (3) respiration. These functions are physical in nature and are activated by the body's temperature-regulating center which is located in the brain.

Vasomotion in the skin. Because blood is usually warmer than the surface of the body, heat loss can be increased or decreased through the inversion of blood from internal regions of the body to the surface, or from the surface to the internal organs. When the body has a need to lose heat, vasodilator nerves dilate the blood vessels in the skin enabling a large amount of blood to flow into them from the heated interior of the body. When heat conservation is needed, vasoconstrictor nerves contract the blood vessels in the skin, sending the blood in them to the interior of the body. Variations in blood volume also occur to control body temperature. A rise in temperature causes an increase in blood volume while low temperatures reduce the volume of the blood. Excessive temperatures also increase the rate of circulation.

Secretion of sweat. Vasomotion enables the body to be cooled by radiation, convection, and conduction. Cooling of the body by evaporation depends upon the activity of the sweat glands. A small amount of perspiration is constantly being produced, but normally this perspiration cannot be seen because of rapid evaporation. Perspiration begins to increase when air temperature is about 66°F. Visible perspiration appears at different temperatures for different individuals, but even women, who perspire less freely than men, have begun to perspire visibly once external temperature has reached about 90°F. As mentioned

previously, the humidity of the atmosphere determines the amount of additional moisture it can take up, and consequently, the possibility of evaporative cooling.

Respiration. Athletes can testify that breathing automatically becomes faster when the body is warmed and slower when cooled. Much moisture can be evaporated from the mouth, throat, and lungs on a hot day.

Among the factors which stimulate heat production a low environmental temperature is an important one. The nude body loses heat rapidly at air temperatures below about 82.4°F. The naked male body is able to maintain the balance between heat loss and heat production within the temperature range between 82.4°F. and 86°F. or 87.8°F. Because the subject feels comfortable at these temperatures this range is called the comfort zone. The comfort zone for women is broader, being from 80.6°F. to 89.6°F. or 91.4°F.[32]

A critical temperature exists below which heat production must be increased in order to maintain a normal body temperature. Increase in heat loss from the body at temperatures below the critical level is primarily by increased radiation. Heat loss continues until the naked body loses more heat than it can produce in the basal state. A chill occurs at about 73.4°F. and heat production then begins in an effort to restore body temperature to its normal level. Heat production does not

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[32] Ibid., pp. 721-25.

occur until after the chill has begun. For men, heat production remains constant within the range of air temperature from 95°F. to 71.6°F. or 73.4°F. [33]

Unfortunately, a great many physiological publications refer to temperatures which have been reached experimentally by collecting data from nude, adult subjects. One has only to hope that standards for clothed children are considered when classroom thermal environments are being planned.

Just as the three previously mentioned physical functions of the body must be in existence in order that heat loss may be controlled, two other functions, chemical in nature, effect changes in heat production when such changes are necessary. These functions include muscle action and endocrine gland action.

Muscle action. Since a large portion of body heat occurs when oxidation takes place in the body's muscles, involuntary changes in heat production within muscles occur when conditions demand more or less body heat.

When the body becomes overheated, muscle tone is reduced and muscles become limp, thus producing less heat. Conversely, when over-cooling has taken place, muscle tone is increased and heat production is increased. The act of shivering is the result of additional demands for heat production. "Goose flesh" also may accompany the chilling. The

[33] _Ibid._, p. 725.

most important effect of such external phenomena is actually the larger muscle motions which are begun.

Endocrine glands. The actual rate at which heat production occurs in the body is regulated by the endocrine glands. The adrenal glands play a twofold role in metabolism regulation, by stimulating heat production and constricting the skin blood vessels in order to restrict heat loss. Long range thermal control of the body is partially due to action of the thyroid gland. Those who secrete too little thyroxine may regularly have subnormal temperature, while those who secrete too much thyroxine may have above normal temperature.

D. EFFECTS OF AN INADEQUATE THERMAL ENVIRONMENT

One can see that the body is capable of maintaining an equilibrium between heat loss and heat gain under varying external conditions. This fact differentiates man from cold-blooded creatures who quickly die after becoming exposed to an unfavorable climate. Even though physical and chemical functions of the body are capable of maintaining such an equilibrium, what effect does extended use of these functions brought about by a poor thermal environment have on the well-being and productivity of the human individual, especially the school child?

One's concept of the need of an adequate classroom thermal environment must, of necessity, be related to one's beliefs concerning the nature of the learner. As previously stated in Chapter I, basic assumptions were made prior to the undertaking of this study which related the

learner to his environment. One assumption accepted the child as an individual who grows, develops, and functions as an integrated whole and who is constantly solving new problems and learning through activity. Environmental factors affect the child's learning experiences, either beneficially or detrimentally. The other assumption named the thermal environment as one of the environmental factors which affects, to a certain extent, the teaching-learning process.

A dualistic view of the learner as an individual composed of mind and body, with the body assuming a role of little importance, definitely would not lend itself to any interest in the production of an adequate thermal environment. Such an environment would serve little purpose. Neither would thermal environment assume a role of importance for those who look upon learning as a process of training and disciplining the various faculties which supposedly make up the mind. A poor thermal environment might even enhance such a learning process.

With the learner viewed as an integrated, whole organism, the classroom becomes more than just a shelter for the body while the mind absorbs and stores knowledge or while various functions of the mind are disciplined. Classrooms become significant parts of the organic child's total educational experiences. Classrooms provide for those organizations of energies which purposeful education demands in developing healthy, productive members of society. Maximizing the learning process, then, becomes the primary purpose in establishing the best physical environment possible.

Thinking educators will not be misled by advertising which makes astounding claims concerning the effects of temperature shifts on the performance of students. A correct thermal environment will not increase a child's basic intelligence, nor will it substitute for purpose, the internal motivating force which is essential to learning. Already established is the fact that the body can adapt to poor thermal conditions. However, children pay for this adaptation in terms of distractions from their purpose because of useless discomfort. Health, comfort, and efficiency do increase as stress and strain due to unfavorable thermal conditions decrease. The child can then select stimuli which apply to his educational purposes best as he is permitted to work in a classroom which permits him to make full use of his abilities. While not being misled into attributing too much worth to classroom thermal environment, then, thinking educators must recognize at least as high a correlation between the thermal environment and the educational process as between the educational process and any other environmental factor.

With this background, consideration is given now to effects of the thermal environment on human action. Data concerning effects of the thermal environment on the human body are limited somewhat because they deal mainly with effects of air temperature only or air temperature and humidity. These data also refer primarily to adults. One must keep in mind that the organic differences between adults and children dictate slightly different thermal environments for each, especially in the area of temperature control.

Thermal Environment and Health

In the studies on heating and ventilation, the New York Commission on Ventilation found that overheating was responsible for two physiological ills. Extreme overheating was found to increase body temperature, pulse rate, respiration and metabolism. A room temperature as low as 75°F. with 50 per cent relative humidity and no air movement was found to cause a definite increase in body temperature and pulse rate. The second ill, an anemic condition of the nasal mucosa which makes it highly receptive to microbic infection, was shown to be caused by exposure to high temperature followed by exposure to chill. Several English investigators have written concerning industrial absenteeism due to overheating, thus confirming the findings of the Commission.[34]

Another interesting effect of overheating is the effect on body posture. Normally, when one feels well he can assume any posture which he might desire without any voluntary concentration or feeling of stress. A sense of fatigue causes one to reinforce necessary postures by an act of will. This type of fatigue is often of climatic origin. Overexposure to heat can completely override posture control and put an individual in a spread-eagled position on the floor with maximum body surface exposed. Overexposure to cold has contrasting results. Posture control is overridden again as all body muscles contract. The

[34]New York Commission on Ventilation, op. cit., pp. 43-45.

individual becomes locked in a folded position in the body's attempt to conserve heat.[35]

Thermal Environment and Comfort

Indication has been given previously that the child's comfort is not the end result desired in providing an optimum thermal environment. As a matter of fact, extreme comfort often describes conditions not conducive to learning. Serious departure from the level of warmth desirable for comfort will lead to direct and natural reactions from children, however. A cold child has a tendency to become restless, move about, and flex his muscles as his body involuntarily restores the equilibrium between heat production and heat loss. An overheated child is prone to cease his concentration on academic matters and relax into daydreams.

Thermal Environment and Efficiency

Discomfort and health deficiencies due to an inadequate thermal environment are supplemented by a loss in efficiency. Considerable data regarding accidents and errors in heavy manual work, light assembly work, and complex mental tasks are available. So many of the data[36] relate to

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[35] L. P. Herrington, "Effect of Thermal Environment on Human Action," American School and University, XXIV (1952-53), 371.

[36] Thomas Bedford, "Thermal Factors in the Environment Which Influence Fatigue," Fatigue (Report of the Ergonomics Research Society, W. F. Floyd and A. T. Welford, editors; London: H. K. Lewis and Company, Ltd.), pp. 11-15; L. P. Herrington, Ibid., p. 368; and "Thermal Comfort Affects Learning," from "Thermal Environment," portfolio on heating, ventilating and air conditioning for today's schools, The Nation's Schools, LXIII (May, 1959), 87.

mine workers and textile workers that they are not elaborated upon to any great extent here.

Research has shown that heavy tasks such as coal mining are done most efficiently in instances when the temperature can be held around 60°F. and that accidents increase two to threefold when the temperature approaches 80°F.

Light assembly work seems to be more void of accidents at 67°F. while accidents increase both above and below 67°F. Accidents seem to be related to the involuntary postural conditions created both at the higher and lower temperature levels.

Most research in connection with skilled work or complex mental tasks has been done with wireless code reception, typing, and office work. Most of these data available are in terms of effective temperature readings, readings which take into consideration both dry and wet bulb temperature readings. All data show that errors increase as thermal stress increases.

Of course, the activities involved in classroom work do not range in heat production as much as the gamut from coal mining to office work. A valid deduction would seem to be, however, that if efficiency is related to the temperature of the classroom, then the temperature should be varied according to the type of activity and heat production involved in a given classroom activity and controlled at that particular level.

E. SUMMARY

Chapter II has been concerned with development of a physiological and psychological understanding concerning effects of the thermal environment upon human activity. As a background to this understanding, the thermal concept was traced historically as it developed through the carbon dioxide theory and the organic effluvia theory to its present form.

Physiological aspects of heat production and heat loss were discussed at length as an analogy was made between the human body and a heat producing machine. The approach to the physiological aspects of thermal control was effected through discussions of metabolism and body temperature control with emphasis given to body functions which regulate heat production and heat loss.

The final portion of the chapter linked the physiological functions of temperature control to the classroom and the educational process. Control of the thermal environment was determined to be essential because of the effect which the thermal environment has on one's health, comfort, and efficiency. Perhaps a noticeable aspect of this chapter has been the fact that slightly more emphasis has been given to the problems of excessive heat gain and excessive environmental temperatures and their control than to heat loss and moderate environmental temperatures. This emphasis has been purposeful because overheating is by far a greater classroom problem than underheating. This phenomenon will be discussed in Chapter III as reasons for overheating

are explored. All aspects of the thermal environment and its measurement along with a description of heating and ventilating equipment that can be used to control the thermal environment will be discussed.

CHAPTER III

ELEMENTS OF THE THERMAL ENVIRONMENT

A. INTRODUCTION

Different elements of the thermal environment, namely, air temperature, mean radiant temperature, relative humidity, and air movement, will be discussed in this chapter. Factors that are responsible for the difficulty entailed in controlling these elements in the classroom are then presented. Particular attention will be given in the latter part of the chapter to a description of the various types of heating and ventilating equipment and their controls which have a tremendous influence upon the thermal environment of the classroom.

B. THERMAL FACTORS INFLUENCING THE CLASSROOM ENVIRONMENT

Winslow and Herrington stated that ideal thermal comfort is experienced when three conditions are maintained: (1) a skin temperature of 91.5°F.; (2) a minimal heat change in the body tissues; and (3) a minimal evaporative rate.[1] The following discussion of the thermal factors that are partially responsible either for the presence or absence of these conditions is essential to an understanding of the subject.

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[1]C.-E. A. Winslow and L. P. Herrington, Temperature and Human Life (Princeton, New Jersey: Princeton University Press, 1949).

Air Temperature

Since bodily functions produce from 250 B.T.U.'s per hour at rest to over 1,200 B.T.U.'s per hour at hard physical labor, the temperature of the air must be such that these quantities of heat may be lost to the surroundings if body temperature is to remain constant. Perhaps this fact prompted the British physiologist, Thomas Bedford, to state, "A room should be as cool as is compatible with comfort."[2]

The effect of air temperature on human activity is perhaps the most important of any single thermal factor, even though all factors are interwoven. The importance of air temperature was stressed by Dr. Herrington in a speech when he declared, "Ambient temperature alone has been found to have a large effect on the precision of skilled muscular acts as well as the execution of practiced logic."[3]

Although American dress customs are somewhat standardized, the fact remains that different people also dress differently. Because of dress differences, differences in metabolic rates, and reactions of different people to various air temperatures, there are sometimes differences of opinions among the occupants of a room concerning desirable temperatures. In a classroom this situation is augmented because older people generally prefer warmer rooms, thus often creating an overheated situation for the children.

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[2]Thomas Bedford, Basic Principles of Ventilation and Heating (London: H. K. Lewis and Company, Ltd., 1948), p. 127.

[3]"Garden of Eden Climate Cited as Man's Ideal," Heating, Piping, and Air Conditioning, 30 (February, 1958), 64.

Taking the above factors into consideration, one might safely say that optimum air temperatures, or any other thermal factor, depend upon what activity will be experienced in a given space. Since this investigation is concerned with normal classroom activity, any criterion developed concerning air temperature will take classroom experiences into consideration.

Normal classroom air temperatures are usually measured either by thermometers or thermocouples. Both instruments were utilized in measuring air temperatures in the twenty-seven selected classrooms included in this study. A description of these instruments is contained in Chapter V.

Mean Radiant Temperature

Every classroom has two temperatures: the air temperature, and the mean temperature of the surrounding surfaces and objects in proportion to the position in which they are located in reference to the body's surface. Mean radiant temperature is best defined as the temperature of a uniform block enclosure in which a solid body, or an occupant, would exchange the same amount of radiant heat as in the given non-uniform environment.[4] If excessive air movement is absent, air temperature and mean radiant temperature have nearly the same effect on comfort. The 959 Heating, Ventilating, Air Conditioning Guide pointed

[4]C. P. Yaglou, "Thermometry," Physiology of Heat Regulation and the Science of Clothing, L. H. Newburgh, editor (Philadelphia: W. B. Saunders Company, 1949), p. 72.

up the fact that different authorities give 0.3 to 1 degree increase of room temperature to compensate for one degree depression of the mean radiant temperature.[5] This would indicate that for every degree the radiant temperature is raised or lowered above or below the air temperature, an opposite air temperature adjustment must be made to produce equal sensations of comfort.

Radiation accounts for about 55 per cent of the total heat loss of the body. Heat loss by radiation is affected by the mean radiant temperature of the room surfaces. The cold outer walls, particularly window surfaces, have a very noticeable effect on body heat loss in the winter. On the other hand, surfaces that are hotter than 86°F. radiate heat back to the skin, thus somewhat offsetting the loss to the cooler surfaces of the room. Mean radiant temperature can be determined by computing the readings of a globe thermometer. The temperature assumed by the globe after at least half an hour is the result of a balance between the heat gained or lost by radiation and the loss or gain by convection.

Relative Humidity

Both dryness and excessive relative humidity of the air are capable of influencing comfort. Since people lose about one pound of moisture per hour by perspiration while at rest, and much more while

[5]American Society of Heating and Air-Conditioning Engineers, Inc., Heating, Ventilating, Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 66.

engaged in strenuous activities, skin clamminess must be prevented by evaporation to air dry enough to pick up the moisture readily, but not so rapidly that the skin, nostrils, and lips are left dry.

Samuel R. Lewis,[6] a consulting mechanical engineer and a member of the Heating, Piping and Air Conditioning's board of consulting and contributing editors, considered that relative humidity was so important that if adjusted adequately, an individual may become quite cold in a temperature of 100°F., or become overheated in a temperature considerably cooler than 70°F., if the surrounding air is damp. Possibly, the effect of humidity is not as great as Mr. Lewis suggested, but if airborne odors, either pleasant or unpleasant are present, the intensity of odor as far as human perception is concerned certainly is increased when the relative humidity is high and decreases as the moisture content decreases.

Henry Wright[7] and Winslow and Herrington[8] are among those who limit the importance of relative humidity on the comfort of heated rooms in the wintertime. The three agreed that relative humidity has a great influence on comfort in hot, humid atmospheres but stated that the influence is practically nonexistent at otherwise favorable temperature conditions. Wright stated: "The humidity problem is actually physical

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[6] Samuel R. Lewis, "Air Conditioning," The American Peoples Encyclopedia (Chicago: The Spencer Press, Inc., 1953, I, 399.

[7] Henry Wright, "Classroom Heating and Ventilating," American School and University, XXIII (1951-52), p. 209.

[8] Winslow and Herrington, op. cit., pp. 187-88.

rather than physiological, and a matter of protecting the building more than one of protecting the pupils."[9] Despite the minimum influence of humidity at comfort temperature levels, an optimum relative humidity range does seem to exist.

Relative humidity is conventionally determined from dry and wet bulb readings of the sling or aspirating psychrometer, using standard aspirating charts or tables. A sling psychrometer was utilized in recording humidity in the twenty-seven selected classrooms included in this study.

Air Movement

Most heating and ventilating authorities are in agreement that some air movement is needed in the classroom. Herrington attached more importance to air movement than to relative humidity and considered air movement an important factor in comparing radiant and convective heating systems.[10]

In pointing out that air movement is necessary, Herrick stated:

> The human body will not be comfortable in a pool of stagnant air. Air movement will prevent pockets of excessive humidity, equalize temperature throughout a given space, and remove odors and vitiated or stale air.[11]

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[9] Wright, *loc. cit.*

[10] L. P. Herrington, "Effect of Thermal Environment on Human Action," *American School and University*, XXIV (1952-53), 372.

[11] John H. Herrick, *et al.*, *From School Plant to School Program* (New York: Henry Holt and Company, 1956), p. 442.

Under most classroom conditions, air in the classroom is in motion. Reasons for air motion include natural differences in temperature, infiltration, ventilation, and the heating and cooling systems.

In measuring air movement, one is concerned primarily with turbulence rather than with linear velocity. One of the principal instruments used for measuring turbulent air motion is the kata thermometer, the instrument used in this study.

Thermal Indexes

There is no satisfactory method of combining the four thermal factors into a single index that would indicate the degree of warmth or cold as perceived by an individual under varying circumstances. Physiologists have tried for years to develop successful integrating instruments and various indexes have been devised to measure various combined factors. These indexes have been successful only under the same circumstances and conditions that each has been developed. The most common practice seems to be the separate measurement of the four thermal factors with appropriate instruments. A thorough description of various thermal indexes can be found in most current articles pertaining to thermal research. There seems to be no need for such a description here. The investigator found some use in two indexes, however, as an integrated method of presenting data.

Effective temperature. The effective temperature index was developed at the Research Laboratory of the American Society of Heating and Ventilating Engineers several years ago. Effective temperature is

based upon subjective feelings of equal degree of comfort under different conditions of air temperature, relative humidity and air movement. The temperature cannot be read directly from a single instrument but must be computed from dry and wet bulb readings and air movement readings.

The ultimate results of the effective temperature concept was the development of the comfort charts for still air. Figures 75, 76, and 77 in Appendix B, pages 303, 304, and 305, are charts which have resulted from the effective temperature concept. Figure 75 gives the effective temperature for any combination of dry- and wet-bulb temperatures for still air. Figure 76 carries the concept one step further by embodying the variable, air velocity. Figure 77 shows the ASHRAE Comfort Chart as published since 1950. This chart shows that a maximum number of people are comfortable at 68° effective temperature.

Effective temperature charts were established empirically by trained workers who compared the relative warmth of different combinations of temperature, humidity and air movement by passing back and forth from one room to another. The numerical value of any given combination of air conditions was determined by the temperature of slowly moving saturated air which induced a similar sensation of warmth or cold.

Some significant limitations of the Effective Temperature Comfort Charts are: (1) the charts were primarily developed for still air; (2) the researchers assumed that threshold comfort levels were the same as those experienced at equilibrium conditions; (3) the charts apply

only to convection type heat; and (4) radiant conditions in the room were not considered significant.[12]

The limitations concerning the application only to convection heat and the lack of consideration for radiant conditions caused the investigator to consider another variation of the Effective Temperature Index. Vernon, Warner, and Bedford,[13] British physiologists, used the globe thermometer reading in place of the dry-bulb temperature in determining effective temperatures. Bedford proved that the radiation correction brought about an improved correlation between effective temperature and comfort votes. The Corrected Effective Temperature Index is used in this study.

Globe thermometer reading. Vernon suggested that simple globe thermometer readings might serve as an index, since globe readings were affected by radiation. Bedford subsequently proved that a higher correlation existed between comfort votes and globe readings used as an index of warmth than between comfort votes and both dry-bulb temperatures and effective temperatures.

Even though the globe thermometer was developed by Vernon as a means of determining mean radiant temperature, it is sometimes used in measuring what is called "black body resultant temperature." The black

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[12]B. H. Jennings, "Research on Human Comfort and Environment," _Heating, Piping and Air Conditioning_, 30 (October, 1958), 111-12.

[13]Thomas Bedford, "Research on Heating and Ventilation in Relation to Human Comfort," _Heating, Piping, and Air Conditioning_, 30 (December, 1958), 129.

globe assumes the "resultant temperature" when exposed to a given combination of air temperature, radiant temperature, and air movement. Since the human body reacts to these factors in much the same way because of surface area to volume proportions, the black body resultant temperature does seem to provide a better index of comfort conditions than air temperature alone. For this reason, the black body resultant temperature is used also as an index in reporting some of the findings in this study.

C. FACTORS IN SCHOOL PLANNING THAT AFFECT THE CLASSROOM THERMAL ENVIRONMENT

Many school administrators are now beginning to give some intelligent thought to selection of heating and ventilating equipment for their schools, but at the same time these same administrators continue to build buildings that would impose a terrific burden on the best heating and ventilating equipment.

A number of factors that may influence thermal environment are: (1) microclimatology; (2) solar control, fenestration, illumination, and insulation; and (3) classroom size, occupancy, and socio-economic status of occupants.[14] The following brief discussion of these factors should give the reader some understanding of the importance of intelligent planning for the classroom thermal environment.

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[14] "Design Controls Temperature," from "Thermal Environment," portfolio on heating, ventilating and air conditioning for today's schools, The Nation's Schools, 63 (May, 1959), 91.

Microclimatology. Microclimatology includes site selection, orientation, landscaping, and base planting. Perhaps the most important factor affecting the indoor thermal environment of a classroom is the outdoor climate. Depending on the season, the child must be protected from outdoor climate, or outdoor climate must be exploited to provide an adequate thermal environment. Because of this, school planners must give careful consideration to the compass orientation of the building and its relation to the moving sun.

Novak[15] reported such factors as the selection of the proper slope of a hill for a building site or proper evaluation of sunny versus shaded areas as being important. Even if the site selected is not completely desirable, proper orientation of the building on the site can do much to improve classroom comfort. Orientation should be effected in relation to summer and winter sun and to prevailing summer and winter winds. Generally, classrooms should face north or south with the main axis of the building east and west. Such an orientation minimizes the tremendous solar heat gains on classroom windows and walls. Novak pointed out that east and west window orientations are so ill-advised that normal roof overhangs or sunshades are almost valueless during most of the school day.

If a selected school site contains several large trees, the architect should attempt to design the building so that every tree may

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[15] Paul M. Novak, "Microclimatology and the School's Indoor Climate," from "Thermal Environment," portfolio on heating, ventilating and air conditioning for today's schools, The Nation's Schools, 63 (May, 1959), 101-103.

be utilized in eliminating excess solar gain. If trees are not growing on the selected site, some should be planted as soon as possible. Base planting such as shrubs and vines can be used advantageously, also, but should be used judiciously around ventilation intakes.

Solar control, fenestration, illumination, and insulation. Any effort to provide the optimum classroom thermal environment must be made with these factors considered as interrelated factors. The selection of the site and orientation of the building also affect the importance of these factors in their relation to the classroom environment.

Since many architects insist on creating walls of glass in their building designs, one of the greatest problems, then, becomes finding some way to keep the sun off the glass. An attempt to accomplish this task has been made by the use of several ingenious devices such as overhangs, awnings, louvers, insulating screens, so-called heat absorbent glass, venetian blinds, draw shades and draperies. Without some method of controlling the sun's rays, solar radiation through glass areas becomes a terrific problem due to the fact that the heat gain through single glass is higher than for almost any other material.

An opposite effect on thermal control is provided by large amounts of glass during extremely cold weather. The temperature of windows may be so far below the air temperature of the room that the pupils sitting near the window, and to a certain extent all pupils in the room, radiate large amounts of body heat to the windows. In addition, currents of cold air rush down the windows and spill out into

the room in the form of a draft. Actually, if the sun is shining brightly on a very cold day, windows may admit great quantities of radiant heat from the sun, and at the same time cool the air immediately adjacent to the window because the air is not affected necessarily by the passage of solar heat.

The phenomenon of window downdraft must be combatted because of the uncomfortable effect which the draft creates. Air must only be a few degrees colder than room temperature and moving at a rate of 40 or 50 feet per minute to produce an uncomfortable draft. Mr. W. W. Kennedy, Manager, Air Distribution Development of the Barber-Colman Company, reported measuring downdrafts from cold glass at a rate of 200 feet per minute.[16]

Attempts to eliminate downdrafts include insulation of the walls beneath the windows, double glazing, and radiation from ceiling panels. The most widely utilized methods of downdraft control, however, are: (1) opposing a rising stream of heated air to the falling current of air cooled by the window, sometimes simply effected by locating radiators beneath the windows; (2) heating the glass itself by directing a high-velocity stream of heated air against it; or (3) drawing off the falling column of cold air at the bottom of the window and either exhausting same through vents or heating and using the air in the room. Regardless of the method used or the relative merits of one method over another, some control of downdraft must be effected.

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[16]Statement by W. W. Kennedy during a conference with Barber-Colman consultants, January 24, 1961.

Fenestration, the arrangement and proportioning of windows, also competes with illumination as a factor affecting thermal control. Evidence shows that architects cannot provide a sunlighted environment that meets lighting requirements as well as artificial lighting does. Many expensive attempts to provide natural lighting have been tried, however, including window-wall fenestration, clerestory windows, skylights and glass block. The expense is increased by the continued supplementary need for artificial lighting. All contribute to excess radiant heat in the classroom.

Although many excellent insulating materials for use in existing buildings are now on the market, insulation really can be considered an important factor in providing a good thermal environment if utilized in the original building design. Insulation in the outer walls, windows, roofs and floors will help to maintain the inside surface temperature close to the classroom air temperature, an important factor in thermal comfort.

Classroom size, occupancy, and socio-economic status. Classroom size and number of occupants have a direct influence on thermal conditions within the classroom. Maintenance of an optimum thermal environment is difficult because the classroom is often as crowded as assembly halls and theaters. This density of occupancy makes a constant, minimum supply of outdoor air mandatory. A commonly accepted minimum quantity of outdoor air is 10 cubic feet of air per minute per person. This is called the ventilation rate. This rate will need to increase as

wintertime cooling is needed. One must keep in mind, however, that the cooling needs of individual rooms vary with size of classroom, number of occupants, activities, and heat gains from solar radiation.

In addition to overheating, ventilation also serves the purpose of freeing the classroom of odors, especially body odors. Even though the body odors seem to be more objectionable aesthetically than physiologically, odors are still undesirable.

The problem of body odor removal in schools in regard to the socio-economic status of the children is illustrated in Table III. This table shows minimum ventilation requirements for various grade school children under laboratory conditions. The suggested air circulation minimums vary with density of occupancy, which would depend upon the number of occupants, floor area of the room, and height of the ceiling. An interesting observation is that the minimum ventilation rate for odor control is more than 10 cubic feet of air per minute per person.

Classroom Overheating

Provision of an optimum thermal environment essentially becomes a problem of controlling overheating. Even though the reasons for overheating are now obvious, a discussion of heat gains will serve as a summary for the physiological and physical background that has been presented.

Heat production of children. Mention has already been made of the density of occupancy of classrooms. Less cubic feet of air space is provided per person in a classroom than in most other types of public

TABLE III

MINIMUM OUTDOOR AIR REQUIREMENTS TO REMOVE OBJECTIONABLE BODY ODORS UNDER LABORATORY CONDITIONS

Type of occupants	Heating season with or without recirculation. Air not conditioned	
	Air space per person cu. ft.	Outdoor air supply cfm per person
Grade school children of average socio-economic status	100	29
	200	21
	300	17
	500	11
Grade school children of lower socio-economic status	200	38
Children attending private grade schools	100	22

Source: American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 61. Used by permission.

buildings. All of these pupils give off heat, with the amount varying according to such factors as age, sex, and activity. Estimates of the amount of heat, expressed in B.T.U.'s that a child will dissipate in an hour range from 250 to 400. Assuming the minimum figure of 250 B.T.U.'s, a class of thirty would emit 7,500 B.T.U.'s per hour. This source of heat will partially compensate for the hourly heat loss that the building experiences because of the temperature differential between the interior and exterior of the building. In most parts of the United States, pupils will produce one-third of the heat needed for comfort during most of the heating season class time. In southern parts of the country, when outside winter temperatures sometimes rise even above 60°F. during the day, the point above which optimum classroom temperatures cannot be maintained by the introduction of outside air into the classroom, the excess heat provided by the pupils becomes a critical factor.

Heat gain of artificial lighting. Rooms that contain incandescent lighting usually require around 4,000 watts of lighting. Wattage output of fluorescent lights is somewhat less. These lights burn most of the time the pupils are in the room and quite often when they are not. Fluorescent and incandescent lights add heat to the classroom at a rate of 3.4 B.T.U.'s per watt per hour. Assuming that a classroom contains 4,000 watts of incandescent lighting, the heat output would be 13,600 B.T.U.'s per hour. The heat gain of pupils and lighting remains fairly constant regardless of outside conditions.

Solar heat gain. In spite of the heat output of pupils and lighting, the greatest source of uncontrolled heat is the sun, especially in classrooms that have large amounts of unshaded glass. The amount of sunlight entering a classroom through windows or skylights will depend upon the directional orientation of the building and the location of the sun above the horizon. Solar heat gain is somewhat uncertain, also, because of its role of lesser importance on a cloudy day. For this reason, engineers do not consider solar heat gain in their winter heating calculations.

The fact remains, however, that wherever the sun is shining, solar heat gain represents the greatest uncontrolled gain. Indirect solar radiation is also substantial, even on cloudy days. Conservative estimates of winter solar gain range from one hundred to two hundred B.T.U.'s per hour per square foot of glass area. Using the minimum of one hundred B.T.U.'s with an assumed glass area of 250 square feet, a heat gain of 25,000 B.T.U.'s per hour could be added to the heat gain of pupils and lighting.

With several thousand B.T.U.'s of heat gain being produced even before the heating system is turned on, one can see that the problem of maintaining a correct thermal environment must be solved by cooling rather than by more heating.

D. HEATING AND VENTILATING EQUIPMENT AND ITS CONTROL

After a new school building is designed with factors that affect thermal control taken into consideration, a decision must be reached concerning heating and ventilating equipment to be used and method of control. The following discussion of heating and ventilating equipment was derived largely from material found in the "School Systems" section of the 1959 Heating, Ventilating, Air Conditioning Guide.[17] Only those heating and ventilating systems found in the selected schools are discussed.

Ventilating Systems

Even though methods of heating and ventilating are interrelated, the two are discussed separately here. The need for ventilation has already been established. The school planner must consider the type of thermal environment that he desires and the ease with which he expects to achieve it when he specifies a particular type of ventilation.

Since circulation of air is an important function of a ventilation system, a method of supply and exhaust must be included. Ventilation systems are often identified according to the method of supply (window or mechanical) or exhaust (window, gravity, or mechanical).

Air supply methods. The least expensive method of air supply is by windows. The reader may recall from Chapter I that the New York

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[17] American Society of Heating and Air-Conditioning Engineers, Inc., *op. cit.*, pp. 657-62.

Commission on Ventilation found that windows could be utilized to produce desirable thermal conditions. The truth is that even though this may be possible, because of the human element involved, desirable thermal conditions are not usually produced. When teachers become engrossed in some of their many other duties, ventilation usually suffers.

The other method of air supply is by mechanical means. The air is usually carried through ducts and delivered through wall grilles, or else admitted into the room through a self-contained unit such as the unit ventilator. Stale air is pushed from the room by the incoming air. The incoming air may be fresh, partially fresh, or completely recirculated air, depending on the thermal needs of the room.

Air exhaust methods. Windows are also the primary method of exhaust in some buildings, even though this method does not do an effective job except in still weather because nearly as much air is introduced through the exhaust area as is exhausted.

Gravity exhaust systems admit the room air into exhaust grilles that are located in the wall opposite the windows or in the ceiling and carry it to roof ventilators. Mechanical exhaust systems do essentially the same job but utilize motor-driven exhaust fans instead of roof ventilators.

Heating Systems

Heating systems are often classified according to the heating medium utilized, such as air, steam, or hot water. Usually, though, systems are identified according to the method utilized in heating and

cooling. Some types of heating systems are combined with means of ventilation, while other types require a separate system of mechanical or natural ventilation.

Choice of a heating system is often related to other aspects of building design. Some of these aspects include: the cold floor problem created by modern slab-on-grade construction; choice of heating medium; method of ventilation and cooling desired; cost; and method of control desired.[18]

The following discussion of heating systems includes those systems found in the geographical area investigated:

Radiation. The use of the word radiation in connection with the type of heater usually connected with the word is a partial misnomer because, actually, a large part of the room is heated by convection. Radiant heating usually includes cast-iron radiators, cast-iron or non-ferrous convectors, and continuous finned-pipe heating elements with steam or hot water used as the heating medium. The heaters are usually extended the entire length of the outside or window wall of the room. Controls may be manual, individual automatic controls for each room, or by valves controlling different zones of the building.

Radiant heating ventilation is limited to an air supply from the windows with any type of exhaust. Since the heating load is quite often

[18]Educational Facilities Laboratories, The Cost of A Schoolhouse. A report from Educational Facilities Laboratories (New York: International Press, 1960), pp. 92-94.

satisfied or over-satisfied early in the morning and no provision is available for mechanical cooling, teachers must spend a large amount of their time opening and closing windows.

Unit ventilators. A unit ventilator is an individual forced air heating unit equipped with dampers for introducing outdoor and recirculated air in varying quantities with the fans running continuously during periods of normal occupancy. The unit ventilator is used in classrooms for a combination of heating, controlled ventilation and cooling, with outdoor air utilized as the cooling medium. The medium for heating can be either steam, hot water, or electricity. The heating element can be either a draw-through or blow-through arrangement.

The unit ventilator, consisting of fans, motors, a heating element, dampers, filters, outlet grilles, or diffusers, and controls, permits heating, ventilating, and cooling to be varied while the fans are in continuous operation. The discharge air temperature from the unit varies according to room requirements, but the units usually are equipped with control devices that prevent the admission of air cold enough to cause discomfort. The unit may be equipped to combat cold window downdrafts by using extended finned-pipe radiation along the window sills, by directing a rising heated stream of air against the glass, or by drawing off the falling column of cold air into grilles located on top of the unit. Unit ventilators using hot water for heating and cold water for cooling can be utilized for year-round air conditioning.

The efficient operation of unit ventilators is dependent upon its automatic controls. Unit ventilators and controls combine to provide the co-ordinated action needed for heating, ventilating, and cooling. Usually a room thermostat controls either a valve or bypass damper to regulate the heat supply and a damper to regulate the outside air supply. An air stream thermostat located in the unit prevents a discharge of air below the desired minimum temperature. Other control devices sometimes operate to vary heating media such as hot water with the outside air temperature.

All unit ventilator control cycles provide the sequence for the following stages recognized by the American Society of Heating and Air-Conditioning Engineers.

Warm-up stage. During the warm-up stage all control cycles provide rapid warm-up by having the unit provide full heat with the outdoor damper completely closed. Throughout this stage 100 per cent room air is recirculated and heated until the room temperature approaches the desired temperature level.[19]

Heating and ventilating stage. When the room temperature rises into the operating range of the thermostat, ventilation begins by the partial or complete opening of the outdoor air damper depending upon the cycle used. Auxiliary heating equipment such as convectors or radiators

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[19] American Society of Heating and Air-Conditioning Engineers, Inc., op. cit., p. 215.

are shut off. As the room temperature continues to rise, the heat supply of the unit ventilator is regulated in some way.[20]

Cooling and ventilating stage. Often the temperature of the room rises above the desired level and cool air is needed for cooling purposes. The room thermostat accomplishes cooling by throttling the heat supply, finally shutting it off (either by valves or dampers) and opening the outdoor air damper to prevent overheating of the room. During this stage the air stream thermostat frequently takes control to prevent the discharge temperature from falling below a set level.[21]

The three basic cycles of control usually called "ASHRAE cycles" by manufacturers are:

Cycle X. One hundred per cent of outdoor air is admitted at all times except during the warm-up stage.

Cycle Y. A minimum amount of outdoor air (normally 25 to 50 per cent) is admitted during the heating and ventilating stage. This percentage is gradually increased to 100 per cent, if needed, during the cooling and ventilating stage.

Cycle Z. Except during the warm-up stage a variable amount of outdoor air is admitted as needed to maintain a fixed temperature of air entering the heating element. This is controlled by the air-stream thermostat which is set low enough (often 55°F.) to provide cooling when needed.[22]

In normal classroom application, Cycle Y is the most commonly used. Cycle Y is also the most compatible cycle for combined winter and summer operation.

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[20]Ibid. [21]Ibid. [22]Ibid., pp. 215-16.

The unit ventilator normally does not utilize any mechanical method of exhaust because the air is forced out of the room through cracks due to the slight increase of atmospheric pressure. This pressure is sometimes relieved by ports or windows into the corridor or by an exhaust shaft.

Fresh air admitted into the room is cleaned by passing through a filter. The efficiency of the unit is lessened seriously if regular cleaning of the filter is not scheduled.

Central direct-fired air systems. These systems are forced circulation warm air furnace systems. Air is supplied for ventilation and heating. The type of central direct-fired system most often used in schools is one which mixes outdoor and return air through a fan and filter and discharges it in either of two paths, over the surfaces of a warm air heater or through a bypass around the heater, with mixing at the outlet of the heater to control the temperature of the supply air. This system requires one supply duct from the heater to each room or zone controlled.

There is usually a fixed quantity of outside air, with the balance being obtained by return from the heated space. Air is admitted into the spaces through wall grilles or ceiling or window outlets and released usually into the corridors through grilles. Proper design should avoid window downdrafts.

Panel heating. Panel heating is a term used to describe a method of space heating by raising the temperature of one or more of its

interior surfaces. Most schools utilize the heating of floors, but any other surface can be heated. The heating elements usually consist of warm water piping, warm air ducts or low temperature electrical resistance elements embedded in or located behind the heated surface. Heat is essentially by radiation. Panel heating is used quite widely in conjunction with slab-on-grade construction, especially in primary classrooms where children play on the floor. With heat gain from pupils and lighting, however, panels have a tendency to overheat the room because of the heat storage effect of the panel. This is especially true when no provision is made for mechanical ventilation. Use of window ventilation alone usually does not prevent overheating; nor does the panel heating serve with any effectiveness in combatting downdraft.

<u>Electric heating</u>. Electric heating is used in some areas where electric power rates are low enough to make such an operation feasible. Electric heat eliminates boiler rooms and a separate fuel supply system and is flexible enough to serve as the heat source in unit ventilators, central duct systems, wall fin convectors and for various types of panel heating. The operating cost is often so prohibitive that any original savings in capital outlay are soon cancelled by operation costs.

Usually electric heating is considered in connection with baseboard radiation extending the entire length of the window wall or electric ceiling panels. Electric heating is automatically controlled by means of individual room thermostats and can be utilized in connection with any ventilating system.

Controls

The discussion of controls will be limited to a brief discussion of automatic controls. Manual controls are not really effective in providing an adequate thermal environment when placed in the hands of a busy teacher.

The primary function of an automatic thermal control system is to "maintain a predetermined thermal environment with minimum attention and expenditure of labor by teacher and custodian."[23] This can be done with modern control equipment by responding to and correcting minute changes in temperature through changes in water or steam temperatures or damper settings.

Automatic controls are essential in reducing man-hours of attendance at the heating plant; thus freeing the custodian for other duties. The reduction of man-hours plus the savings in fuel costs due to automatic controls can bring about a reduction in operating costs. This study was concerned primarily, however, with control of the thermal environment in a given occupied space where density of occupancy varied and the space was constantly being affected by variation in solar density, wind, and the output of the heating equipment.

Essentials of an automatic control system are: (1) a controller, (2) a controlled device, and (3) a source of energy.

[23]"Controls Reduce Guesswork," from "Thermal Environment," portfolio on heating, ventilating and air conditioning for today's schools, The Nation's Schools, 63 (May, 1959), 93.

A controller is a device which measures a variable condition such as temperature, humidity, pressure, and liquid level, and produces a suitable action or impulse for transmission to the controlled devices. Thermostats, humidistats, and pressure controllers are examples.

A controlled device reacts to the impulse received from a controller and varies the flow of the control agent. It may be a valve, damper, electric relay, or a motor driving a pump, fan, etc.

The control agent is the medium manipulated by the controlled device. It may be air or gas flowing through a damper; gas, steam, water, etc., flowing through a valve; or an electric current.[24]

Control systems are usually identified according to the primary source of energy utilized. Three types are used for purposes of classroom control:

Pneumatic controls. The source of energy for pneumatic controls is compressed air, usually maintained at a pressure of 15 to 25 pounds per square inch. The compressed air is supplied to the controller which in turn regulates pressure supplied to the controlled device.

Pneumatic controls are used to a great extent in controlling unit ventilators and central forced air systems. Collateral control devices allow for complex cycles such as day-night operation or heating-cooling cycle change-overs.

Electric controls. An electric control system utilizes electricity as the energy medium. The controller regulates the electrical energy supply either directly or through relays. Due to simplicity of

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[24]American Society of Heating and Air-Conditioning Engineers, Inc., op. cit., p. 609.

operation, electric controls are used to control gas and oil furnaces and some unit ventilators.

Electronic controls. Electronic controls are the newest development in classroom controls. They also use electric energy but take advantage of an electronic amplifier to increase the minute voltage variations of the measuring element to values needed for operation of standard electrically controlled devices.

The element of automatic controls that is most familiar to room occupants is the thermostat. The thermostat is usually mounted on the wall but is sometimes mounted in return air ducts of central systems or in a return air sensing chamber of a unit ventilator.

The degree and method of thermal control is one of the most important factors in provision of an adequate thermal environment. For such heating and ventilating systems as the unit ventilator, the control system plays as important a role as the heating and ventilating system itself. The question of providing individual controls for each classroom as opposed to control of a zone of several rooms often becomes a debatable one when the situation lends itself to either degree of control. Even assuming the same solar exposure, an important fact to remember is that as density of occupancy and activity vary from classroom to classroom different heating and cooling needs are experienced. Zoned controls cannot always meet these needs.

E. SUMMARY

Chapter III concluded the development of a thermal background prior to the identification of criteria for thermal control. The four elements of the thermal environment, i.e., air temperature, mean radiant temperature, relative humidity and air movement were identified and discussed together with physical factors that affect the control of these elements. Special emphasis was given throughout the chapter to the control of overheating.

The concluding portion of the chapter dealt with various types of heating and ventilating equipment found in the area investigated and the methods of automatic control essential to the proper regulation of the thermal environment. Heating systems discussed included: radiation, unit ventilators, central direct-fired air systems, panel heating and electric heating. Controls discussed were those that normally are utilized in these heating systems.

In Chapter IV criteria of thermal control for use in evaluating thermal conditions in selected schools are identified. Procedures employed in the identification process are discussed.

CHAPTER IV

CRITERIA FOR THE ESTABLISHMENT OF A RANGE OF ACCEPTABLE CLASSROOM THERMAL CONDITIONS

A. INTRODUCTION

The purpose of this chapter is to identify the best available criteria relating to thermal factors in the classroom environment so that these criteria may be utilized for the evaluation of the thermal environment in selected classrooms.

Identification of criteria was one of the major sub-problems of the study. The task was a delicate, time-consuming one and, in the opinion of the investigator, assumed a role of importance second to no other phase of the study. Materials utilized were so exhaustive that only a partial list is included in the bibliography at the conclusion of Chapter VIII. These materials included standard reference works, physiological and medical texts, graduate studies in the fields of education, engineering, and psychology, educational texts and periodicals which related in any way to the problem, reports of independent organizations such as the School Facilities Laboratories and the Ergonomics Research Society, publications of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, laws and regulations of the various states concerning school heating and ventilating, and advertising and public service material of various heating and ventilating equipment manufacturers.

Some background information was obtained as a result of correspondence between the investigator and other people throughout the country who were interested in the mutual problem of thermal environment. Of tremendous aid was the visit to the Environmental Research Laboratory of the American Society of Heating, Refrigerating and Air-Conditioning Engineers in Cleveland, Ohio, and the discussion there with Dr. B. H. Jennings, Director of Research, and Mr. Clark M. Humphreys, Assistant Director of Research. Of equal importance was the discussion with Henry Wright that resulted from his visit to the University of Tennessee. Mr. Wright, former managing editor of The Architectural Forum, is a prolific writer on aspects of environmental control. Data obtained from professional personnel and materials from different fields were integrated in the formulation of tentative criteria. .

As investigation of the problem and formulation of tentative criteria continued, several obvious observations were made: (1) many widely held thermal environment beliefs were based on research, but others were based on opinions and tradition; (2) many conflicts were evident regarding standards for the various aspects of the thermal environment; (3) thermal concepts were highly evolutionary in nature; (4) the most active interest in the field of thermal control as evidenced by research and literature was that expressed by the engineering profession and manufacturers of heating and ventilating equipment; and (5) perhaps the least amount of interest in the thermal environment as it related to the educational process was shown by the education profession.

Since study of the thermal environment of the selected schools was to be conducted during the winter heating season, an obvious inference was that control of the thermal environment within the classroom depended to a great extent upon the performance of the heating and ventilating equipment utilized in the school. After tentatively selecting a number of criteria that were consistent with each other and with the basic assumptions made prior to the beginning of the study, the investigator then proceeded to find if these criteria were compatible with the capabilities of modern heating and ventilating equipment and with operational beliefs of those who were directly involved in some phase of providing for classroom thermal environment. For this aid in refining and strengthening the tentative criteria, the investigator turned to a group of architects, engineers, heating and ventilating equipment manufacturer representatives, and education and engineering professors.

Individuals who served as a sounding board for the final selection of criteria included: Dr. John W. Gilliland, Professor of Educational Administration, the University of Tennessee; Professor Mack Tucker, University of Tennessee College of Engineering; Mr. George Galloway and Mr. Charles Guthrey, architect and engineer, respectively, for the architectural firm of Galloway and Guthrey, Knoxville, Tennessee; Mr. Chester A. MacCallum, engineer for the architectural firm of Barber and McMurry, Knoxville, Tennessee; Mr. C. A. Spears, Jr., Mr. Don Carter, Mr. Jim Ferguson, and Mr. Gordon Rome, engineers and heating and ventilating equipment dealers, Knoxville, Tennessee; and Mr. W. W. Kennedy, Manager, Air Distribution Development, Mr. Bill Young

and Mr. Dick Plettner, engineers, all representing the Barber-Colman Company, Rockford, Illinois.

B. CRITERIA FOR CLASSROOM THERMAL CONTROL

No claim is made that the five criteria of thermal control presented in this chapter represent the ultimate in ideas concerning the thermal environment. Many factors can produce a change in optimum thermal conditions for individuals or a group over a period of years. As an example of the veracity of the previous statement, one must consider the gradual increase in the optimum winter temperature over the past several years as indicated by research. The criteria set forth here do represent the most acceptable criteria known today for establishment of an optimum classroom thermal environment for grades kindergarten through twelve during the period of the winter heating season. The criteria that follow were developed for the analysis and appraisal of the thermal environment in the classrooms selected for this study.

Criterion Number 1

The provision and control of a relatively narrow range of air temperature conditions which is commensurate with variations in air velocity, humidity, radiant effects, age, basic metabolism, human heat production as a result of work, and clothing are important factors in providing an adequate classroom thermal environment. An optimum air temperature for most classroom activity can be found within the range of

70°F. to 75°F. An air temperature slightly below 70°F. is needed for more strenuous activities such as physical education. For the optimum desired temperature for any activity, this temperature should not vary more than ±2 degrees.

The importance of temperature control was expressed by Winslow and Herrington when they stated: "For ordinary winter conditions, the adjustment of air temperature to metabolic activity is the main issue involved."[1] Research by Bedford in England showed the same correlation between air temperature and sensations of warmth as existed between effective temperature, an index consisting of air temperature, relative humidity, and air movement, and sensations of warmth.[2] Even though all factors of the thermal environment are interrelated, air temperature seems to assume a role of importance of its own.

As a point of departure, consideration should be given to the location of the indoor air temperature within a space that is intended to reflect optimum air temperature conditions. For purposes of this study, one of the locations specified by the 1959 Heating, Ventilating, Air Conditioning Guide was used. The Guide stated:

> The indoor air temperature that must be maintained within a building is understood to be the dry-bulb temperature at

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[1]C.-E. A. Winslow and L. P. Herrington, Temperature and Human Life (Pri eton, New Jersey: Princeton University Press, 1949), p. 192.

[2]Thomas Bedford, Basic Principles of Ventilation and Heating (London: H. K. Lewis and Company, Ltd., 1948), p. 89.

> the breathing line, 5 ft. above the floor, or at the seating level, 30 in. above the floor, and not less than 3 ft. from the outside walls.[3]

In schools included in this study, air temperature was measured at thirty inches above the floor for purposes of relating air temperature to Criterion Number 1. Other measurements were taken from six inches above the floor to the level of five feet or sixty inches and averaged to determine what the investigator termed the "working area temperature."

The variables mentioned in Criterion 1, i.e., air velocity, humidity, radiant effects, age, basic metabolism, human heat production as a result of work, and clothing, must be considered before the optimum temperature range for any activity is determined.

Table IV shows the importance of considering air velocity in determining optimum air temperature conditions and illustrates the fact that no single temperature can be considered the optimum but rather a range of temperatures. In Table IV, Herrington has shown the effect of variations in air movement on the air temperature required to produce a standard heat loss. The table illustrates the need for increased air temperature to balance the cooling effect of increased air movement. For example, equal heat loss is experienced at a temperature of 73.2°F. with air movement of 45 feet per minute as is experienced at a temperature of 69.6°F. with air movement of 15 feet per minute. Air movement

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[3] American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 157.

TABLE IV

VARIOUS ENVIRONMENTS FOR CONSTANT HEAT LOSS

Air velocity Fpm	°F. temperature difference to transfer .984 Met[a]	Comparable air temperature loss for noted air velocities °F.
9	16.2	68.0
15	14.6	69.6
30	12.4	71.8
45	11.0	73.2
60	10.1	74.1
75	9.4	74.8
88	8.8	75.4
176	7.0	77.7
264	5.9	78.3
352	5.4	78.8
440	4.9	79.3
528	4.5	79.7
616	4.1	80.1
704	4.0	80.3
792	3.8	80.4
880	3.6	80.6

[a]1 Met equals human heat production of 50 calories square meter per hour.

Source: L. P. Herrington, "Effect of Thermal Environment on Human Action," American School and University, XXIV (1952-53), 373.

of 15 feet per minute is somewhat typical of a radiantly heated classroom while air velocities around 45 feet per minute are often found in classrooms heated with some type of forced air system. An obvious inference seems to be that optimum air temperature conditions can vary easily with amount of air movement or type of heating and ventilating system utilized.[4]

The individual factors named in the criterion statement as being important variables, namely, age, basic metabolism, human heat production as a result of work, and clothing, are equally as important as the environmental factors. Winslow and Herrington[5] considered those factors directly related to metabolic activity as being the most important of the human factors.

Perhaps clothing does not assume the role of importance held by metabolic activity in ascertaining an optimum temperature range, but, obviously, different optimum temperature conditions exist for the nude individual and the fully clothed person. In establishing optimum air temperature conditions for the classroom, an assumption must be made that most clothing worn by pupils will be fairly uniform in regard to the individual's heat gain or loss.

A factor that was not named in the criterion statement as being an important variable is acclimatization, the body's adaptation to new

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[4]L. P. Herrington, "Effect of Thermal Environment on Human Action," American School and University, XXIV (1952-53), 372-73.

[5]Winslow and Herrington, op. cit., p. 189.

environmental conditions. Winslow and Herrington[6] considered clothing and acclimatization to be responsible for the slight rise in optimum temperature conditions today as compared with those established by the New York State Commission several years ago. Winter clothing is considerably lighter today, while at the same time, the average American school child is acclimatized to a warmer indoor climate than that experienced by his grandfather. Clothing and acclimatization perhaps account for the lower temperatures preferred in England, temperatures similar to those preferred in this country in the 1920's.

Acclimatization is not always complete enough to prevent fatigue, however. Dr. Lucien A. Brouha of the DuPont Company's Haskell Laboratory of Toxicology and Industrial Medicine considers man as the owner of a "physiological capital" which he spends as he works. When man works too long or too hard without a rest, fatigue forces him into physiological debt. Work in warm environments produces fatigue more rapidly than work in cooler environments. While the body's wonderful ability to acclimatize itself is helpful, health, efficiency, and productivity can be affected seriously in higher temperatures.[7]

In determining the optimum air temperature condition for any given classroom activity, effort must be made to control the environmental factors. Because of comparable ages, a typical class will be

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[6] Ibid.

[7] Emily Heine, "Taking the Heat Off Industrial Workers," DuPont Magazine (August-September, 1955), 2-4.

somewhat homogeneous in regard to the various individual factors that affect selection of an optimum temperature, but complete homogeneity of all of these factors is highly improbable. Perhaps this is the reason why many engineers who deal with thermal problems claim they can provide complete optimum conditions for a given space, provided there is only one occupant of that space. Certainly the necessity of an optimum range rather than a specific temperature is apparent.

The selection of an optimum air temperature range for classroom activities was a difficult task. Research in this area is still in the neophyte stage, so identification of accurate temperature levels for a specific grade level or classroom activity was impossible. The identified range needed to be large enough to encompass nearly all normal classroom activities, kindergarten through grade twelve. The range also had to partially consider the needs both of children and adults. The task was complicated more by the fact that many hygiene textbooks recommend an optimum classroom temperature of 68°F. while experience now proves that most children complain about being too cold at that temperature. The range identified in the criterion statement was approved unanimously by all individuals who aided in the final selection with the exception of a few who considered the upper limit slightly low for sedentary work in the summer. These criteria were used only to evaluate winter thermal conditions, however, and were considered highly adequate for that purpose by all who aided in the identification.

As expressed previously, more information is available concerning optimum temperatures for adults than for school age children, although

metabolic activity actually accounts for most needed differences between standards for adults and children. The latest research conducted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers in the ASHRAE Research Laboratory has indicated that adults tested in the Laboratory now find a mean temperature of approximately 75°F., based upon feelings of those tested, to represent optimum air temperature comfort conditions for sedentary activity.[8] Kaiser[9] found that most people at rest or engaged in light work were able to lose excess heat and maintain a high degree of comfort at 75°F. ±2°F. L. P. Herrington,[10] in the John B. Pierce Foundation Laboratory of Hygiene, Yale University, found that adults engaged in complete sedentary activities with no particular tasks involved preferred an air temperature of 78° or 79°F. Carrying out any ordered mental or clerical work lowered the preference to 70°F. or lower.

Standards for classroom air temperatures usually are somewhat lower than adult standards because of the differences between adult and child metabolic rates. Many states have laws and regulations regarding school heating and ventilation with provisions within the regulations for air temperature standards for various activities. Most design air temperatures seem to be about 70°F. as expressed in these standards.

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[8]Statement by Clark M. Humphreys, personal interview, November 7, 1960.

[9]E. R. Kaiser, "How Thermal Factors Affect Comfort," Heating, Piping and Air Conditioning, 29 (August, 1957), 109.

[10]Herrington, op. cit., p. 371.

Some of the standards are confusing, however, as some specify optimum conditions in terms of operative temperature, the mean effect of the air of a room and of its walls, while others are concerned with air temperature only. The New York State Commissioner's Regulation on Heating and Ventilation is specific enough as the Regulation specifies a design operative temperature for classrooms of 70°F. and a corresponding room air temperature of 68°-72°F.[11]

The 1959 Heating Ventilating Air Conditioning Guide listed the winter indoor dry-bulb temperatures usually specified as being 72°-74°F. with optimum temperatures being slightly higher when relative humidity is not controlled.[12] Herrick pointed out that building codes usually recommend a temperature of 68°-72°F. for sedentary activities.[13] Bucher,[14] and Jacobson, Reavis, and Logsdon[15] agreed with the 68°-72°F. figure.

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[11]Winslow and Herrington, op. cit., p. 213.

[12]American Society of Heating and Air-Conditioning Engineers, Inc., loc. cit.

[13]John H. Herrick, et al., From School Plant to School Program (New York: Henry Holt and Company, 1956), p. 442.

[14]Charles A. Bucher, Administration of School Health and Physical Education Programs (second edition; St. Louis: The C. V. Mosby Company, 1958), p. 220.

[15]Paul B. Jacobson, William C. Reavis, and James D. Logsdon, Duties of School Principals (second edition; New York: Prentice-Hall, 1950), p. 679.

In a 1957, third edition of their secondary hygiene text, Meredith, Irwin, and Staton[16] advised 70°F. as a standard for indoor winter temperature. This standard was unchanged from the one advocated by Meredith[17] in a 1941 college text. In a similar secondary text, Clemensen, *et al.*,[18] considered 68° to 70°F. as being adequate for optimum heat loss. This range represented no change from their earlier editions dating back to 1942.

Henry Wright cast some criticism toward those who advocate 70°F. or less as an optimum temperature when he stated:

> It is one of the shibboleths of the heating business that 70 degrees, Fahrenheit, represents the temperature at which people "should" be comfortable. The fact that most classrooms and offices are usually kept about 74 degrees during the heating season is quietly ignored. One reason for this is that 70 is a nice round number; another is that the theory of thermal comfort has never quite caught up with the realities of the heat exchanges between the human being and his surroundings.[19]

With all of the above factors in mind, and the background information presented in Chapters II and III considered, the investigator incorporated the statement, "An optimum air temperature for most

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[16]Florence L. Meredith, Leslie W. Irwin, and Wesley M. Staton, *Health and Fitness* (third edition; Boston: D. C. Heath and Company, 1957), p. 92.

[17]Florence L. Meredith, *Hygiene* (third edition; Philadelphia: The Blakiston Company, 1941), p. 552.

[18]Jessie Williams Clemensen, *Your Health and Safety* (fourth edition; New York: Harcourt, Brace and Company, 1957), p. 92.

[19]Henry Wright, "Classroom Heating and Ventilating," *American School and University*, XXIII (1951-52), p. 209.

classroom activity can be found within the range of 70°F. to 75°F.," in Criterion 1. To further strengthen the criterion, the optimum desired temperature for any activity was not permitted to vary more than plus or minus 2 degrees. The optimum desired temperature was regarded as the mean temperature for any given series of readings with a maximum allowance for readings above or below the mean of 2 degrees either way. For example, an optimum range of 68°-72°F. around the mean of 70°F. would be possible for younger children while a range of 73°-77°F. around the mean of 75°F. is possible for older secondary children. The reader must understand that the plus or minus component of the criterion statement would set the lowest mean optimum for a specific activity at 70°F. with no reading for that mean below 68°F., while the highest mean optimum for a specific activity would be 75°F. with no reading for the mean of 75°F. permitted to vary above 77°F. At least the lower limits of adult temperature needs are met also. No attempt was made to establish temperature standards for a specific age group or classroom activity.

Criterion Number 2

An ideal classroom temperature exists when both air temperature and mean radiant temperature are identical and within the optimum range. Since this situation does not always exist, some provision must be made for counteracting or eliminating the heat loss of the body to cold walls and windows.

The British have long regarded mean radiant temperature as an important factor in maintaining an adequate thermal environment.

Bedford reported that in 1857 some Commissioners appointed by the General Board of Health to investigate the warming and ventilating of dwellings listed as one of their essentials for comfort that the walls of a room should be at least as warm as the air. They listed cold walls or floors among the conditions causing discomfort.[20]

Due to the fact that the Commissioners had no experimental evidence for their statements about mean radiant temperature, Bedford and his colleagues later experimented with cold and warm surfaces. Their findings substantiated the belief of the Commissioners. Their findings also enabled Bedford to list the following as one of his requirements for a pleasant and invigorating environment:

> The average temperature of the walls and other solid surroundings should not be appreciably lower than that of the air, and should preferably be higher. The combination of cold walls and warm air often causes feelings of stuffiness.[21]

Henry Wright bemoaned the fact that the American Society of Heating and Ventilating Engineers for years ignored the importance of radiant temperature in determining comfort temperature. Even though the Society now states that for every degree the radiant temperature is raised or lowered above or below the temperature of the air an adjustment of one-half degree should be effected in the air temperature in the opposite direction, Wright maintained that physiological data clearly

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[20] Thomas Bedford, "Research on Heating and Ventilation in Relation to Human Comfort," Heating, Piping, and Air Conditioning, 30 (December, 1958), 131.

[21] Thomas Bedford, Basic Principles of Ventilation and Heating (London: H. K. Lewis and Company, Ltd., 1948), p. 128.

indicate that any adjustment should be on a degree-for-degree basis for still air. The one-for-two basis recommended by the Society should be the adjustment ratio only if air movement is around 65 feet per minute, according to Wright.[22]

Herrington, through his experiments at the Pierce Laboratory, concluded that cold walls have such an effect on thermal comfort that air temperature may need to be elevated in order to compensate for the body heat loss experienced. For example, air temperature must be raised to 75.9°F. in a room having three walls with a temperature of 50.0°F. in order to produce equivalent heat loss and comfort effect as that found in a room with air and wall temperatures of 70°F. Conversely, Herrington also found that warm walls and windows created by the rays of the sun and other solid surfaces within the room such as lights that have become heated due to some particular function they perform create an opposite effect on the thermal environment and provide the necessity for the air temperature to be lowered to compensate for the radiant heat gain directed toward the students.[23]

In addition to the direct heat loss of the body to cold walls and windows by means of radiation, the problem of cold downdraft produces additional body heat loss through convection. As discussed in Chapter III, these downdrafts must be combatted in some effective manner.

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[22]Wright, op. cit., p. 210.

[23]Herrington, op. cit., p. 373.

Effort should be made to keep the air temperature and mean radiant temperature identical and within the optimum limits. If the mean radiant temperature is impossible to control, the air temperature should be adjusted to compensate for the mean radiant conditions. If the problem of heat loss of the body by direct radiation to cold surfaces or by convection because of downdrafts is great, the problem should be attacked by (1) directing a stream of air upward by natural convection from the heat source beneath the window; (2) blowing a high-velocity stream of heated air directly against the glass; or (3) drawing off the falling column of cold air at the bottom of the window.

Criterion Number 3

With air temperature and mean radiant temperature at the optimum level, optimum relative humidity seems to be around 50 per cent, ±10 per cent.

The greatest amount of controversy that surrounds any thermal factor envelops relative humidity. The American Society of Heating, Refrigerating and Air-Conditioning Engineers has emphasized the effective temperature concept for several years. The 1959 Guide listed 67°-68°F. Effective Temperature as optimum winter temperature for sedentary activities.[24] As one can see in Figure 75, Appendix B, page 303, combinations of temperature and humidity that would create an optimum effective temperature of 68°F. range from 68°F., 100 per cent relative

[24]American Society of Heating and Air-Conditioning Engineers, Inc., op. cit., pp. 157-58.

humidity to better than 77°F. at 10 per cent relative humidity. In order to illustrate the effective temperature concept, corrected effective temperatures using globe readings instead of dry bulb readings are presented in Chapter VII.

The latest experiments of the ASHRAE Research Laboratory have proven that within the optimum temperature range relative humidity does not make the difference once attributed to it.[25] Wright stated:

> Actually, more recent investigations have shown that whereas the relative humidity has a great deal to do with the sensation of comfort in hot humid atmospheres, it has practically no effect on the comfort temperature of heated rooms in the wintertime.[26]

Despite the effective temperature concept, no evidence was found to indicate that a high relative humidity is desirable, even at low temperatures. Bedford indicated this when he wrote: ". . . from the standpoint of comfort a humidity much above 60 per cent is undesirable."[27]

Kaiser was also interested in the physiological effects of humidity on comfort when he said:

> Most people are comfortable when the relative humidity is between 30 and 70 per cent. The optimum for comfort is probably near 50 per cent when the air is at 75°F.[28]

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[25]Statement by Clark M. Humphreys, personal interview, November 7, 1960.

[26]Wright, op. cit., p. 209.

[27]Thomas Bedford, "Research on Heating and Ventilation in Relation to Human Comfort," loc. cit.

[28]Kaiser, loc. cit.

Education and hygiene texts previously quoted recommend relative humidity ranges from 40 to 60 per cent. Some people, recognizing the fact that winter humidity is lower than summer humidity recommend forcing the warmed air to absorb moisture in order to keep the relative humidity above 40 per cent.

Shupp[29] indicated that relative humidity assumes a role of importance only as it acts to increase the effects of heat. Herrington,[30] while agreeing that a relative humidity of 40 to 50 per cent is more agreeable to many people than a lower humidity often found during winter conditions, urged a better regulation of combined thermal effects rather than too much attention to control of relative humidity.

With all of the above factors being considered, a range of 40 to 60 per cent relative humidity was selected as representing optimum conditions with the lower per cent applying more to temperatures at the upper limits of the temperature range and the higher per cent applying more to temperatures at the lower limits of the temperature range. Slight deviations from the 40-60 per cent range are not regarded as serious at optimum temperature conditions.

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[29] David Eugene Shupp, "A Proposed Research Study on the Effects of Air-Conditioning on Learning Activities Within a Classroom" (unpublished project report, Leland Stanford Junior University, Palo Alto, 1957), pp. 46-49.

[30] Herrington, op. cit., p. 375.

Criterion Number 4

Classrooms should be ventilated adequately with clean, fresh, outdoor air to maintain control over overheating and to dissipate odors.

In some respects, Criterion 1 and Criterion 4 are overlapping as both have some regard for temperature control. Some people claim, however, that overheating can be controlled by turning off the heat. Where radiant heating is involved, though, heat may continue to be released in a classroom long after it is needed. The entire Thermal Theory of ventilation is based on the need for fresh outdoor air, at the specific time needed, to control overheating. Some arguments still persist concerning the relative merits of mechanical ventilation as opposed to window ventilation, but regardless of method used one of the primary functions of ventilation is the prevention of overheating through cooling.

Other than for cooling purposes, the need for ventilation becomes a matter of aesthetics. Research indicates that no harmful physiological effects can result from any type of chemical vitiation to be found in a classroom. The aesthetic problem still remains, however, in the form of odors.

Classroom odors usually occur in inverse proportion to the socioeconomic status of the pupils and require varying ventilation rates for elimination. Unfortunately, occupants of the classroom are usually unaware of the gradual formation of odors and visitors to a classroom are sometimes the first to be offended by the build-up of odors. This fact necessitates some continuous ventilation.

The intensity of odors, at least as far as human detection is concerned, is increased when the relative humidity is high and decreases as the moisture content is lowered. Perhaps one of the fortunate aspects of relatively low heating season relative humidity is the lessening of objectional odors, yet odors still remain in crowded classrooms and the most desirable method of correction, other than removing the source, is to dilute the odors with new fresh air.

No numerical standard for ventilation rates was included in Criterion 4, partially because the investigator had no adequate means of measuring the ventilation rate in selected schools. Some ventilation should be present at all times for the control of odors, however, and excess ventilation for cooling should be instantly available when needed.

Criterion Number 5

Air movement within the classroom should be continuous and sufficient to distribute heat evenly throughout the working level of the room at the horizontal plane and to minimize excessive temperature gradients from the floor to the ceiling.

As was the case in Criterion 4, no specific rate for air movement was set. Henry Wright believed that an important criterion of air movement was that those affected by it should not be conscious of it. He stated, "I do not believe that people will be unhappy without a lot of air movement."[31] His views were shared by Clark Humphreys who believed

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[31]Statement by Henry Wright, personal interview, November 18, 1960.

that air movement perhaps should be so low that individuals are not conscious of it.[32]

Just what constitutes the ideal air movement is not a completely established fact. Bedford[33] has conducted much research in the area of air movement and has concluded that individuals become conscious of air movement because of the temperature of the air rather than because of its velocity. An analysis of Bedford's writings establishes an optimum air movement rate of 30 to 50 feet per minute for winter heating. Although believing in continuous movement, Bedford also believed that air movement should be variable rather than uniform and monotonous, whether by window or mechanical ventilation. He considered the prevention of drafts the greatest air movement problem.

Kennedy[34] also recommended an air movement of 30 to 50 feet per minute as being necessary for optimum well-being, while Kaiser[35] adhered to a standard exceeding 15 feet per minute but not over 50 feet per minute. Herrick, on the other hand, set a maximum of 25 feet per minute on heating season air movement.

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[32] Statement by Clark M. Humphreys, personal interview, November 7, 1960.

[33] Thomas Bedford, Basic Principles of Ventilation and Heating, op. cit., pp. 107, 127-28.

[34] Statement by W. W. Kennedy during a conference with Barber-Colman consultants, January 24, 1961.

[35] Kaiser, loc. cit.

The criterion statement has been limited to a description of two conditions that adequate air movement will bring about, namely, an even distribution of heat throughout the working level of the room at the horizontal plane and the prevention of excessive temperature gradients from the floor to the ceiling. The importance of an even horizontal distribution of heat is obvious if the same thermal conditions are desired in all parts of the classroom. The importance of minimizing excessive temperature gradients may not be as obvious or as easily understood.

Winslow and Herrington[36] considered vertical temperature differences as being the most important effect of poor air movement and reported situations with a 10° to 15°F. differential between floor and ceiling air. Bedford[37] insisted that air at head level should not be distinctly warmer than that at floor level and in another source[38] stated that the gradient from floor to head level should be less than 5°F. He maintained that feelings of stuffiness are experienced when the temperature at head level exceeds that at floor level by a great extent. The New York State Commissioner's Regulation on Heating and Ventilation

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[36] Winslow and Herrington, op. cit., p. 189.

[37] Bedford, op. cit., p. 128.

[38] Bedford, "Research on Heating and Ventilation in Relation to Human Comfort," op. cit., p. 132.

specifies that "maximum air temperature gradient from floor to 60" above floor shall not exceed 5° and preferably shall not exceed 3°."[39]

Although ceiling temperatures perhaps are not as important as those at head level, excessive stratification from head level to ceiling should be avoided. Table V shows the temperature differentials normally expected between the breathing level and ceiling level in a room utilizing a forced air system. For rooms containing a direct radiation system, the values increase from 50 to 100 per cent. The figures in Table V are based on an increase of 1 per cent per foot of height above the breathing level. These figures are not necessarily considered optimum conditions, but represent conditions that usually exist and are recommended by the American Society of Heating and Air-Conditioning Engineers to be used with discretion in determining ceiling heat loss.

C. SUMMARY

This chapter has presented five criteria of thermal control, identified by the investigator after an exhaustive analysis of available literature relating to thermal environment. These criteria were identified for the analysis and appraisal of the thermal environment in selected schools.

The criteria identified related to: (1) an optimum air temperature, (2) mean radiant temperature, (3) relative humidity, (4) ventilation, and (5) air movement. No attempt was made to establish these

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[39]Winslow and Herrington, op. cit., p. 214.

TABLE V

APPROXIMATE TEMPERATURE DIFFERENTIALS BETWEEN BREATHING LEVEL AND CEILING, APPLICABLE TO CERTAIN TYPES OF HEATING SYSTEMS[a]

Ceiling height ft.	Breathing level temperature (5 ft. above floor)									
	60	65	70	72	74	76	78	80	85	90
10	3.0	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.3	4.5
11	3.6	3.9	4.2	4.3	4.4	4.6	4.7	4.8	5.1	5.4
12	4.2	4.6	4.9	5.0	5.2	5.3	5.5	5.6	6.0	6.3
13	4.8	5.2	5.6	5.8	5.9	6.1	6.2	6.4	6.8	7.2
14	5.4	5.9	6.3	6.5	6.7	6.8	7.0	7.2	7.7	8.1
15	6.0	6.5	7.0	7.2	7.4	7.6	7.8	8.0	8.5	9.0

[a]The figures in this table are based on an increase of 1 per cent per foot of height above the breathing level (5 ft.) up to 15 ft. This table is generally applicable to forced air types of heating systems. For direct radiation or gravity warm air, increase values 50 per cent to 100 per cent.

Source: American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 159. Used by permission.

criteria as the ultimate in ideas concerning the thermal environment. These criteria were considered, however, as representing the most acceptable ideas to be found at the present time in available literature. The criteria were also strengthened through acceptance by professional people.

Chapter V deals with a discussion of the schools and classrooms selected for study, method of selection, and equipment utilized in collecting data.

CHAPTER V

DESCRIPTION OF SELECTED SCHOOLS AND INSTRUMENTS UTILIZED TO COLLECT THERMAL DATA

A. INTRODUCTION

The purpose of this chapter is to relate the method utilized in selecting the schools and classrooms used in this study and to describe the physical characteristics of the schools and classrooms that contributed to the thermal environment. A description of the instruments used in collecting the thermal data is then presented for the purpose of familiarizing the reader with procedures involved in collecting thermal data.

B. SELECTION OF SCHOOLS

Before attempting to gain entree into any school, an attempt was made to establish some guidelines for selection. The following criteria were developed by the investigator, some of the members of his doctoral committee, and fellow doctoral students for use in determining schools that were appropriate for the study:

Type of building and directional orientation on site. In order to select classrooms that were typical of classrooms to be found in the geographical area, it was necessary to make an attempt to select buildings that utilized exterior building materials common to the area. These materials included masonry and various curtain wall materials.

Frame buildings were common at one time but usually are not constructed in modern building programs. One frame building was selected, however, because other criteria were met. Although most modern school buildings are single story structures, some multistoried buildings are built on sites that lend themselves to such construction. An attempt was made to find one such structure.

Extensive discussion has been given to the effect of glass on the classroom thermal environment. Selection of classrooms containing varied amounts of glass was considered necessary in obtaining a cross section of buildings. Directional orientation of the building was felt to be the factor that contributed most to the effect of window glass upon thermal environment, so it was felt necessary to select classrooms facing north, south, east, and west.

Finally, in order that no phase of the building or its equipment might have an adverse effect on the classroom thermal environment because of the age of the building or equipment, effort was made to select only buildings or portions of buildings that had been completed ten years or less. Using such selectiveness, perhaps buildings containing the worst thermal conditions were avoided.

Type of heating and ventilating system. One of the most important guidelines used in selecting schools was the type of heating and ventilating system used, with more attention given to the method of heating. Schools were selected that contained the following systems of

heating: radiation, unit ventilators, central direct-fired air systems, floor panel, and electric heating.

Proximity to the University of Tennessee. After the criteria had been identified, an immediate observation was that several large and rather expensive instruments that required time-consuming installation were necessary to measure adequately the various aspects of the thermal environment. Because of this fact, selection of schools and classrooms was limited to those found within a radius of one hundred miles from the University of Tennessee.

Organization of school. Due to the different thermal requirements of different age groups as expressed in literature, the need to discover thermal conditions experienced by children of various ages was felt to be important. An attempt was made to include classrooms that housed children of representative public school age groups.

Size of school and classrooms. In order to have a choice of classrooms possessing various window orientations and housing different age groups, the investigator felt that each school should contain a minimum of eight classrooms, that is, at least a room for each grade level provided the organization of the school was 1-8. No maximum size was established. No specific size was set for the classrooms with the exception that the classroom must have been a room originally built to serve as a classroom.

<u>Willingness of school personnel to co-operate with the project</u>. Without the complete assistance of school administrators, teachers, children, and building custodians, a project of such proportions would be impossible. Collection of the thermal data entailed the placement of several instruments in various critical areas of the room that were often within the range of classroom activity. The method of collecting data also required the presence of the investigator within the classroom for a period of one day.

Since the heating system utilized in the classroom plays such an important role in determining thermal environment, the investigator made an initial survey to determine the most predominant system utilized in schools within a radius of one hundred miles from the University of Tennessee. This survey showed that unit ventilators and some form of radiation heating, usually convectors, shared equally in popularity in schools in this area. The survey showed that occasionally floor panels, some form of electric heat, or central forced air systems were used. Using this knowledge, a decision to collect thermal data in nine schools was made. These schools would include three that utilized unit ventilators, three that utilized radiation, and one each that utilized hot water floor panels, electric baseboards, and a central direct-fired air system. The thermal environment was to be studied for one day in each of three rooms in every school, two rooms with opposite window orientations and a corner room, for a total of twenty-seven rooms in twenty-seven days.

The investigator then approached a group of architects, engineers, and heating equipment personnel with an invitation for them to submit a list of schools using the five methods of heating, and meeting the other criteria with the exception of willingness of school personnel to co-operate with the project. This group was asked to submit only schools in which they considered the particular heating system in use to be doing the best job that the equipment was capable of doing under the specific conditions present.

The list of schools contained schools in seven different school systems. As a first step in selecting schools, the investigator secured the permission of the various school superintendents to investigate the thermal environment in schools on the original list within their system. The superintendents also were requested to recommend the schools in which the personnel might be more receptive to the project.

After obtaining approval of the superintendents, the investigator selected a list of nine schools that contained the five required types of heating systems with at least one school being located in each of the seven school systems. The schools were then visited and the project was explained to the building principals. The first nine principals contacted agreed to co-operate and twenty-seven of the first twenty-eight teachers contacted pledged co-operation to the project. One of the nine original buildings selected did not offer the desired window orientations, so an alternate building was selected in the same system.

C. DESCRIPTION OF SCHOOLS AND CLASSROOMS

Of the nine schools selected, one was organized on a K-6 basis, three on a 1-6 basis, four on a 1-8 basis, and one on a 7-9 basis. Although a senior high school was desired, none was included in the study.

The following discussion more fully describes what is condensed in Tables VI and VII, pages 124-128, concerning the selected schools.

School A

School A, a small town elementary school, grades 1-8, in a county school system had an enrollment of 657. The portion of the building included in the study was constructed in 1959 and was of a single story design. The complete building contained twenty classrooms and other educational facilities. The new section of the building used in the study was constructed with a curtain wall exterior with no roof overhang. Floors were concrete slab on grade.

The ventilation system, as shown in Table VI, was mechanical and heating was by unit ventilators, that is, both heating and ventilating was by unit ventilators. The particular system utilized in School A was a hot water system employing unit ventilators located in the center of the rooms for heating or ventilating as required. The unit ventilators had their own fresh air intake through the wall discharging air from the central unit while at the same time drawing off the falling column of cold air from window glass into grilles located on top of book shelves extending along the entire window walls for the purpose of combatting

TABLE VI

DESCRIPTIVE DATA OF SELECTED SCHOOLS

School	Type of school system	Organization of school	Enrollment	Construction date of classrooms used in study	Number of classrooms	Exterior building materials	Ventilation system	Heating system	Heating medium	Type of controls
A	County	1-8	657	1959	20	Curtain wall	Mechanical	Unit ventilator	Hot water	Electric
B	County	1-8	500	1960	20	Masonry	Window	Radiation	Steam	Manual
C	City	K-6	430	1943	20	Wood	Mechanical	Unit ventilator	Steam	Pneumatic
D	City	1-6	200	1960	8	Masonry	Mechanical	Central direct fired air system	Air	Pneumatic
E	County	1-8	760	1959	25	Masonry	Window	Electric baseboard	Electricity	Electric
F	County	1-8	715	1958, 1960	27	Curtain wall and masonry	Window	Panel heating	Hot water	Electric
G	City	1-6	426	1957	21	Curtain wall and masonry	Window	Radiation	Steam	Electric
H	City	7-9	530	1959	17	Masonry	Mechanical	Unit Ventilator	Hot water	Pneumatic
I	County	1-6	467	1952	18	Masonry	Window	Radiation	Hot water	Manual

TABLE VII

DESCRIPTIVE DATA OF SELECTED CLASSROOMS

Classroom number	Date visited	Grade level or subject	Average number of occupants	Square feet of floor space	Square feet of window space	Height of ceiling	Directional orientation of classroom windows	Location of thermostat, if any	Wattage and description of classroom lights	Weather
A-1	2- 7-61	4th	35	900	65	9'	West (South corner)	In unit ventilator	960 W. (white fluorescent)	Cloudy and rainy
A-2	2- 8-61	5th	33	900	65	9'	East	In unit ventilator	960 W. (white fluorescent)	Cloudy
A-3	2- 9-61	2nd	29	900	65	9'	West	In unit ventilator	960 W. (white fluorescent)	Cloudy with sun shining at 2 p.m.
B-1	2-16-61	5th	28	716	147	10'	Northeast	None	3,500 W. (frosted incandescent)	Clear
B-2	2-17-61	5th	29	716	147	10'	Southwest	None	3,400 W. (frosted incandescent)	Partly cloudy to cloudy
B-3	2-20-61	4th	23	716	147	10'	Southwest (Northwest corner)	None	3,500 W. (frosted incandescent)	Cloudy and rainy
C-1	2-22-61	5th	28	880	164	11' 9"	Northeast	Wall	1,240 W. (cool white fluorescent)	Rainy
C-2	2-23-61	5th	28	880	164	11' 9"	Southwest	Wall	1,400 W. (cool white fluorescent)	Clear

TABLE VII (continued)

Classroom number	Date visited	Grade level or subject	Average number of occupants	Square feet of floor space	Square feet of window space	Height of ceiling	Directional orientation of classroom windows	Location of thermostat, if any	Wattage and description of classroom lights	Weather
C-3	2-24-61	6th	31	880	164	11' 9"	Southwest (Northwest corner)	Wall	1,400 W. (cool white fluorescent)	Sunny to cloudy
D-1	2-27-61	6th	29	758	118	11' 5"	North	On wall 3 rooms down corridor	3,500 W. (frosted incandescent)	Clear and warm
D-2	2-28-61	4th	23	758	118	11' 5"	South	On wall 2 rooms down corridor	4,000 W. (frosted incandescent)	Cloudy and rainy to partly cloudy
D-3	3- 1-61	Special Ed.	18	816	118	11' 5"	North (East corner)	Wall	4,000 W. (frosted incandescent)	Cloudy and rainy
E-1	3- 2-61	5th	27	816	167	10' 10" at window to 9' 6" at corridor wall	North	Wall	3,000 W. (clear incandescent with globe)	Clear and warm
E-2	3- 3-61	5th	29	816	167	10' 10" at window to 9' 6" at corridor wall	South	Wall	3,000 W. (clear incandescent with globe)	Clear and warm to overcast

TABLE VII (continued)

Classroom number	Date visited	Grade level or subject	Average number of occupants	Square feet of floor space	Square feet of window space	Height of ceiling	Directional orientation of classroom windows	Location of thermostat, if any	Wattage and description of classroom lights	Weather
E-3	3- 6-61	4th	31	816	167	10' 10" at window to 9' 6" at corridor wall	South (West corner)	Wall	3,000 W. (clear incandescent with globe)	Partly cloudy to cloudy and rainy to sunny to cloudy
F-1	3- 7-61	6th,7th and 8th Science	34	773	212	11' 4" at window to 9' 6" at corridor wall	South (East corner)	On wall 3 rooms down corridor	3,000 W. (clear incandescent with globe)	Cloudy and rainy
F-2	3- 8-61	5th	27	744	212	11' 4" at window to 9' 6" at corridor wall	South	On wall of next room	3,000 W. (clear incandescent with globe)	Partly cloudy to sunny
F-3	3- 9-61	5th	25	744	212	11' 4" at window to 9' 6" at corridor wall	North	On wall 2 rooms down corridor	3,000 W. (clear incandescent with globe)	Cloudy, some snow
G-1	3-17-61	6th	35	964	255	10'	North (West corner)	Wall	1,920 W. (warm white fluorescent)	Clear

TABLE VII (continued)

Classroom number	Date visited	Grade level or subject	Average number of occupants	Square feet of floor space	Square feet of window space	Height of ceiling	Directional orientation of classroom windows	Location of thermostat, if any	Wattage and description of classroom lights	Weather
G-2	3-20-61	5th, 6th	23	964	255	10'	South	Wall	1,920 W. (warm white fluorescent)	Clear to partly cloudy
G-3	3-21-61	4th	33	964	255	10'	North	Wall	1,920 W. (warm white fluorescent)	Cloudy and rainy
H-1	3-22-61	9th Eng. 8th His. 7th Geo.	35	750	45	9'	Northwest	Wall	1,440 W. (warm white fluorescent)	Cloudy to sunny
H-2	3-23-61	9th Alg. Arith. Spanish English	31	963	55	9'	Northwest (Southwest corner)	Wall	2,160 W. (warm white fluorescent)	Partly cloudy to cloudy
H-3	3-24-61	9th Sc. 8th Sc.	21	1,068	80	9'	Southeast	Wall	2,400 W. (warm white fluorescent)	Cloudy
I-1	3-27-61	6th	29	911	260	11'	North (East corner)	Wall in office	2,100 W. (clear incandescent with globe)	Cloudy and rainy to partly cloudy
I-2	3-28-61	2nd	29	754	260	11'	East	Wall in office	1,800 W. (clear incandescent with globe)	Cloudy and rainy
I-3	3-29-61	2nd	29	754	260	11'	West	Wall in office	1,800 W. (clear incandescent with globe)	Clear to cloudy

downdraft. Electric controls with unit mounted thermostats and sampling chamber controlled on ASHRAE Cycle Y. Further control was provided by an electronic reset that varied the discharge water temperature with the outside temperature.

The control cycle used a modulating face and bypass damper and modulating return air-fresh air mixing dampers set to give a minimum of 25 per cent outside air and controlled by an additional thermostat which limited the discharge air stream to a minimum of 55°F.

Classroom A-1. Table VII, pages 125-128, contains a summary of descriptive data relating to the different classrooms visited. Since each classroom is discussed, a reference is not made to the table at each discussion.

Classroom A-1 was visited by the investigator on February 7, 1961. Outside weather on that day was cloudy and rainy. Classroom A-1 was a fourth-grade classroom with thirty-five occupants for the entire day. The classroom contained 900 square feet of floor space with 65 square feet of window space. The windows were oriented toward the west with an outside wall facing the south. The height of the ceiling was 9 feet with the room lighted by 960 watts of white fluorescent lights.

Classroom A-2. Classroom A-2 was visited on February 8, 1961, a cloudy day. Thirty-three fifth grade pupils and adult occupants were present. Classroom windows had an orientation toward the east. All other physical features of the room were the same as those found in Classroom A-1.

Classroom A-3. Classroom A-3 was visited on February 9, 1961, another cloudy day with the sun finally shining at 2 p.m. Classroom A-3 was a second grade classroom with twenty-nine occupants present. The windows were oriented toward the west. Other physical features of the room were the same as those found in classrooms A-1 and A-2.

School B

School B, another school organized on a 1-8 basis, was a rural school located in a small county system. The enrollment of the school at the time of the study was five hundred. The portion of the building included in the study was constructed in 1960 and was of a single story design. The complete building contained twenty classrooms and other educational facilities. The building was constructed with a masonry exterior and a roof overhang of three feet, including guttering. Floors were concrete slab-on-grade. Ventilation was by windows with heating within the classrooms effected by convectors. The heating medium was steam supplied by a stoker-fed boiler producing eight pounds of pressure. Control over the heat was furnished by suspending boiler operation or by use of a hand valve located in the classroom.

Classroom B-1. Classroom B-1, a fifth grade classroom, was visited by the investigator on February 16, 1961, the first clear day of the study. Twenty-eight occupants were present. The classroom contained 716 square feet of floor space with 147 square feet of window area, over twice as much as that found in School A. The windows were

oriented toward the northeast. The height of the ceiling was 10 feet with the room lighted by 3,500 watts of frosted incandescent lights.

Classroom B-2. Classroom B-2, another fifth grade classroom, was visited by the investigator on February 17, 1961, a partly cloudy day. Twenty-nine occupants were present. Classroom windows were oriented toward the southwest. The room was lighted by 3,400 watts of frosted incandescent lights with other physical features the same as those found in Classroom B-1.

Classroom B-3. Classroom B-3, a fourth grade classroom, was visited on February 20, 1961, a cloudy and rainy day. Twenty-three occupants were present. Classroom windows were oriented toward the southwest with an outside wall facing the northwest. All other physical features of the building were the same as those found in Classroom B-1.

School C

School C, a city elementary school, grades K-6, administered by a city school system had an enrollment of 430. This building, constructed in 1943, was the only building included in the study more than ten years of age. The building was also the only building with frame walls and floors. The building was of a single story design and contained twenty classrooms and other educational facilities.

The building actually was selected because the heating and ventilating system was a new one installed to replace cast-iron radiators. The system was a low pressure steam system employing unit ventilators

for heating or ventilation as required. The room unit was a free standing floor mounted unit ventilator having its own fresh air intake through the wall discharging air from the central unit as well as from lateral extensions on one or both sides. Pneumatic controls installed with remote room thermostats controlled on ASHRAE Cycle Y. Some units of the previous cast-iron radiation, one per room, were left installed with a manual valve for emergency service.

The control cycle used a modulating steam valve, modulating return air-fresh air mixing dampers set to give a minimum of 33-1/3 per cent outside air and limited by an additional thermostat which admitted steam to maintain a minimum supply air of 60°F.

Classroom C-1. Classroom C-1, a fifth grade classroom, was visited on February 22, 1961, a rainy day. School C was departmentalized in its instructional program to a certain extent, so varying numbers of pupils were present at various periods of the day. An average of twenty-eight occupants was present for the day. The classroom contained 880 square feet of floor space and 164 square feet of window area. The windows were oriented toward the northeast. Ceiling height was 11 feet, 9 inches with light supplied by 1,240 watts of cool white fluorescent lights. The unit ventilator was located about midpoint between the center and corner of the room.

Classroom C-2. Classroom C-2, another fifth grade classroom, was visited on February 23, 1961, a clear day. An average of twenty-eight occupants was present. Classroom windows were oriented toward the

southwest. Light was furnished by 1,400 watts of cool white fluorescent lights with other physical factors the same as those found in Classroom C-1.

Classroom C-3. A sixth grade class was housed in Classroom C-3, the classroom visited on February 24, 1961. The day was sunny to cloudy. An average of thirty-one was present throughout the day. Classroom windows were oriented toward the southwest with the classroom situated so that one wall was an outside wall facing northwest. All other features of the room were the same as those found in Classroom C-2.

School D

School D, a small city elementary school, grades 1-6, located in a small city school system had an enrollment of two hundred pupils. The single story building was constructed in 1960. The building contained eight classrooms and administrative and cafeteria facilities. The exterior walls were constructed from masonry with a roof overhang of two feet, ten inches. Floors were concrete slab-on-grade.

Although some ventilation was obtained occasionally through open windows, the school was designed to be heated and ventilated by a central direct fired air system. A mixture of outdoor and return air was taken through a fan and filter and discharged in either of two paths, over the surfaces of the gas fired industrial heater or through a bypass around the heater, with mixing, at the outlet of the heater to control the temperature of the air supplied to the rooms. One supply

duct extended from the heater to each of the two zoned classroom areas, four rooms and auxiliary areas being served by each zone.

The system operated with a fixed, although manually variable, outdoor air quantity of 25 per cent, the balance of the air being obtained by returning it from the spaces heated. The air was released into the classrooms by two wall grilles located ten feet high on the corridor-room wall opposite the outside windows. No positive heat source was directed toward the windows. Provision for return air was afforded by door grilles (although the doors usually were left open) so that the return air might return down the corridor to the return grille and back to the unit. Such a procedure is forbidden by law in some states because of the smoke hazard in case of a fire.

Each of the two room zones and the cafeteria zone were controlled by a zone thermostat which positioned a face and bypass damper motor to maintain the required space temperature. The automatic controls were pneumatic.

Classroom D-1. The investigator visited Classroom D-1 on February 27, 1961, a sunny to cloudy day. Twenty-nine occupants were present for most of the day. The classroom contained 758 square feet of floor space and 118 square feet of window area. Orientation of windows was toward the north. The height of the ceiling was 11 feet, 5 inches with light furnished by 3,500 watts of frosted incandescent lights. The thermostat for the particular zone affecting Room D-1 was located in the room at the end of the corridor, D-3, three doors away.

Classroom D-2. Classroom D-2 was visited the following day, February 28, 1961, a cloudy and rainy to partly cloudy day. Twenty-three occupants were present in the fourth grade classroom. The windows were oriented toward the south and the room was lighted by 4,000 watts of frosted incandescent lights. The thermostat controlling the temperature was located two doors down the corrodor. Other features of the room were the same as those found in Classroom D-1.

Classroom D-3. Collection of thermal data in Classroom D-3 was conducted on March 1, 1961, a cloudy and rainy day. Eighteen occupants were present in the classroom, a special education room. The room was slightly larger than the other two, containing a floor area of 816 square feet. Window orientation was toward the north with one outside wall facing east. The thermostat for one zone of four rooms and auxiliary spaces was located on the wall of the room. All other physical features were the same as those in Classroom D-2.

School E

School E, a suburban, county operated elementary school, grades 1-8, had an enrollment of 760 pupils. The single story building was constructed in 1959 and consisted of twenty-five classrooms and auxiliary spaces. The exterior walls were constructed from masonry and the roof of the double-loaded corridors sloped downward from the windows of each side to the corridor. The roof overhang was approximately three feet. Floors were uncovered concrete slab-on-grade.

Rooms were heated by electric baseboards placed underneath the window wall and controlled by remote, wall mounted room thermostats. Ventilation was by open windows with air escaping by an opening into the unheated corridor running continuously along the corridor wall at ceiling level.

Classroom E-1. Thermal data pertaining to Classroom E-1 were collected on March 2, 1961, a clear and warm day. Twenty-seven occupants were present for most of the day. Floor area was 816 square feet, while the window area was 167 square feet. Orientation of windows was toward the north. Ceiling height varied from ten feet, ten inches at the window to nine feet, six inches at the corridor wall. Three thousand watts of clear incandescent lights with globes lighted the room.

Classroom E-2. The investigator obtained thermal data in Classroom E-2 on March 3, 1961, another clear and warm day that became partly overcast for a short period beginning about 11 a.m. Like Classroom E-1, E-2 was a fifth grade classroom. Twenty-nine occupants were present. The window wall of the room faced south with the other physical features of the room being similar to those in Classroom E-2.

Classroom E-3. The investigator visited Classroom E-3 on March 6, 1961, a day presenting all of the various types of weather conditions indicated in Table VII, pages 125-128. A fourth grade class was conducted in Classroom E-3 with thirty-one occupants present. The window wall faced south with an outside wall facing west. An auxiliary

baseboard heater extended the length of the outside wall within the classroom. Other physical features were similar to those found in the other two classrooms.

School F

School F, another suburban, county operated elementary school, grades 1-8, had an enrollment of 715 pupils. The single story building was constructed in 1958 and expanded in 1960. Classrooms in both sections of the building were utilized in the study. The entire building consisted of twenty-seven classrooms and auxiliary spaces. The exterior walls were constructed from a combination of masonry and curtain wall. The roof overhang was approximately five feet with the roof sloping downward from the corridor to the window, an opposite design from that found in School E.

Ventilation in School F was by open windows with heat supplied by hot water floor panels embedded in the concrete floor. Hot water was supplied by a combination gas-oil fired boiler. The building was divided into seven control zones with seven wall mounted electric thermostats sensing the room temperature and controlling the supply of hot water. An electronic reset also varied the discharge water temperature with the outside temperature. In addition to air exhaust by windows, air escaped into the unheated corridors through an opening of six inches between the corridor wall and the ceiling on room F-1 and an opening of two feet, three inches between the corridor wall and the ceiling in rooms F-2 and F-3.

<u>Classroom</u> <u>F-1</u>. Thermal data were obtained for Classroom F-1 on March 7, 1961, a cloudy and rainy day. An average of thirty-four sixth, seventh, and eighth grade students were in the departmentalized science room throughout the day. Floor area of the room was 773 square feet with a window area of the room of 212 square feet. Orientation of the room was toward the south with an outside wall facing east. The ceiling sloped from eleven feet, four inches at the corridor wall to ten feet, six inches at the window. Artificial light was furnished by three thousand watts of clear incandescent lights with globes. The thermostat was located on the wall of the room three doors down the corridor.

<u>Classroom</u> <u>F-2</u>. Partly cloudy to sunny weather influenced the thermal environment of Classroom F-2 on March 8, 1961, the date of the visit to that room. Classroom F-2 was a fifth grade classroom with twenty-seven occupants present for the day. The window wall of the room faced south. The thermostat was located on the wall of the next door room with other physical features of the room being the same as those found in Classroom F-1.

<u>Classroom</u> <u>F-3</u>. An abrupt change of weather was evidenced by the only snow encountered during the project on March 9, 1961. Twenty-five occupants were present in room F-3, the fifth grade classroom visited on that day. The window wall of the classroom was positioned on the north side of the building. The wall thermostat was located two rooms down the corridor with other factors similar to those encountered in the other two rooms.

School G

School G, a city elementary school, grades 1-6, located within a large city school system had an enrollment of 426 pupils. The structure was a two-story structure built in 1957 to take advantage of the sloping site. The three classrooms selected were located on the first floor. The entire building consisted of twenty-one classrooms and auxiliary spaces. Exterior materials included face brick and aluminum curtain walls with porcelain enamel panels. The roof overhang was four feet and nine inches.

Heating was effected by a gas-oil fired steam boiler supplying steam to room convectors. Flow of steam into the convectors was controlled by individual wall-mounted electric thermostats located in each classroom. Ventilation was by open windows.

Classroom G-1. The thermal investigation was conducted on March 17, 1961, in Classroom G-1. The day was clear and thirty-five occupants were present in the classroom, a sixth grade room. Both floor area and window area were large with a floor area of 964 square feet and a window area of 255 square feet. The room was a corner room with the window wall oriented toward the north and the outside wall facing west. Ceiling height was ten feet with light furnished by 1,920 watts of warm white fluorescent lights.

Classroom G-2. Thermal data for Classroom G-2, a combination fifth and sixth grade class, were gathered on March 20, 1961, a clear to partly cloudy day. Twenty-three occupants were present. The windows of

the classroom faced south with other physical factors similar to those found in Classroom G-1.

Classroom G-3. The final day of thermal investigation in School G was March 21, 1961, a cloudy and rainy day. Room G-3, the fourth grade room investigated on that day, had thirty-three occupants present for the day. The window wall had a northern orientation and other physical factors were similar to those found in the other two rooms.

School H

School H, a city junior high school, grades 7-9, was located within the same large city school district as school G. The enrollment was 530. The two-story building was constructed in 1959 and consisted of seventeen classrooms and other auxiliary spaces. Exterior construction was masonry with small visual strips utilized instead of large windows.

Heating and ventilation were by unit ventilators. The particular system utilized in School H was a hot water system employing unit ventilators for heating or cooling as required. The units used in School H were year-round units with no provision for chilled water to provide summer cooling having been made at the time of the study. The unit ventilators had their own fresh air intake through the wall discharging air from the central unit toward the ceiling. No specific provision was made for combatting downdrafts. Pneumatic controls installed with remote room thermostats controlled on ASHRAE Cycle Y. Further control was

provided by a water temperature reset schedule that varied the discharge water temperature with the outside temperature.

In cold weather room air was circulated through the heating element for rapid warm-up. As the room approached the desired temperature, the units were designed so that the outdoor air damper would open to admit 33-1/3 per cent outside air for ventilation purposes. The room thermostat positioned the bypass dampers to vary the quantity of air passing through the heating element for precise control of discharge air temperature in accordance with the heating or natural cooling requirements. On further rise in room temperature, the outdoor air damper opened to take more than 33-1/3 per cent outdoor air, if needed, but the air stream thermostat prevented the discharge of less than 60°F. by reversing the movement of the outdoor air damper, and if necessary, opening the precooler damper for partial preheat.

Classroom H-1. Investigation of the thermal environment in Classroom H-1 was conducted on March 22, 1961. Classroom H-1 was used for ninth grade English, eighth grade history, and seventh grade geography with an average of thirty-five being present throughout the day. The day was cloudy to sunny. The floor area was 750 square feet with only 45 square feet of window space, the windows oriented toward the north. Room H-1 was a ground floor room with a ceiling height of nine feet. The warm white fluorescent bulbs furnished 1,440 watts of light.

Classroom H-2. Ninth grade algebra, arithmetic, Spanish and English were conducted in classroom H-2 on March 23, 1961, the date of the thermal investigation in that room. An average of thirty-five pupils was maintained for the day, a cloudy to partly cloudy day. The floor area was 963 square feet and the window area was 55 square feet. The room was located on the first floor with the windows facing northwest and the outside wall facing southwest. The warm white fluorescent bulbs provided 2,160 watts of artificial light. Ceiling height was the same as in Classroom H-1, nine feet.

Classroom H-3. An average of twenty-one pupils was present in Classroom H-3 on March 24, 1961, a cloudy day. The room was used as an eighth and ninth grade science classroom. Floor area was 1,068 square feet and the area of the visual strips was 80 square feet. The first floor room provided a southwest window orientation and 2,400 watts of warm white fluorescent lights.

School I

School I, a suburban, county operated elementary school, grades 1-6, had an enrollment of 467. The single story brick building was constructed in 1952 and consisted of eighteen rooms and additional auxiliary educational facilities. The roof was not projected into an overhang but terminated at the edge of the building. Floors were concrete slab-on-grade.

Classroom heating was produced by room convectors with hot water used as the medium. One electric thermostat for the entire building was

located in the principal's office with individual hand valves located in each classroom. Ventilation was by open windows.

Classroom I-1. Investigation of the thermal environment by the investigator was conducted on March 27, 1961, a cloudy and rainy to partly cloudy day. The class was composed of sixth graders with twenty-nine occupants present on the day of the investigation. Area of the floor was 911 square feet and window area was 260 square feet. Windows were oriented toward the north with an east corner wall on one side of the room. Ceiling height was 11 feet with 2,100 watts of clear incandescent lights with globes illuminating the room.

Classroom I-2. Classroom I-2 was visited by the investigator on March 28, 1961, a cloudy and rainy day. Twenty-nine were present in the second grade classroom. Floor area was 754 square feet with the area of the eastern oriented windows 260 square feet. Wattage of the incandescent lights was 1,800 watts with other physical factors being the same as those found in Classroom I-1.

Classroom I-3. March 29, 1961, marked the final day of the investigation. Other than the presence of clear weather, and the fact that the windows of Classroom I-3 faced west, all other physical factors were similar to those found in Classroom I-2.

D. DESCRIPTION AND USE OF THERMAL INSTRUMENTS UTILIZED IN THE STUDY

In order to obtain any thermal data relative to the identified criteria, it was necessary for the investigator to use several instruments that were known to be highly accurate in measuring the phenomena of air temperature, mean radiant temperature, relative humidity, and air movement. The instruments used are identified under the phenomenon measured.

Air Temperature

Measurement of air temperature was indeed the most important single thermal element measured because the measurement of air temperature was needed either directly or indirectly for the application of all five criteria. The following instruments were utilized for collection of data in this study:

Palmer mercurial thermometer. Two Palmer mercurial thermometers with a range of 20°-120°F. were used throughout the study as calibration instruments.

Wheelco twelve-point thermocouple recorder. A thermocouple is an electrical device used for measuring differences in temperature. When two wires made of dissimilar metals such as copper and iron are joined by soldering, welding, or merely by twisting, a thermocouple or thermojunction is formed. An electromotive force, which depends upon the temperature of the junction is found to exist between the two wires. A

thermocouple junction is formed by joining the wires at two points. If one junction is kept at a temperature different from the other, an electric current flows through the circuit due to the difference in electromotive force developed by the two junctions. In the potentiometer, an instrument for measuring or comparing electromotive forces, the electromotive force generated by the thermocouples is balanced against an electromotive force from the battery so that observations are made with no flow of current through the thermocouple circuit.

The Series 8000 Recorder used in the study was a continuous null balance type d-c potentiometer. The recorder was capable of recording thermocouple readings from 0° to 200°F. with the recorder calibrated at the factory to an accuracy of one-fourth of 1 per cent. The recorder printed the thermocouple readings in multicolor in a cycle of one reading per five seconds or all twelve points within a minute. The chart speed was twenty inches per hour.

To insure maximum accuracy of the thermocouple readings, the investigator calibrated the recorder twice daily with a Palmer mercurial thermometer. This was accomplished by adjusting the set screw in the micro-adjust block that held the point wheel to the shaft.

<u>Bristol's</u> <u>Thermo-Humidigraph</u>. The Thermo-Humidigraph was an instrument used to record continuously temperature and humidity on a 24-hour chart. The instrument was equipped with an electric fan, thus drawing air over the sensitive coil from throughout the room. The range of temperatures that the instrument was capable of recording was 0°-100°F. with the range of relative humidity from 0 to 100 per cent.

Short and Mason Hygro-Thermograph. The Hygro-Thermograph served the same purpose as the Thermo-Humidigraph except that the chart for the Short and Mason product operated on a seven-day rotating drum with the chart divided in 2-degree divisions. The relative humidity element was composed of composite strands of specifically treated hair. The temperature was measured by a bi-metal coil.

Bacharach tempscribe temperature recorders. The Bacharach tempscribe recorder was an instrument that continuously printed air temperature for a seven-day period over a range of -30° to 120°F. The last three mentioned instruments are all easily calibrated with a mercurial thermometer.

Mean Radiant Temperature

Measurement of the mean radiant temperature was necessary in obtaining data relative to Criterion 2. The instrument used was a homemade instrument that was developed by Vernon in England.

Globe thermometer. The globe thermometer normally consists of a hollow copper sphere, six inches in diameter, coated with flat black paint and having a thermometer or thermocouple at its center. Herrington[1] pointed out that the diameter of the sphere was not critical within a range of several inches and recommended the use of a copper float sold for toilet tank use. The investigator made two such instruments from ordinary toilet floats, painted them flat black, inserted a

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[1] L. P. Herrington, "Effect of Thermal Environment on Human Action," American School and University, XXIV (1952-53), 374.

Palmer mercurial thermometer, range 20°-120°F., in each of two corks, and placed the corks in a small hole that had been cut into one end of each float.

In order to determine the mean radiant temperature from a globe reading, the air temperature and air velocity around the globe must also be determined. Once all three factors are determined, the charts found in Figures 78 and 79 in Appendix B, pages 306 and 307, can be used to estimate radiation of the surroundings.

In determining the mean radiant temperature from Figures 78 and 79, a line is drawn from the appropriate point on Scale A, through the point on Scale B which corresponds with the air velocity, and it is produced to cut Scale C. From the point of intersection on Scale C, another line is drawn to the point in Scale D which represents the observed globe thermometer temperature, and the point at which this line cuts Scale E indicates the mean radiant temperature.

Relative Humidity

Measurement of the relative humidity was essential to the application of Criterion 3. The following instrument was the one used to measure relative humidity throughout the study:

Sling psychrometer. Normally, any instrument used to measure the humidity of the air is called a hygrometer. A psychrometer is a particular kind of hygrometer consisting of two mercury thermometers, one of which has a cloth wick applied to its bulb. In the sling psychrometer, the two thermometers are mounted side by side on a frame fitted with a

handle by which the device can be whirled through the air after the cloth wick is wetted. The whirling motion is arrested for reading the thermometers and continued until the thermometer readings become steady. Due to evaporation of the moisture in the wick, the wet-bulb thermometer will indicate a lower temperature than the dry-bulb thermometer. The difference between the two is known as the wet-bulb depression. Charts and tables (not included in this study) are available for the purpose of determining relative humidity from the dry-bulb and wet-bulb readings.[2]

The particular sling psychrometer used in this study contained two Taylor Etched-Stem mercury thermometers with a range of 20°-120°F.

Air Movement

Air movement plays an essential role in determining thermal comfort and measurement of air movement was essential in applying Criterion 2 and helpful in Criterion 5. The following instrument was used to measure air movement during the study:

Kata thermometer. The Kata thermometer used in the study was an alcohol thermometer with a very large bulb and the scale divisions 95°-100°F. etched on its stem. In use, the thermometer was heated in a bottle warmer until the alcohol had risen above the 100°F. calibration on the stem. It was then dried with a cloth and held in the spot where

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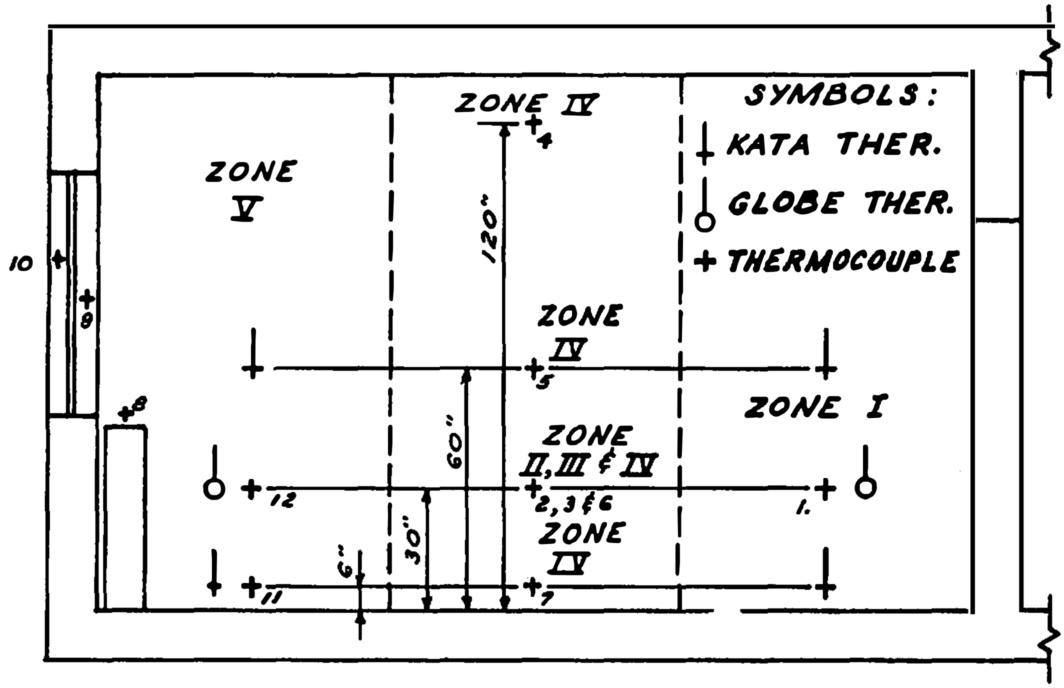
[2]American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 633.

the air velocity was to be measured. The number of seconds necessary for the temperature to drop from 100° to 95°F. was recorded with a stop watch. From the cooling time in seconds and the calibration factor 452 inscribed on the thermometer, the air velocity was determined from the chart pictured in Figure 80, Appendix B, page 308.

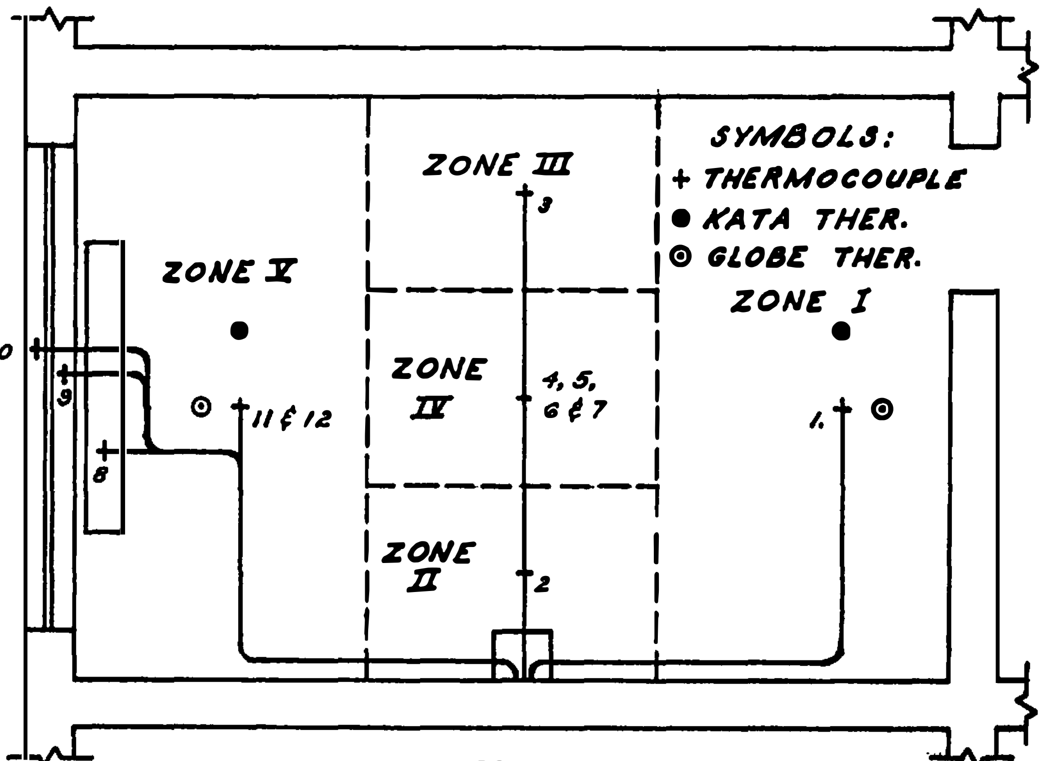
Figure 1 shows the elevation and plan of a typical classroom and the location within that room of the instruments described above that were used to collect the thermal data. Figure 2 shows a schematic diagram of the same typical classroom with locations of the measuring instruments designated.

For convenience in tabulating some of the data, all classrooms were divided into five imaginary zones. Zone I extended the entire length of the wall opposite the outside window and from the wall for a distance equal to one-third the width of the room as illustrated in Figure 1. Zone II included an area in the middle third of the room going away from the window on the right side and running parallel to the window for a distance of one-third of the length of the room. Zone III included an area in the middle third of the room going away from the window on the left side and running parallel to the window for a distance of one-third of the length of the room. Zone IV was located between Zones II and III and comprised one-ninth of the total floor space as did Zones II and III. Zone V included the third of the room next to the window wall.

The thermocouple recorder was always placed in operating position and tested on the afternoon or night before a particular room was to be



ELEVATION



PLAN

Figure 1. Elevation and plan of typical classroom showing locations of thermal measurement instruments.

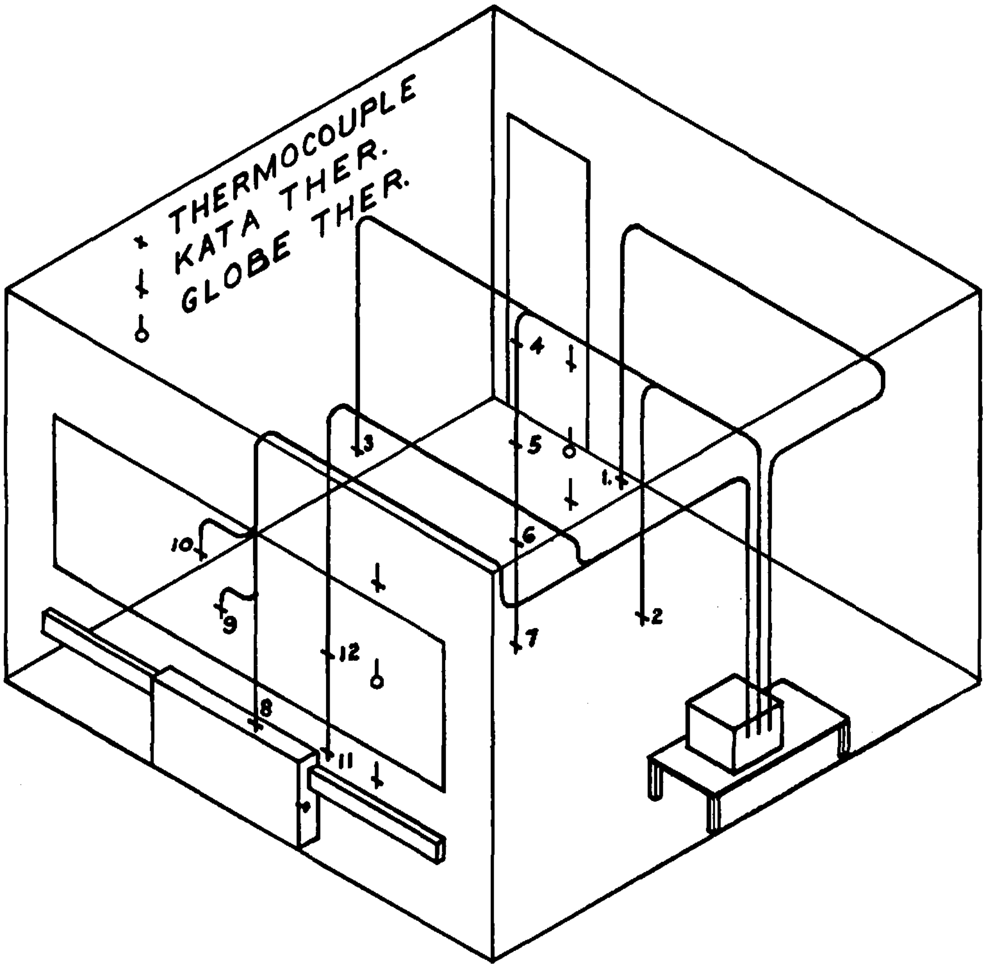


Figure 2. Schematic of typical classroom showing locations of thermal measurement instruments.

visited, an operation that required two or more hours. Locations of the thermocouple points are as follows: position 1, four and one-half feet from the corridor wall of the room at a spot perpendicular to the center of the length of the wall in Zone I (The position was located at the thirty-inch level.); position 2, within Zone II at a point equidistant between the center of the room and the end of the room at a height of thirty inches; position 3, within Zone III at a point equidistant between the center of the room and the end of the room at a height of thirty inches; position 4, within Zone IV at the center of the room six inches from the ceiling but designated as a mean figure of one hundred twenty inches in order that the same figure for each room might be used; position 5, directly below position 4, sixty inches above the floor; position 6, directly below position 5, thirty inches above the floor; position 7, directly below position 6 six inches above the floor; position 8, about one inch above or in front of the heating unit used in the classroom; position 9, taped to the window at a height of approximately one-half the height of the window; position 10, just outside the classroom window with the window securely fastened; position 11, four and one-half feet from the window at a spot perpendicular to the center of the length of the window wall in Zone V, six inches from the floor; and position 12, directly above position 11, thirty inches above the floor. These arrangements can be seen from three different vantage points in Figures 1 and 2. The reader must keep in mind that the temperature of each position was recorded automatically once a minute.

Figures 1 and 2, pages 150 and 151, also show the permanent location of each of the two globe thermometers. One globe was located in Zone I at the identical thirty-inch position as thermocouple position 1 and the other globe was located in Zone V at the identical thirty-inch position as thermocouple position 12. Globe thermometers were read and recorded once each hour along with the corresponding thermocouple reading for future mean radiant temperature calculations.

Air movement readings were taken with the Kata thermometer at each of the four locations shown in Figures 1 and 2 once each hour unless some emergency detained the investigator. The locations utilized to measure air movement are as follows: (1) four and one-half feet from the corridor wall of the room at a spot perpendicular to the center of the length of the wall in Zone I, five feet above the floor; (2) directly below the first location, six inches above the floor; (3) four and one-half feet from the window at a spot perpendicular to the center of the length of the window wall in Zone V, five feet above the floor; and (4) directly below the third location, six inches above the floor.

Not shown in Figures 1 and 2, pages 150 and 151, is the location of the sling psychrometer reading. Once each hour the investigator recorded the outdoor relative humidity and the relative humidity of the inside working area, that is, beneath the height of five feet.

A phenomenon not previously mentioned in this discussion, but one that directly applied to Criterion 4 is unpleasant odors. No scientific instrument was obtained to measure classroom odors. After failing in an attempt to obtain some type of odor detecting instrument, the

investigator attempted to secure the services of a jury to check the odor in each classroom. This attempt also failed because of the scattered locations of the selected schools. In order to present some evidence of this thermal factor, the investigator subjectively measured the intensity of odors within the classroom immediately after returning from his outdoor measurement of the relative humidity. For this purpose the Sensory Scale developed by ASHRAE for tobacco-smoke evaluations was used. The scale is as follows:

0 - Imperceptible odor, or irritation.
1 - Perceptible odor, or irritation, but not objectionable.
2 - Moderate odor, or irritation, little or no objection, acceptable level.
3 - Objectionable odor, or irritation; condition regarded with disfavor.
4 - Strong odor, or irritation, but endurable.
5 - Very strong odor, or irritation, intolerable.[3]

The Bristol Thermo-Humidigraph was placed in each room on the afternoon or evening before the data were to be collected in that particular room and permitted to operate for twenty-four hours, or until the next afternoon. The data obtained from these charts were used primarily to strengthen the data obtained from the thermocouples and sling psychrometer.

The two Bacharach tempscribe temperature recorders and the Short and Mason Hygro-Humidigraph were each placed in one of the three classrooms used in each school and left for the entire period of three days.

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[3]W. F. Kerka and C. M. Humphreys, "Temperature and Humidity Effect on Odor Perception," American Society of Heating and Air-Conditioning Engineers Transactions, Vol. 62 (New York: American Society of Heating and Air-Conditioning Engineers), p. 534.

The readings from these instruments also were used to strengthen data obtained from the thermocouple and sling psychrometer. The readings of the two days in which the complete thermal check was not made were used in a particular room in order to locate any drastic changes in the thermal environment of a room from one day to another.

Occasionally the writer checked air movement within the classroom with the use of a titanium tetrachloride smoke gun. Use of the gun was very distracting to the regular classwork of the pupils, however, and use of the gun was kept to a minimum.

Several of the readings that have been discussed were recorded automatically on charts. Many other readings and observations required manual recording by the investigator, quite often on an hourly basis. The two data sheets included in Appendix A were used by the investigator to record readings, observations, and other pertinent facts related to the thermal environment of the school or selected classrooms.

E. SUMMARY

Chapter V has listed criteria for the selection of schools and classrooms, described the nine schools and twenty-seven classrooms selected, and discussed the various instruments used in collecting thermal data. The exact location of each of the thermal instruments in the data collecting process was disclosed.

The following chapter presents the analyses of the data obtained from the thermal study in light of the criteria identified in Chapter IV.

CHAPTER VI

ANALYSES OF AIR TEMPERATURE AND MEAN RADIANT TEMPERATURE DATA

A. INTRODUCTION

The purpose of Chapter VI is to present the data relating to air temperature and mean radiant temperature in a meaningful way in textual, tabular, and graphic forms after it has been classified and condensed, and to analyze the data as related to the criteria. Although references will be made to physical factors that have affected the thermal environment in certain instances, data are basically presented in terms of their relationship to the first two criteria.

Because of the large quantity of numerical data obtained, the arithmetic mean often was used to describe the mass of data in terms of a central tendency. Since one of the disadvantages of the mean is that its value may be greatly distorted by extreme values and therefore it may not be typical, the range and standard deviation, statistics often used to determine dispersion, also were utilized. These data, sometimes reduced to mean figures, are presented in figures and tables in this chapter. Analysis of data pertaining to each criterion is by inspection from the tables and figures.

In order to aid the reader, the investigator has applied four terms in describing to what extent classroom thermal conditions met specific criteria. The terms are: completely, adequately,

inadequately, and not at all. The term "completely" implies that every phase of the criterion was met as stated. The term "adequately" was used to describe the relationship of thermal conditions to a criterion in situations where the criterion was not completely met, but enough of the components of the criterion were met to produce satisfactory results. "Inadequately" was used in situations where some phase of the criterion was met but not to the extent that thermal conditions were favorable. The term, "not at all," implies that no segment of the criterion was met to any degree. The investigator was able to utilize this procedure better with some data than with others.

Because of the varying factors that make each classroom an entity within itself in regard to thermal conditions, thermal data are presented in terms of each classroom.

B. ANALYSIS OF THERMAL DATA PERTAINING TO AIR TEMPERATURE

Criterion 1. The provision and control of a relatively narrow range of air temperature conditions which is commensurate with variations in air velocity, humidity, radiant effects, age, basic metabolism, human heat production as a result of work, and clothing are important factors in providing an adequate thermal environment. An optimum air temperature for most classroom activity can be found within the range of 70°F. to 75°F. An air temperature slightly below 70°F. is needed for more strenuous activities such as physical education. For the optimum

desired temperature for any activity, this temperature should not vary more than ±2 degrees.

Most of the thermal data relating to air temperature were obtained through use of the thermocouple recorder. Thermocouple recordings yielded approximately 140,000 air temperature readings. Because of the great volume of readings, the decision was made to utilize a systematic random sampling of one out of ten of the original temperature readings. The numbers zero through nine were each written on a piece of paper and one was drawn from a hat to determine which recording from a ten-minute sequence would be used for analysis purposes. The number zero was drawn, so all readings beginning at the first recorded time ending in zero and continuing at ten-minute intervals until the end of the school day were used.

A complete listing of all sample thermocouple readings for each ten-minute interval and location is presented in Appendix C. Other pertinent data such as notes recorded by the investigator and calculations such as means, ranges, variances, standard deviations, and standard errors of the mean are presented for the convenience of the reader.

All analyses in relation to individual criteria were based upon all sample readings for the day, regardless of outside temperature. Separation of readings into categories relating to classroom readings when the outside temperature exceeded or fell below a certain point would have been outside the scope of the study. However, because of the fact that outside temperature has such an influence upon classroom

temperature and because engineers claim that refrigeration often is needed if an appropriate classroom temperature is maintained after the outside temperature has risen above 60°F., some attention was given to outside temperature in regard to classroom temperature.

Table VIII points out the fact that of the 1,158 sample outside temperature readings recorded during the twenty-seven days during which thermal conditions were investigated, 419 readings, or 36.2 per cent, were above 60°F. On only ten of the twenty-seven days were no temperatures above 60°F. recorded. On two days, all readings were above 60°F. and on eleven other days over 50 per cent of the outside air recordings were above 60°F. This perhaps would indicate need at times for some type of cooling other than the introduction of outside air alone.

Since, technically, the heating season exists only when the outside air is 60°F. or below, Table IX, page 161, indicates the percentages of various temperatures found in the working area of each selected classroom when the outside temperature was 60°F. or below. Underheating seems not to have presented a problem as only 3.4 per cent of the total readings were below 70°F. On the other hand, 31 per cent of the classroom readings were above 75°F.

Table X, page 162, presents the percentage of all sample classroom working area thermocouple readings at different temperatures. Since none of the classrooms utilized any refrigeration for cooling purposes, 20.2 per cent of all working area readings were above 77°F. and 44 per cent of the readings were above 75°F. Conversely, less than 1 per cent of the total working area readings were below 68°F. and only

TABLE VIII

PERCENTAGE OF 1,158 SAMPLE OUTSIDE AIR TEMPERATURE THERMOCOUPLE READINGS ABOVE 60° FAHRENHEIT[a]

Classroom	Date	Percentage of readings above 60°F.
A-1	2- 7-61	None
A-2	2- 8-61	None
A-3	2- 9-61	None
B-1	2-16-61	51.1
B-2	2-17-61	55.6
B-3	2-20-61	None
C-1	2-22-61	None
C-2	2-23-61	51.2
C-3	2-24-61	72.1
D-1	2-27-61	54.5
D-2	2-28-61	84.8
D-3	3- 1-61	None
E-1	3- 2-61	None
E-2	3- 3-61	52.3
E-3	3- 6-61	100.0
F-1	3- 7-61	95.4
F-2	3- 8-61	100.0
F-3	3- 9-61	None
G-1	3-17-61	4.8
G-2	3-20-61	74.4
G-3	3-21-61	2.4
H-1	3-22-61	12.5
H-2	3-23-61	None
H-3	3-24-61	None
I-1	3-27-61	69.0
I-2	3-28-61	39.5
I-3	3-29-61	61.3
Total percentage of all readings above 60°F.[b]		36.2

[a]Temperature above which an optimum classroom temperature cannot be maintained by the introduction of outdoor air into the classroom.

[b]Computed by dividing 1,158, the total number of sample outside air temperature readings, by 419, the total number of sample outside air temperature readings above 60°F.

TABLE IX

PERCENTAGE OF 5,779 SAMPLE CLASSROOM WORKING AREA THERMOCOUPLE READINGS AT GIVEN TEMPERATURES WHEN OUTSIDE AIR TEMPERATURE WAS 60° FAHRENHEIT OR LESS

Classroom	Temperature											
	Below 68°F	68°F	69°F	70°F	71°F	72°F	73°F	74°F	75°F	76°F	77°F	Above 77°F
	%	%	%	%	%	%	%	%	%	%	%	%
A-1	None	1.0	1.0	2.6	3.9	7.1	13.3	39.0	29.2	2.9	None	None
A-2	1.9	0.3	3.2	3.8	11.4	9.2	20.0	39.4	10.8	0.3	None	None
A-3	None	None	None	0.3	5.8	13.3	2.6	6.2	22.1	40.6	8.8	0.3
B-1	2.3	2.8	4.0	6.8	7.3	17.6	15.3	14.2	4.0	4.0	1.7	19.9
B-2	None	None	None	None	None	5.0	1.3	4.4	5.0	5.6	25.0	53.7
B-3	9.7	5.0	7.8	15.0	14.2	16.7	10.6	10.0	3.7	1.1	1.4	5.0
C-1	None	None	None	None	None	10.1	17.0	37.5	30.6	3.3	1.5	None
C-2	None	None	None	None	0.6	10.1	43.5	34.5	11.3	None	None	None
C-3	None	None	None	None	5.2	5.2	11.5	19.8	30.2	16.7	5.2	6.2
D-1	None	None	0.6	1.9	4.4	8.8	9.4	8.8	29.4	14.3	8.8	13.7
D-2	None	None	None	None	None	None	None	5.4	19.6	16.1	34.0	25.0
D-3	None	None	None	None	0.5	1.1	3.5	10.4	33.2	31.1	18.3	1.9
E-1	None	None	None	0.3	1.2	10.1	25.3	30.7	30.4	2.1	None	None
E-2	1.2	2.4	4.8	1.2	4.8	9.5	12.5	16.7	29.8	16.1	1.2	None
E-3	None	None	None	None	None	None	None	None	None	None	None	None
F-1	None	None	None	None	None	None	None	6.3	12.5	37.5	25.0	18.7
F-2	None	None	None	None	None	None	None	None	None	None	None	None
F-3	4.0	1.7	3.7	7.9	11.1	15.9	7.7	17.9	26.7	3.4	None	None
G-1	0.6	0.9	0.9	1.2	3.8	5.3	9.7	17.5	23.8	22.8	9.4	4.1
G-2	None	None	None	None	None	2.3	12.5	27.3	29.5	18.2	7.9	2.3
G-3	None	None	None	0.9	1.2	1.9	5.6	11.3	19.1	20.6	28.4	10.9
H-1	None	None	None	None	None	None	None	None	3.6	15.4	23.9	57.1
H-2	None	None	None	0.3	0.6	2.6	4.6	9.4	21.0	34.7	23.0	3.7
H-3	None	None	2.0	11.9	8.4	22.1	32.6	16.9	6.1	None	None	None
I-1	None	2.9	1.9	1.0	None	14.4	9.6	6.7	8.7	16.3	7.7	30.8
I-2	None	None	None	1.1	0.5	4.3	7.6	17.4	17.4	18.0	6.5	27.2
I-3	None	2.1	2.1	3.1	4.2	8.3	11.5	5.2	7.3	8.3	15.6	32.3
Total Percentage	1.1	0.8	1.5	3.0	4.3	8.8	12.2	17.9	19.4	13.2	8.7	9.1

TABLE X

PERCENTAGE OF ALL SAMPLE CLASSROOM WORKING AREA THERMOCOUPLE READINGS AT GIVEN TEMPERATURES

Temperature	Percentage
Below 68°F.	0.7
68°F.	0.5
69°F.	0.9
70°F.	2.0
71°F.	3.1
72°F.	6.6
73°F.	9.8
74°F.	15.0
75°F.	17.4
76°F.	13.5
77°F.	10.3
Above 77°F.	20.2

2.1 per cent were below 70°F. Since 72°F. probably is referred to in the literature as an optimum classroom temperature more than any other temperature, an interesting note is that 86.2 per cent of the total readings were above 72°F., a figure only slightly higher than the 80.5 per cent above 72°F. when the outside temperature was 60°F. or less.

Table XI presents the mean temperature readings of all thermocouple points within the working zone of each room. The lowest mean temperature, 69.07°F., was recorded in position 11 of Classroom B-3, a six-inch reading four and one-half feet from the window wall. The highest mean temperature at any one point in a classroom was 82°F. and was recorded at the position 5, sixty-inch level in the center of Classroom E-3.

The highest single temperature reading for any point anywhere within the air space from the floor to the ceiling was the 7:50 a.m. 100°F. reading at the position 4, 120-inch level in Classroom B-3, while the lowest single temperature recorded was the 58°F. position 11, 6-inch reading taken at 9:50 a.m. in the same classroom. This substantial difference resulted from the shutting down of the boiler at 8 a.m. These data are shown in Appendix C, pages 322-324.

The following description of air temperature conditions in each classroom relates the text to the accompanying illustrations and analyzes the data in terms of Criterion 1. Table XII, page 165, lists the mean temperature of all sample thermocouple readings at the thirty-inch level for the purpose of relating the mean to the criterion, while Figures 3-29 show, among other important data, the mean working area

TABLE XI

MEAN DAILY TEMPERATURE READINGS FOR THERMOCOUPLE POINTS WITHIN THE WORKING ZONE[a]

Classroom	Thermocouple level							
	No. 1 30" level	No. 2 30" level	No. 3 30" level	No. 5 60" level	No. 6 30" level	No. 7 6" level	No.11 6" level	No.12 30" level
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
A-1	74.09	73.86	74.30	74.95	74.66	70.91	None	73.30
A-2	73.29	73.29	73.29	73.98	73.38	69.98	None	72.98
A-3	75.07	75.00	75.11	75.25	75.07	73.41	None	74.84
B-1	75.62	75.60	75.91	77.96	75.89	73.29	73.13	75.87
B-2	77.36	77.40	77.18	79.09	77.58	74.89	74.04	77.29
B-3	72.24	71.98	71.64	73.49	72.02	70.73	69.07	71.36
C-1	74.19	74.17	74.21	74.33	74.26	73.45	73.60	74.14
C-2	75.37	75.26	75.67	76.21	75.60	74.12	74.21	75.79
C-3	75.33	75.56	75.47	75.84	75.44	74.37	74.93	75.69
D-1	77.29	77.25	77.34	78.43	77.48	74.45	74.27	77.14
D-2	79.80	79.61	79.46	80.02	79.87	78.41	80.57	80.65
D-3	75.67	75.45	75.39	75.98	75.77	74.32	74.74	77.26
E-1	71.43	71.57	71.71	74.67	74.36	73.07	72.59	74.19
E-2	74.93	74.68	75.55	75.89	75.39	73.30	72.82	75.34
E-3	81.73	81.36	81.45	82.00	81.80	80.55	81.59	81.98
F-1	76.74	76.26	77.19	77.44	76.86	76.33	74.23	75.55
F-2	74.63	74.18	74.95	75.05	74.98	74.36	73.11	74.23
F-3	73.18	73.41	73.45	74.34	73.66	70.93	69.79	72.86
G-1	75.21	74.64	75.38	76.24	75.27	73.64	72.98	74.19
G-2	76.49	76.39	76.65	77.42	76.72	75.19	75.07	76.77
G-3	76.02	75.95	71.29	77.51	71.46	74.37	73.56	75.88
H-1	77.98	78.02	78.05	78.72	78.68	77.85	77.30	77.50
H-2	75.91	75.77	76.25	76.70	76.23	75.25	73.86	74.98
H-3	73.51	72.63	73.12	73.37	73.14	72.72	70.47	70.74
I-1	75.43	75.90	75.50	78.02	75.73	72.14	72.24	75.62
I-2	78.21	78.16	78.16	80.26	78.58	75.53	75.32	78.39
I-3	75.90	75.94	76.06	77.90	76.32	73.26	72.84	76.03

[a]Refer to Figure 1 for a more complete description of thermocouple point locations.

TABLE XII

COMPARISON OF THERMAL DATA WITH CRITERION 1

	Component A	Component B	
	Temperature within the range of 70°F.-75°F.	Temperature should not vary more than ±2°F.	
Classroom	Mean temperature of all sample thermocouple readings at the 30" level (Expressed to nearest whole degree)	Range of the mean temperature of all sample thermocouple readings at the 30" level for each ten-minute sampling interval	Standard deviation from mean of all sample thermocouple readings at the 30" level
A-1	74°F.	75°-73°F.	±0.755°F.
A-2	73°F.	75°-72°F.	±1.233°F.
A-3	75°F.	77°-72°F.	±1.758°F.
B-1	76°F.	86°-69°F.	±4.002°F.
B-2	77°F.	87°-73°F.	±3.547°F.
B-3	72°F.	88°-63°F.	±3.702°F.
C-1	74°F.	76°-72°F.	±1.058°F.
C-2	76°F.	85°-73°F.	±3.245°F.
C-3	75°F.	77°-73°F.	±1.217°F.
D-1	77°F.	81°-72°F.	±2.283°F.
D-2	80°F.	83°-75°F.	±2.015°F.
D-3	76°F.	77°-73°F.	±1.237°F.
E-1	74°F.	75°-72°F.	±0.286°F.
E-2	75°F.	77°-72°F.	±2.629°F.
E-3	77°F.	84°-78°F.	±1.175°F.
F-1	77°F.	79°-72°F.	±1.900°F.
F-2	75°F.	78°-71°F.	±1.493°F.
F-3	73°F.	76°-67°F.	±1.982°F.
G-1	75°F.	78°-70°F.	±1.772°F.
G-2	77°F.	79°-73°F.	±1.367°F.
G-3	76°F.	78°-73°F.	±1.428°F.
H-1	78°F.	80°-76°F.	±1.229°F.
H-2	76°F.	77°-73°F.	±1.153°F.
H-3	73°F.	75°-71°F.	±1.546°F.
I-1	75°F.	80°-72°F.	±2.343°F.
I-2	78°F.	84°-74°F.	±3.203°F.
I-3	76°F.	80°-72°F.	±2.232°F.

temperature for each ten-minute interval, that is, the mean of each set of sample thermocouple readings for thermocouple positions, 1, 2, 3, 6, 7, 11, and 12. To strengthen the analysis of the data relating to Criterion 1, the standard deviation of temperatures from the mean was used in addition to the range. A range can give one a false impression of the dispersion from the mean if the highest and lowest items are representative of only one or two readings. Assuming a normal distribution of temperatures, one standard deviation would indicate the maximum distance that approximately two-thirds of the observations would lie above and below the mean. If both the mean temperature and range of a specific classroom failed to meet the criterion requirements, yet one standard deviation was ± 2 degrees or less, the criterion was considered to be met inadequately rather than not at all.

Classroom A-1. Figure 3 indicates a mean classroom working area temperature of 73.75°F., a mean window glass temperature of 66.36°F. and a mean outside air temperature of 39.59°F. An interesting comparison of the effect of some type of positive heat on the temperature of window glass can be made by comparing the glass temperature in Figure 3 with the glass temperature of Classroom F-3 in Figure 20, page 192, a classroom with hot water floor panel heating. Difference in mean outside air temperatures was only about three degrees, difference in mean working area temperatures was less than one degree, but difference in mean glass temperatures was approximately fifteen degrees.

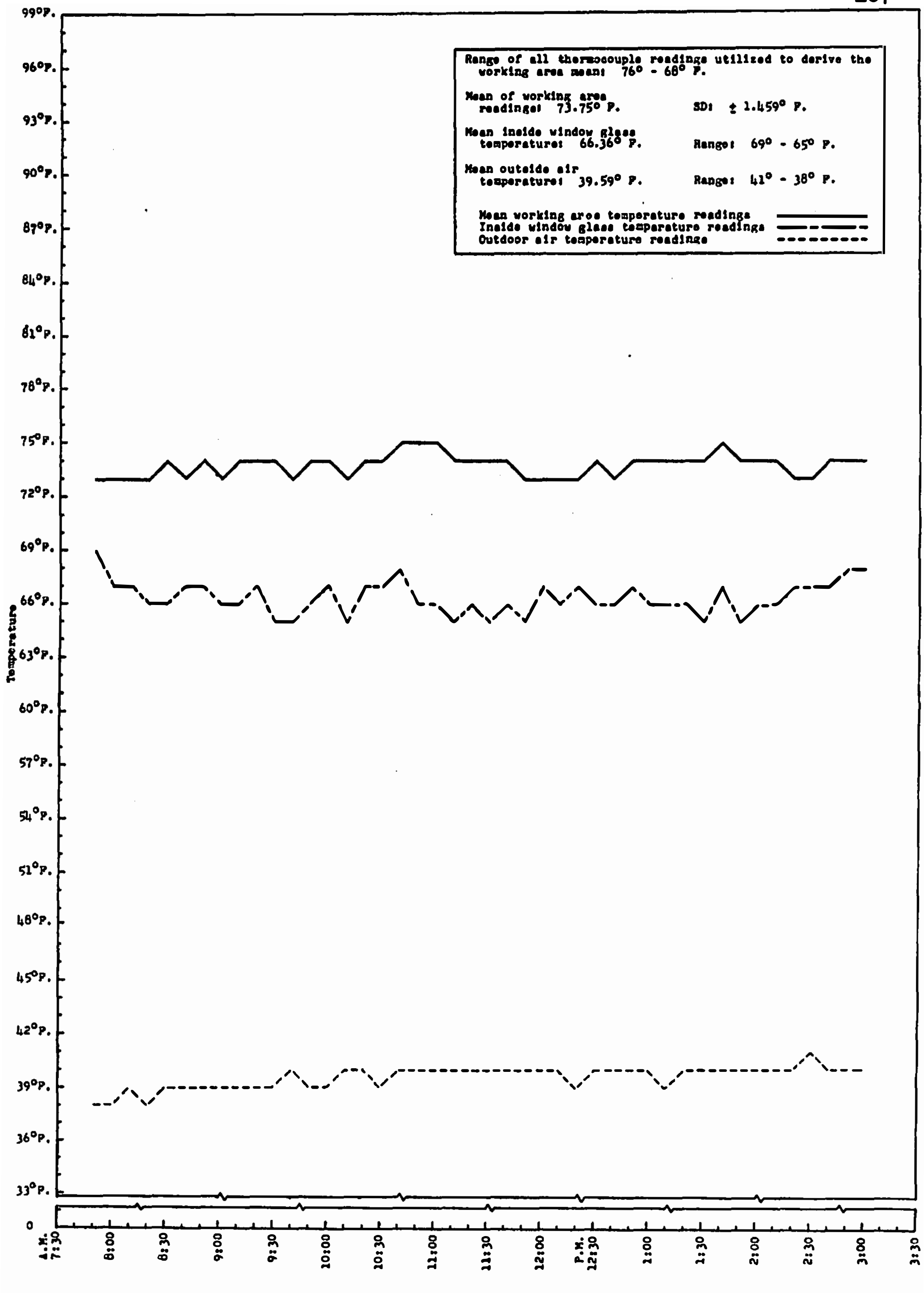


Figure 3. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom A-1.

Classroom A-1 had a mean thirty-inch level temperature of 74°F., expressed to the nearest whole degree, and a range of 75°-73°F. To strengthen the favorable thermal condition, the standard deviation was only ±0.755°F. The investigator considered air temperature conditions in Classroom A-1 to have met Criterion 1 completely.

Classroom A-2. Figure 4 shows the mean of the working area readings to have been 72.88°F. for Classroom A-2, while the mean inside window glass temperature was 64.73°F. and the outside temperature was 38.89°F. The 10:20 a.m. window glass reading presented an interesting example of the effect of the sun upon glass when the glass temperature immediately climbed above the room temperature when the sun came out from behind the clouds for the only time that day.

Thermal conditions in Room A-2 also completely met Criterion 1. The mean temperature at the thirty-inch level was 73°F., the range of mean thirty-inch readings for the day was 75°-72°F. and the standard deviation was ±1.233°F.

Classroom A-3. In studying Figure 5, page 170, the reader can see the general effect of sunlight on the total room air temperature when the sun shines for a short period in a room that utilizes unit ventilators while the outside air temperature is still at a low level. Over a thirty-minute interval the sun shone intermittently bringing the outside temperature up nine degrees and the window temperature up nineteen degrees, while the mean room temperature went up only one degree. One can also see that the mean working area temperature did not vary as

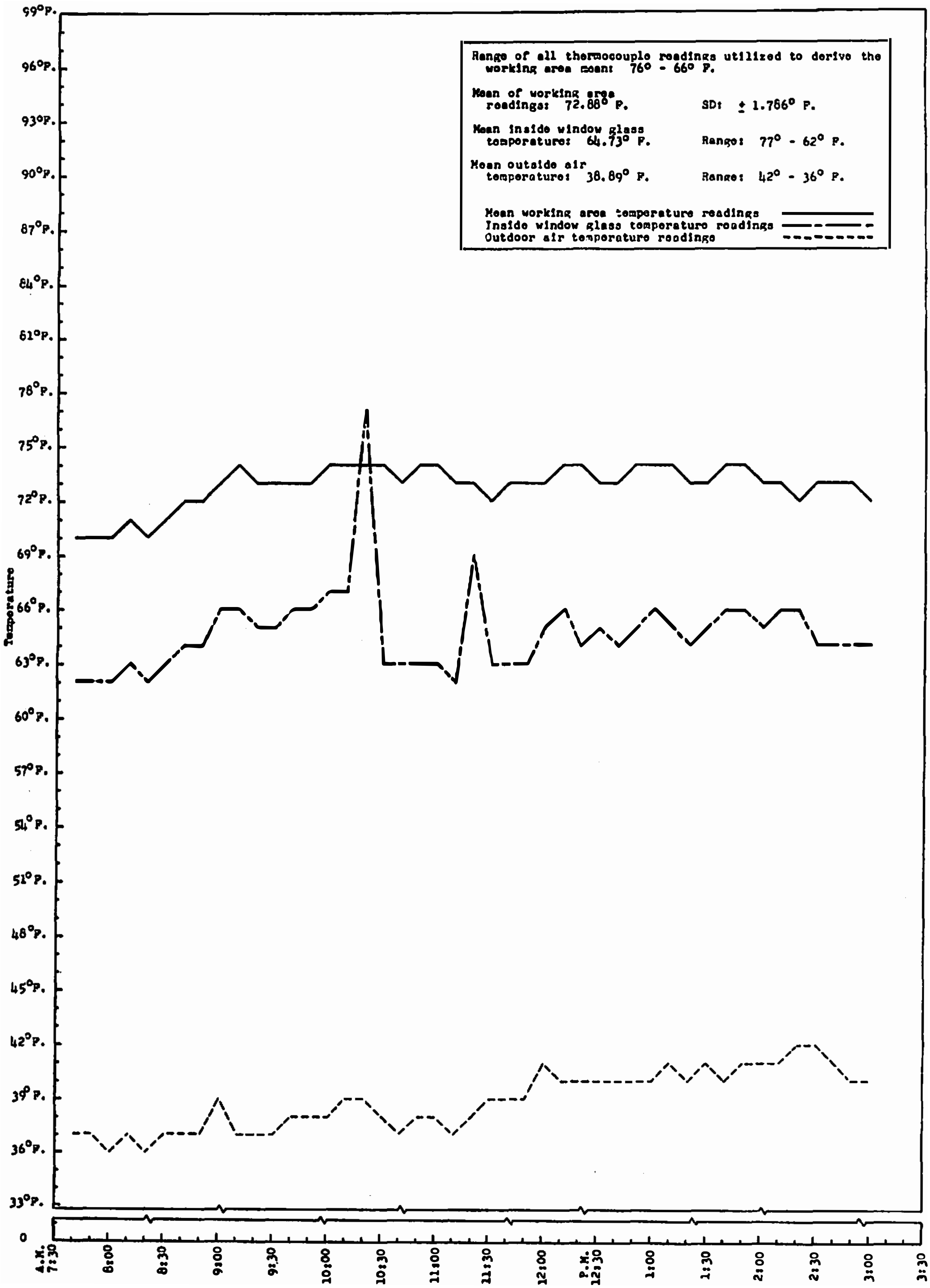


Figure 4. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom A-2.

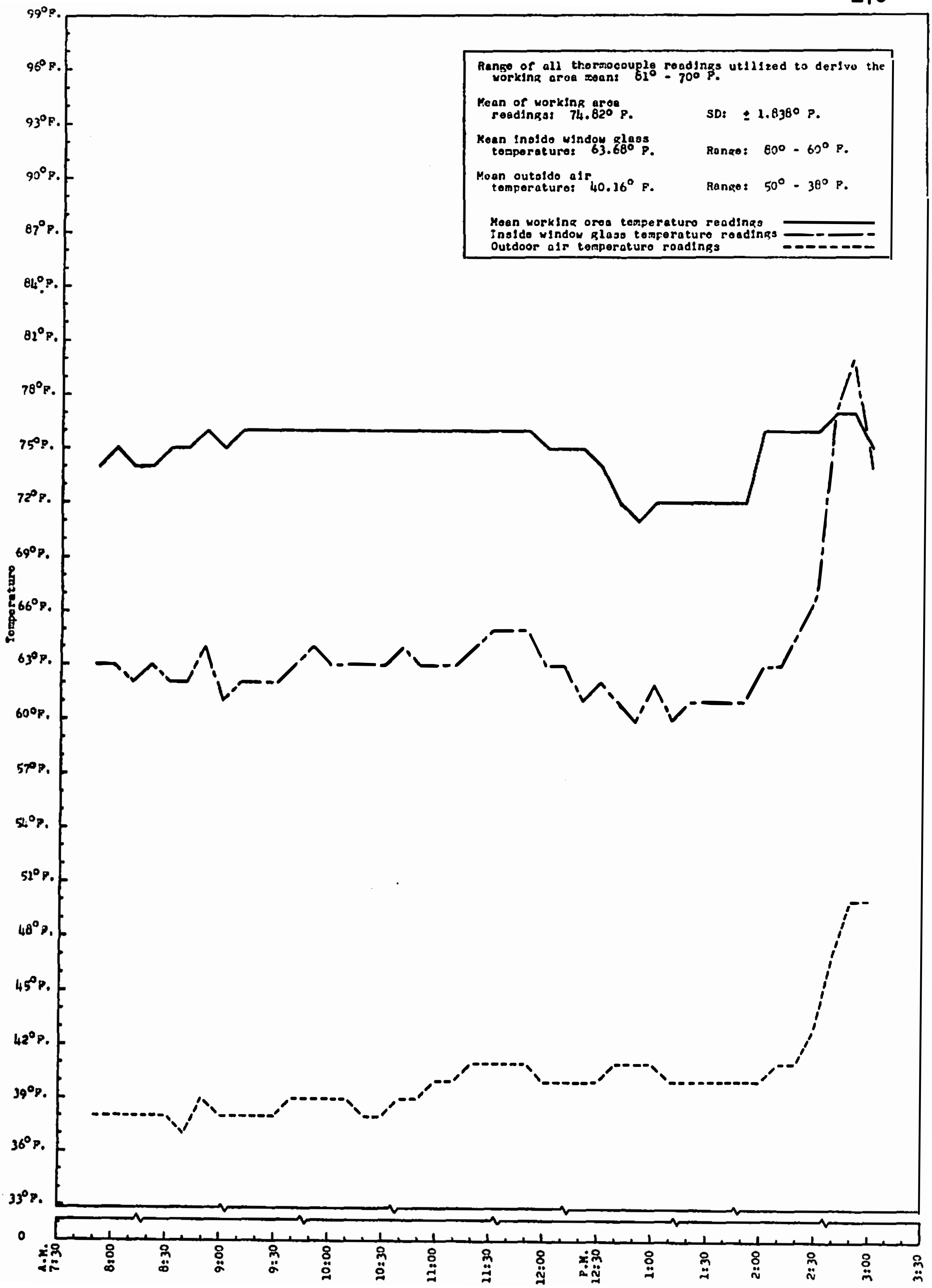


Figure 5. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom A-3.

much as one degree for a period beginning at 9:10 a.m. and ending when the class went to lunch at 11:50 a.m. The lower temperatures recorded in the early afternoon resulted from some minor maintenance work, including changing of filters, that the custodian performed on the unit ventilator while the children were out of the room.

The reader must keep in mind that rooms in School A had small visual strips for windows, but at the same time had no roof overhang or venetian blinds. The effect of sun on glass is shown immediately in both Classrooms A-2 and A-3. The effect on the classroom air temperature was not evident in the short period that the sun was shining, but the reader must remember that most of the time spent in School A was during cloudy weather conditions. The real effect of the brief sunlight upon the room will be presented in connection with Criterion 2.

Of interest was the effectiveness of the unit ventilator mounted electric thermostat in School A. Column 11, in the School A section of Appendix C, pages 310-315, contains air sampling chamber readings. A look at those readings indicate why temperatures were controlled so well in the three School A classrooms.

The mean working area temperature, mean window glass, and mean outside air temperature on the day thermal conditions in Classroom A-3 were studied compared favorably with those found in Classrooms A-1 and A-2. Table XII, page 165, shows that Criterion 1 was met adequately and was prevented from being met completely only because the range was one degree too low during a time when the children were out of the room and the custodian was performing maintenance on the unit ventilator.

Classroom B-1. Data presented graphically in Figure 6 illustrate intelligent decision-making on the part of the building principal and custodian, even though the decision was not an ordinary one for mid-February. Boiler operation was completely suspended early in the morning as one can see in Figure 6. Since no automatic controls were afforded the classrooms for this radiantly-heated school, the action was a wise one. The mean working area temperature had risen to 79°F. without another source of heat, when the outside temperature reached 68°F. at 1:50 p.m. This situation existed even though the orientation and roof overhang kept the sun from shining directly on the large windows and windows were open most of the day.

The classroom thermal conditions in Classroom B-1 did not meet Criterion 1 at all. The standard deviation of ±4.002°F. was the highest of any found in the twenty-seven schools. This was brought about partly by the 27-degree range in all of the sample working area readings that the children experienced throughout the day.

Classroom B-2. Figure 7, page 174, shows much the same pattern for Classroom B-2 that existed for B-1. Boiler operation was suspended again, a beneficial move for everyone if early morning temperatures were indicative of those that would have ensued throughout the day if heat had continued to have been provided by the heating system. Criterion 1 was not met at all in Classroom B-2.

Classroom B-3. Figure 8, page 175, depicts the best conditions found by the investigator in a manually controlled, radiantly-heated

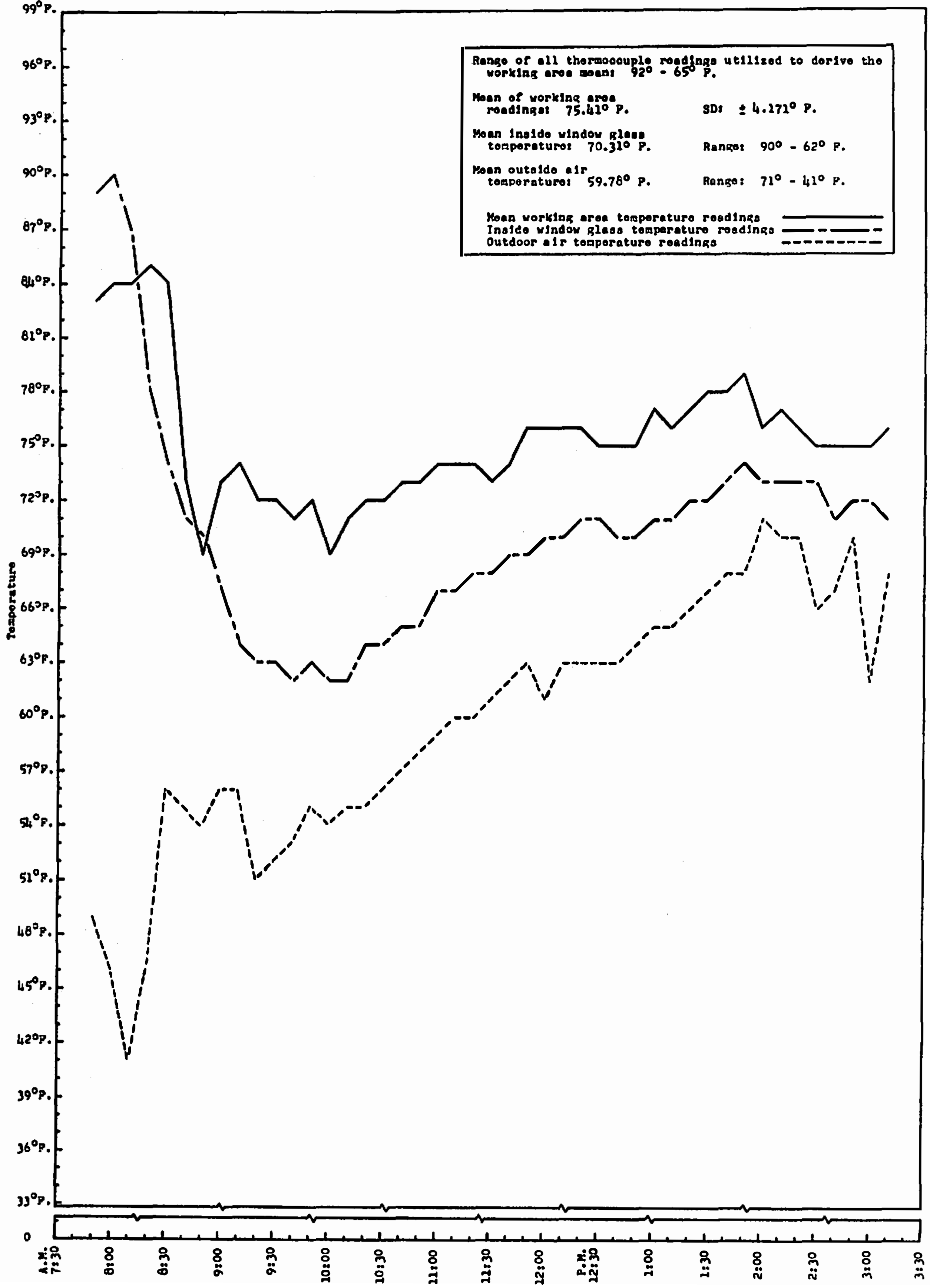


Figure 6. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom B-1.

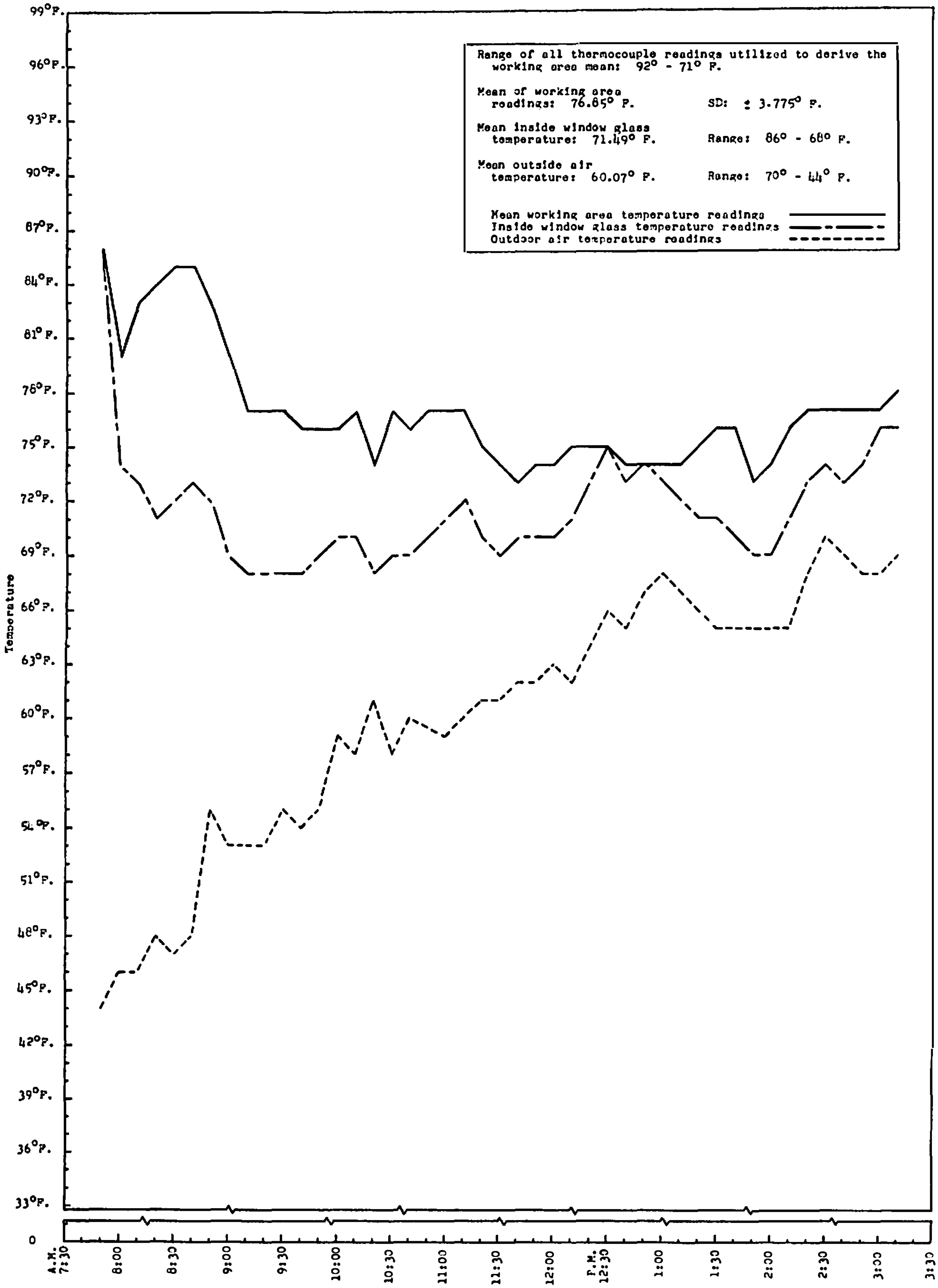


Figure 7. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom B-2.

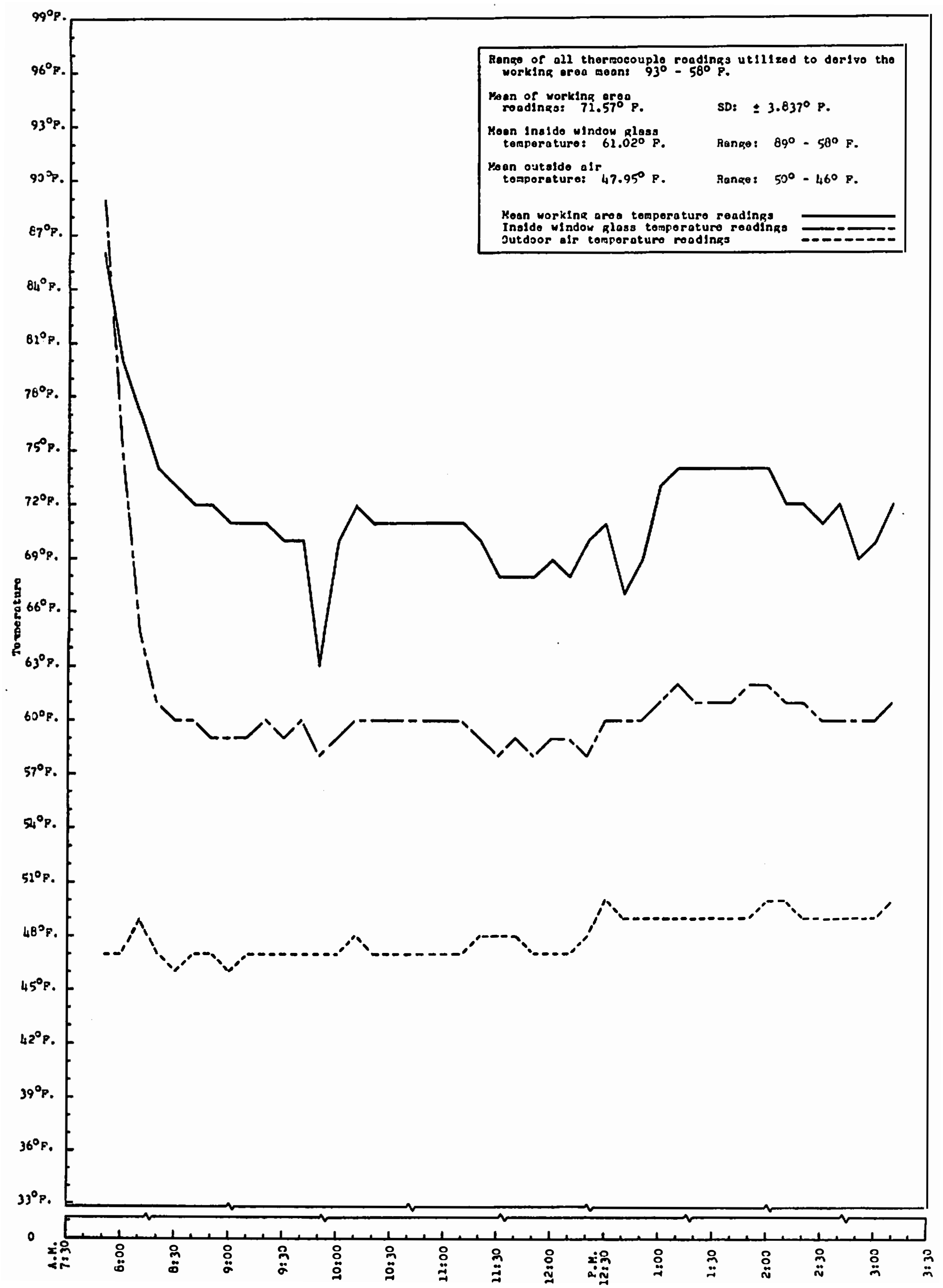


Figure 8. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom B-3.

classroom, even though the conditions shown were far from ideal. The working area conditions shown in Figure 8, page 175, were produced even though boiler operation was suspended from 8:00 a.m. to 11:50 a.m. and the hand valve in the classroom was in the off position for the remainder of the day although the highest outside temperature recorded was 50°F. The reader also must remember that there was no sunshine. There were a few complaints about the coldness of the classroom when the children returned from morning recess to find a mean temperature of 63°F., but heat from the children plus less heat loss because a few windows were closed raised the working area temperature seven degrees in five minutes. There were no more complaints throughout the day.

Criterion 1 was met inadequately in Classroom B-3, thus permitting none of the three classrooms in School B to meet the criterion. The mean thirty-inch temperature of 72°F. was acceptable but the dispersion from the mean as illustrated by the range and standard deviation really tended to make the mean meaningless.

Classroom C-1. Figure 9 illustrates air temperature that varied only ±2 degrees. With outside air conditions nearly constant, however, and no sunshine, the primary variables with which the heating and ventilating system had to cope were those inside the classroom. Criterion 1 was completely met.

Classroom C-2. Figure 10, page 178, is a classic portrayal of the operation of a unit ventilator on a very warm day. The custodian, anticipating a very warm day from the morning weather report, cut the

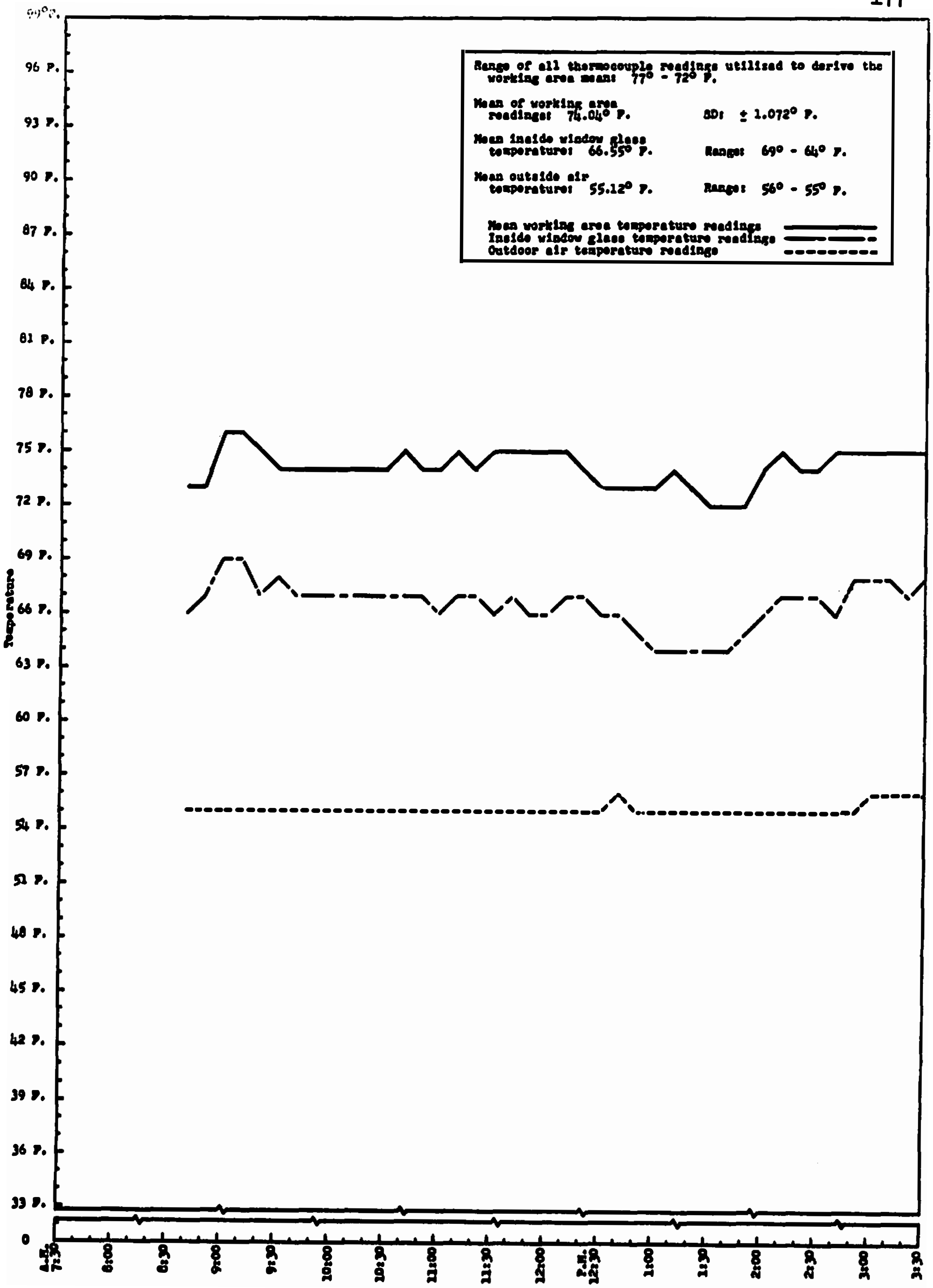


Figure 9. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom C-1.

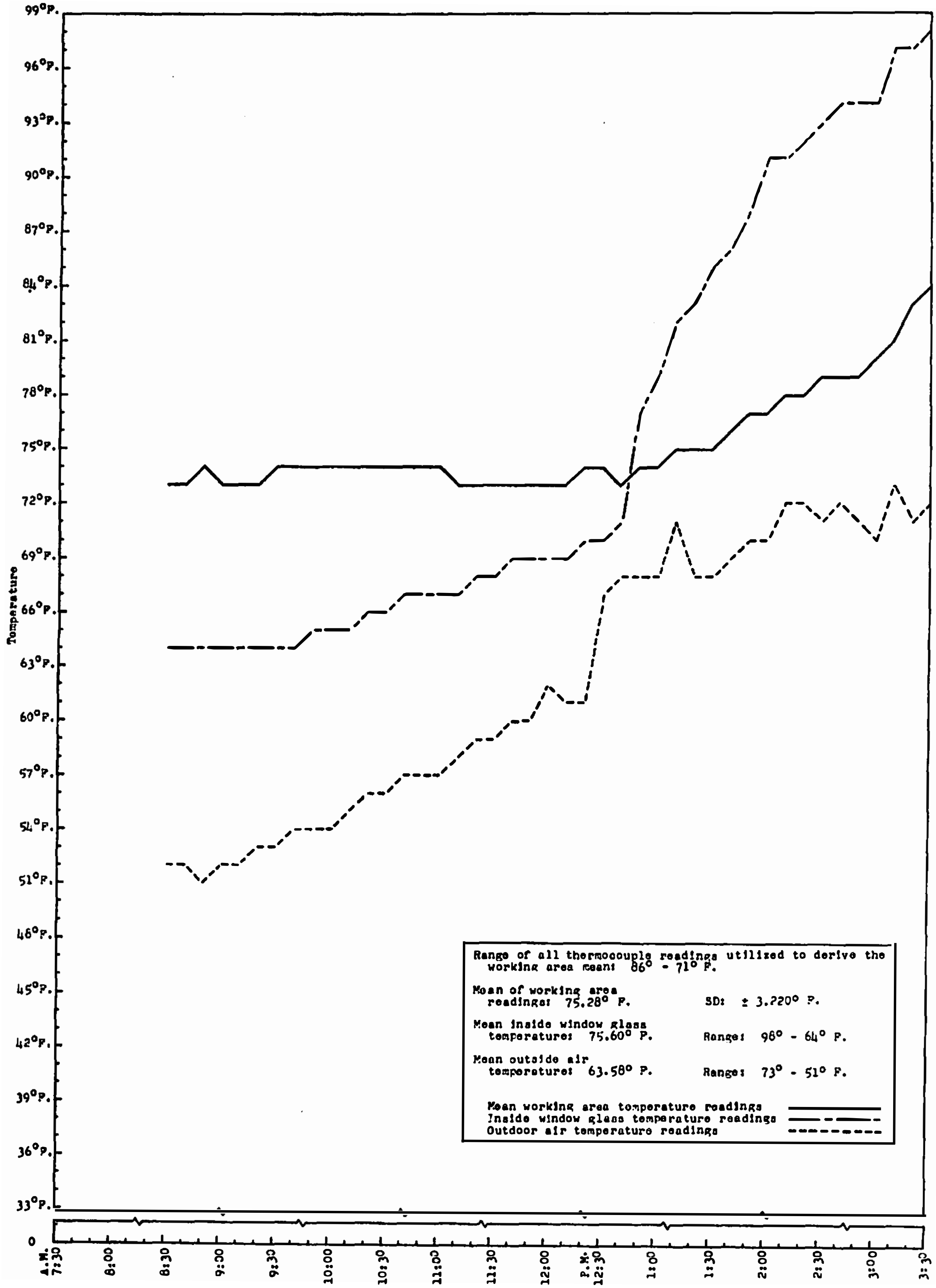


Figure 10. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom C-2.

boilers completely off at exactly 8:30 a.m. when the children began to come into the classrooms. The unit then utilized only recirculated room air and outside air for the remainder of the day. An assumption is made that conditions would have been the same if the heat had remained on.

From 8:30 a.m. until 1:00 p.m. the mean working area temperature varied only one degree even though the outside temperature climbed sixteen degrees during the same period. At 1:10 p.m., though, the class had returned from lunch and sunlight was streaming directly into the room through the large windows. For the remainder of the day outside temperature was above 68°F., thus creating conditions that outside air could not solve. The unit ventilator was able to maintain perfect temperature conditions within the classroom even without any heat while the outside temperature was in the fifty's, and failed only when outside temperature reached the high sixty's.

Thermal conditions in Classroom C-2 did not meet Criterion 1 at all. Conditions were meeting the criterion completely, however, until the outside temperature reached 68°F.

<u>Classroom C-3</u>. The custodian again cut off the boiler after hearing the weather report for the day, this time at 9:15 a.m. Figure 11 shows the working area readings were generally within the optimum range even though the outside temperature reached 69°F. at 1:50 p.m. This was possible because of the cloudy condition that prevailed during the afternoon. Classroom C-3 conformed to the upper limits of the criterion completely.

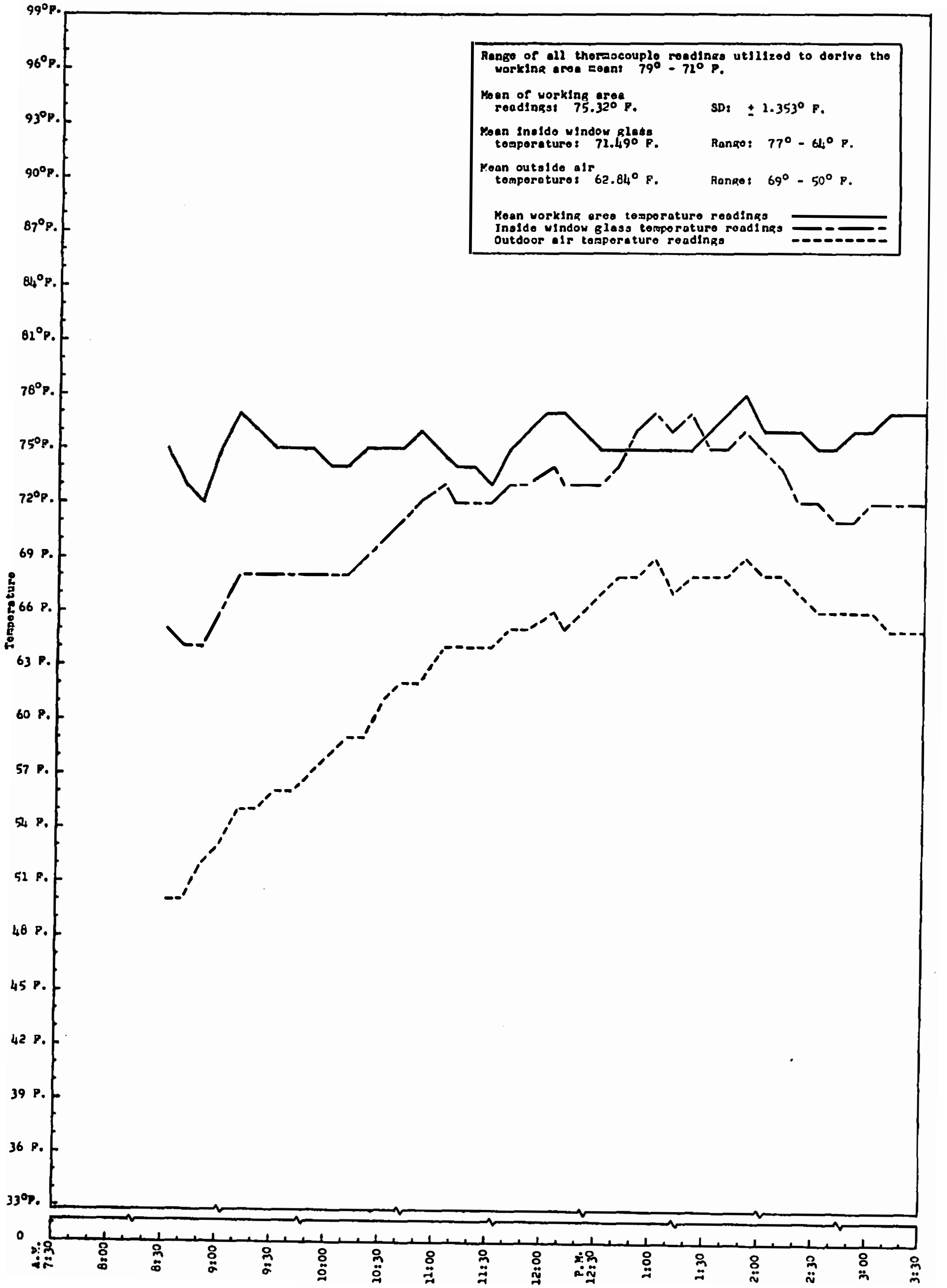


Figure 11. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom C-3.

<u>Classroom</u> <u>D-1</u>. One of the weaknesses of a zoned, central-direct fired system is evident in Figure 12. Even though the room was located on the north side of the building, thus allowing no sun through the windows, the mean working area had reached 80°F. by 1:30 p.m. when the outside temperature was only 66°F. This condition existed in spite of the low thermostat setting. An inference here would be that each room needs its individual fresh air supply for cooling. Classroom D-1 did not meet Criterion 1 at all.

<u>Classroom</u> <u>D-2</u>. Figure 13, page 183, indicates the type of room temperature conditions that would exist in nearly any situation when high outside air conditions and excessive glass unite to create unfavorable conditions. The children in Classroom D-2 probably were fortunate that the sun shone very little that day. Needless to say, room temperature conditions did not meet Criterion 1 at all.

<u>Classroom</u> <u>D-3</u>. With a mean outside temperature of only 48.62°F., with the highest temperature only 52°F., a north window orientation, and a cloudy day, temperature conditions in Classroom D-3 were very constant as evidenced by Figure 14, page 184. Air temperature conditions met Criterion 1 adequately, even though the thirty-inch mean temperature of 76°F. was one degree higher than the maximum criterion figure.

<u>Classroom</u> <u>E-1</u>. Air temperature conditions in electrically heated Classroom E-1 were similar to those found in Classroom D-3, as shown in Figure 15, page 185. With a north orientation and a three-foot window

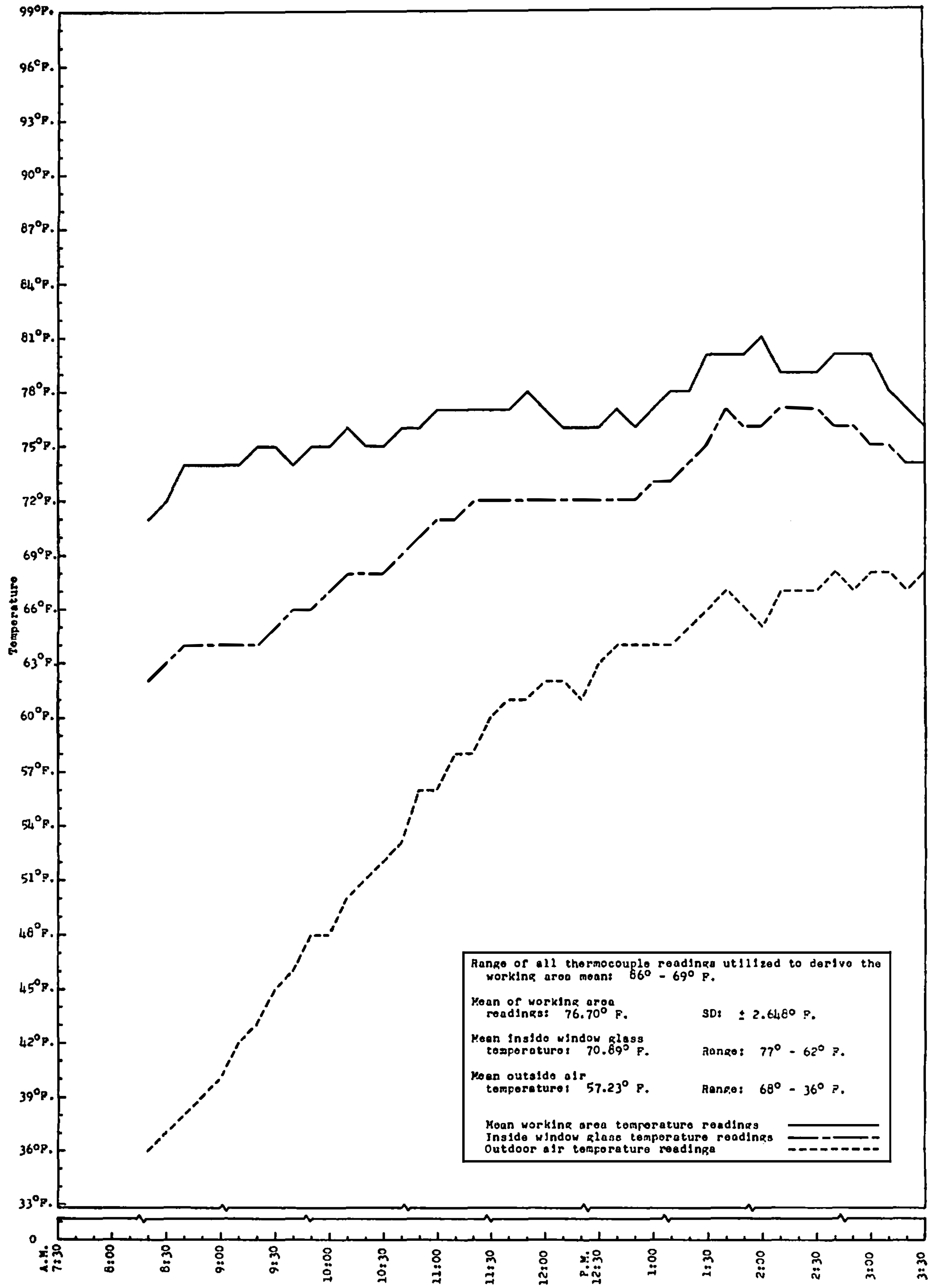


Figure 12. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom D-1.

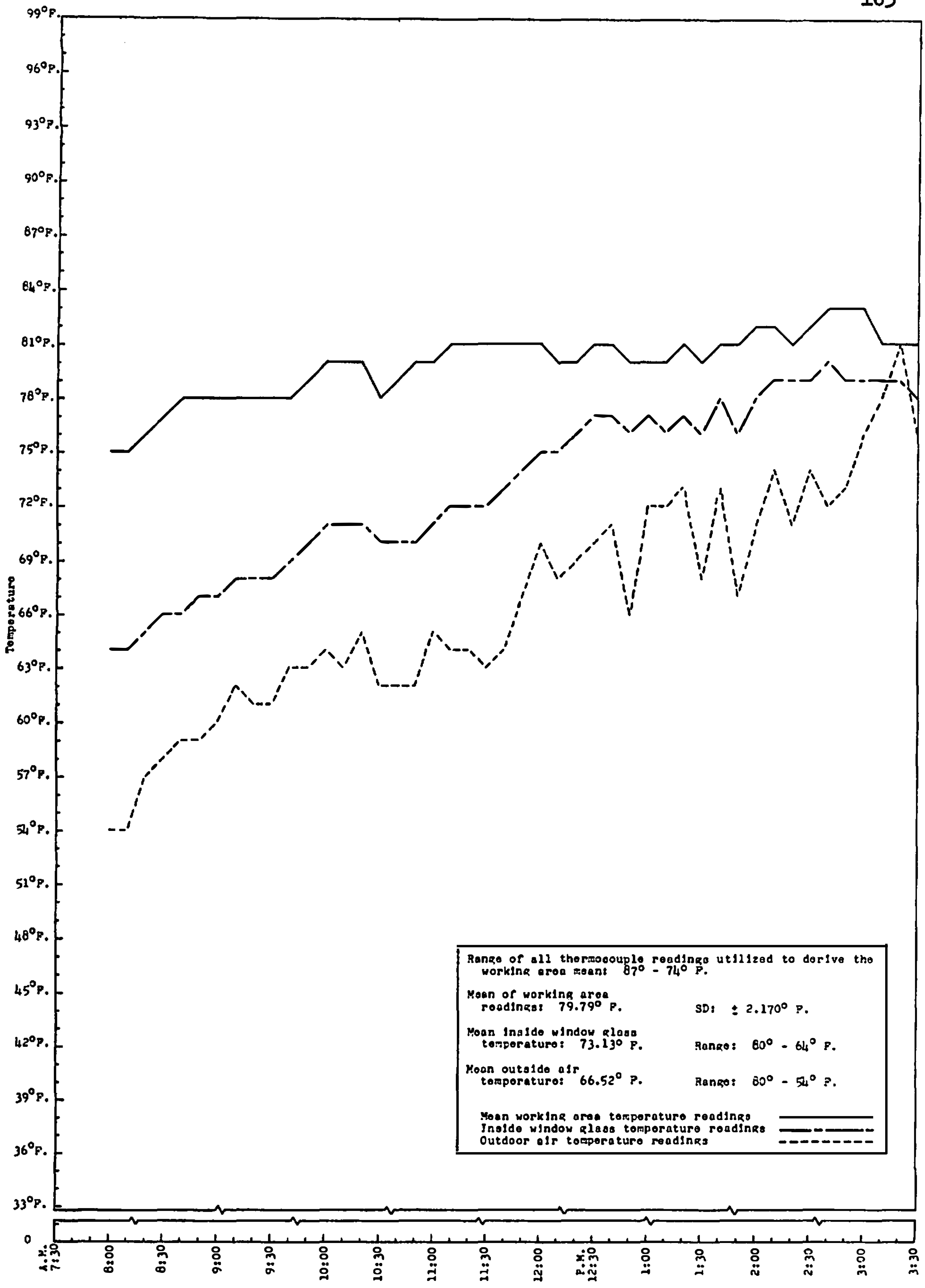


Figure 13. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom D-2.

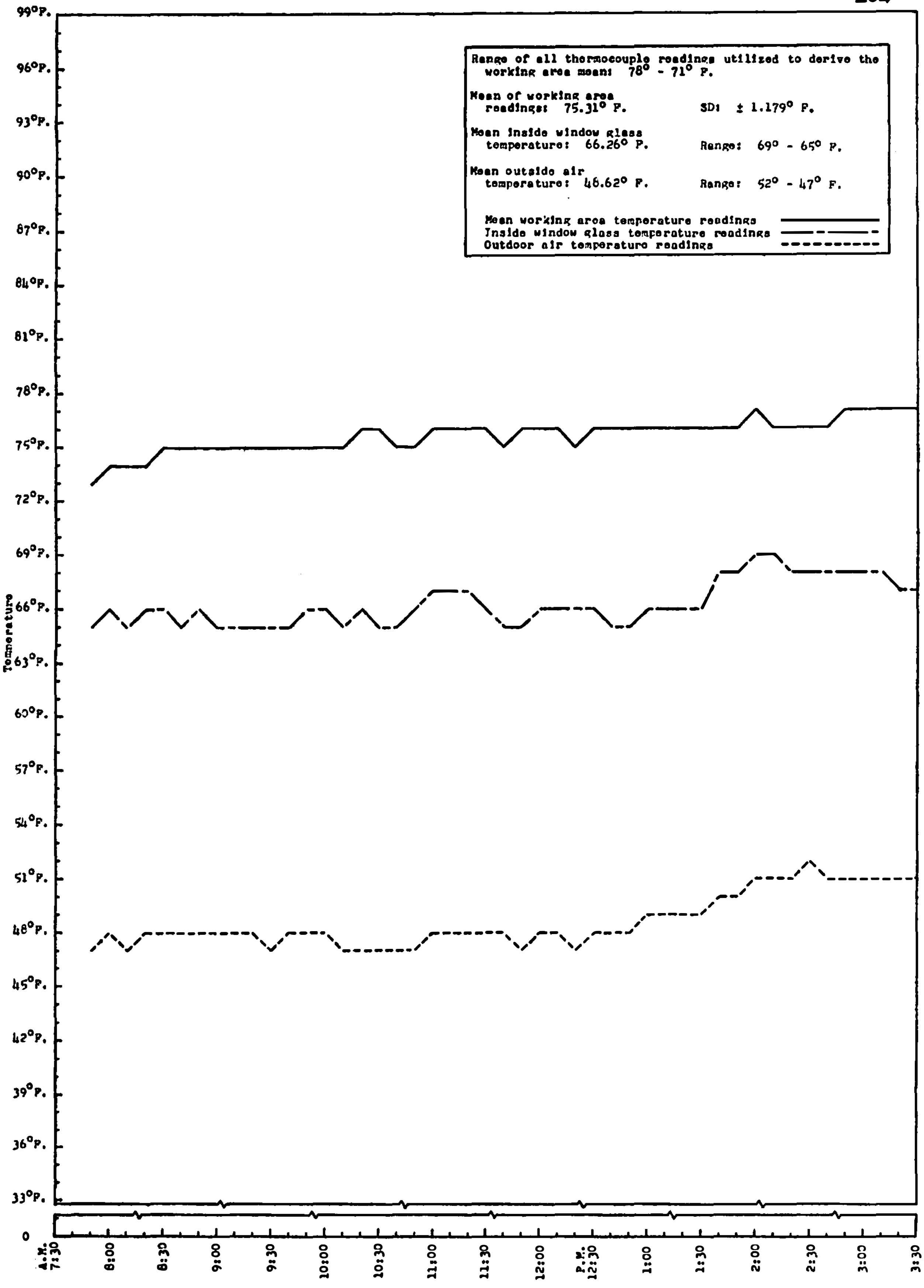


Figure 14. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom D-3.

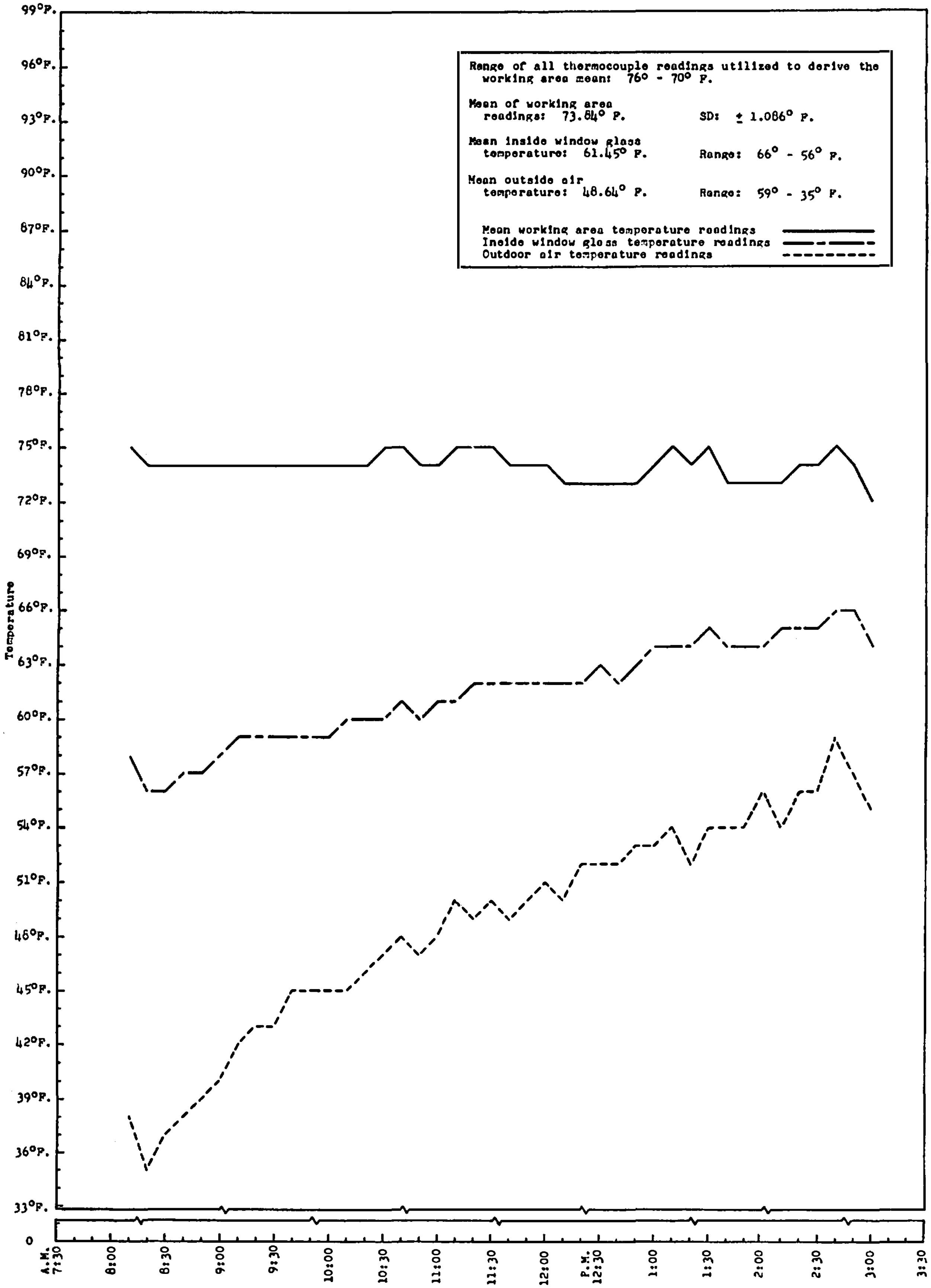


Figure 15. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom E-1.

overhang, no sun shone into the room throughout the day. Maximum outdoor temperature was 59°F. so classroom temperature conditions completely met Criterion 1.

Classroom E-2. Figure 16 again indicates some of the effects of solar gain upon the classroom. The room was slightly overheated throughout the day in spite of real attempts to cool by window ventilation, manipulation of the draw drapes that covered the 167 square feet of window area, and the fact that maximum outside temperature was only 64°F. The mean thirty-inch reading was only 75°F., but the 77°-72°F. range and the ±2.629°F. standard deviation indicate that the criterion was inadequately met.

Classroom E-3. Temperature conditions in Classroom E-3 were some of the worst found in any school. Figure 17, page 188, shows that the mean outside temperature was 67.57°F., with a low of 64°F. for the day, so any heating and ventilating system would have experienced difficulty. Fortunately, conditions were not aggravated by the sun. Although heat was not needed at all, the three baseboard units operated intermittently throughout the day, thus adding to the heat. With a mean temperature of 77°F. and a range of 84°-78°F., no component of Criterion 1 was met. With a standard deviation of ±1.175°F., however, the criterion was considered to have been met inadequately rather than not at all.

Classroom F-1. Even though rigid controls kept the supply of heat from the panel heating system under control, Figure 18, page 189,

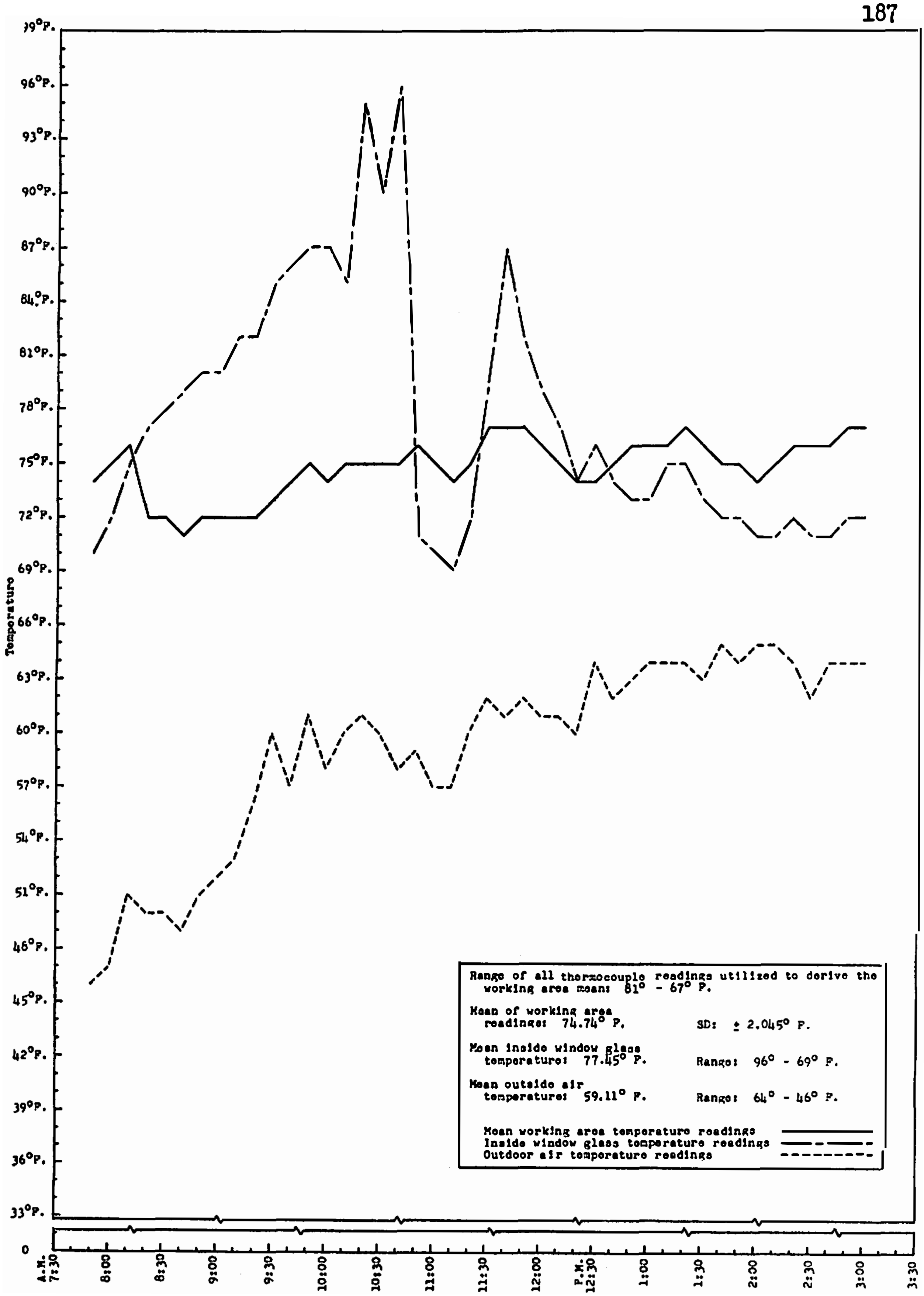


Figure 16. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom E-2.

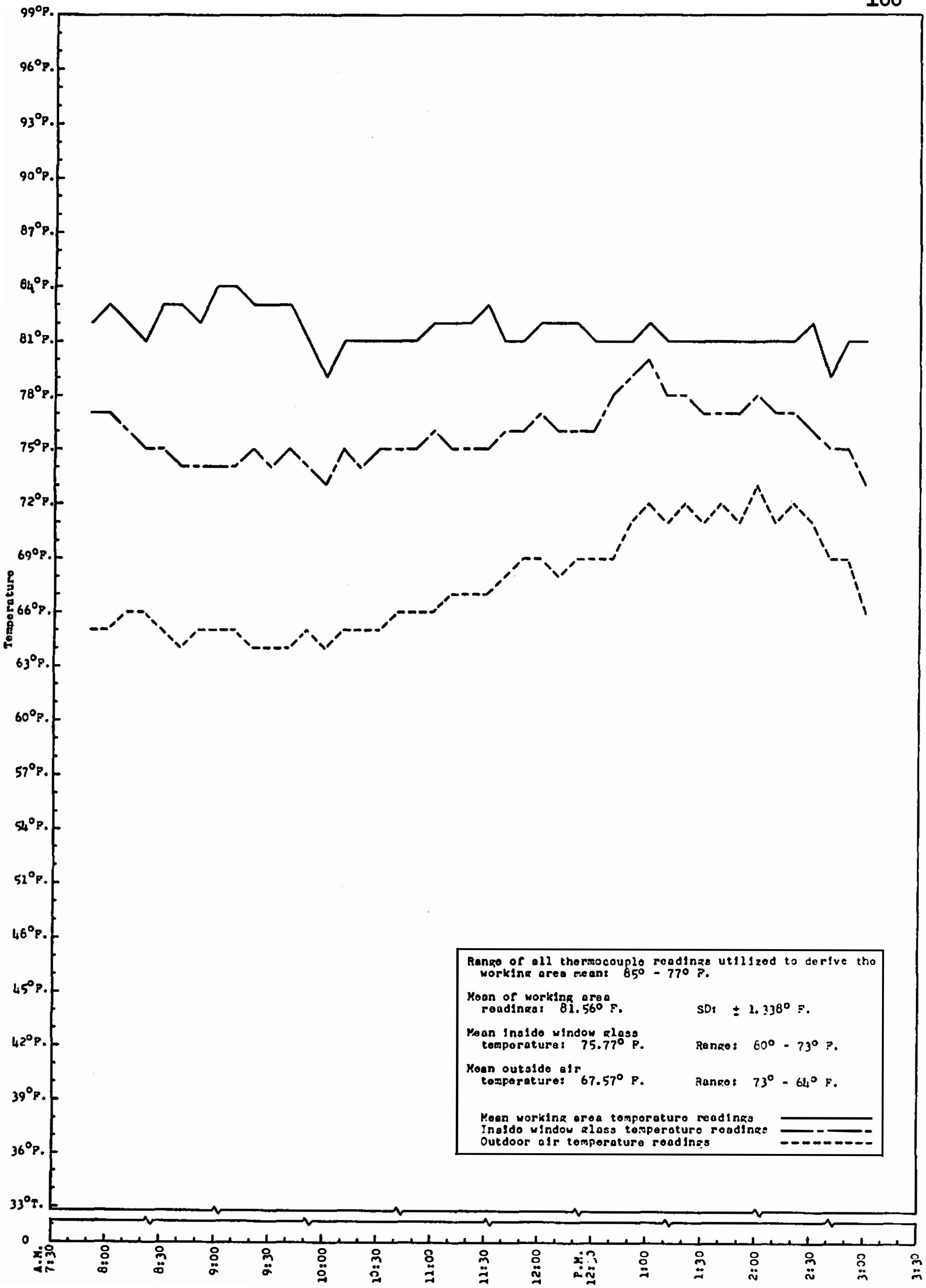


Figure 17. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom E-3.

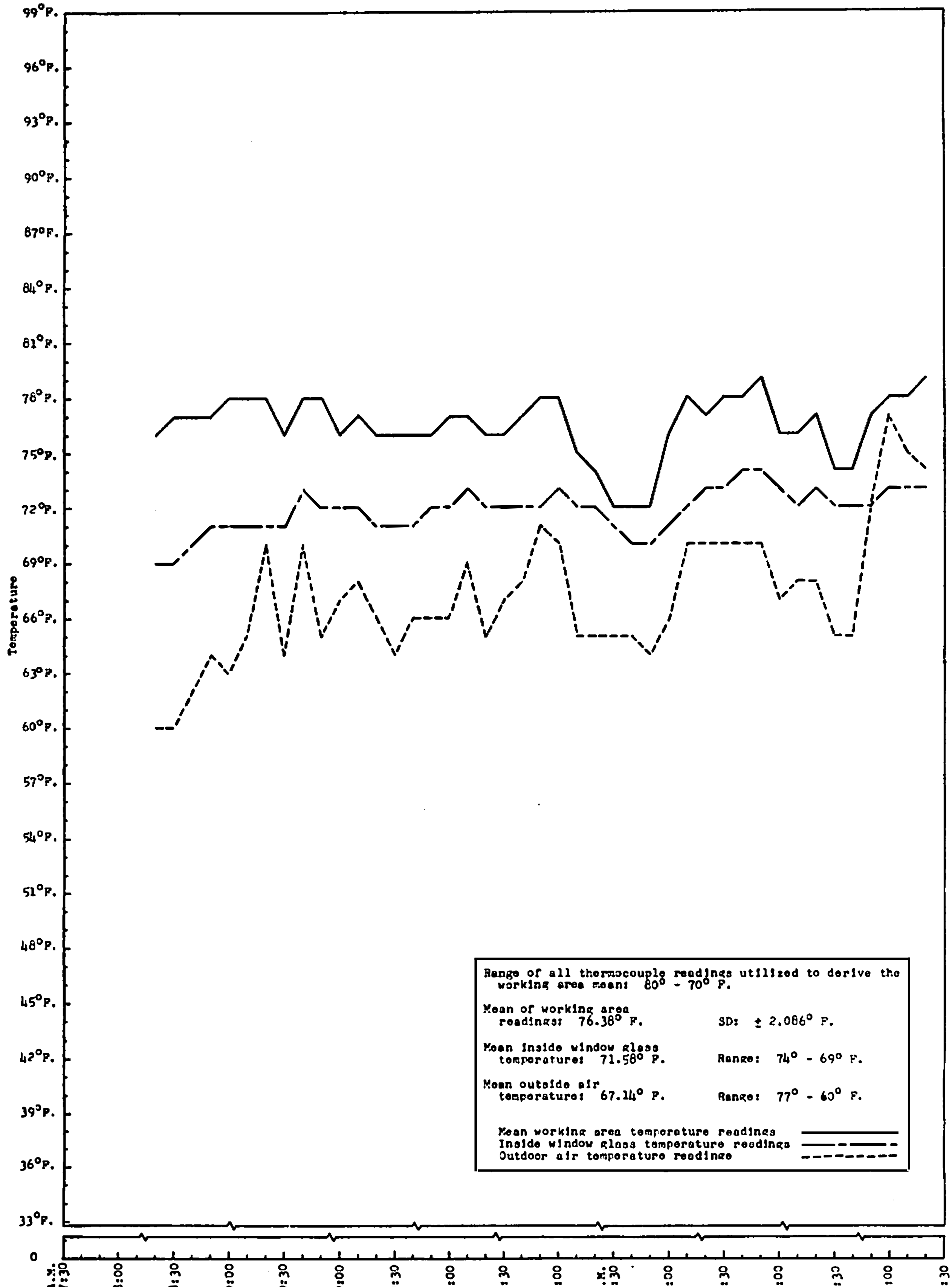


Figure 18. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom F-1.

shows again why a classroom needs no heat on days when the outside temperature rises above 60°F. The room temperature, without positive heat and with no window ventilation, was 76°F. when the outside temperature was 60°F. The low period of 72°F. beginning at 12:30 p.m. illustrates a fall in room temperature of six degrees when the class had gone to lunch. The mean thirty-inch temperature readings inadequately met the criterion.

Classroom F-2. A slightly more conscientious teacher in regard to classroom thermal environment was able to create slightly better temperature conditions than those that existed in Classroom F-1, even though Figure 19 indicates that outside temperature conditions were comparable. The teacher simply used window ventilation to a greater advantage and was aided by a higher wind velocity outside. As was true in Classroom F-1, the heating system supplied no heat. Thermal conditions were considered to have met Criterion 1 adequately, even though the range was 78°-71°F. The standard deviation was only ±1.493°F.

Classroom F-3. Figure 20, page 192, illustrates temperature conditions similar to several other north oriented classrooms with cloudy weather and low outside temperatures, regardless of heating system involved. The investigator considered the temperature conditions in Classroom F-3 to have adequately met the criterion even though the range of temperatures was too high (76°-67°F.).

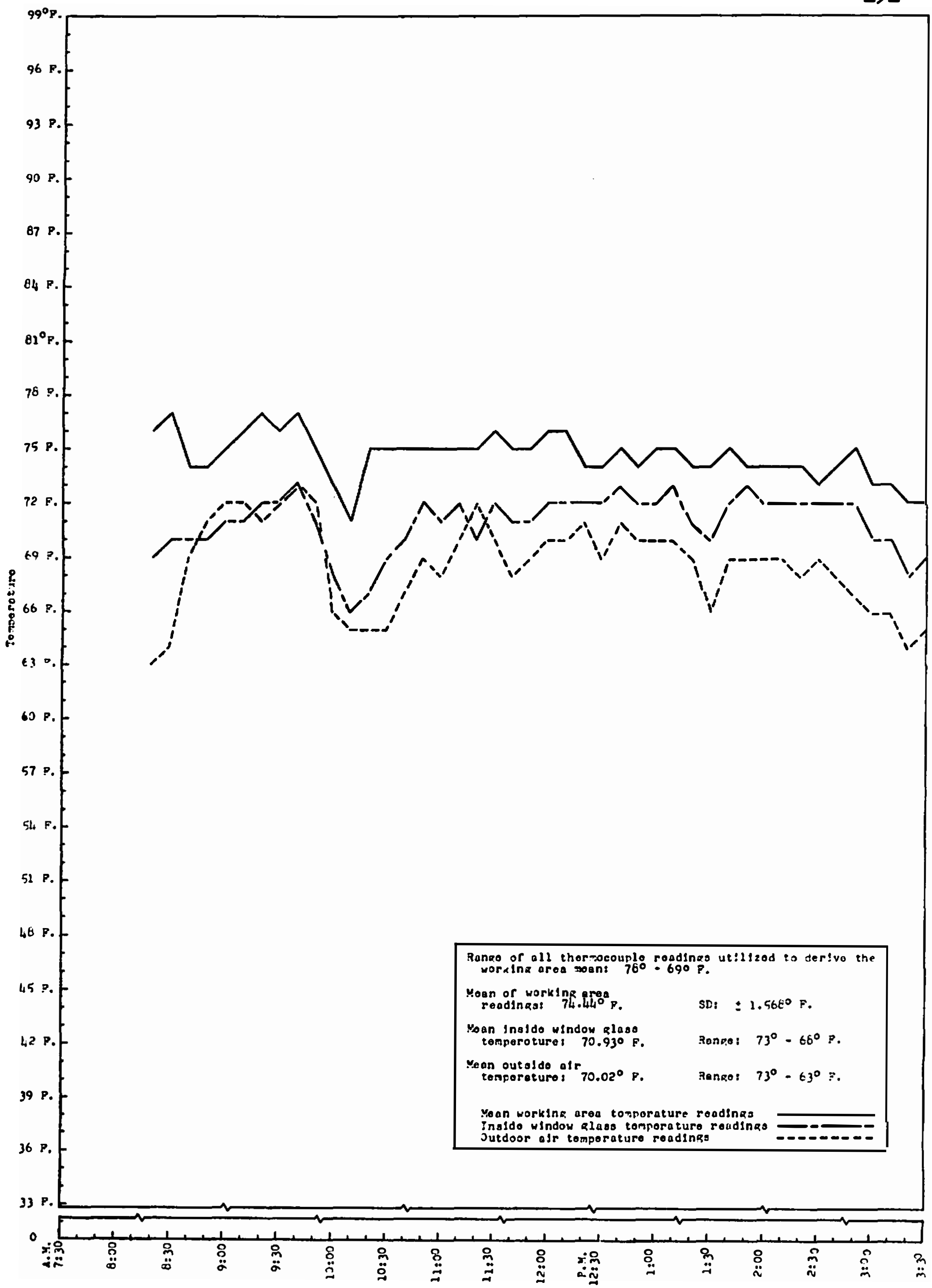


Figure 19. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom F-2.

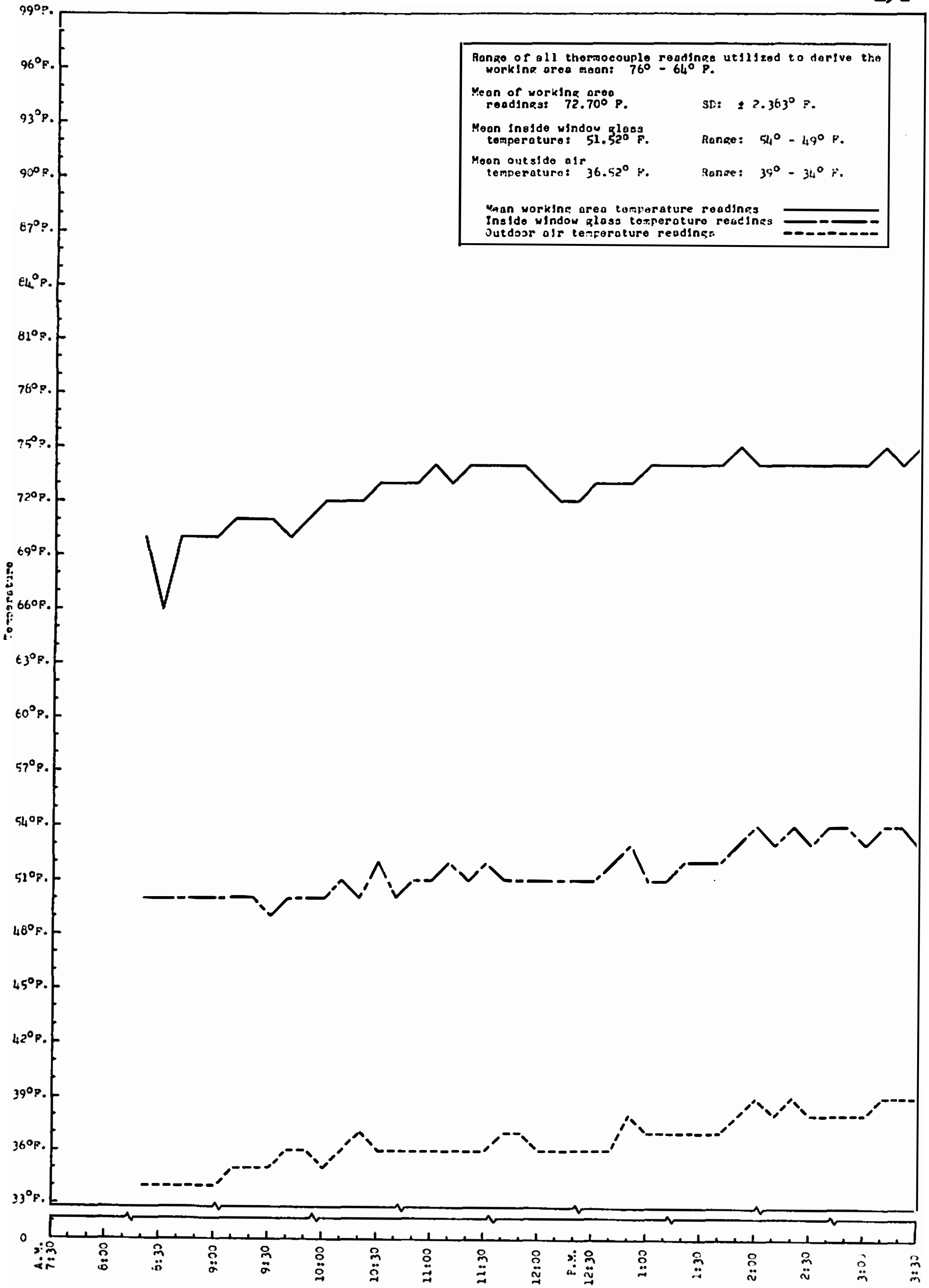


Figure 20. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom F-3.

Classroom G-1. Individual room controls, a north window orientation, a four-foot, nine-inch overhang, and window ventilation all interacted to create the somewhat favorable conditions in Classroom G-1 pictured in Figure 21. The mean thirty-inch temperature reading was 75°F., however, while the outside temperature was only 61°F. at the end of the school day. The investigator considered temperature conditions in Classroom G-1 to have met the criterion adequately although the range of 78°-70°F. was not acceptable.

Classroom G-2. With a mean of 77°F. and a range of 79°-73°F., the thirty-inch temperature conditions in Classroom G-2 were considered to have inadequately met Criterion 1. Figure 22, page 195, shows that the window glass temperature rose to a high of 82°F., but classroom temperature conditions did not rise proportionately as had been observed in other classrooms, probably because the blinds were drawn all day.

Classroom G-3. Classroom temperature conditions in Classroom G-3 also inadequately met Criterion 1 because both the mean thirty-inch temperature (76°F.) and range (78°-73°F.) were considered to be too high. Since the outside weather was cloudy and rainy, and the outside temperature was below 60°F. nearly all day, as shown in Figure 23, page 196, overheating could have been prevented by more adequate ventilation.

Classroom H-1. Figure 24, page 197, illustrates a classroom employing a unit ventilator for heating and cooling that did not completely control the room temperature at the desired level, even though the

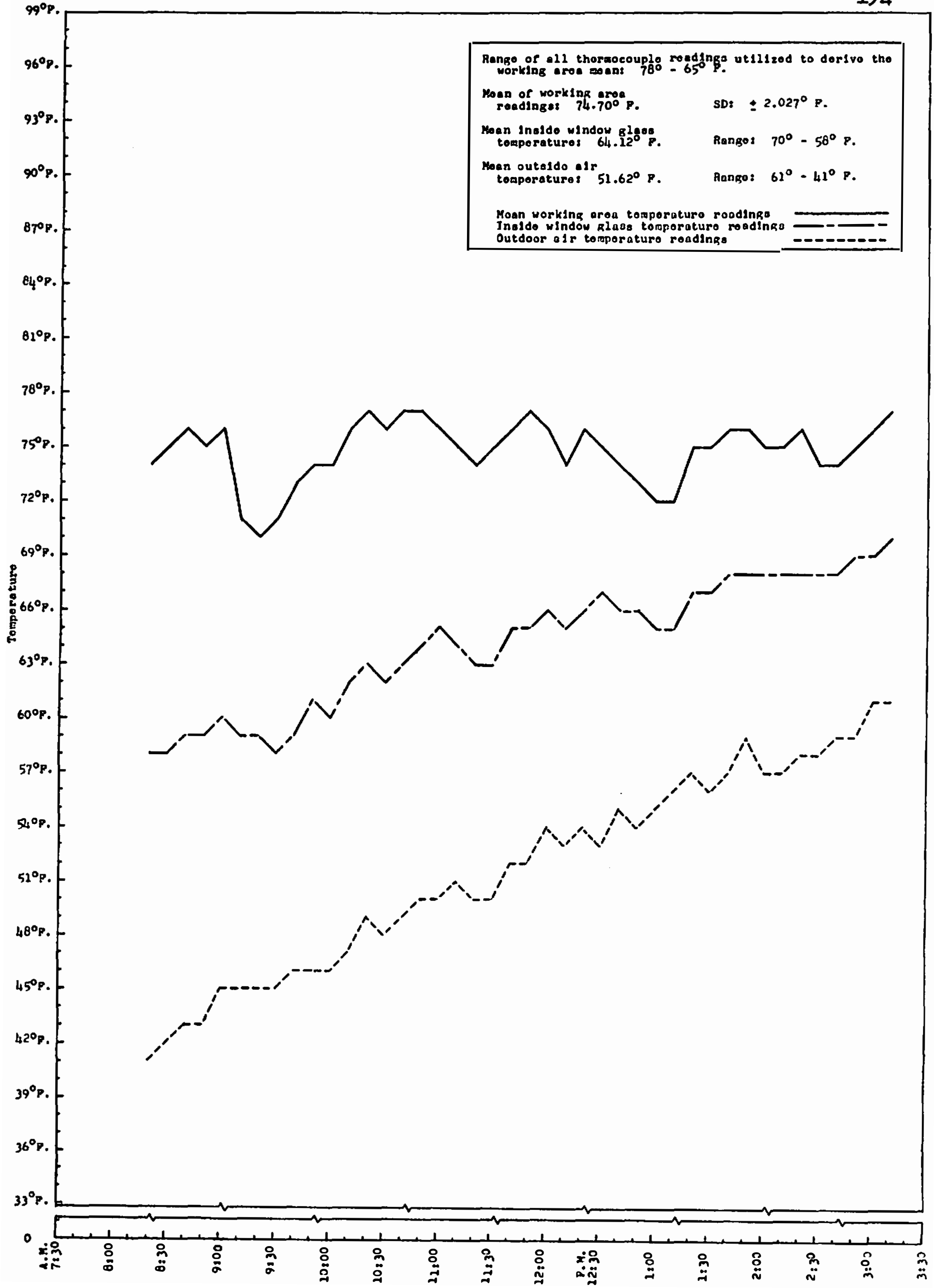


Figure 21. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom G-1.

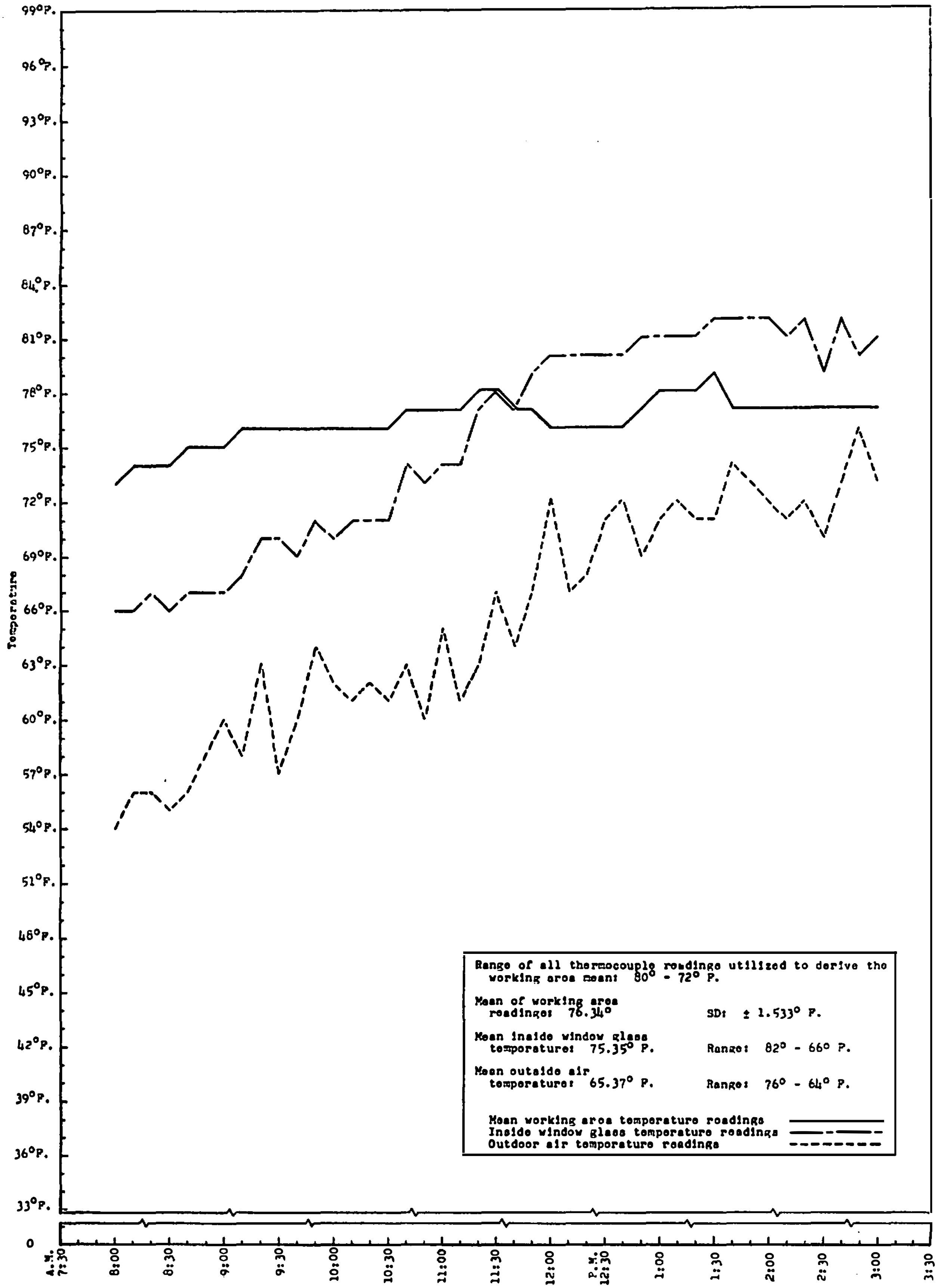


Figure 22. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom G-2.

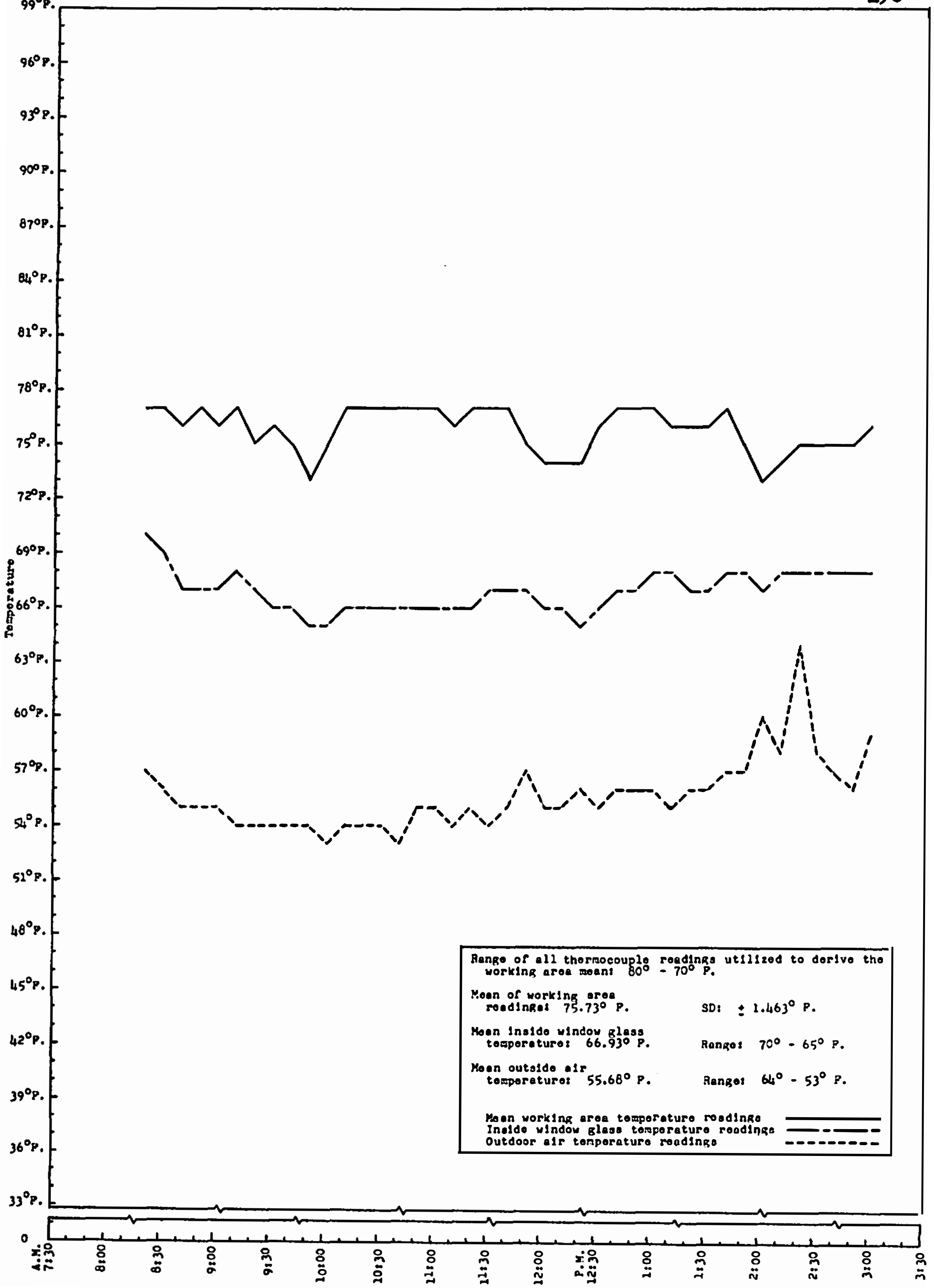


Figure 23. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom G-3.

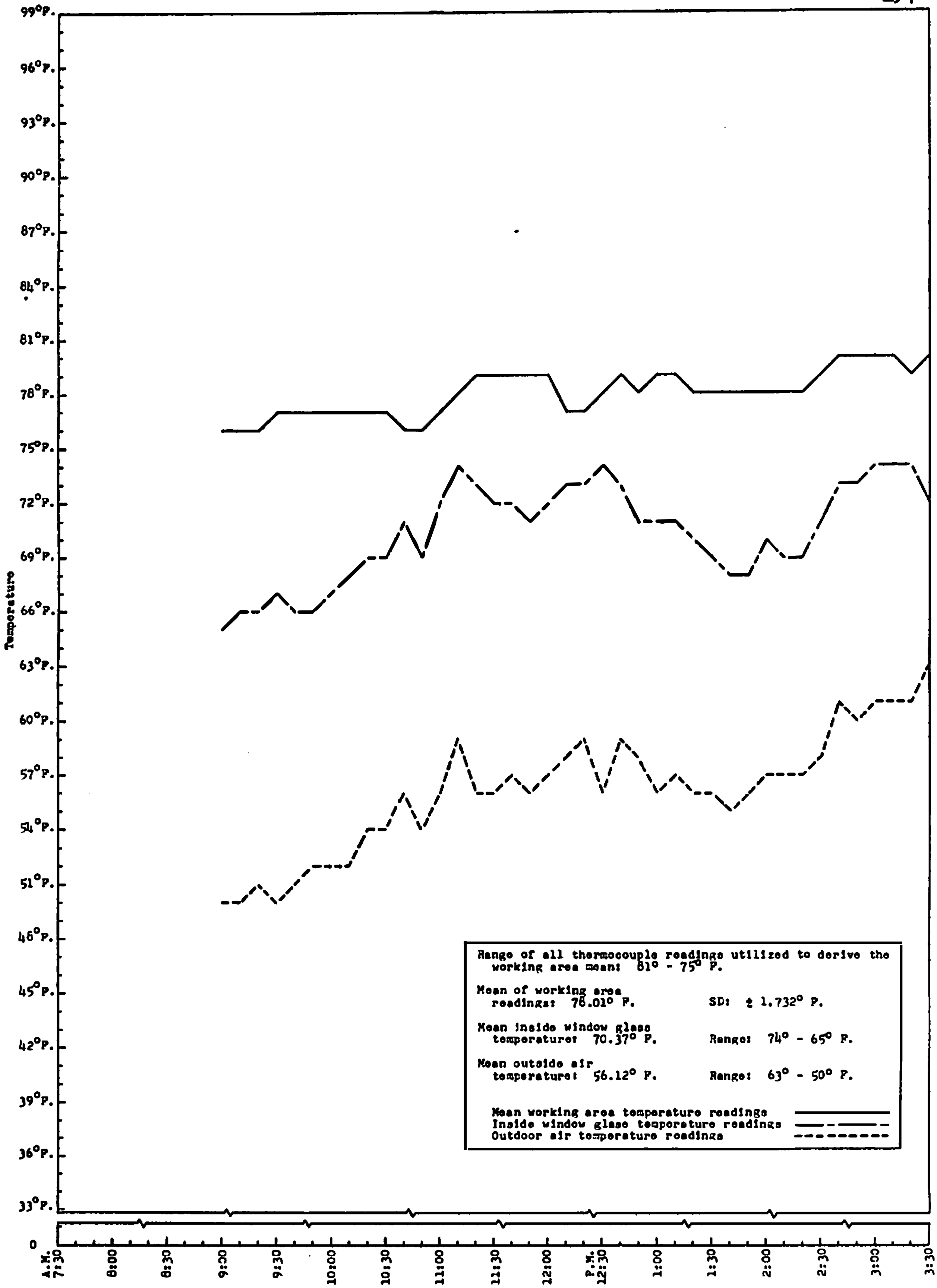


Figure 24. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for classroom H-1.

outside temperature only rose to 61°F. at 2:40 p.m. Investigation showed three factors that perhaps were jointly responsible for the overheating: (1) poor engineering in regard to the placement of hot water pipes throughout the building; (2) failure of the pneumatic thermostat to adequately admit outside air for cooling; and (3) failure of the custodial staff to clean the unit filters for seven months.

In spite of the overheating, the investigator considered the criterion to have been met adequately because of the four-degree range and the low standard deviation of ±1.229°F.

Classroom H-2. Figure 25 shows that Classroom H-2 was slightly overheated also, but that the temperature was quite constant. The same factors that produced the overheating in Classroom H-1 were responsible for the slight overheating in Classroom H-2. The classroom seems to have met Criterion 1 adequately, however, even though the mean thirty-inch reading was one degree high at 76°F.

Classroom H-3. Upon the request of the investigator, the custodial staff of School H cleaned the unit ventilator filters before the day's investigation began. The results depicted in Figure 26, page 200, were much more satisfactory than those found in Classrooms H-1 and H-2. Some teen-age girls complained about being too cold, however, when the mean working area temperature registered 71°F. from 12:50 p.m. to slightly after 1:00 p.m. Other girls in the room were questioned then, and the responses were that they were comfortable.

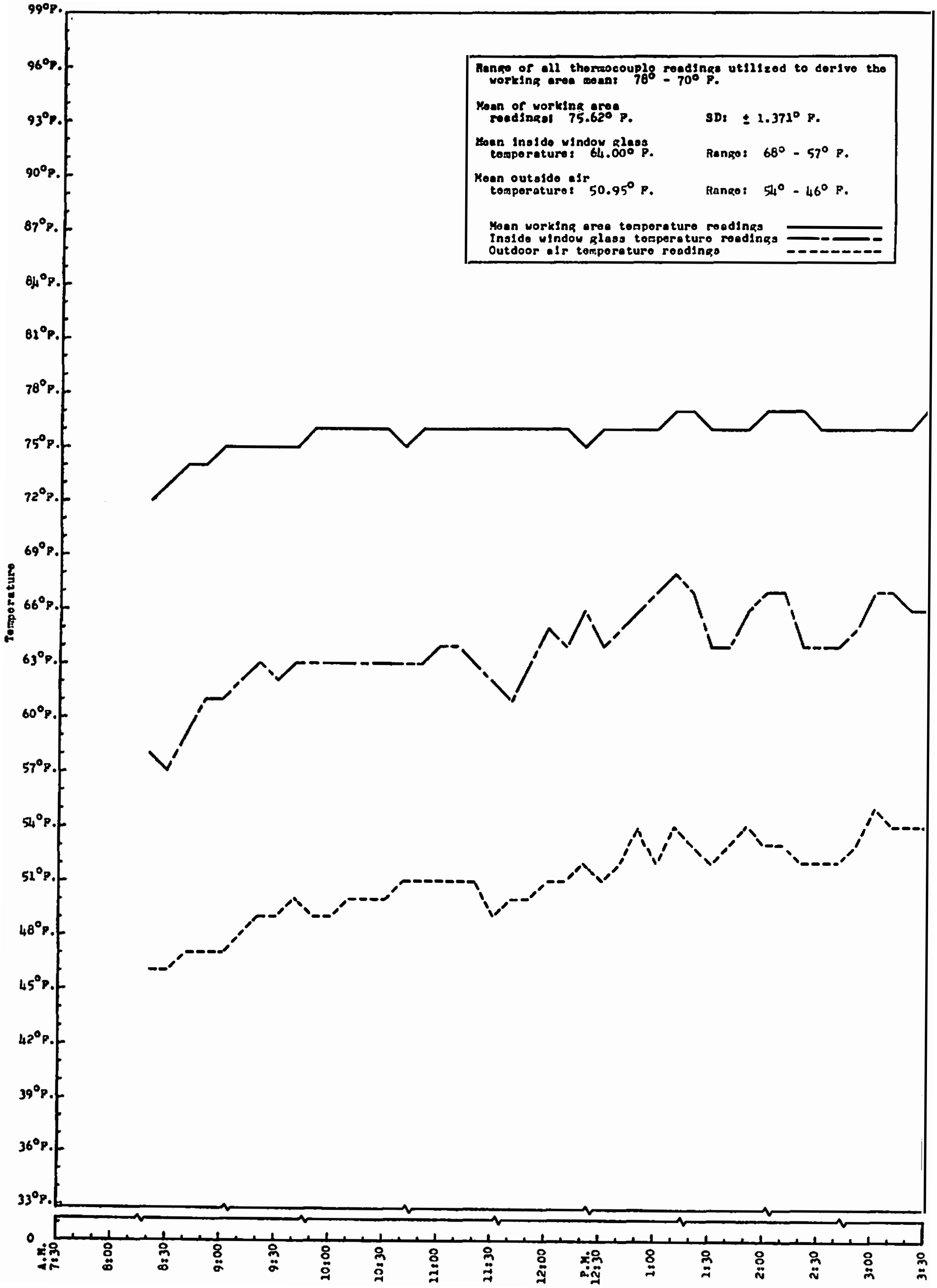


Figure 25. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom H-2.

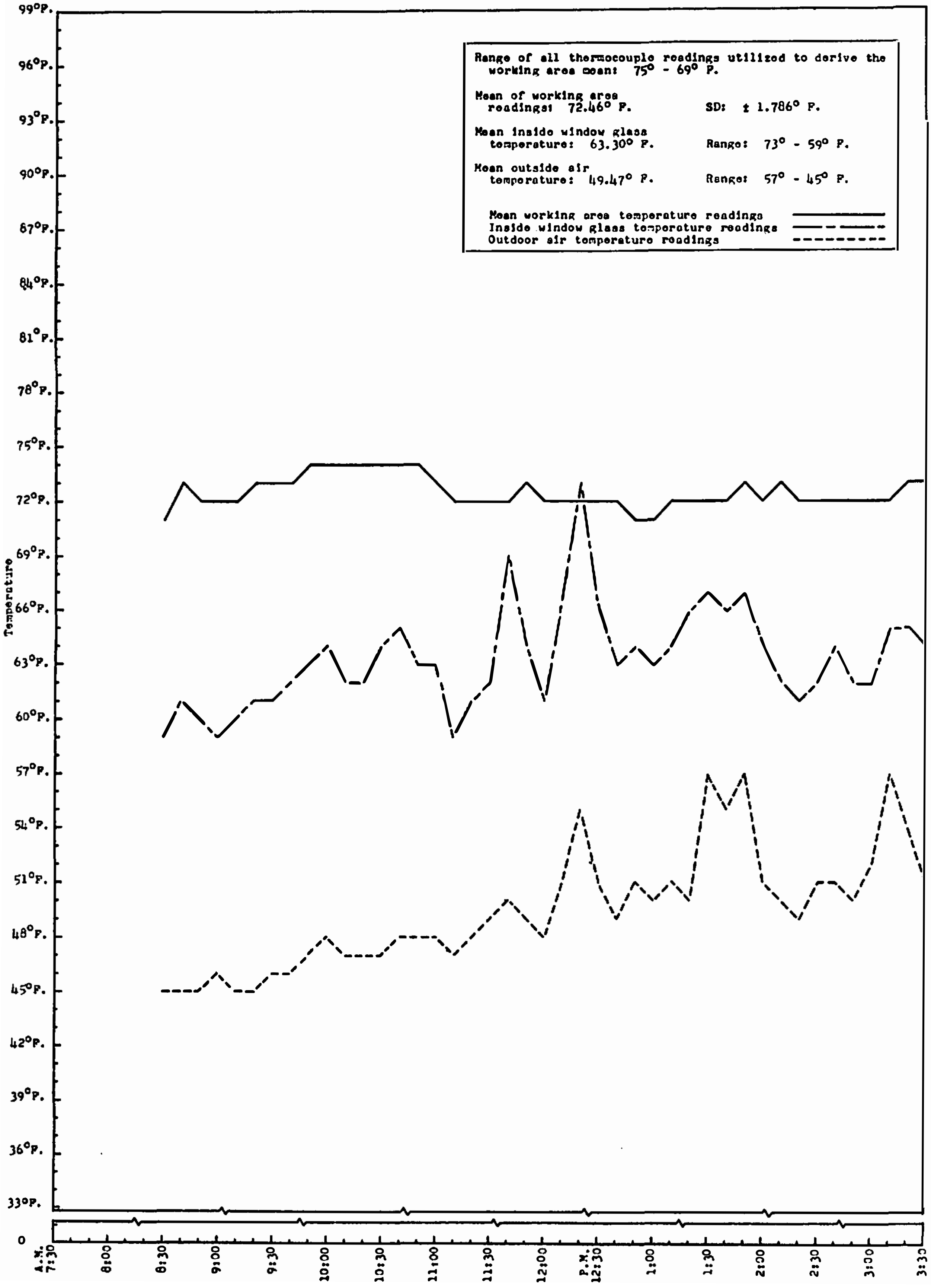


Figure 26. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom H-3.

Thermal conditions reported in Classroom H-3 met the standards of Criterion 1 in every way.

Classroom I-1. The mean thirty-inch Classroom I-1 temperature of 75°F. is quite misleading when one notes the 80°-72°F. range and the ±2.343°F. standard deviation of the thirty-inch readings. The investigator considered temperature conditions to have met Criterion 1 inadequately.

Figure 27 illustrates the fact that temperatures had already risen above the desired level even before the outdoor temperature reached 61°F. The brief effect of sunshine upon the windows in the afternoon is shown also.

Classroom I-2. Figure 28, page 203, adequately illustrates the effect of manually controlled convectors that are permitted to operate most of the day while the room temperature demands cooling. When the mean working area temperature reached 83°F. in the afternoon, the second graders were complaining about being too hot. By 1:00 p.m. the window glass temperature had reached 84°F. even though the sun did not shine all day. The window glass evidently was heated from the convectors. Classroom I-2 did not meet Criterion 1 in any way because of the 78°F. mean, 84°-74°F. range, and ±3.203°F. standard deviation.

Classroom I-3. Figure 29, page 204, shows that the mean working area temperature of Classroom I-3 had reached 80°F. at 9:30 a.m. while

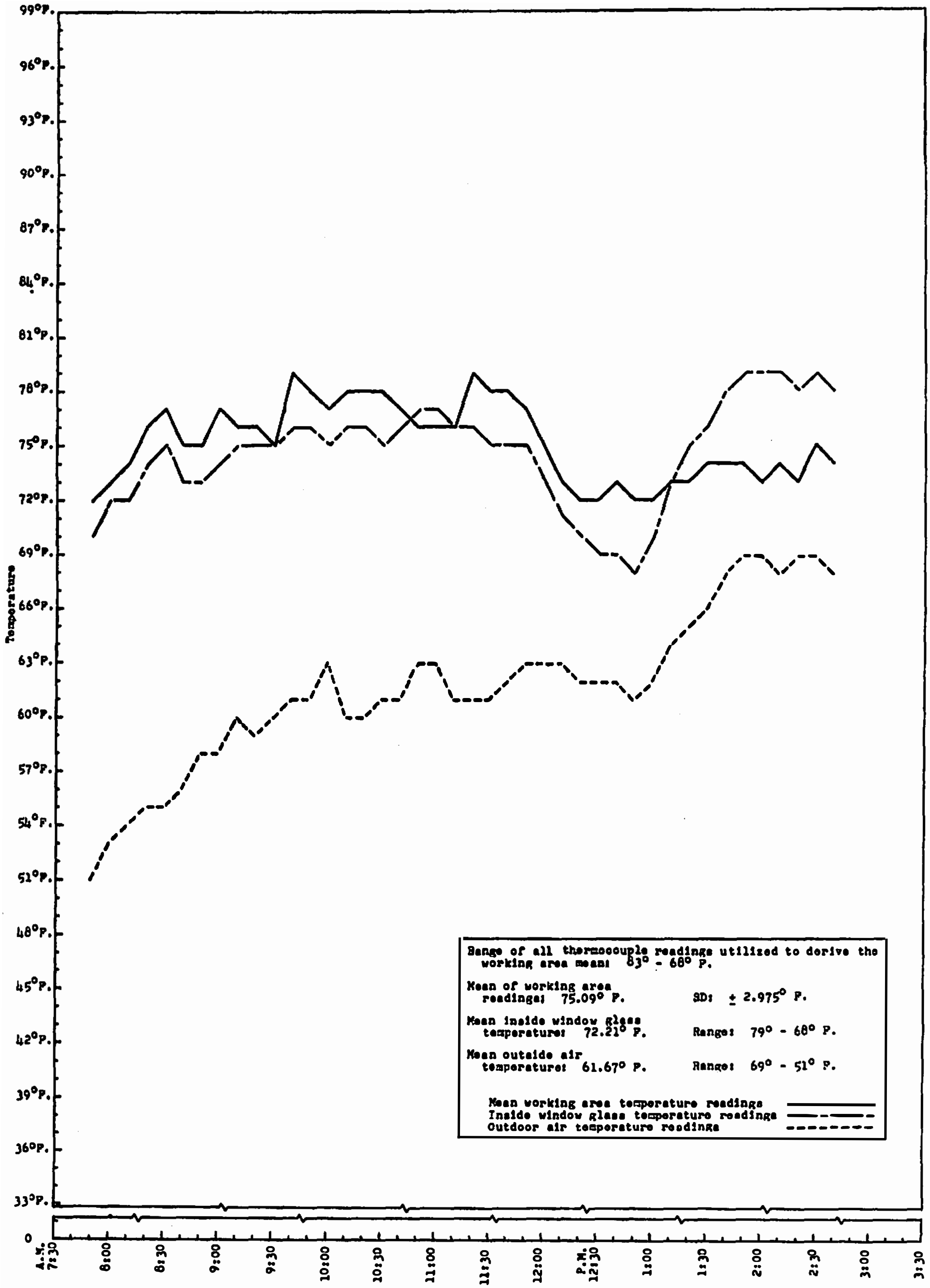


Figure 27. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom I-1.

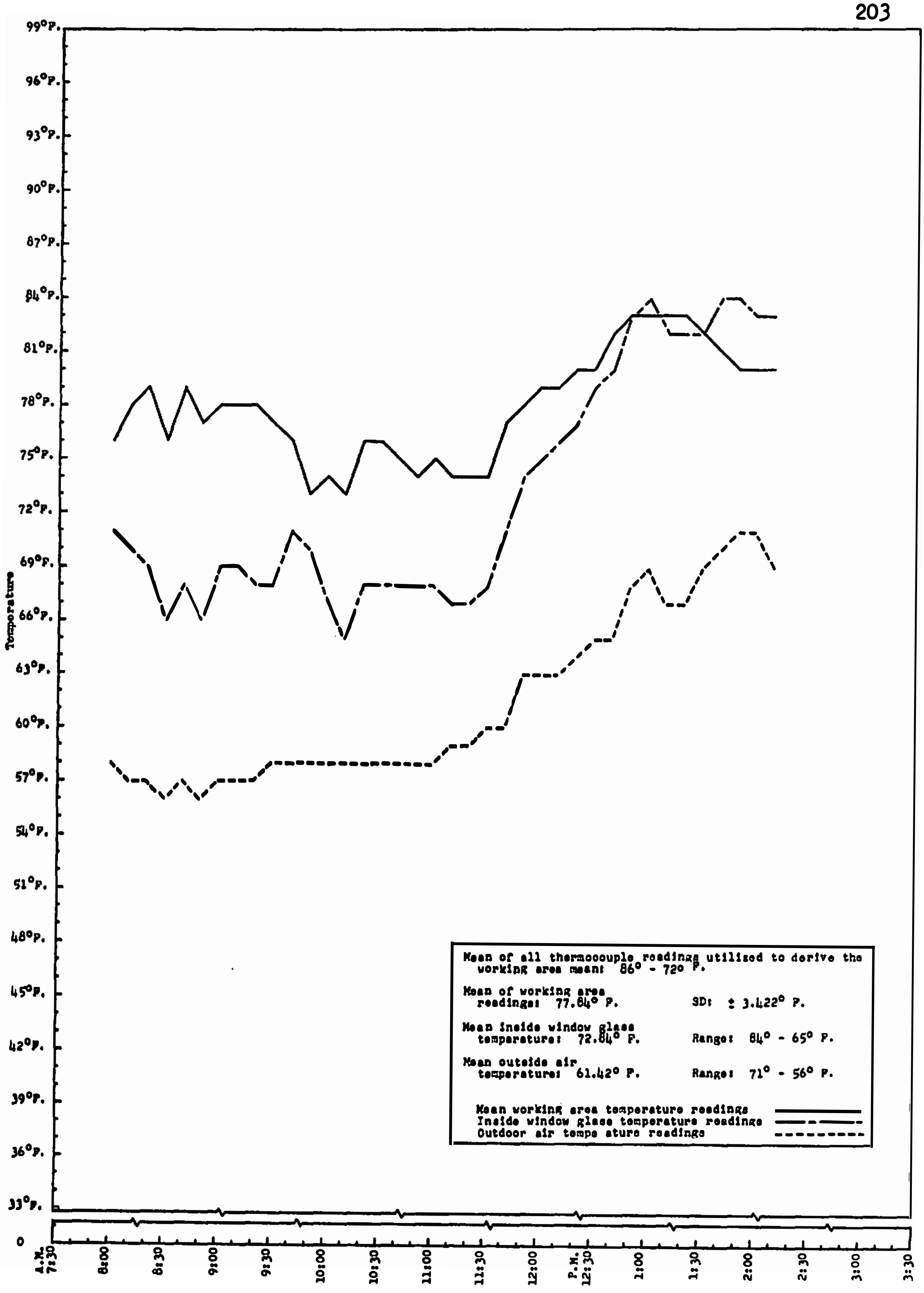


Figure 28. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom I-2.

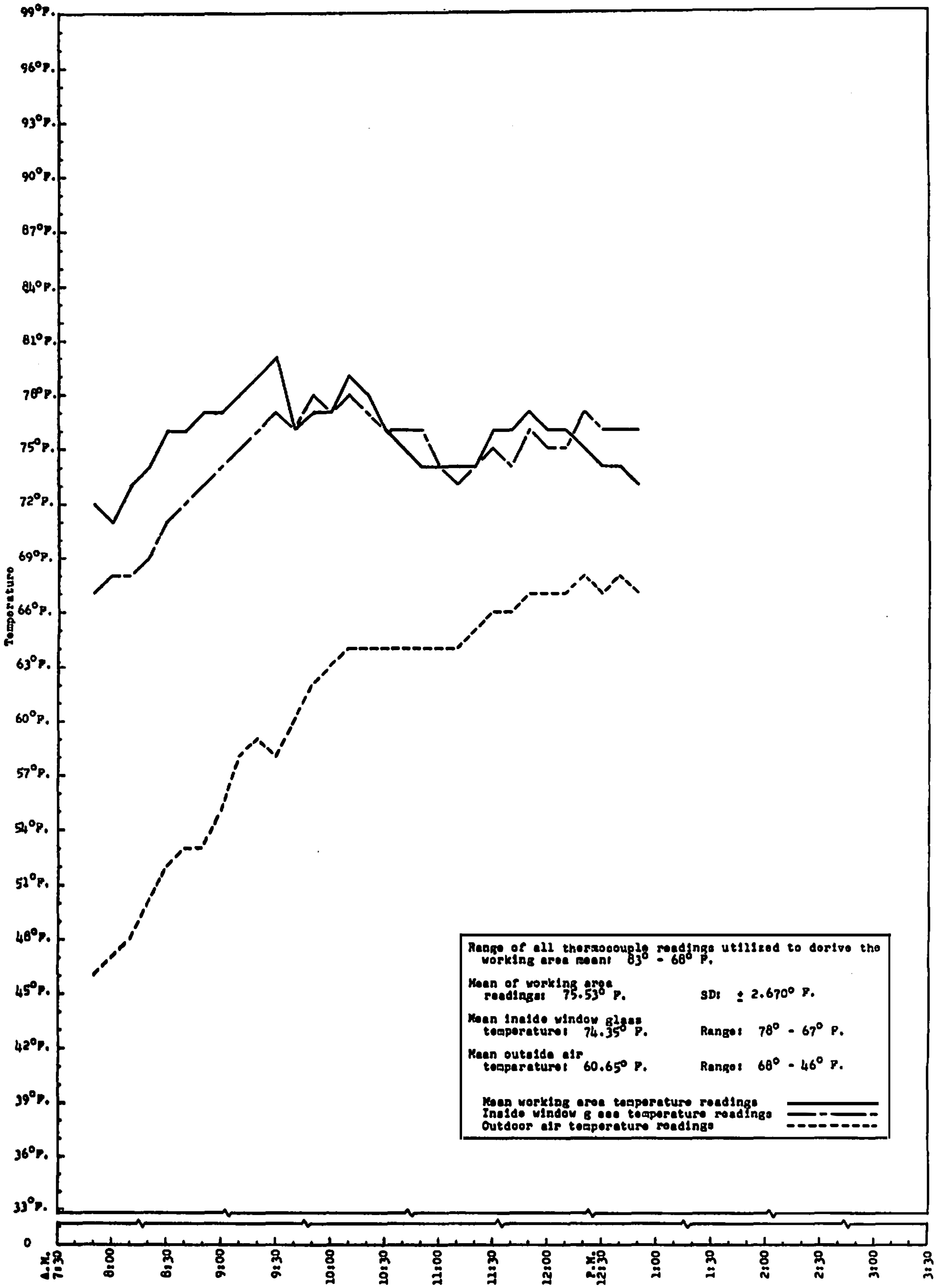


Figure 29. Comparison of thermocouple temperature readings of the classroom working area, inside window glass, and outside air for Classroom I-3.

the outside temperature was only 58°F. With hardly any ventilation to supply cooling, the criterion was not met in any way.

Earlier in the chapter, mention was made that all criteria did not lend themselves to as rigid an analysis of the data as did Criterion 1. Because air temperature is such an important element of the thermal environment an evaluation of room temperature conditions in terms of the type of heating system employed seems appropriate. The reader must keep in mind, however, the following limitations of such a comparison: (1) air temperatures were judged in light of Criterion 1 with the assumption that all other factors were favorable, since each factor was assessed separately. This assumption was not always a valid one; (2) the temperature conditions found in each classroom represented only the readings of that room for one particular day; and (3) thermal data were not collected for any two rooms on a single day.

Considering the above limitations, the following percentages of rooms utilizing various heating systems were found to completely or adequately meet Criterion 1: (1) unit ventilators, 88.9 per cent (8 out of 9); (2) radiant heat, 11.1 per cent (1 out of 9); (3) central direct-fired air system, 33.3 per cent (1 out of 3); (4) electric baseboard, 33.3 per cent (1 out of 3); and (5) hot water floor panel, 66.7 per cent (2 out of 3).

C. ANALYSIS OF THERMAL DATA PERTAINING TO THE MEAN RADIANT TEMPERATURE

Criterion 2. An ideal classroom temperature exists when both air temperature and mean radiant temperature are identical and within the optimum range. Since this situation does not always exist, some provision must be made for counteracting or eliminating the heat loss of the body to cold walls and windows.

Classroom mean radiant temperatures were not as easily analyzed as air temperature readings. The reader will recall that the mean radiant temperature was measured hourly at the thirty-inch level in Zones I and V. These findings are presented in graphs and a table and briefly discussed. Table XIII compares that data with the criterion, while Figures 30-38 compare the comparable air temperature, globe thermometer, and mean radiant temperature readings for each classroom.

Classroom A-1. Table XIII and Figure 30, page 208, both indicate that the mean of the hourly mean radiant temperatures in both zones exceeded the equivalent air temperature reading and the upper limits of the optimum range. Perhaps because of the feature employed in the unit ventilator to prevent downdrafts or because of small visual strip windows, the average mean radiant temperatures were nearly identical (.3 difference) for both zones. In order for the globe thermometer reading to have been within the optimum range, the air temperature should have been lowered.

TABLE XIII

COMPARISON OF THERMAL DATA WITH CRITERION 2

Classroom	Criterion Air temperature and mean radiant temperature identical and within the optimum range (70°F.-75°F.) Zone I (Readings at 30" level) Mean of hourly air temperatures	 Zone I (Readings at 30" level) Mean of hourly mean radiant temperatures	 Zone V (Readings at 30" level) Mean of hourly air temperatures	 Zone V (Readings at 30" level) Mean of hourly mean radiant temperatures
A-1	74.6°F.	79.0°F.	74.0°F.	78.7°F.
A-2	75.0°F.	77.0°F.	74.3°F.	76.2°F.
A-3	74.9°F.	77.0°F.	75.4°F.	82.3°F.
B-1	75.4°F.	78.5°F.	76.3°F.	78.4°F.
B-2	76.7°F.	79.4°F.	76.3°F.	79.5°F.
B-3	70.4°F.	74.4°F.	70.0°F.	73.0°F.
C-1	74.3°F.	73.8°F.	74.0°F.	72.7°F.
C-2	76.0°F.	75.8°F.	76.6°F.	77.0°F.
C-3	74.7°F.	74.8°F.	74.8°F.	74.8°F.
D-1	76.8°F.	78.8°F.	76.4°F.	76.0°F.
D-2	80.2°F.	80.4°F.	81.4°F.	90.1°F.
D-3	75.7°F.	76.0°F.	76.3°F.	75.0°F.
E-1	74.2°F.	74.4°F.	74.3°F.	74.5°F.
E-2	75.0°F.	75.4°F.	75.1°F.	80.7°F.
E-3	81.4°F.	82.2°F.	82.2°F.	88.3°F.
F-1	77.0°F.	77.3°F.	75.9°F.	74.9°F.
F-2	75.6°F.	76.2°F.	75.1°F.	77.5°F.
F-3	73.4°F.	73.5°F.	73.4°F.	69.9°F.
G-1	75.4°F.	74.7°F.	74.4°F.	74.6°F.
G-2	77.0°F.	75.8°F.	77.1°F.	79.2°F.
G-3	76.0°F.	76.6°F.	76.3°F.	76.1°F.
H-1	78.2°F.	78.1°F.	77.7°F.	77.9°F.
H-2	75.8°F.	76.0°F.	74.9°F.	74.9°F.
H-3	73.3°F.	74.7°F.	70.5°F.	71.1°F.
I-1	75.4°F.	76.3°F.	75.6°F.	76.3°F.
I-2	78.4°F.	80.4°F.	78.5°F.	81.4°F.
I-3	75.9°F.	76.4°F.	75.8°F.	77.1°F.

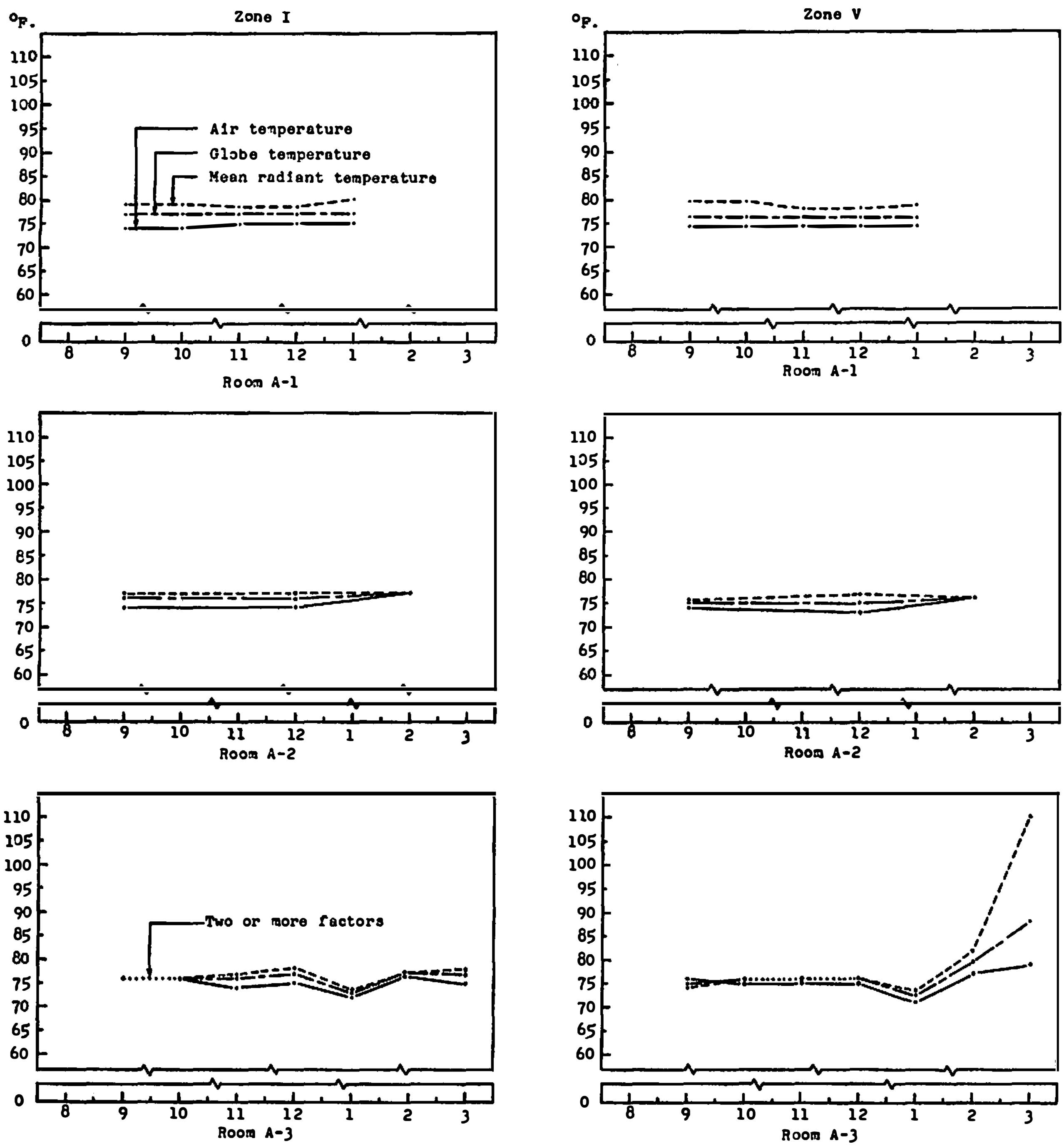


Figure 30. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School A.

Classroom A-2. With practically the same type of situation existing in Classroom A-2 as in Classroom A-1, as shown in Table XIII, page 207, and Figure 30, page 208, the same recommendation would have aided that particular situation, that is, a slight lowering of the air temperature within the room.

Classroom A-3. Thermal conditions in Classroom A-3 represent a different mean radiant temperature problem than the one that existed in Classrooms A-1 and A-2, but one which would have been encountered in those rooms had the sun shone any on the two days the two rooms were investigated. Table XIII, page 207, shows that the average mean radiant temperature of Zone V next to the window was over five degrees higher than the average for Zone I, while both mean radiant readings were higher than the air temperature readings for the same locations. This situation was brought about when the sun shone directly into the room bringing the globe reading up to 98°F. Lowering the room air temperature enough to compensate for the high mean radiant temperature in Zone V would have made the air temperature in Zone I too low. Perhaps venetian blinds over the windows would have kept out the solar effects.

Classroom B-1. Even though the heating system was not functioning, the mean radiant temperature in both zones of Classroom B-1 exceeded the upper limits of the optimum range as illustrated by Figure 31, page 210, and Table XIII, page 207. Some form of cooling other than outside air would have been necessary in order for the optimum conditions to have resulted.

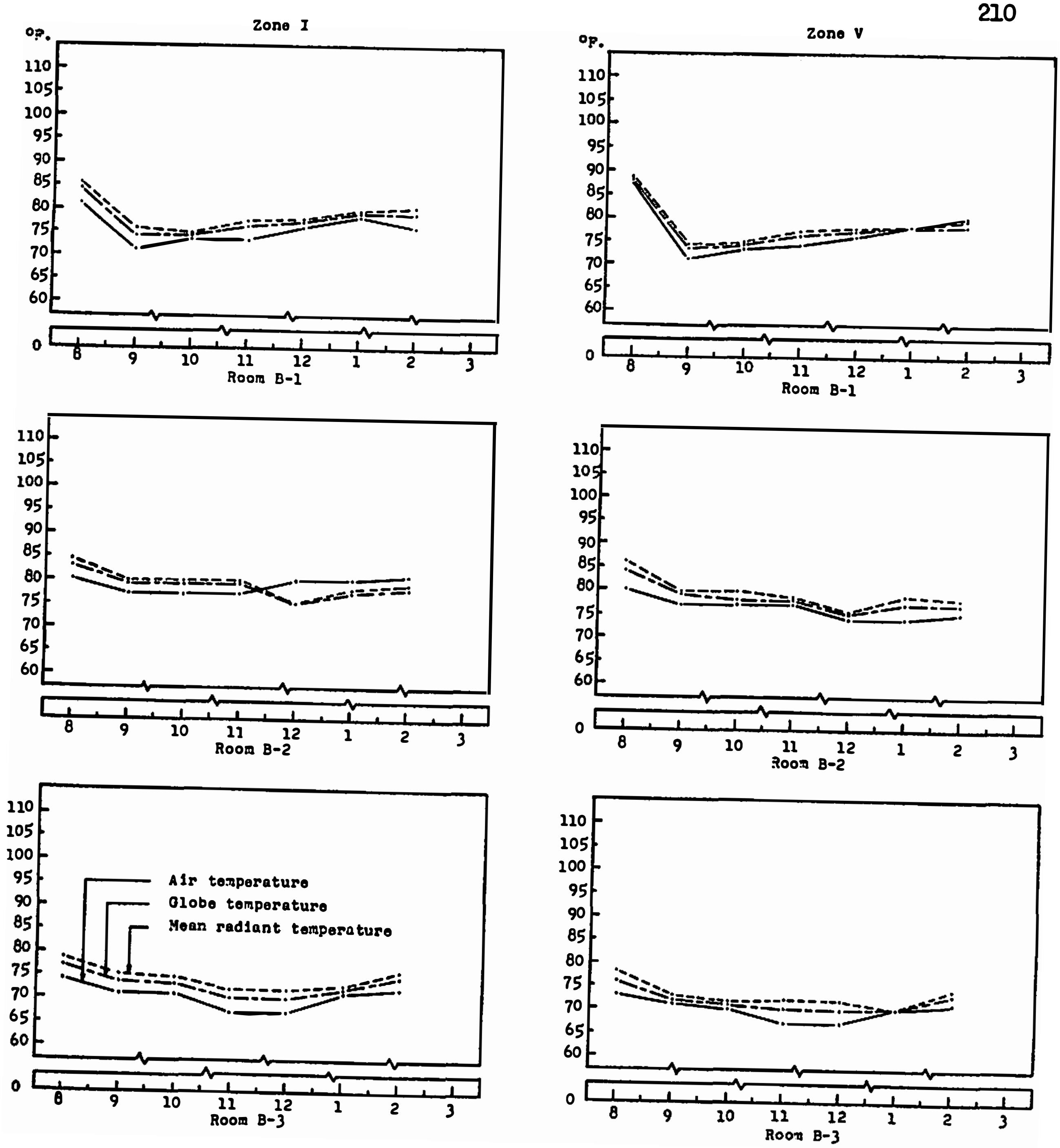


Figure 31. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School B.

Classroom B-2. Table XIII, page 207, and Figure 31, page 210, show that the air temperature and mean radiant temperature of both zones were above the upper limits of the optimum range. Some form of cooling other than outside air would have been necessary to have provided the proper combined conditions or globe reading.

Classroom B-3. Table XIII, page 207, and Figure 31, page 210, show that, although air temperature readings and mean radiant readings were not identical, the mean radiant temperature was higher than air temperature and both were within the optimum range.

Classroom C-1. Although Table XIII, page 207, and Figure 32 show that the mean radiant temperature was generally slightly lower than the air temperature, both were within the optimum range. The differences that existed between these readings and those recorded on similarly rainy days during the investigation of School A were probably brought about by the larger window wall and higher ceilings of rooms in School C.

Classroom C-2. Figure 32 shows that the mean radiant temperature, air temperature, and globe readings of Classroom C-2 were often identical, although slightly above the upper limit of the optimum range. Solar gain through the window glass, even though venetian blinds were utilized, probably accounted for the fact that the mean radiant temperature was as high as the air temperature in Classroom C-2 and lower than the air temperature in Classroom C-1 when cloudy weather prevailed.

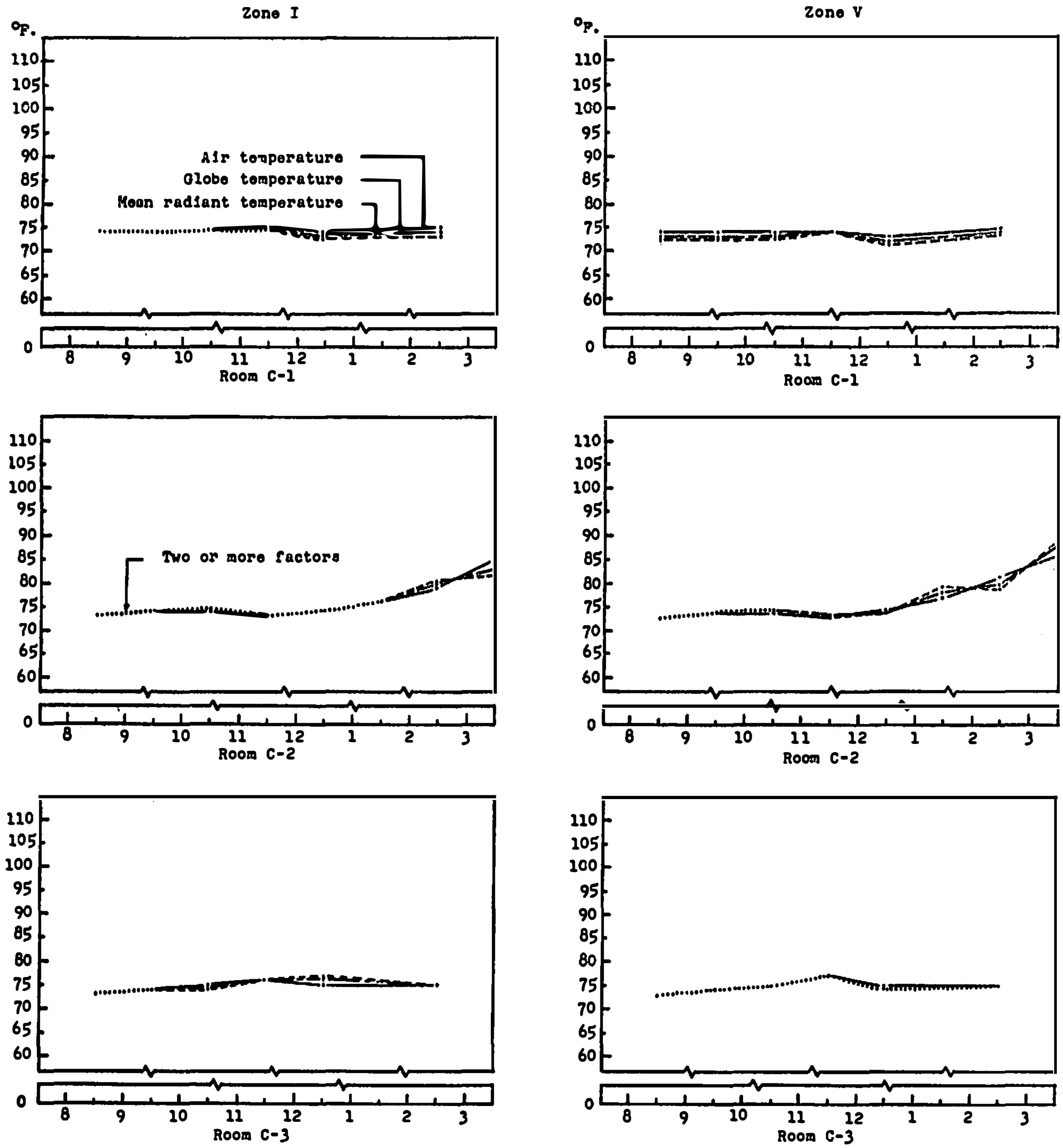


Figure 32. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School C.

Table XIII, page 207, helps to show that the average mean radiant temperatures in both zones were within one degree of each other.

<u>Classroom C-3</u>. Excellent conditions relating to the mean radiant temperature were present in Classroom C-3. Table XIII, page 207, and Figure 32, page 212, show that air temperature and mean radiant temperature were identical in both zones and within the optimum range.

<u>Classroom D-1</u>. Without any positive heating at the window wall of Classroom D-1, Table XIII, page 207, and Figure 33 show that the mean radiant temperature for Zone V was slightly lower than the corresponding mean radiant temperature at Zone I, although the mean radiant temperature and air temperature for Zone V were identical. Readings for both zones were above the optimum level.

<u>Classroom D-2</u>. Mean radiant temperature for Zone I, Classroom D-2, was identical with the air temperature for the zone, but the mean radiant temperature average of Zone V as shown in Table XIII, page 207, was nearly nine degrees higher than the corresponding air temperature. Figure 33 shows that the mean radiant temperature climbed to better than 111°F. at 2:30 p.m. in Zone V because of the radiant effects of the sun upon the window glass. Conditions in neither zone were within the optimum range.

<u>Classroom D-3</u>. Table XIII, page 207, and Figure 33 reveal that mean radiant temperature and air temperature of Zone I, Classroom D-3, were practically identical, but both slightly high, while the mean

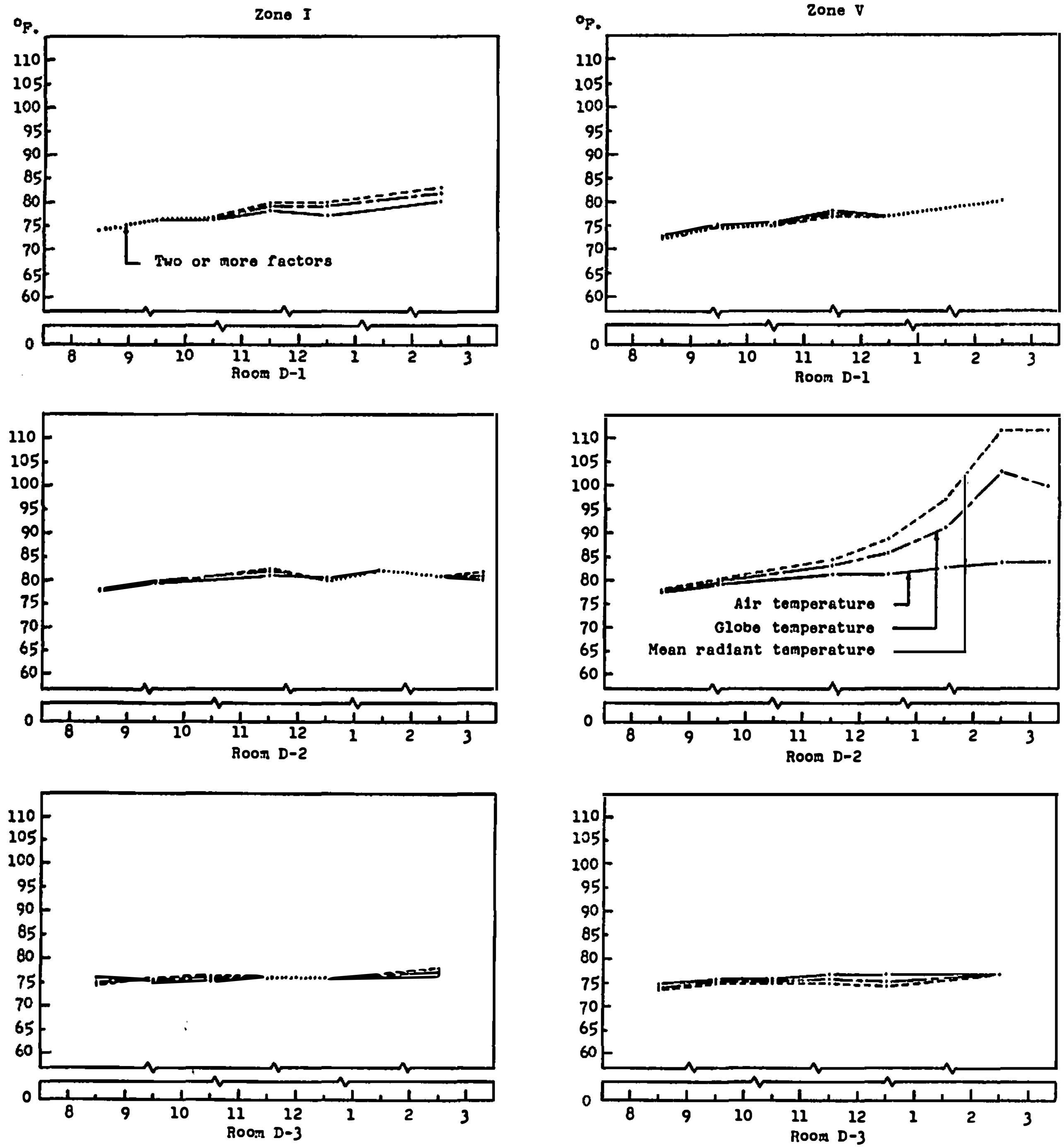


Figure 33. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School D.

radiant temperature was slightly lower than the corresponding air temperature of Zone V because of the lack of heat at the window wall.

<u>Classroom</u> <u>E-1</u>. Table XIII, page 207, and Figure 34 indicate that mean radiant temperature conditions in both zones of Classroom E-1 were identical and within the optimum range.

<u>Classroom</u> <u>E-2</u>. Mean radiant temperature and air temperature were practically identical and within the optimum range in Zone I of Classroom E-2, according to Table XIII, page 207, and Figure 34. Solar gain again boosted the mean radiant temperature of Zone V, however, to an average of better than five degrees higher than the corresponding air temperature in spite of the use of drapes.

<u>Classroom</u> <u>E-3</u>. Radiant conditions in Classroom E-3 were somewhat similar to those encountered in Classroom E-2 with the exception that the entire room was too hot. Table XIII, page 207, and Figure 34 indicate that mean radiant temperature and air temperature in Zone I were identical but far too high, while the mean radiant temperature of Zone V was six degrees higher than the 82°F. air temperature. The difference in Zone V can be attributed to some solar gain and excessive radiant heat.

<u>Classroom</u> <u>F-1</u>. The need for some type of positive heat at the window wall can be seen in analyzing radiant conditions in School F. Table XIII, page 207, and Figure 35, page 217, show high, but identical

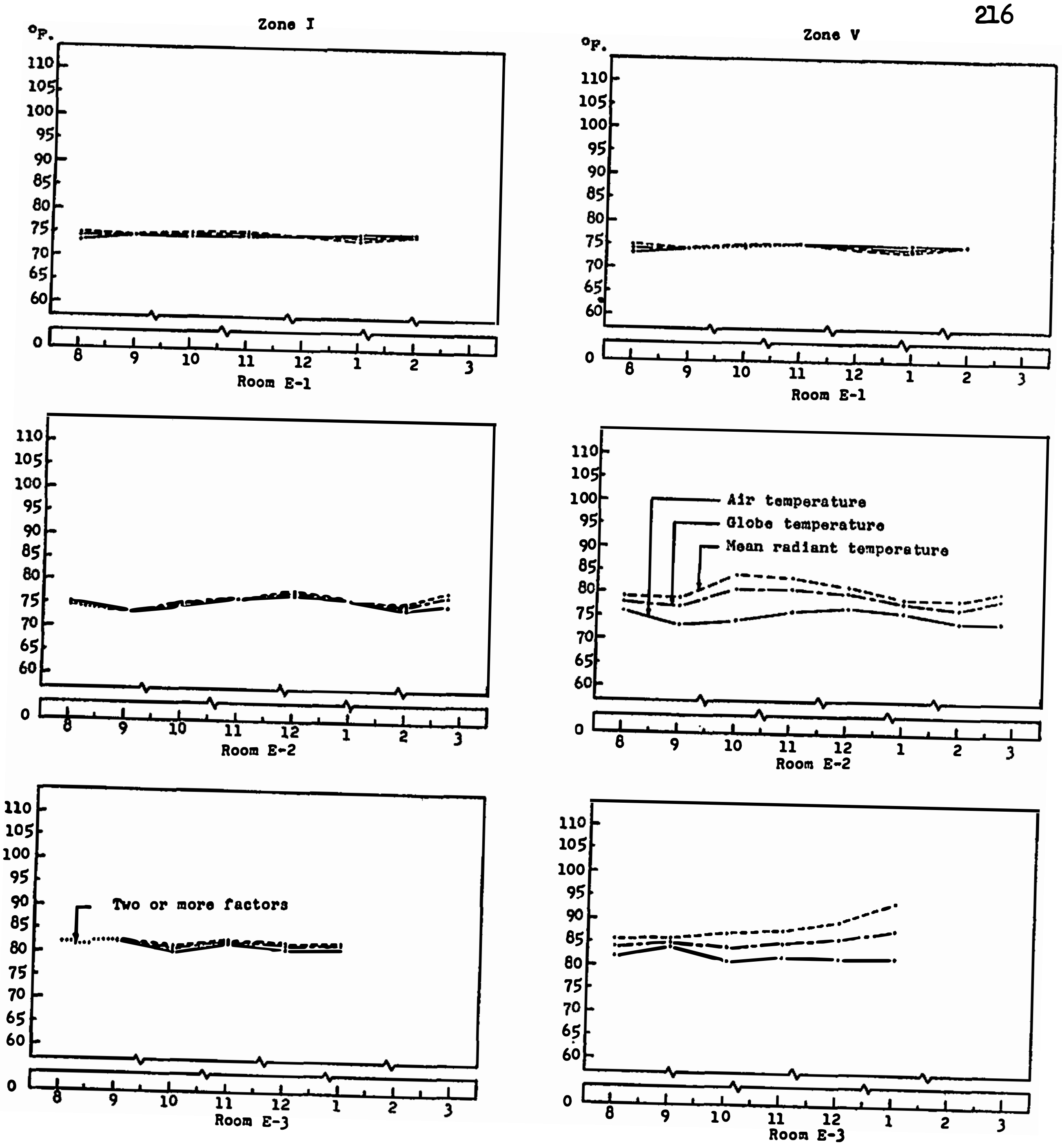


Figure 34. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School E.

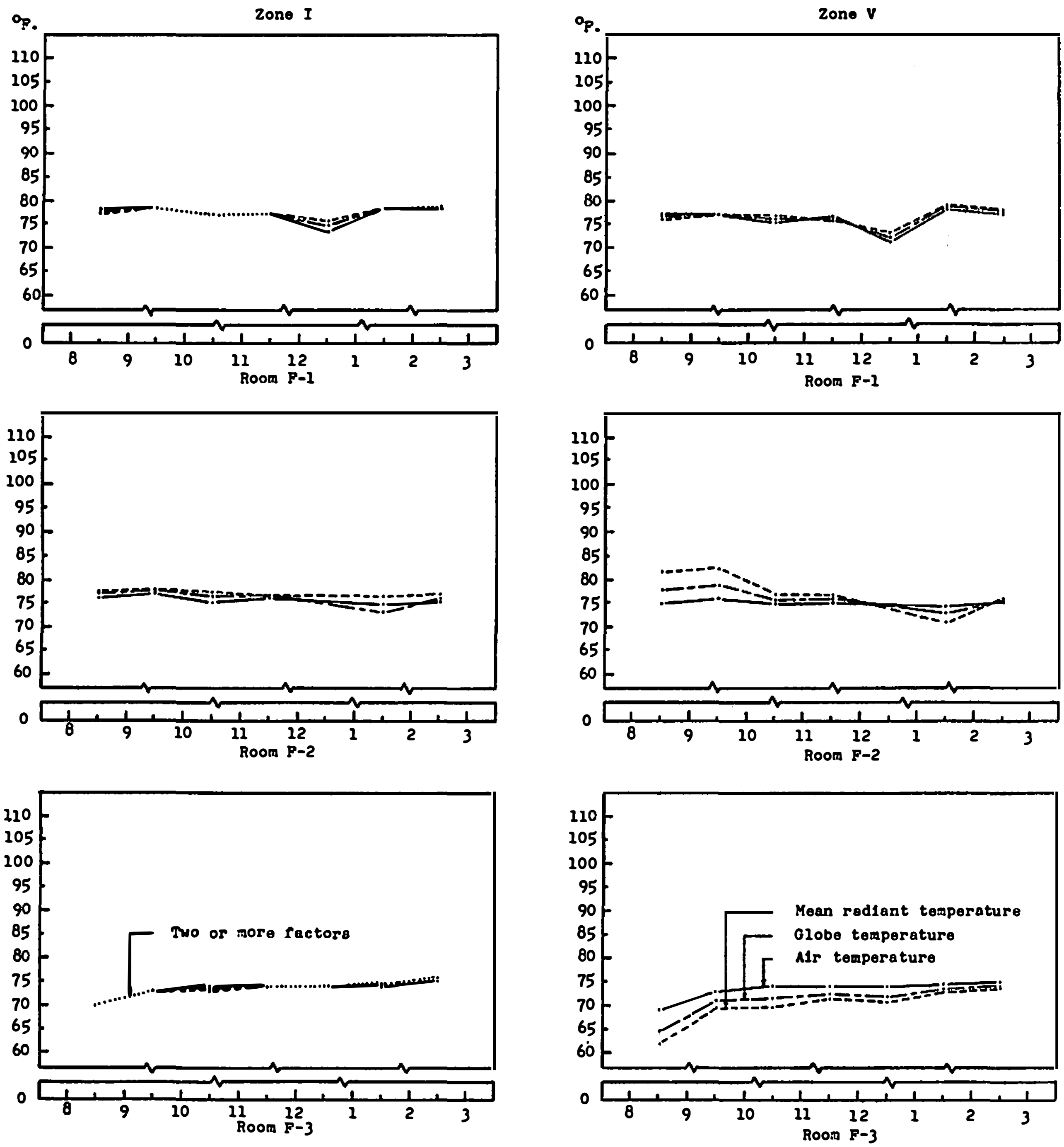


Figure 35. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School F.

conditions in Zone I of Room F-1, with slightly lower air conditions and still lower mean radiant conditions in Zone V.

Classroom F-2. Radiant conditions in Classroom F-2 were similar to those found in Room F-1. Table XIII, page 207, and Figure 35, page 217, show that air temperature and mean radiant temperature readings were nearly identical and just about within the upper limits of the optimum range in Zone I, while the average of the mean radiant temperature readings for Zone V was higher than the corresponding air temperature. However, the individual Zone V mean radiant reading for 1:30 p.m. was over three degrees lower than the air temperature when a cloud momentarily covered the sun. This would indicate that solar gain helps to provide the needed radiant temperature in Zone V of a room heated with floor panels.

Classroom F-3. The mean radiant temperature and air temperature of Zone I, Classroom F-3, were identical and within the optimum range as indicated by Table XIII, page 207, and Figure 35, page 217. The need of some type of positive heat directed toward the window wall of rooms heated with floor panels is indicated by a look at conditions in Zone V, however, especially when outside weather is cold and there is no sunshine. At 8:30 a.m. the mean radiant temperature at Zone V was only 62°F., with a downdraft very much in evidence. At no time during the day did the mean radiant temperature equal the air temperature.

Classroom G-1. Table XIII, page 207, and Figure 36 present data that show the mean radiant temperature and air temperature of Classroom G-1 to have been almost identical and within the optimum level.

Classroom G-2. Mean radiant temperature of Zone I, Classroom G-2, was slightly below the air temperature of that area of the room while the mean radiant temperature of the window wall area was slightly above the air temperature, according to Table XIII, page 207, and Figure 36. Both air temperature and mean radiant temperature were above the optimum range.

Classroom G-3. With no effects from the sun on the day Classroom G-3 was visited, Table XIII, page 207, and Figure 36 show mean radiant temperature and air temperature to have been nearly identical but slightly high.

Classroom H-1. Perhaps because of the small windows, the lack of any auxiliary heat for downdraft protection, and the absence of sunshine, mean radiant conditions in the classrooms studied in School H were more nearly balanced with air temperatures than in any other school as evidenced by analyzing Figure 37, page 221 in its entirety. Conditions in Classroom H-1 were identical but too hot.

Classroom H-2. Mean radiant temperature was identical to air temperature in each zone of Classroom H-2, with Zone I one degree warmer than Zone V. Zone I had a mean of about 76°F. which may have been just a little too warm.

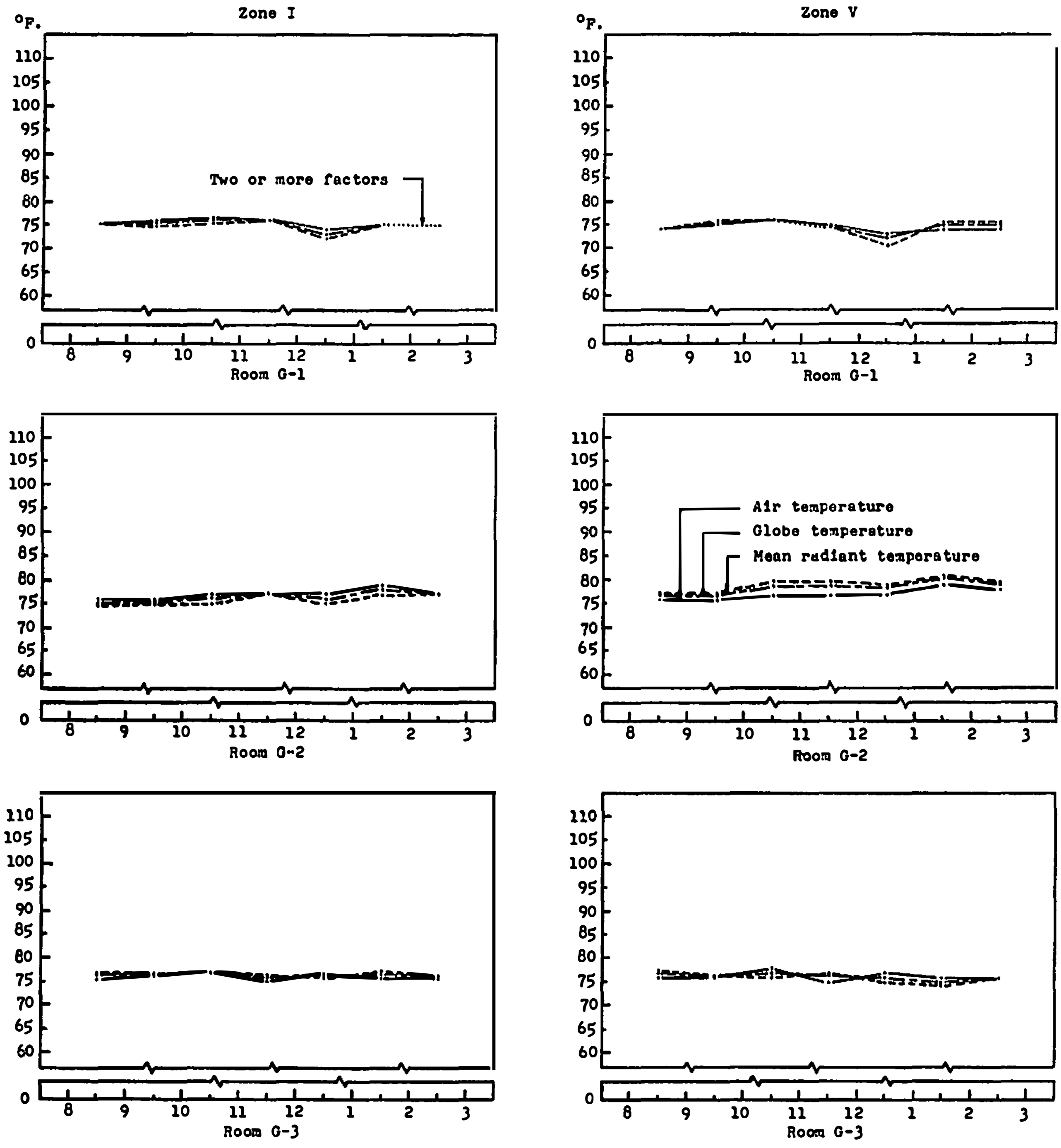


Figure 36. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School G.

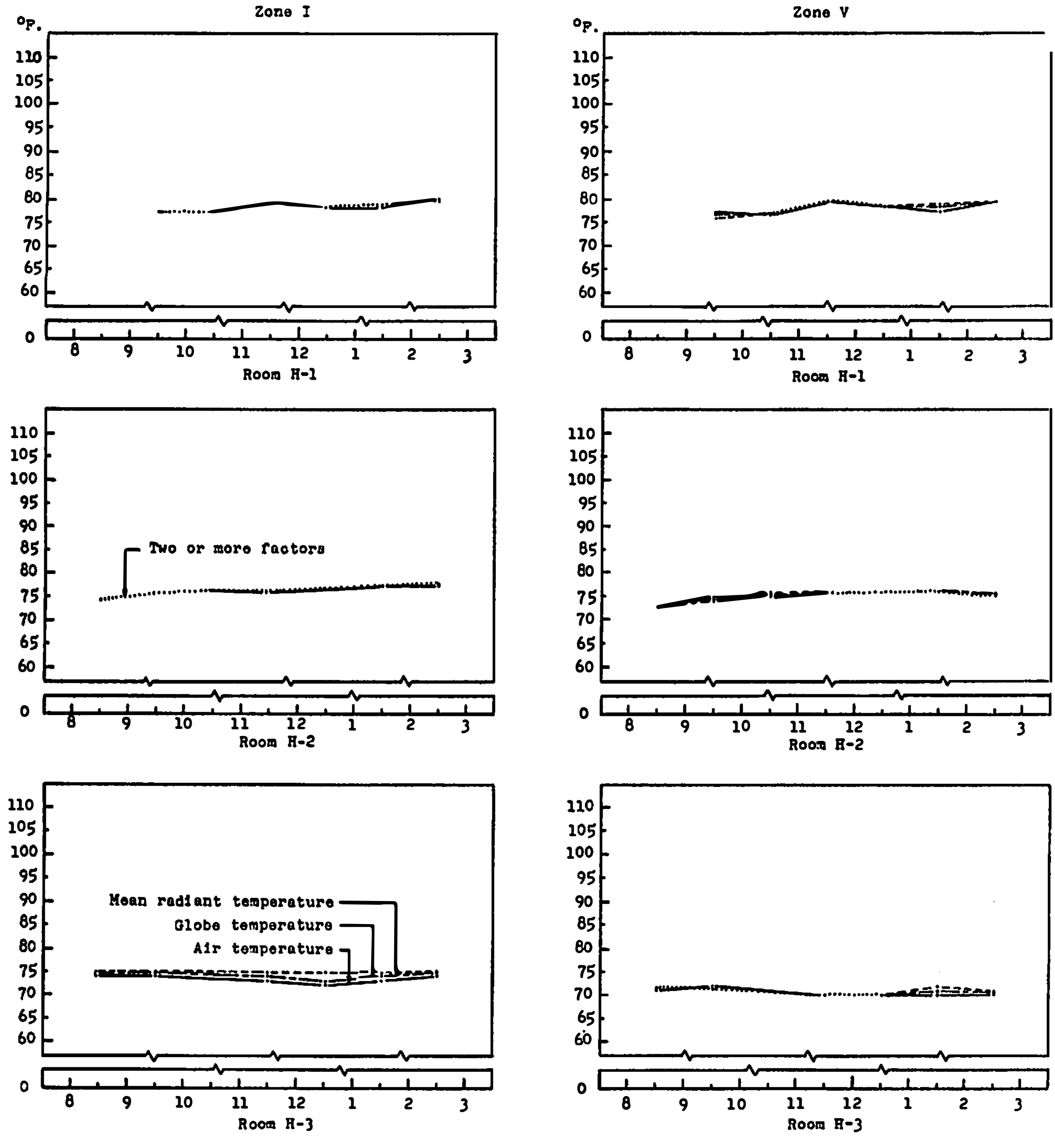


Figure 37. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School H.

Classroom H-3. According to Table XIII, page 207, and Figure 37, page 221, the mean radiant temperature and air temperature of Zone V, Room H-3, were approximately three degrees lower than the mean radiant temperature and air temperature of Zone I. All readings were within the optimum range, however.

Classroom I-1. Figure 38 and Table XIII, page 207, show no special radiant problems for Classroom I-1 other than that the mean of both zones were about one degree too high.

Classroom I-2. Although Classroom I-2 was not subjected to any appreciable solar gain because of the rainy outside weather conditions, Table XIII, page 207, and Figure 38 show mean radiant temperatures in both zones to have been in excess of 80°F. Excessive radiant heat from the convectors created this situation.

Classroom I-3. The final graphs in Figure 38 indicate that excessive radiant heat from the convectors was responsible for the somewhat higher radiant temperature found in both zones. Since the air temperature was too high also, conditions outside the optimum range existed in I-3.

G. SUMMARY

Chapter VI has been concerned with analyses of the thermal data pertaining to air temperature and mean radiant temperature collected in twenty-seven classrooms in nine selected schools. Raw data were

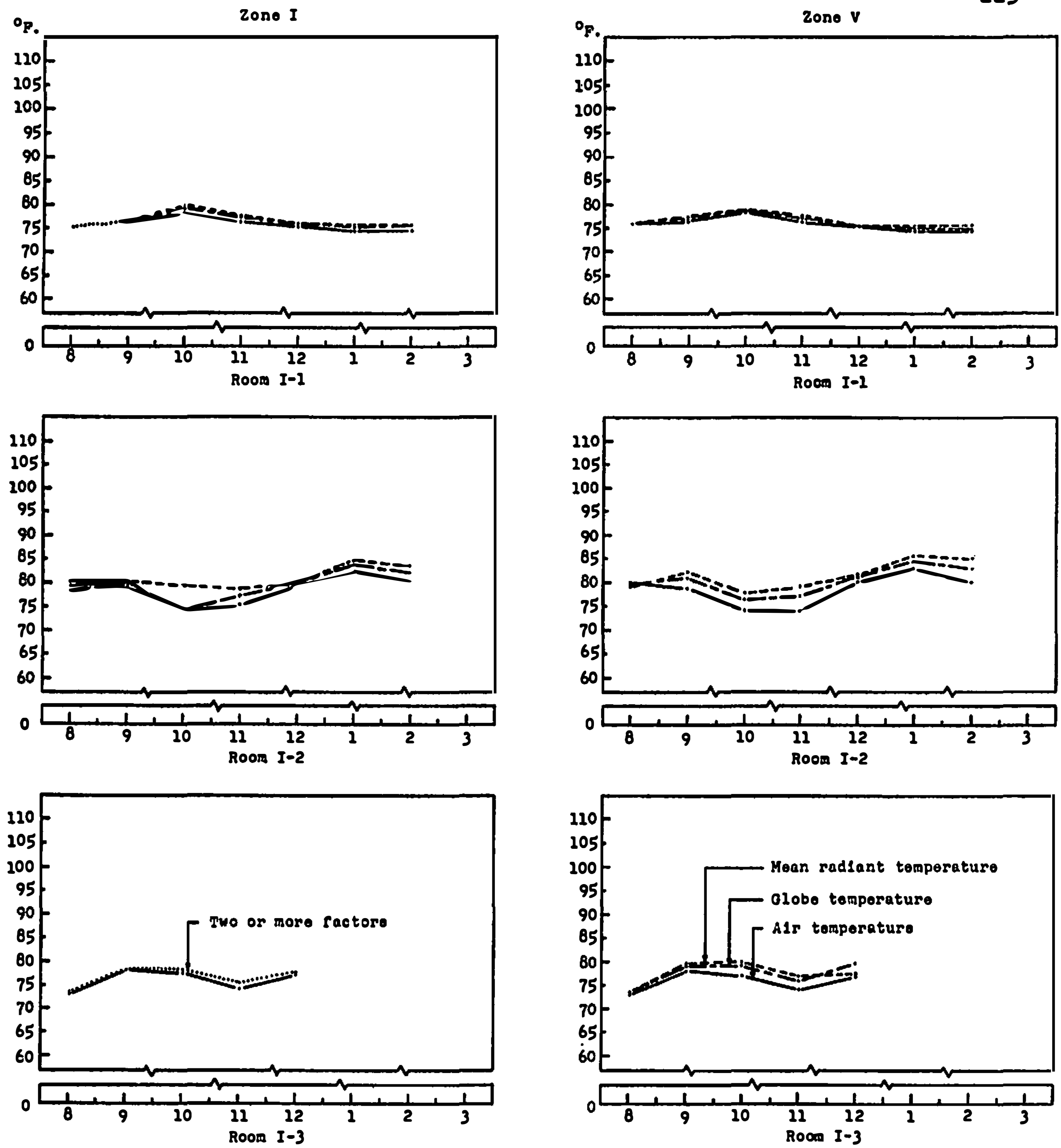


Figure 38. Comparison of air temperature, globe thermometer readings, and mean radiant temperature in classrooms in School I.

converted to mean scores, when advisable and dispersions from the mean were indicated in terms of ranges and standard deviations. Presentation was made in textual, tabular, and graphic form, with analyses of the data effected by inspection in terms of the thermal criteria identified in Chapter IV.

Attention was given to the thermal environment that existed in each classroom rather than to the school as a whole because of the various thermal factors that can affect each individual classroom. The investigator used the terms, completely, adequately, inadequately, and not at all, when the situation warranted their use, to explain to what extent specific room conditions met the different criteria.

Temperature conditions were not found to be too compatible with Criterion 1. Forty-four per cent of all working area readings were above 75°F., the upper limit of the optimum range. Since 72°F. is often considered the optimum temperature by some, an interesting finding revealed that 86.2 per cent of the working area temperatures recorded were above 72°F. Only six of the twenty-seven classrooms completely met Criterion 1, while seven did not meet the criterion in any way. Five of the six completely meeting Criterion 1 were classrooms using unit ventilators for heating and ventilating.

Most classrooms did not meet adequately Criterion 2 relating to mean radiant temperature. Sun shining through window glass was the factor that quite often created considerably higher mean radiant temperatures than air temperatures.

Chapter VII will be concerned with the analyses of data related to the relative humidity, ventilation, and air movement of the twenty-seven classrooms in the nine selected schools.

CHAPTER VII

ANALYSES OF RELATIVE HUMIDITY, VENTILATION AND AIR MOVEMENT DATA

A. INTRODUCTION

The purpose of Chapter VII is to present analyses of data pertaining to relative humidity, ventilation, and air movement in the twenty-seven selected classrooms. Measurements of these phenomena were converted to means and ranges, presented in textual, tabular, and graphic form and analyzed through inspection of the graphs and tables in terms of the various criteria.

B. ANALYSIS OF THERMAL DATA PERTAINING TO RELATIVE HUMIDITY

Criterion 3. With air temperature and mean radiant temperature at the optimum level, optimum relative humidity seems to be around 50 per cent, ±10 per cent.

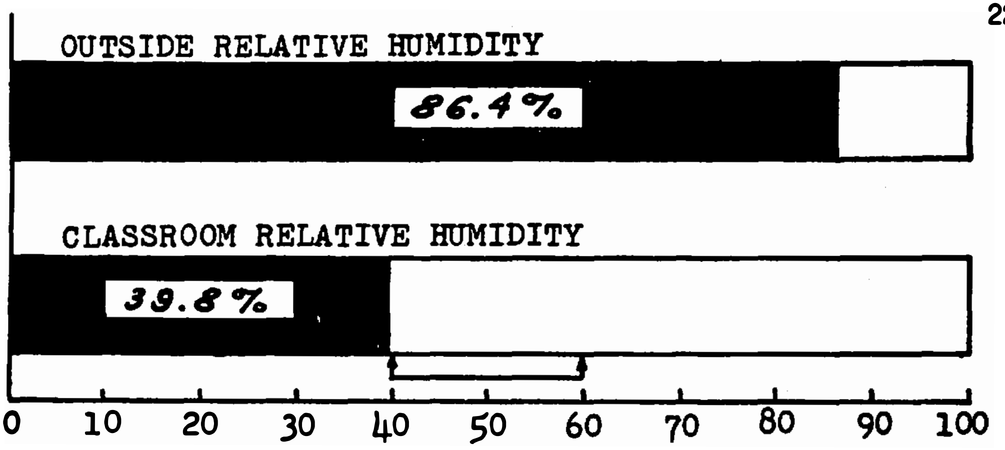
The criterion, as stated, could have been met either completely or not at all. Table XIV and Figures 39-47 enable the reader to denote which rooms met the criterion and which did not. The relative humidity figures presented are means of the hourly humidity readings that were taken each day.

In addition to denoting the classroom relative humidity in relation to Criterion 3, Figures 39-47, pages 228-236, also graphically

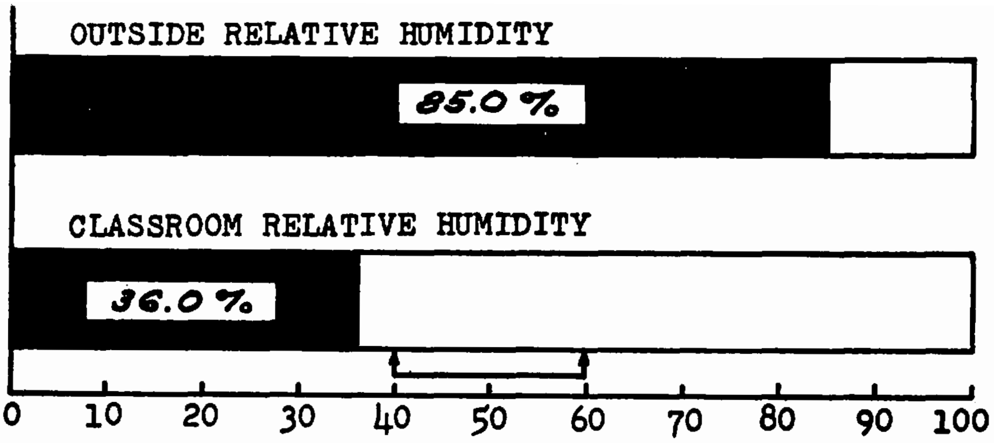
TABLE XIV

COMPARISON OF THERMAL DATA WITH CRITERION 3

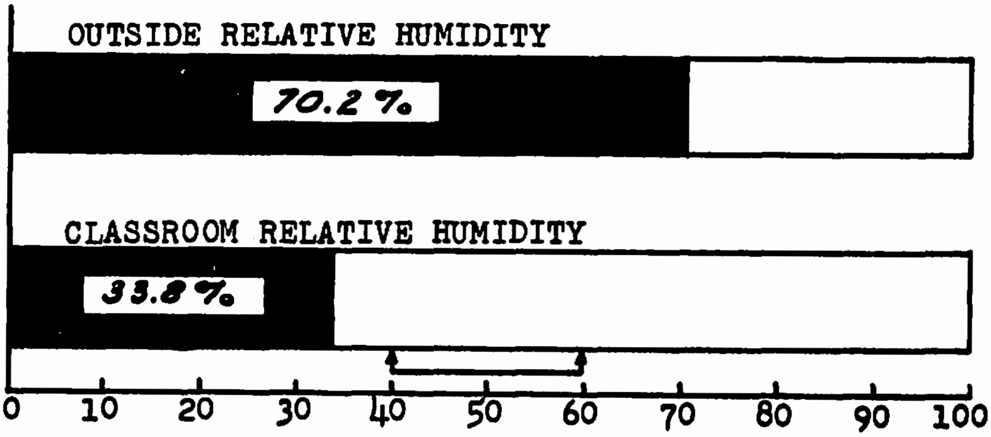
Classroom	Criterion Relative humidity of 50 per cent ±10 per cent Relative humidity (To nearest whole per cent)	Mean corrected effective temperature
A-1	40%	68.5°F.
A-2	36%	68.0°F.
A-3	34%	69.5°F.
B-1	34%	70.0°F.
B-2	38%	71.0°F.
B-3	43%	67.0°F.
C-1	54%	69.0°F.
C-2	45%	70.5°F.
C-3	41%	69.0°F.
D-1	37%	70.0°F.
D-2	42%	74.5°F.
D-3	38%	69.5°F.
E-1	41%	68.5°F.
E-2	31%	69.5°F.
E-3	52%	74.5°F.
F-1	61%	72.0°F.
F-2	44%	69.5°F.
F-3	41%	67.25°F.
G-1	26%	67.5°F.
G-2	38%	71.0°F.
G-3	43%	70.0°F.
H-1	42%	71.0°F.
H-2	38%	69.0°F.
H-3	32%	67.0°F.
I-1	44%	69.5°F.
I-2	54%	74.0°F.
I-3	44%	71.0°F.



Classroom A-1



Classroom A-2



Classroom A-3

Figure 39. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School A.

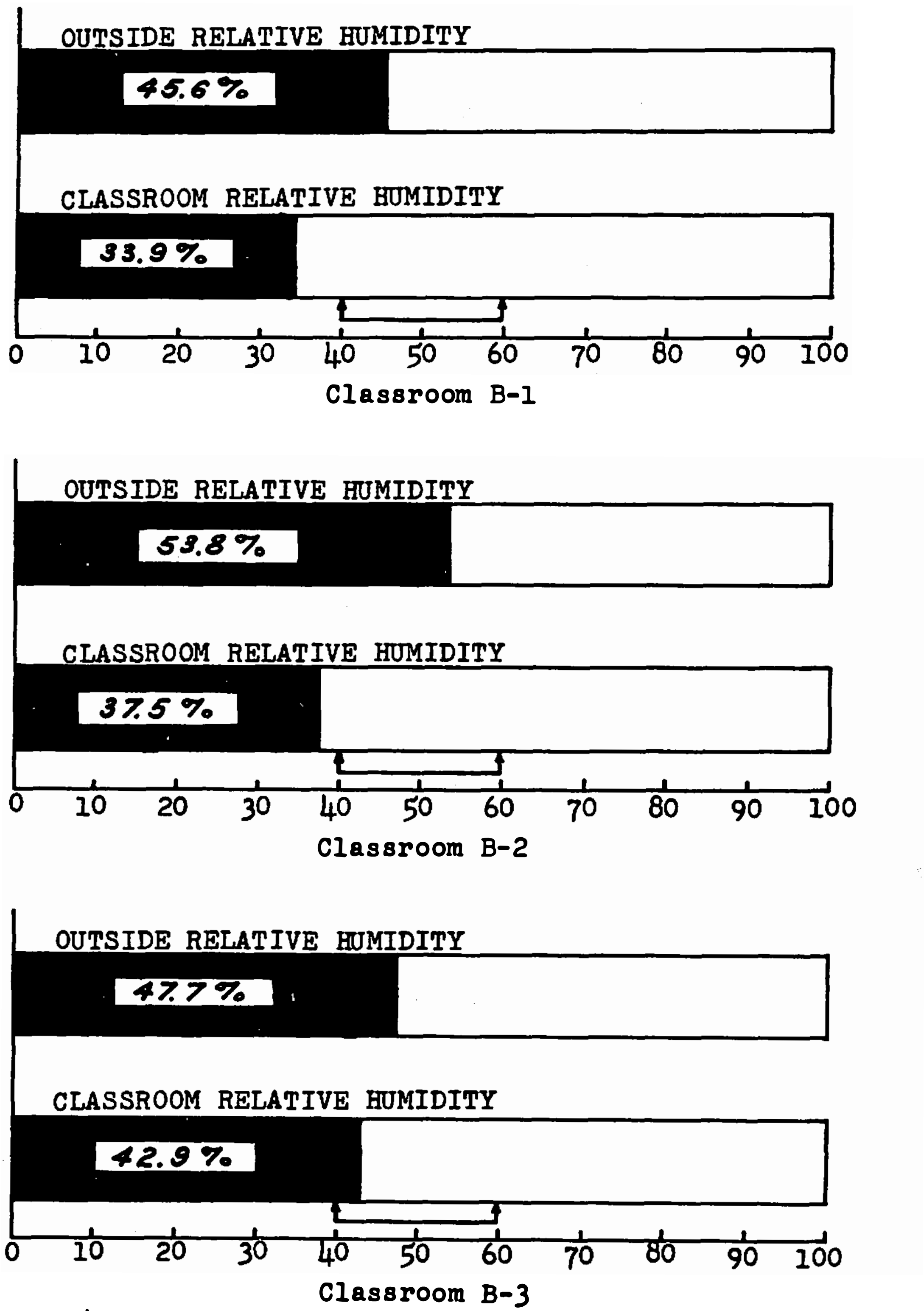
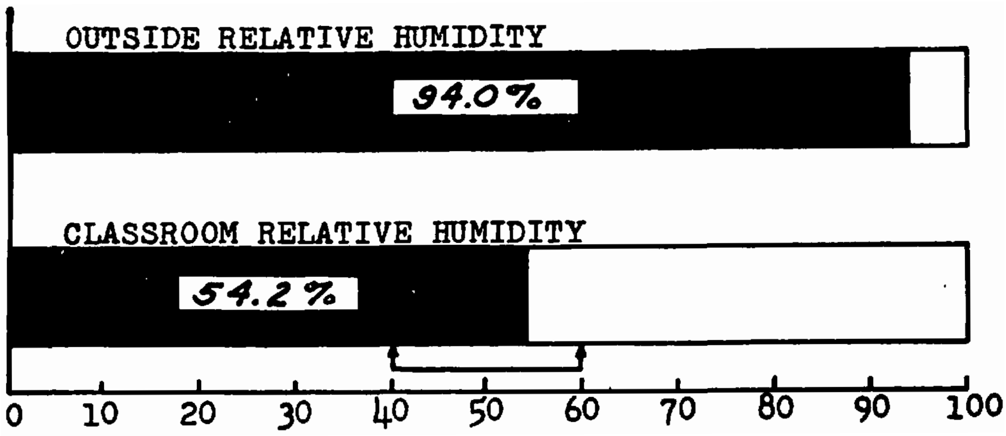
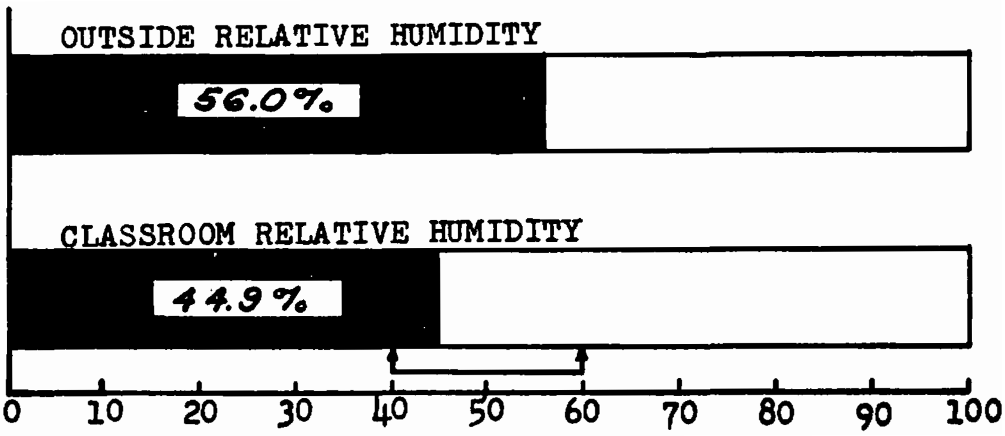


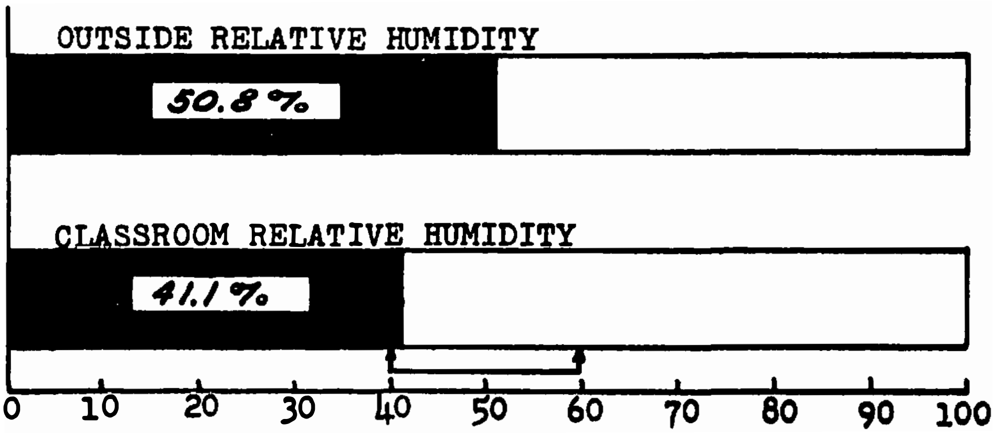
Figure 40. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School B.



Classroom C-1

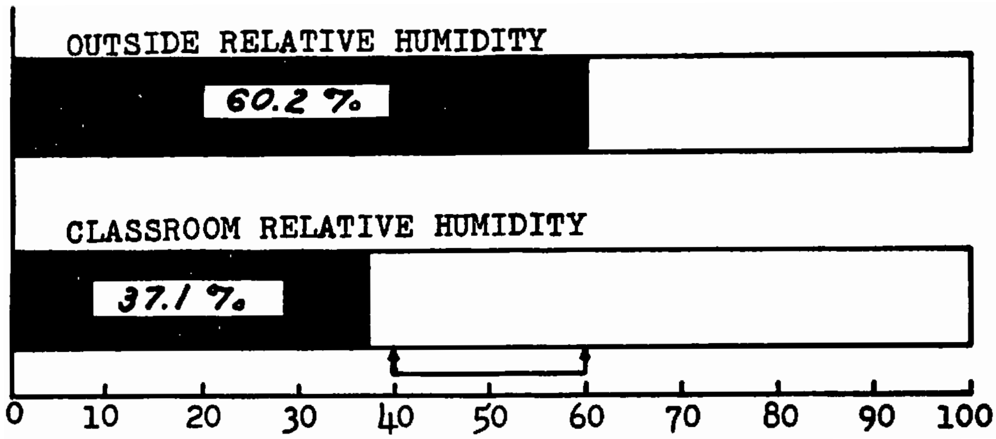


Classroom C-2

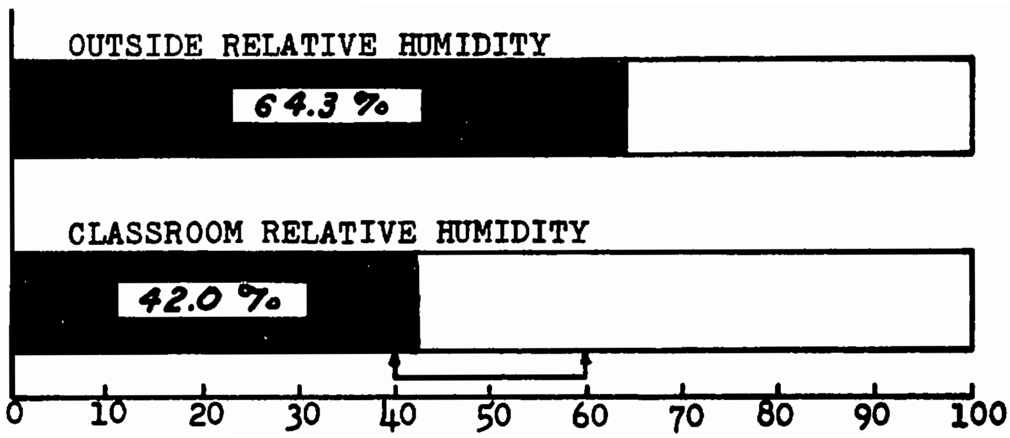


Classroom C-3

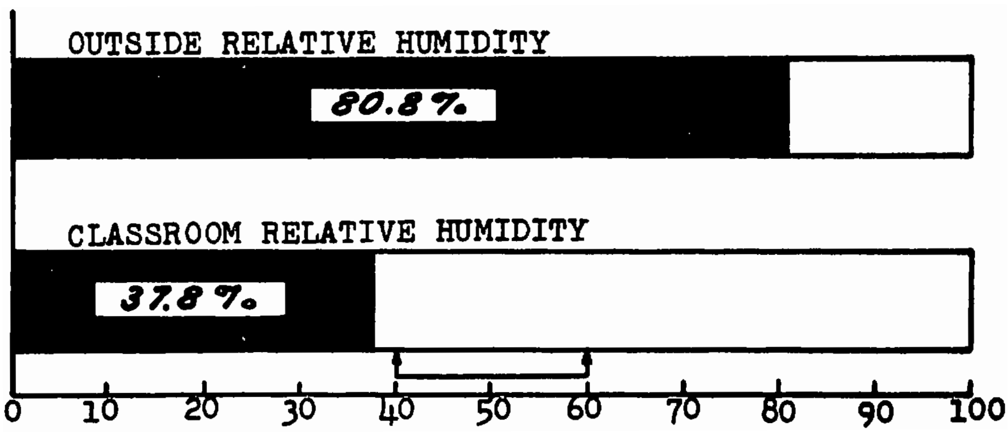
Figure 41. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School C.



Classroom D-1



Classroom D-2



Classroom D-3

Figure 42. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School D.

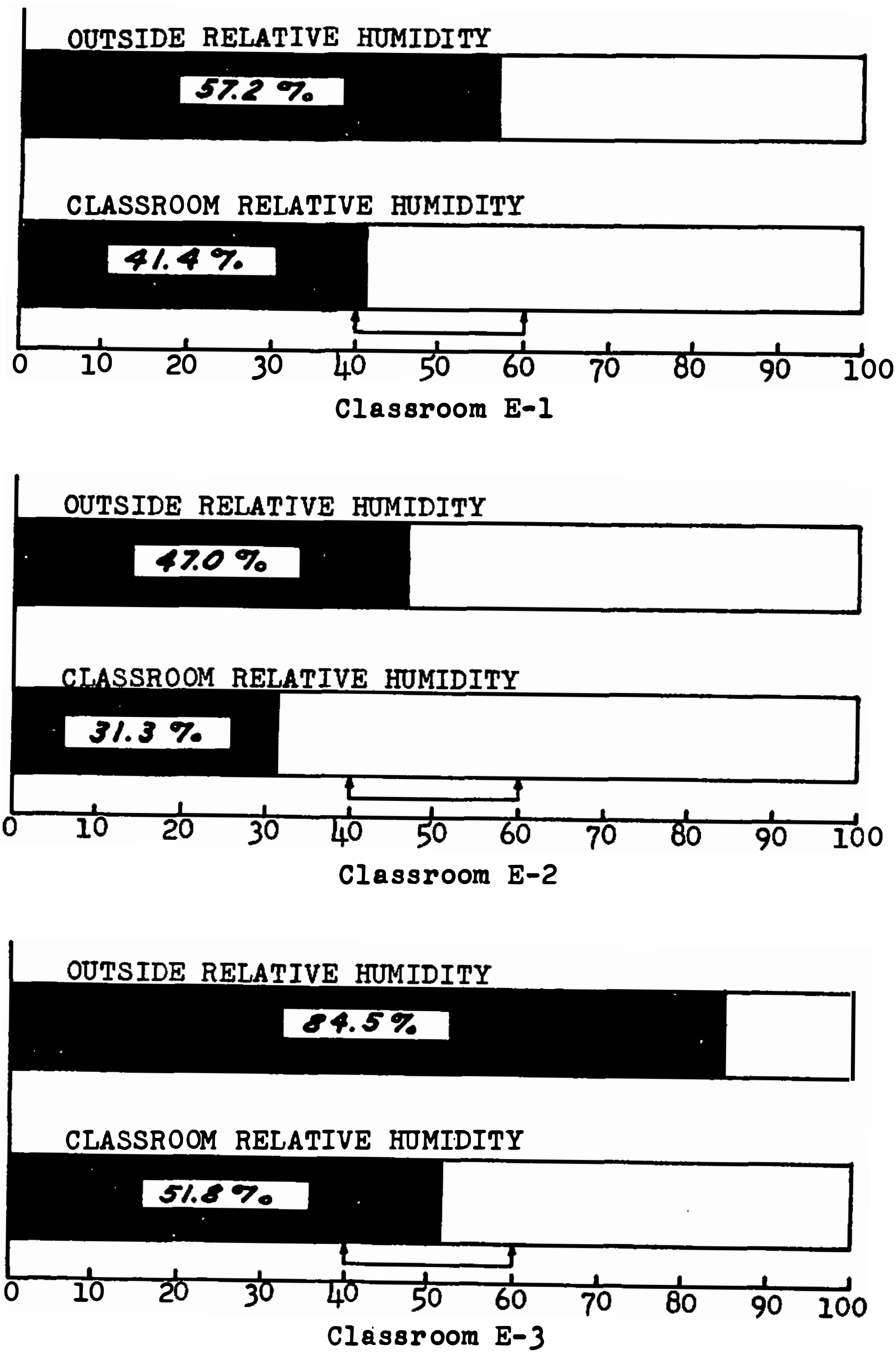


Figure 43. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School E.

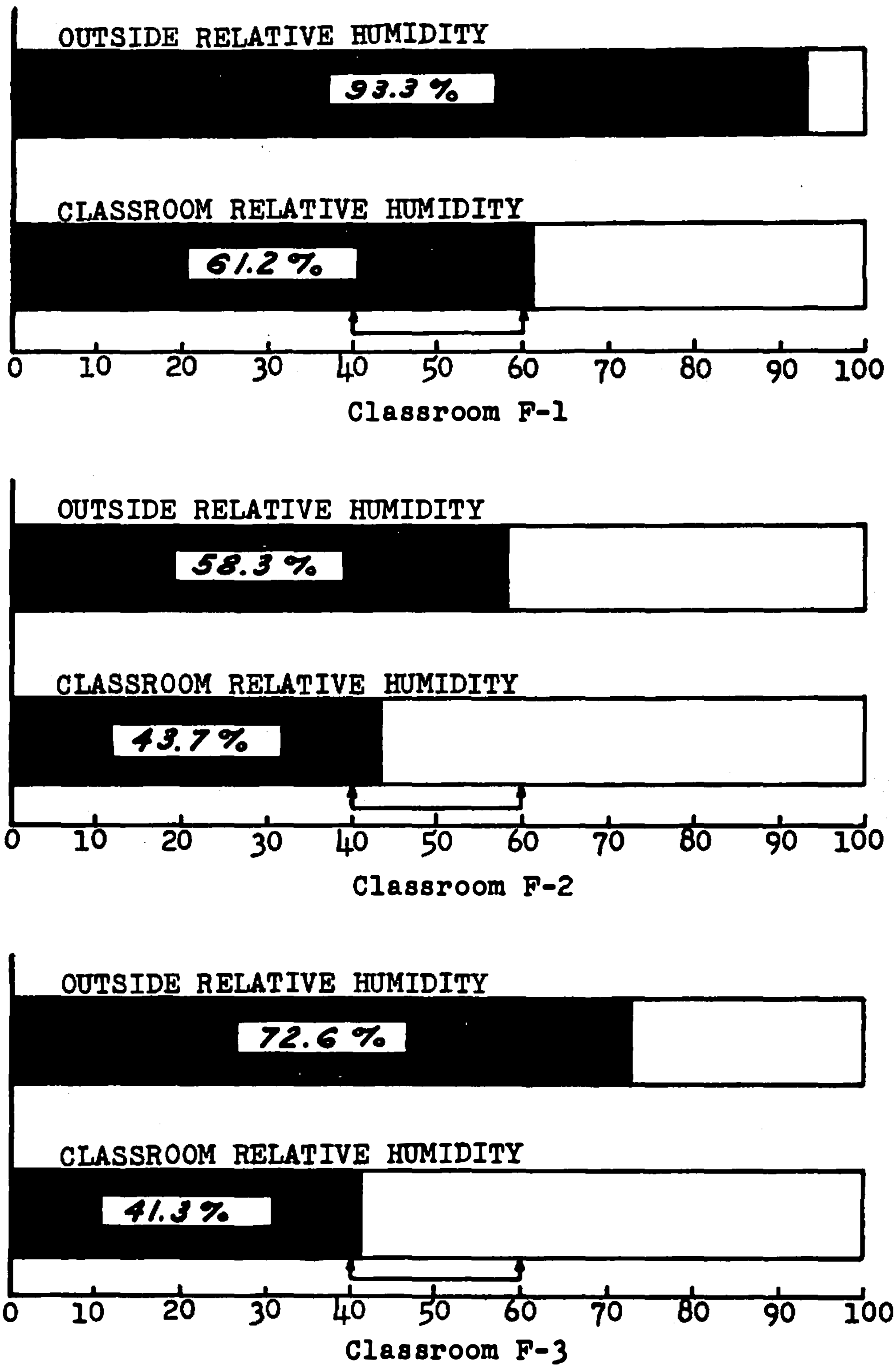


Figure 44. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School F.

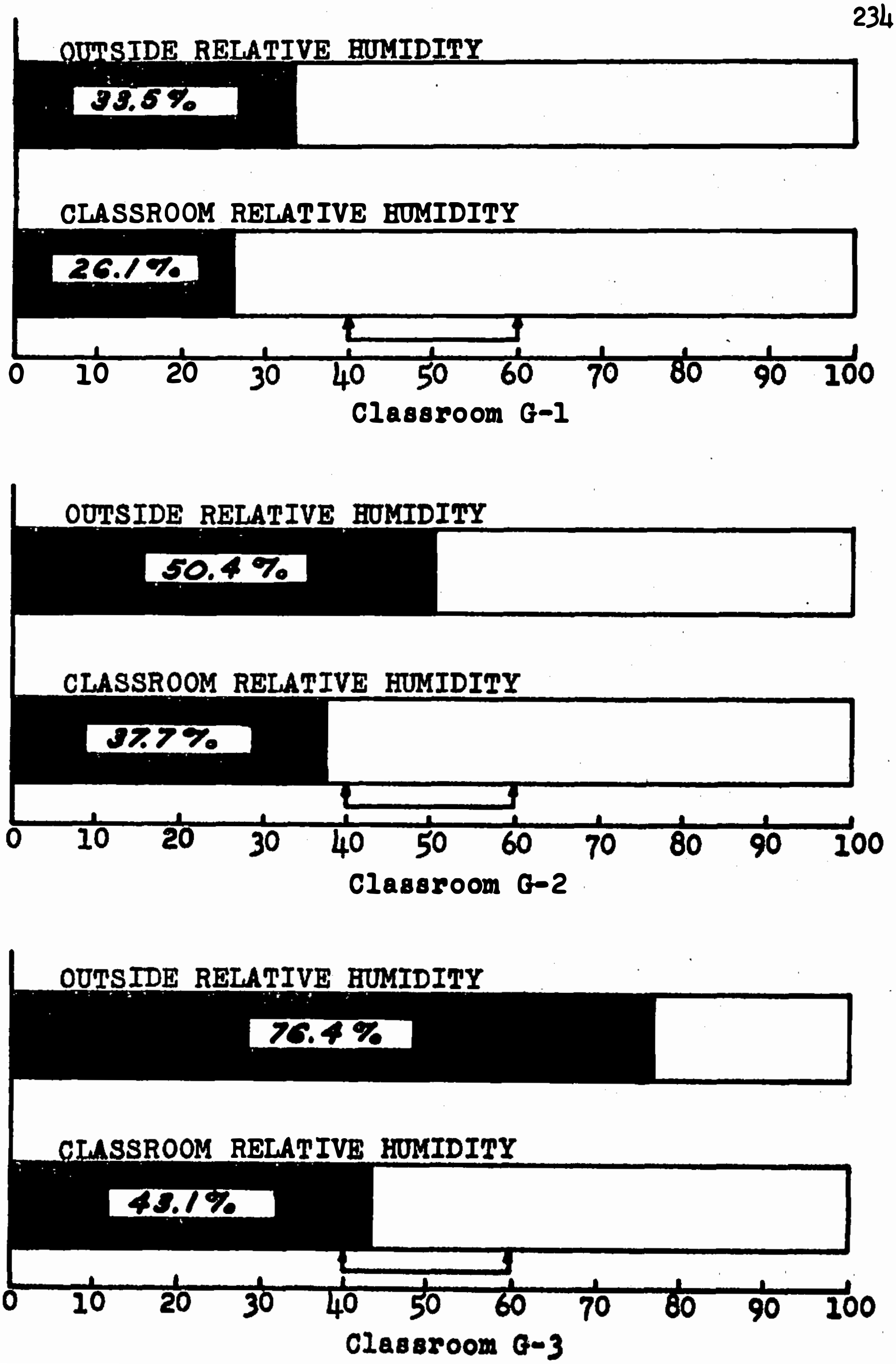
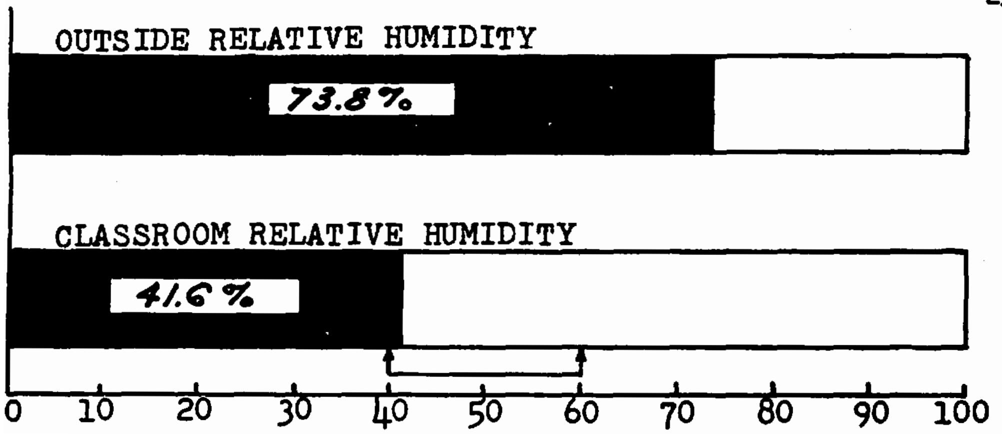
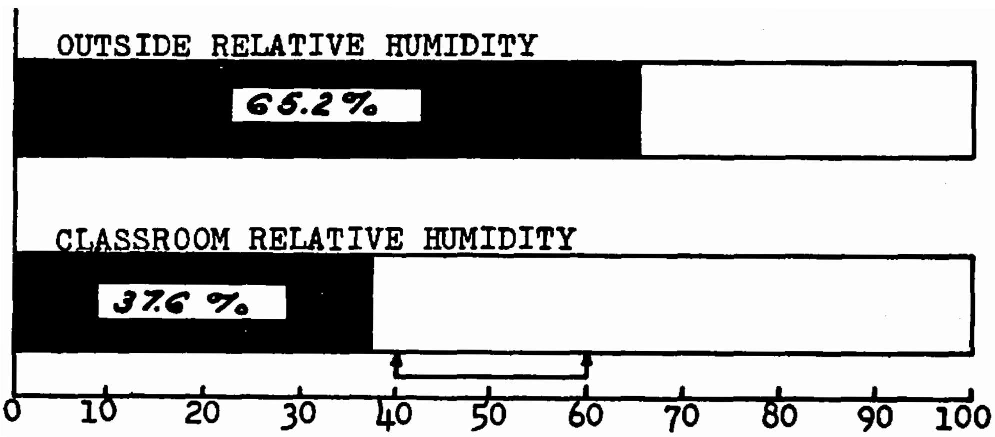


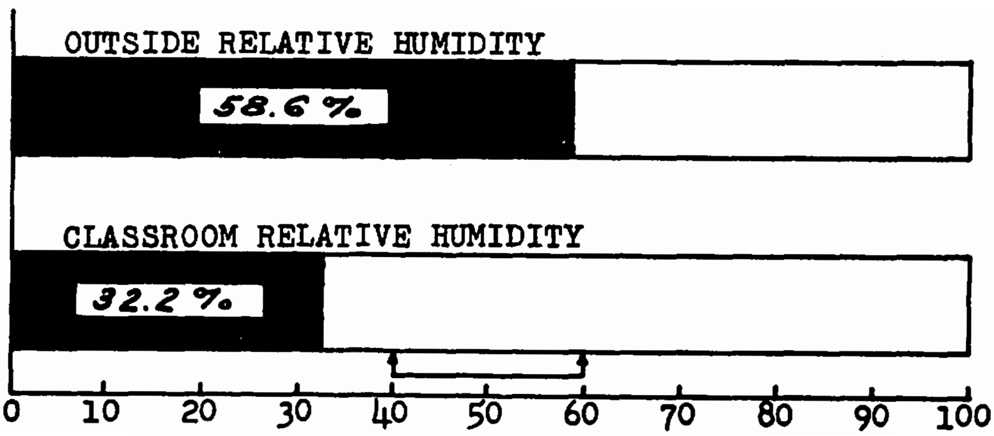
Figure 45. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School G.



Classroom H-1



Classroom H-2



Classroom H-3

Figure 46. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School H.

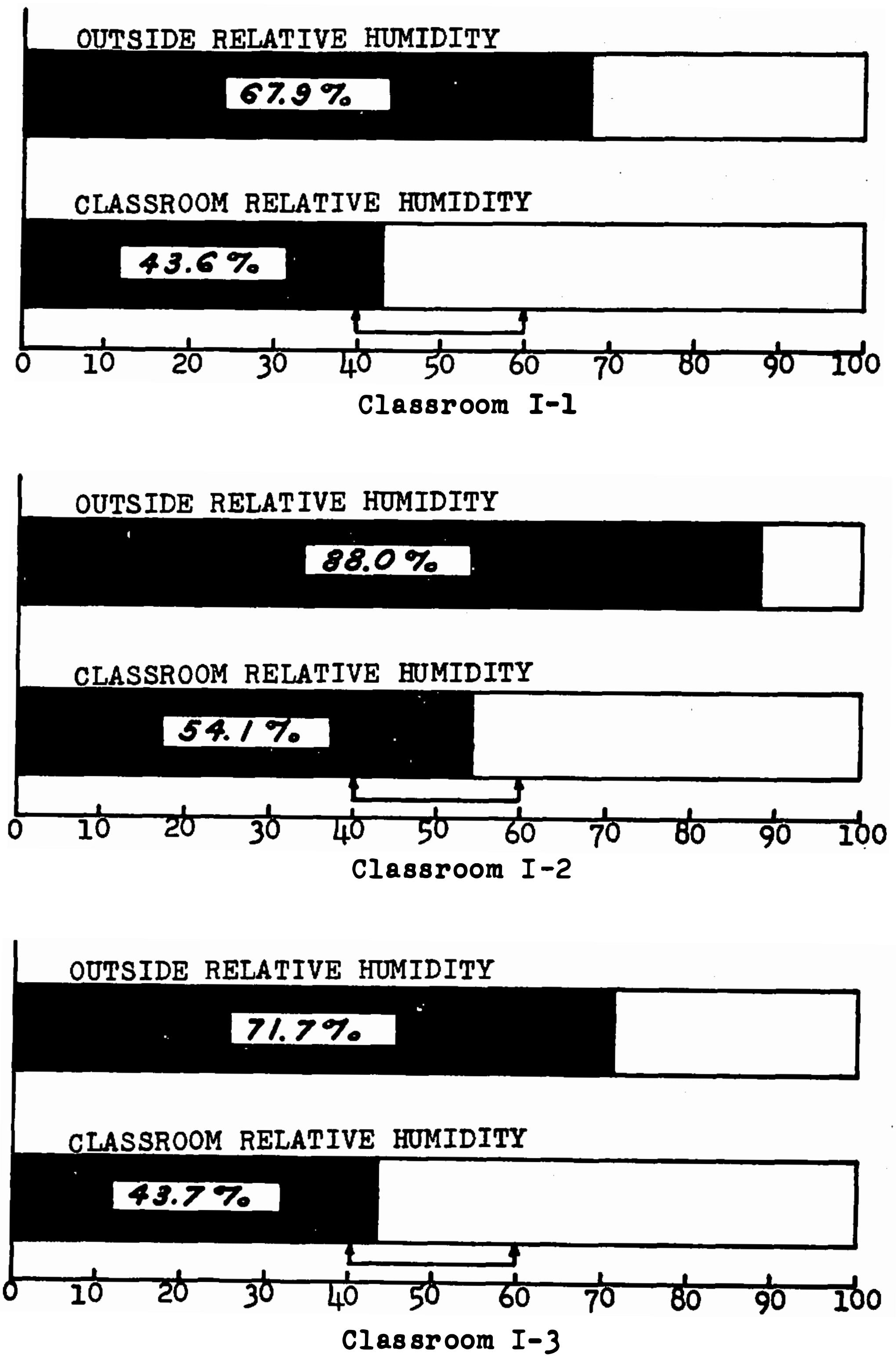


Figure 47. Comparison of mean classroom relative humidity with mean outside relative humidity for classrooms in School I.

portray the mean outside relative humidity for the particular day involved. As illustrated by the figures, each of the twenty-seven days but one recorded a mean relative humidity of at least 40 per cent. The one exception was the 33.5 per cent recording on March 17, 1961, when data were collected in Classroom G-1.

Table XIV, page 227, also presents the mean corrected effective temperature for each day. The mean corrected effective temperature was derived by utilizing the mean globe readings for the day instead of the mean dry bulb reading, the mean air movement as measured by the Kata thermometer and the mean wet bulb reading taken from the sling psychrometer. The corrected effective temperature was then derived from an enlarged copy of the effective temperature chart shown in Figure 76, Appendix B, page 304.

Although this study did not endorse the effective temperature concept as being a criterion for thermal control, an interesting comparison of the mean corrected effective temperature with the optimum winter temperature of 67°-68°F. Effective Temperature listed in the 1959 Guide and previously discussed in this report can be made. The reader must keep in mind that the use of the globe readings added a correction factor that increased most of the corrected effective readings because mean radiant temperature was higher than air temperature in most instances.

Only the mean corrected effective temperature of five rooms met the standard of 67°-68°F. Effective Temperature. The five rooms are A-2, B-3, F-3, G-1, and H-2. In meeting the Effective Temperature standard, an interesting observation is that three of the rooms did not

meet the 40 per cent minimum named in Criterion 3 of this study; in fact, the mean figure of 26 per cent recorded in Classroom G-1 represented the lowest mean relative humidity of all schools studied. This certainly seems to indicate that control of a combination of factors is essential for the establishment of an optimum Effective Temperature; yet the range of combinations of factors is relatively wide. The range did not seem to be wide enough for twenty-two of the rooms, however. The adjustment of the mean corrected temperature recorded in the various rooms to 67°-68°F. Effective Temperature would have required an adjustment of either air temperature, mean radiant temperature, air movement, or relative humidity, or a combination of all four factors.

Turning specifically to Criterion 3, fifteen of the twenty-seven rooms investigated (A-1, B-3, C-1, C-2, C-3, D-2, E-1, E-3, F-2, F-3, G-3, H-1, I-1, I-2, and I-3) had relative humidities within the desired range. Seven of the fifteen rooms had temperatures above the upper limits of Criterion 1, however. The temperature could have been reduced to the criterion level in all seven of the rooms and optimum relative humidity still have been maintained. Only the temperature of one of the rooms, H-1, could have been reduced completely with the use of outside air for cooling, though, on the specific days studied because of high outdoor temperatures.

The mean relative humidity of eleven of the twenty-seven rooms (A-2, A-3, B-1, B-2, D-1, D-3, E-2, G-1, G-2, H-2, and H-3) fell below 40 per cent. The temperature of all of the rooms but G-1 could have been reduced enough to have allowed a minimum relative humidity of 40

per cent and still maintained a thirty-inch temperature within the Criterion 1 range. On the particular days studied, the temperature could have been reduced to the desired level completely by the use of outdoor air in six of the eleven rooms (A-2, A-3, D-3, G-1, H-2, and H-3).

The relative humidity of one room, F-1, was one degree above the Criterion 3 range at 61 per cent. This deviation, of course, is not critical; nor were many of the readings that were 2 or 3 per cent below the minimum per cent listed in the range. The room temperature of Room F-1 was too high, however, and normal cooling would have increased the relative humidity. If strict adherence to the criterion were desired in this case, some method of wringing excessive moisture from the air would have been needed.

Although only fifteen of the classrooms investigated met the criterion in a literal sense, the data would seem to substantiate Herrington's belief that a better regulation of combined thermal effects would be more desirable than too much attention to the control of relative humidity.

C. ANALYSIS OF THERMAL DATA PERTAINING TO VENTILATION

Criterion 4. Classrooms should be ventilated adequately with clean, fresh, outdoor air to maintain control over overheating and to dissipate odors.

Table XV indicates whether the particular functions of ventilation, control over overheating and dissipation of odors, have been

TABLE XV

COMPARISON OF THERMAL DATA WITH CRITERION 4

Classroom	Criterion: Classroom ventilated adequately with clean, fresh, outdoor air to: Maintain control over overheating — Is overheating present?	Dissipate odors — Degree of odor
A-1	No	Imperceptible odor (0.0)
A-2	No	Imperceptible odor (0.0)
A-3	No	Imperceptible odor (0.0)
B-1	Yes	Objectionable odor (2.9)
B-2	Yes	Moderate odor (2.0)
B-3	No	Imperceptible odor (0.4)
C-1	No	Imperceptible odor (0.0)
C-2	Yes	Imperceptible odor (0.0)
C-3	No	Imperceptible odor (0.0)
D-1	Yes	Perceptible odor (0.7)
D-2	Yes	Perceptible odor (0.9)
D-3	Yes	Objectionable odor (3.0)
E-1	No	Perceptible odor (0.8)
E-2	No	Perceptible odor (1.0)
E-3	Yes	Objectionable odor (3.0)
F-1	Yes	Moderate odor (1.9)
F-2	No	Perceptible odor (1.0)
F-3	No	Moderate odor (1.9)
G-1	No	Moderate odor (1.9)
G-2	Yes	Moderate odor (1.9)
G-3	Yes	Moderate odor (1.7)
H-1	Yes	Imperceptible odor (0.1)
H-2	Yes	Imperceptible odor (0.0)
H-3	No	Imperceptible odor (0.0)
I-1	No	Objectionable odor (2.6)
I-2	Yes	Objectionable odor (2.9)
I-3	Yes	Moderate odor (2.2)

carried out. Overheating is considered a mean thirty-inch reading in excess of the maximum of 75°F. specified in Criterion 1. Degree of odor presented in Table XV, page 240, represents a mean of the hourly subjective odor checks made by the investigator. The reader may note the type of ventilation employed in each school by referring to Table VI, page 124.

Fourteen of the twenty-seven rooms were overheated including three out of the nine rooms employing unit ventilators, all three rooms using a central system of ventilation, and eight of the fifteen using window ventilation. Seven of the fourteen could have had the overheating problem greatly improved by adequate outdoor air, while four could have maintained complete control over overheating by admitting adequate outdoor air. Of the remaining three, the unit ventilator did an excellent job in one until the outside temperature reached the high sixties, and the outside temperature was in the sixties and seventies for the complete day when the thermal environment of the other two rooms was investigated.

The investigator considered that ten of the rooms had imperceptible odor, five had perceptible odor, seven had moderate odor, and five had objectionable odor. Four of the five rooms having objectionable odor also were overheated. Four of the five rooms with objectionable odors were rooms depending upon windows for ventilation while the fifth room was a room with a central system of ventilation. The objectionable odors in the fifth room perhaps were more closely related to the low socio-economic status of the retarded class than to overheating.

Using the data presented in Table XV, page 240, the investigator considers the classroom thermal conditions present on the day investigated to have met Criterion 4 in the following manner: A-1, completely; A-2, completely, A-3, completely; B-1, not at all; B-2, inadequately; B-3, completely; C-1, completely; C-2, adequately; C-3, completely; D-1, inadequately; D-2, inadequately; D-3, not at all; E-1, adequately; E-2, adequately; E-3, not at all; F-1, inadequately; F-2, adequately; F-3, adequately; G-1, adequately; G-2, inadequately; G-3, inadequately; H-1, adequately; H-2, adequately; H-3, completely; I-1, inadequately, I-2, not at all; and I-3, inadequately.

D. ANALYSIS OF THERMAL DATA PERTAINING TO AIR MOVEMENT

Criterion 5. Air movement within the classroom should be continuous and sufficient to distribute heat evenly throughout the working level of the room at the horizontal plane and to minimize excessive temperature gradients from the floor to the ceiling.

Pertinent data relating thermal conditions in all classrooms to Criterion 5 are found in Table XVI. The mean differential between maximum and minimum 30-inch readings, the mean differential between the 6-inch and 60-inch readings at the center of the room, and the mean differential between the 60-inch and 120-inch readings at the center of the room are presented in order to determine to what extent Criterion 1 is met. Since no optimum air movement was stated in the criterion statement, the range of air movements as measured by a Kata thermometer

TABLE XVI

COMPARISON OF THERMAL DATA WITH CRITERION 5

Classroom	Range of measured air movement	Criterion: Air movement continuous and sufficient to: Distribute heat evenly throughout the working level of the room at the horizontal plane — Mean differential between maximum and minimum 30" readings	Minimize excessive temperature gradients from the floor to the ceiling — Mean differential between 6" and 60" readings	Minimize excessive temperature gradients from the floor to the ceiling — Mean differential between 60" and 120" readings
A-1	10-50 fpm	1.45°F.	4.09°F.	0.98°F.
A-2	5-50 fpm	0.82°F.	4.00°F.	0.56°F.
A-3	2-55 fpm	0.77°F.	1.84°F.	1.09°F.
B-1	1-11 fpm	1.04°F.	4.67°F.	6.78°F.
B-2	Imperceptible-32 fpm	0.93°F.	4.24°F.	5.12°F.
B-3	Imperceptible-42 fpm	1.56°F.	2.84°F.	5.72°F.
C-1	3-18 fpm	0.45°F.	0.88°F.	0.36°F.
C-2	1-18 fpm	0.65°F.	2.07°F.	3.12°F.
C-3	2-24 fpm	0.67°F.	1.46°F.	1.40°F.
D-1	Imperceptible-10 fpm	0.57°F.	3.98°F.	2.68°F.
D-2	7-25 fpm	1.98°F.	1.61°F.	0.78°F.
D-3	2-13 fpm	1.51°F.	1.85°F.	1.70°F.
E-1	4-20 fpm	0.67°F.	1.60°F.	0.16°F.
E-2	Imperceptible-20 fpm	1.18°F.	2.55°F.	0.11°F.
E-3	2-50 fpm	1.18°F.	1.45°F.	2.23°F.
F-1	9-20 fpm	2.09°F.	1.12°F.	1.16°F.
F-2	8-100 fpm	1.25°F.	0.91°F.	1.14°F.
F-3	7-20 fpm	1.04°F.	3.41°F.	0.48°F.
G-1	2-30 fpm	1.45°F.	2.60°F.	3.64°F.
G-2	Imperceptible-5 fpm	0.60°F.	2.23°F.	2.89°F.
G-3	Imperceptible-10 fpm	0.88°F.	3.15°F.	2.87°F.
H-1	5-25 fpm	1.20°F.	0.88°F.	-0.03°F.
H-2	5-31 fpm	1.27°F.	1.45°F.	0.12°F.
H-3	10-31 fpm	2.67°F.	0.65°F.	0.42°F.
I-1	Imperceptible-50 fpm	1.14°F.	5.83°F.	4.72°F.
I-2	2-28 fpm	0.92°F.	4.53°F.	8.00°F.
I-3	Imperceptible movement	0.77°F.	4.65°F.	4.03°F.

that are recorded in Table XVI actually serves more as a guide than as a component of the criterion. Some types of classroom heating systems do not require as much air movement as do others in order to perform the functions specified in Criterion 5.

Figures 48-74 that follow graphically illustrate temperature gradients at the 6-inch, 30-inch, 60-inch, and 120-inch levels from the floor to the ceiling at the center of each room. The discussion to follow will refer to the various figures as they relate to the discussion, while the data contained in Table XVI, page 243, should be assumed to be incorporated in the conclusions regarding conditions found in each classroom.

Classroom A-1. Figure 48 illustrates a mean difference of slightly more than four inches from the 6-inch to the 60-inch level, with less than a degree difference from the 60-inch to the 120-inch level. The reader will note throughout Figures 48-74 that the gradient between the 6-inch and the 30-inch level is actually greater than that existing between any other two levels. Cold slab-on-grade floors partially account for such a differential at the floor level. The recorded 6-inch reading was 68°F. while the maximum 120-inch reading was 78°F. Neither extreme of the range were typical readings. Air movement was continuous. The investigator considered the criterion to have been met adequately.

Classroom A-2. Figure 49, page 246, shows the same difference of 10 degrees that existed between the minimum 6-inch reading and the

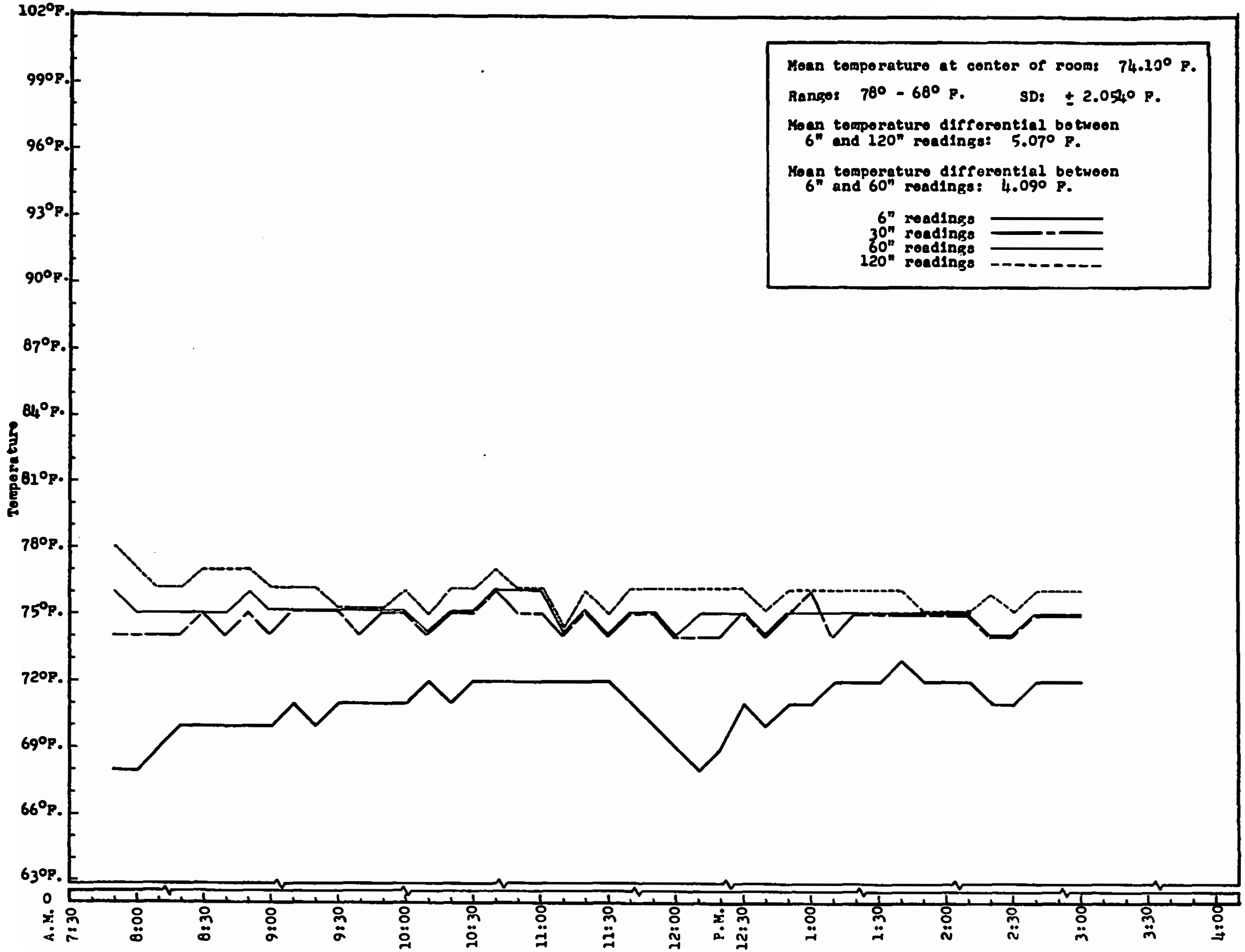


Figure 48. Temperature gradients from floor to ceiling at center of Classroom A-1.

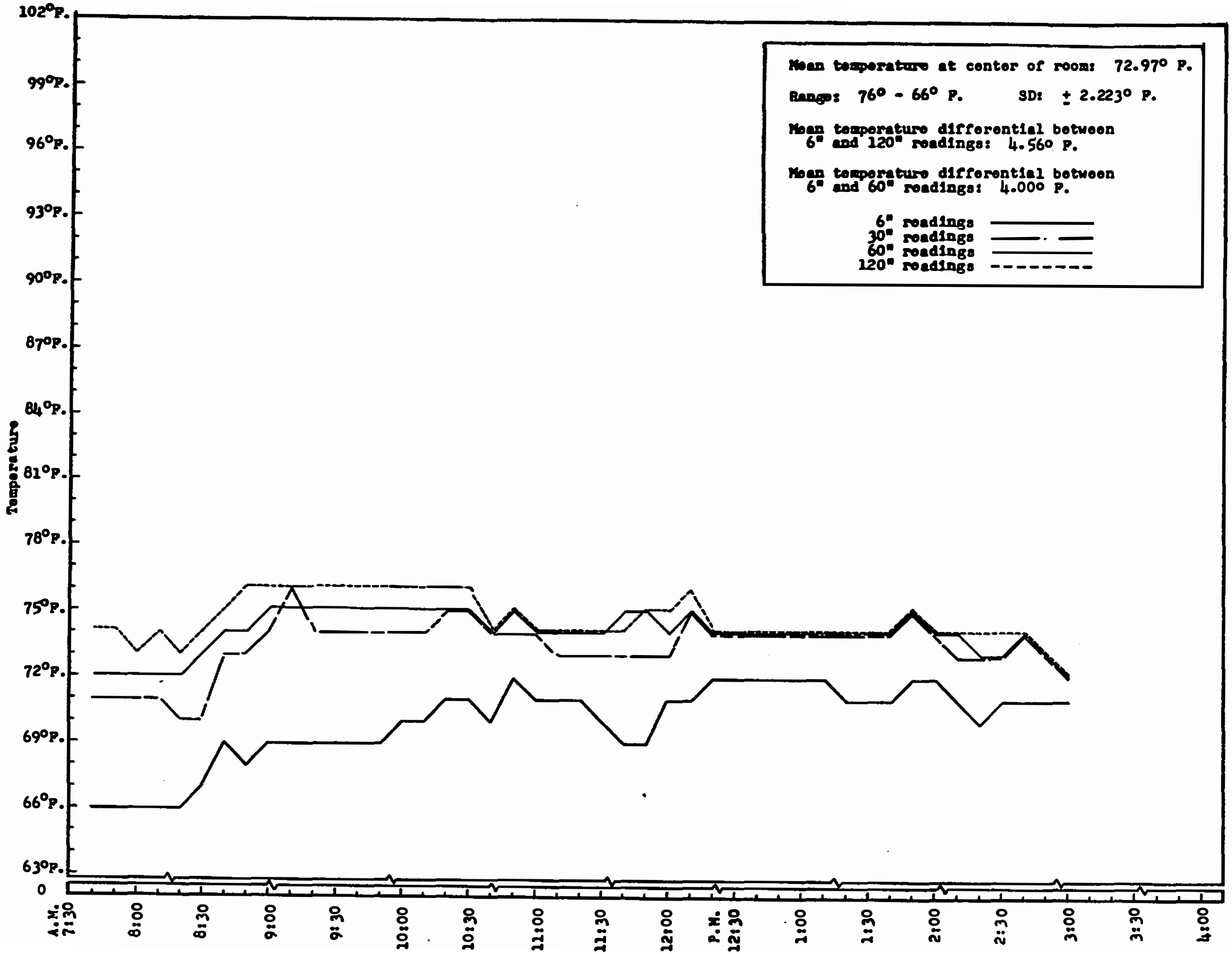


Figure 49. Temperature gradients from floor to ceiling at center of Classroom A-2.

maximum 120-inch reading that existed in Classroom A-1. The mean differential at the 30-inch horizontal plane was less than a degree. Air movement was continuous so the criterion was considered to have been met adequately.

Classroom A-3. Figure 50 shows gradient conditions that existed in Classroom A-3. Although the range of air movement was as great as that found in Rooms A-1 and A-2, mean air movement was less, and the results seem to have been better. A mean difference of less than two degrees existed between the 6-inch and 60-inch reading. All data enabled the criterion to have been met completely.

Classroom B-1. Air movement evidently was insufficient in Classroom B-1. Figure 51, page 249, shows a mean floor to ceiling difference of better than 10 degrees with a difference range of 35 degrees. Average air movement was less than six feet per minute as recorded by the Kata thermometer. Thermal conditions seemed to have met Criterion 5 rather inadequately.

Classroom B-2. Conditions relating to air movement in Classroom B-2 were almost as bad as those in B-1. At one time, the Kata thermometer could reveal no air movement in Zone V at the 5-foot level and the range between the highest 120-inch reading and the lowest 6-inch reading was 27 degrees. The mean differential at the 30-inch horizontal level was less than 1 degree, but conditions over-all inadequately met the criterion. (See Figure 52, page 250.)

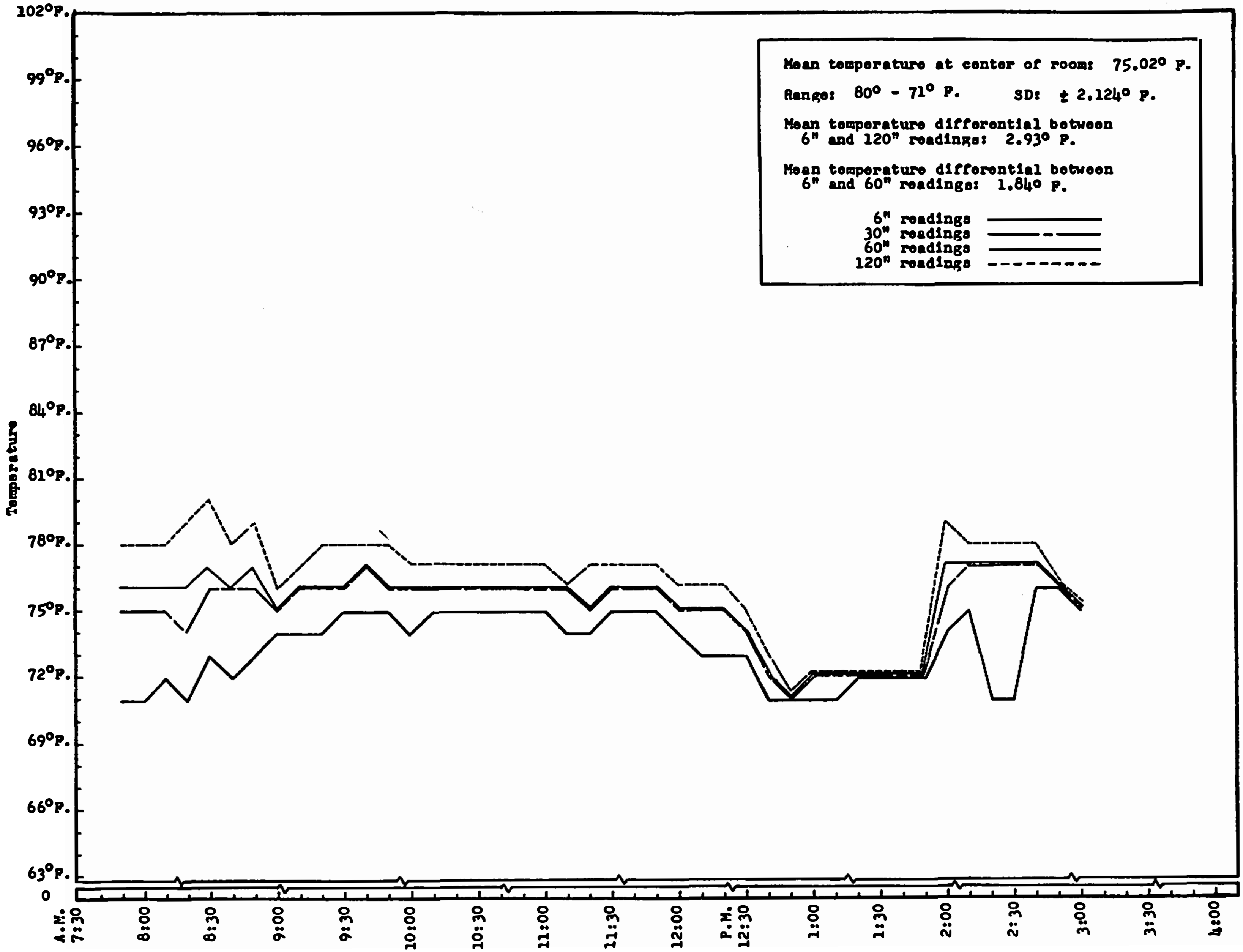


Figure 50. Temperature gradients from floor to ceiling at center of Classroom A-3.

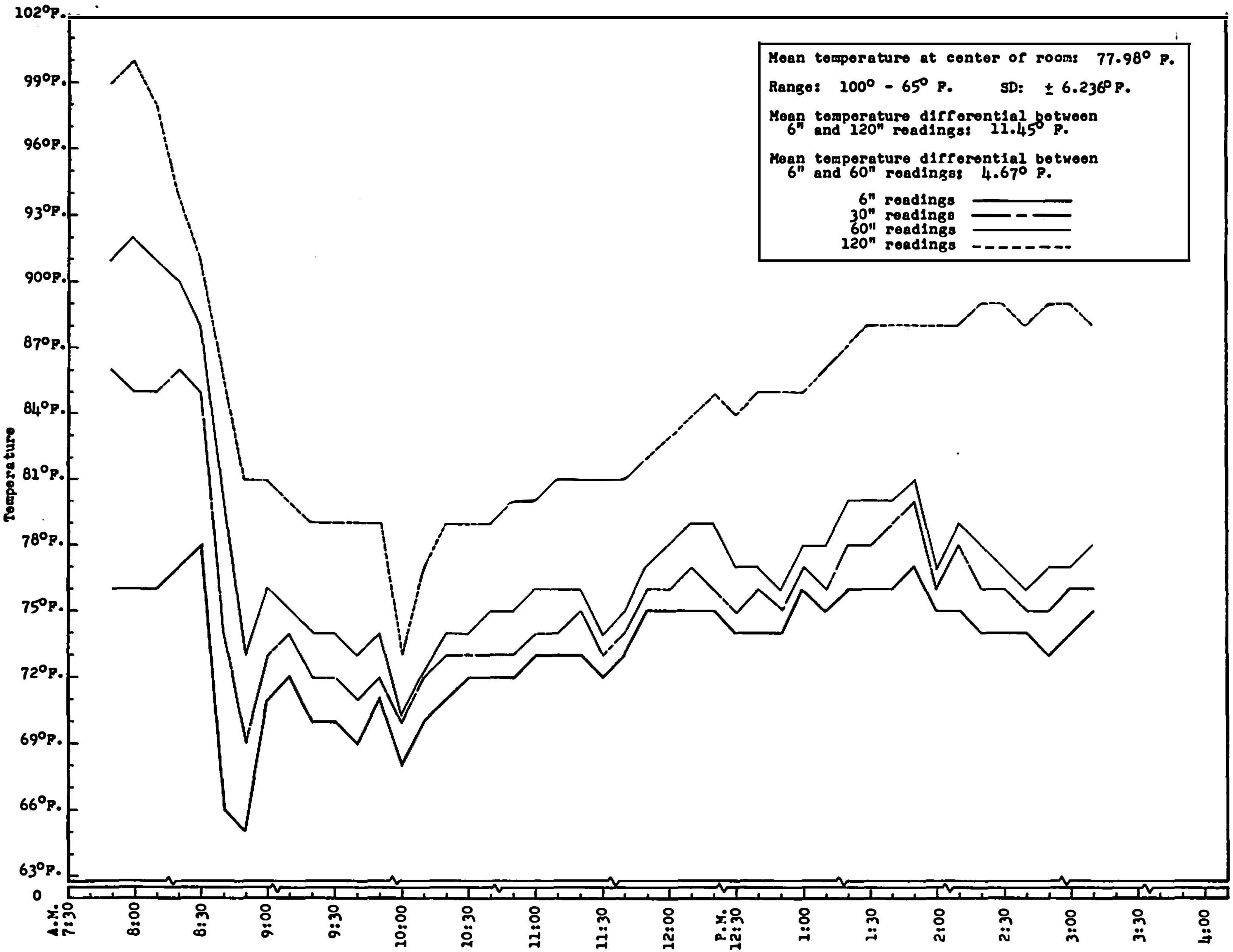


Figure 51. Temperature gradients from floor to ceiling at center of Classroom B-1.

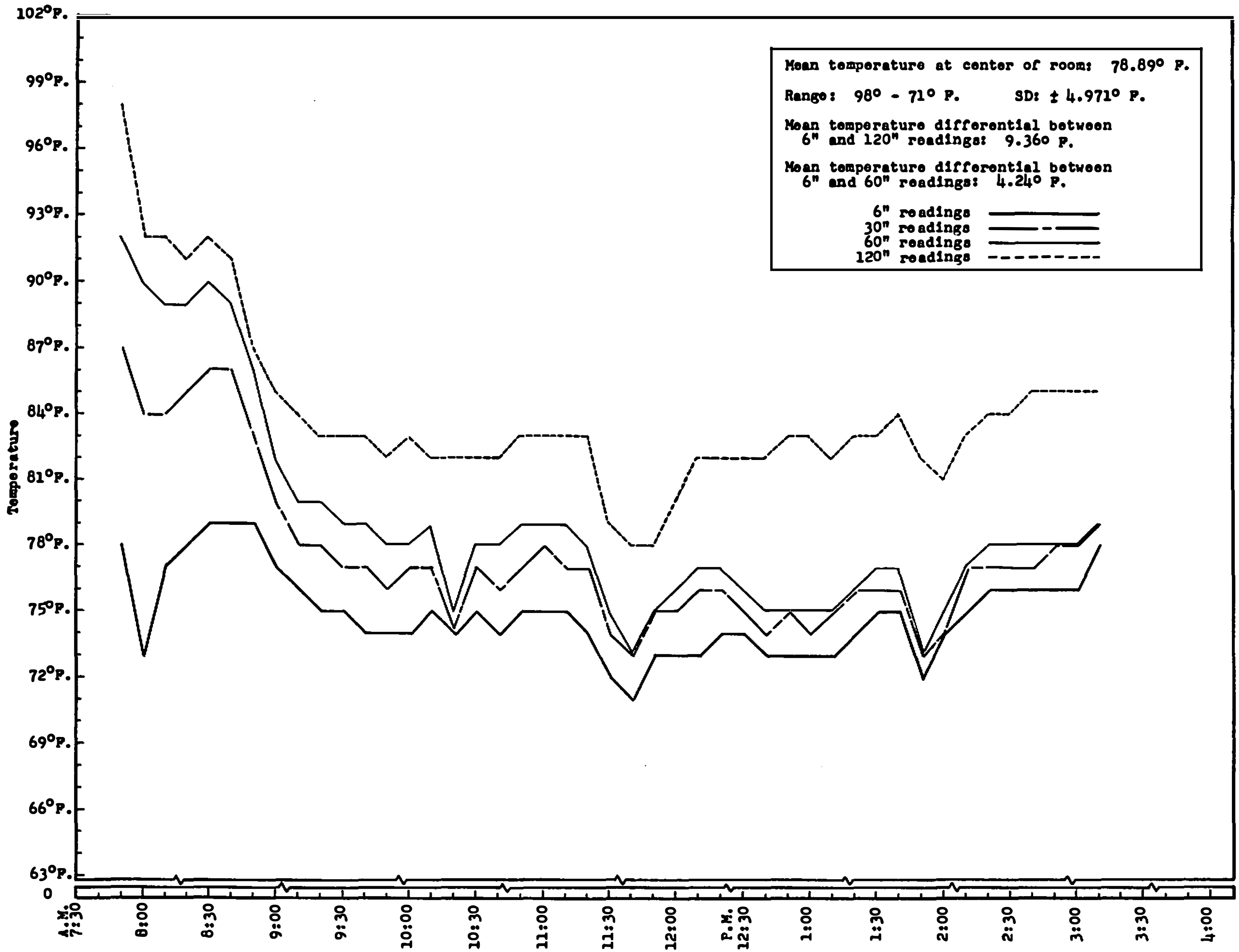


Figure 52. Temperature gradients from floor to ceiling at center of Classroom B-2.

Classroom B-3. Figure 53 shows the three lower readings, 6-inch, 30-inch, and 60-inch, to be grouped closely together with less than 3 degrees separating the 6- and 60-inch levels. The mean differential between the 60-inch and 120-inch level was within the differential normally expected with radiant heat. The average air movement for the day was nearly 17 feet per minute. Despite the tremendous range of 37 degrees between the maximum 120-inch reading and the lowest 6-inch reading, the criterion seems to have been met adequately for the day investigated.

Classroom C-1. Classroom C-1 contained some of the best examples of good air movement of any room visited. Figure 54, page 253, illustrates a mean differential of slightly more than one degree between the floor and ceiling. The reader also can observe the close relationship that existed between temperatures at the lower two levels. Continuous air movement and a mean horizontal differential of less than one-half of a degree enabled the classroom to completely meet the criterion.

Classroom C-2. The reader can observe the same type of relationship between the lower levels of readings in the C-2 graph, Figure 55, page 254. Perhaps the wooden floors influenced the pleasant environment. Certainly the adequacy of the ventilation and air movement system is evident and the criterion was completely met.

Classroom C-3. The criterion also was completely met in Classroom C-3 as shown by Figure 56, page 255. The mean horizontal differential at the 30-inch level was less than 1 degree, as was true in all

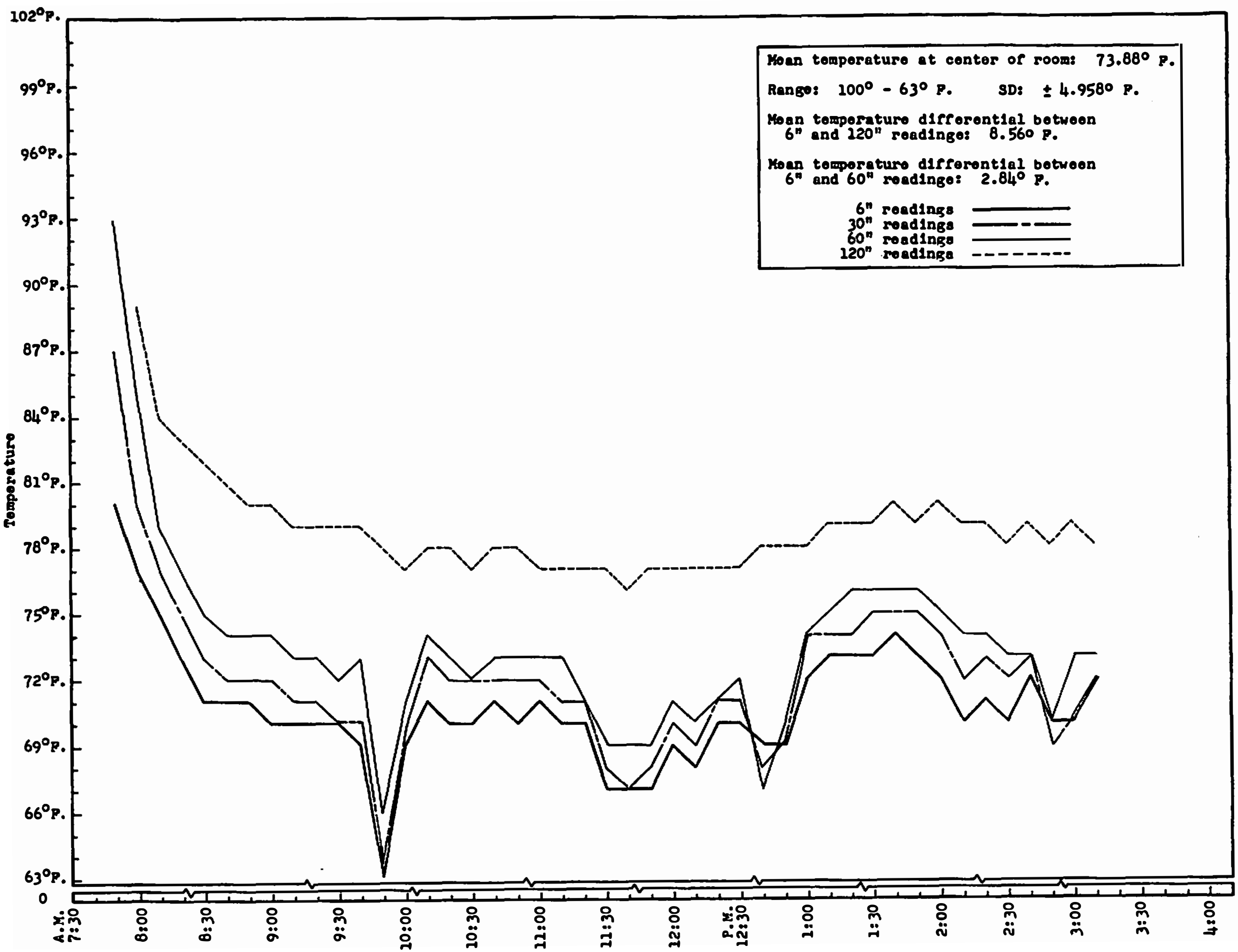


Figure 53. Temperature gradients from floor to ceiling at center of Classroom B-3.

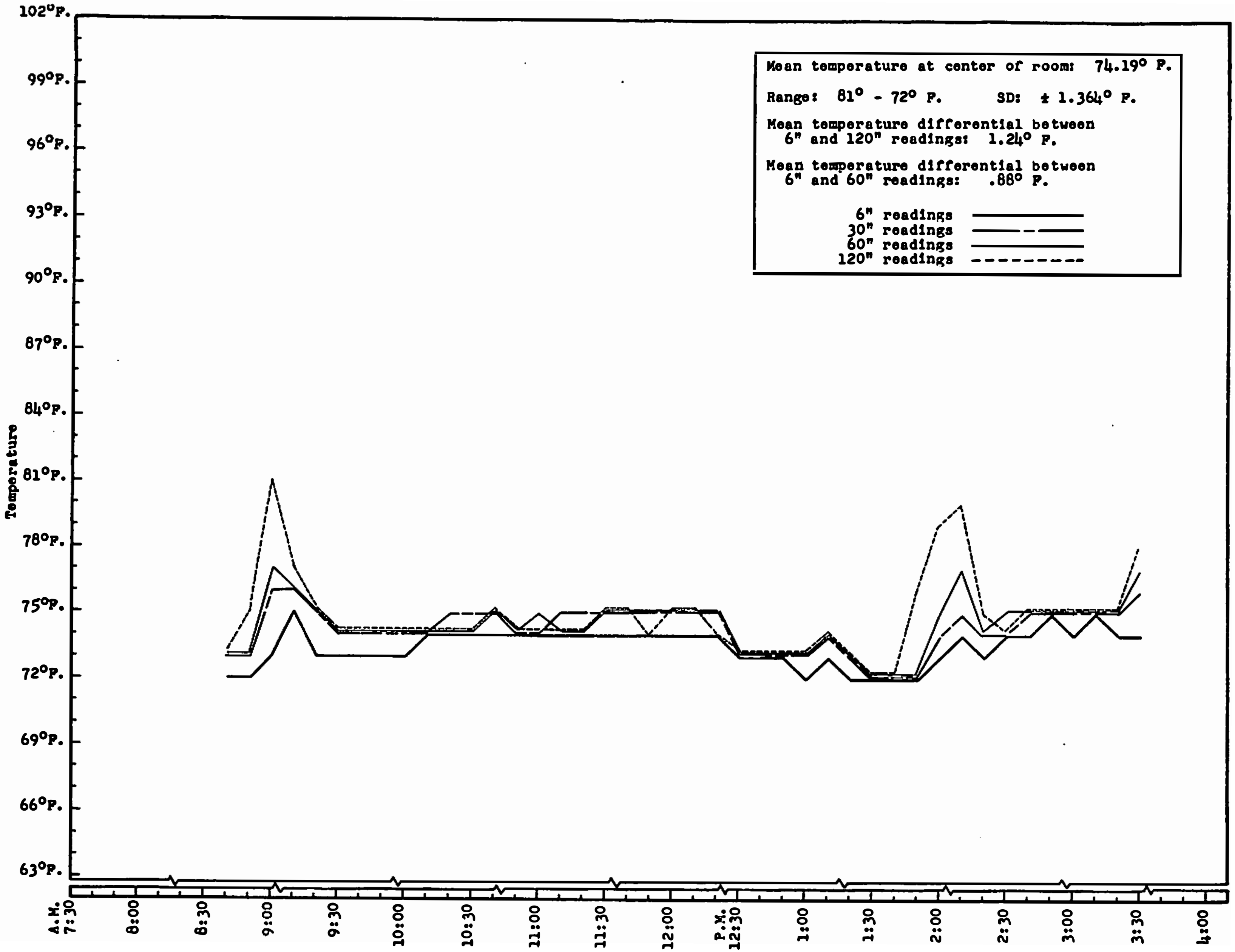


Figure 54. Temperature gradients from floor to ceiling at center of Classroom C-1.

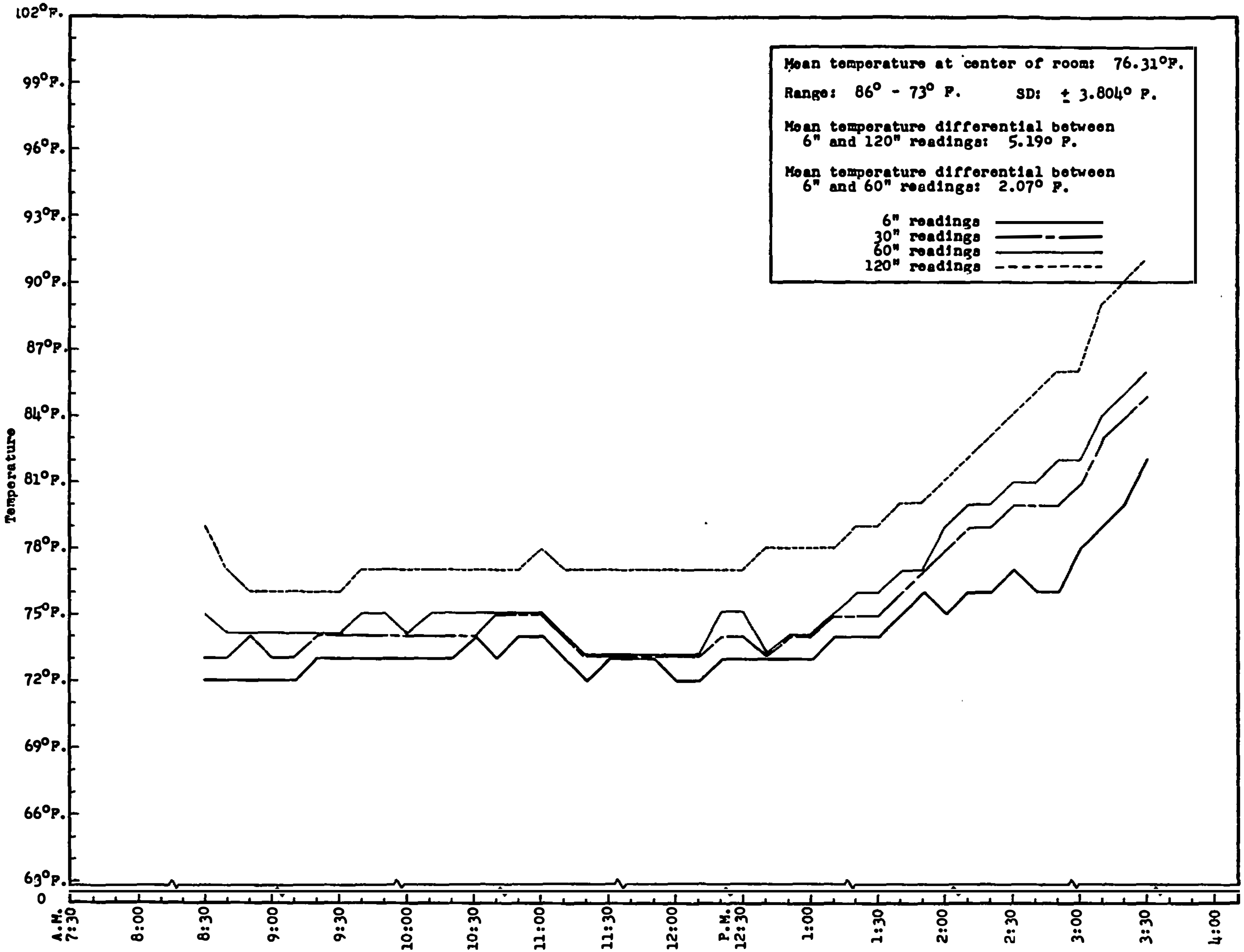


Figure 55. Temperature gradients from floor to ceiling at center of Classroom C-2.

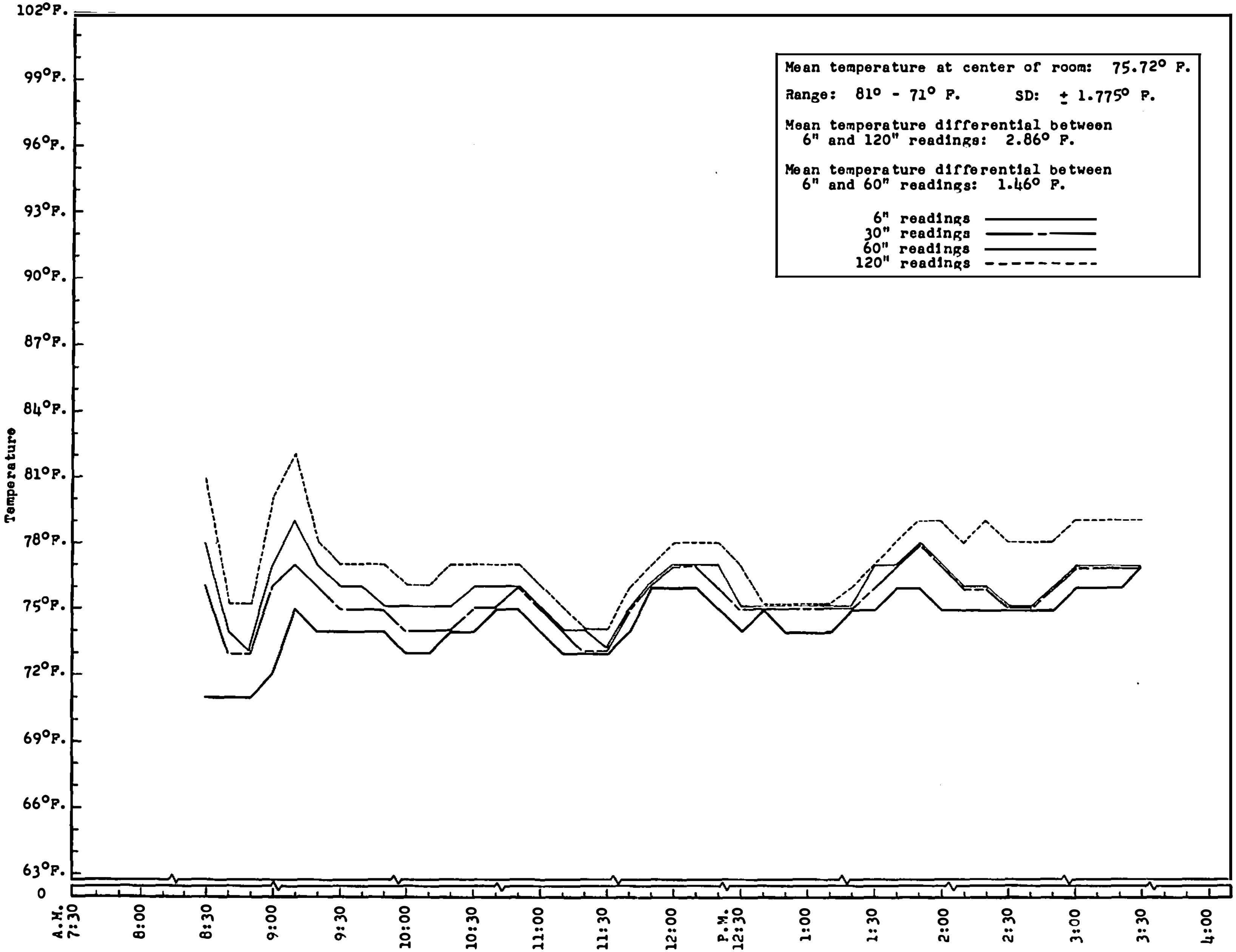


Figure 56. Temperature gradients from floor to ceiling at center of Classroom C-3.

classrooms in School C. The mean differential from floor to ceiling was less than 3 feet.

Classroom D-1. No air movement was recorded in Zone I of Room D-1 beneath the discharge grilles of the heating and ventilating system, and maximum air movement on the window-wall side of the room within the working zone was only 10 feet per minute. Figure 57 shows conditions not as good as those in School C but good enough to meet the criterion adequately, the only criterion that Classroom D-1 met.

Classroom D-2. For some reason, air movement in Classroom D-2 was higher than that found in D-1, and the differential between the floor and ceiling was correspondingly better. As shown in Figure 58, page 258, a mean differential of slightly over 2 degrees existed between the 6-inch and 120-inch level. A fairly large mean differential of nearly 2 degrees existed between maximum and minimum 30-inch horizontal readings. This differential was due partly to slight differences between the corridor wall and window wall temperatures. The criterion was met adequately, however.

Classroom D-3. Figure 59, page 259, shows gradients for Classroom D-3. Of interest is the 3-hour and 30-minute span beginning at 10:00 a.m. when the differential between the 60-inch and 120-inch levels were constant at 2 degrees apart. Excessive gradients were avoided and Criterion 5 was met adequately.

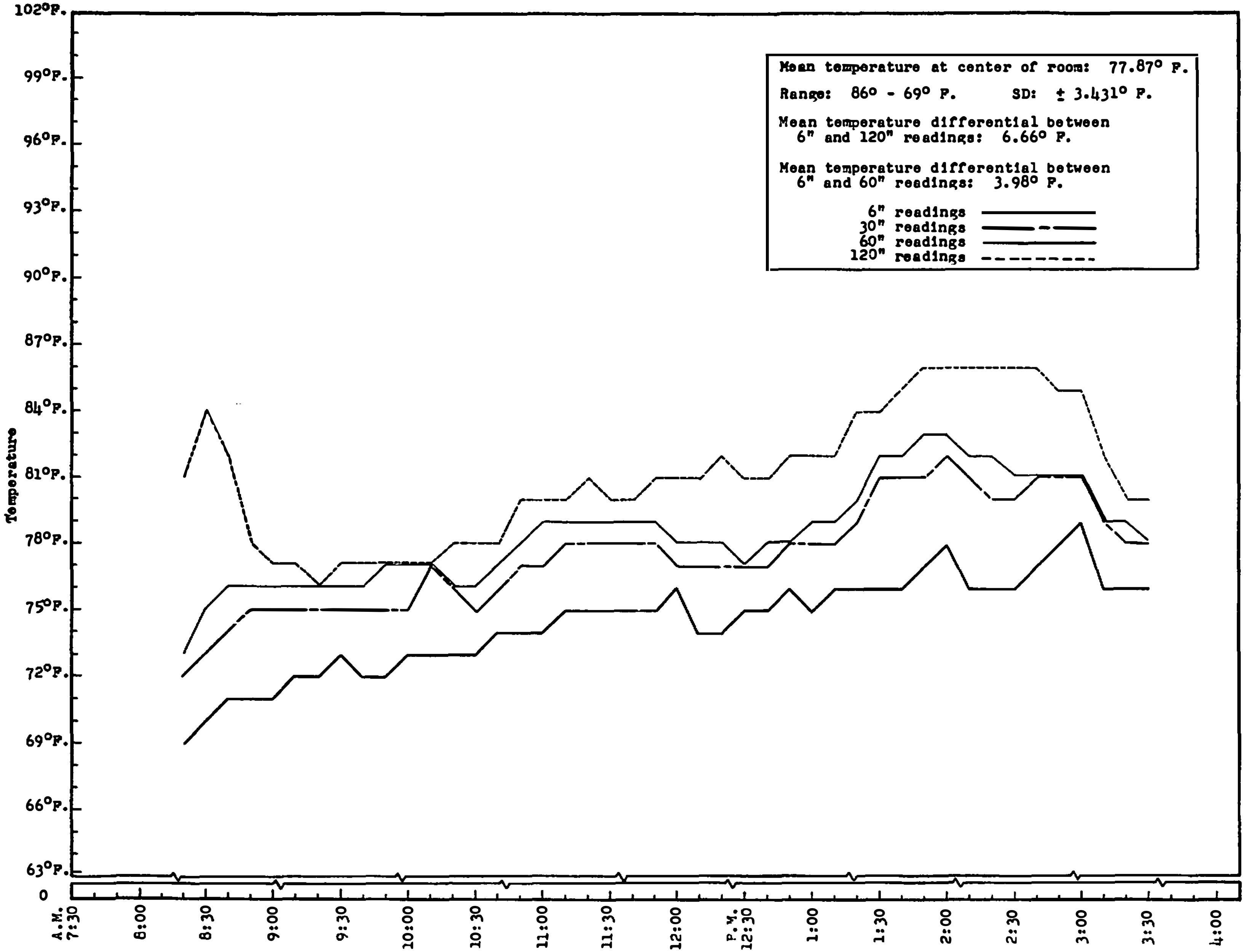


Figure 57. Temperature gradients from floor to ceiling at center of Classroom D-1.

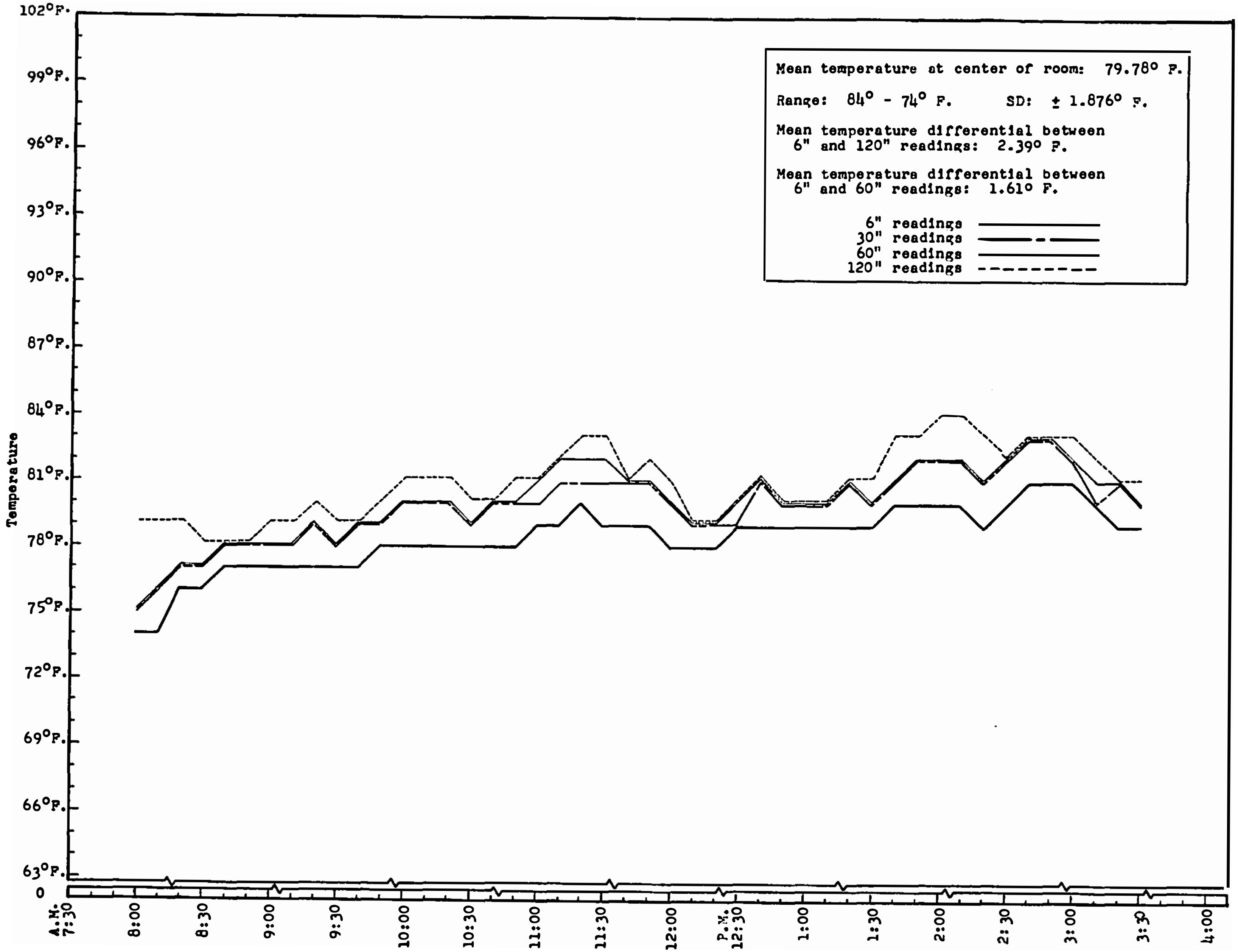


Figure 58. Temperature gradients from floor to ceiling at center of Classroom D-2.

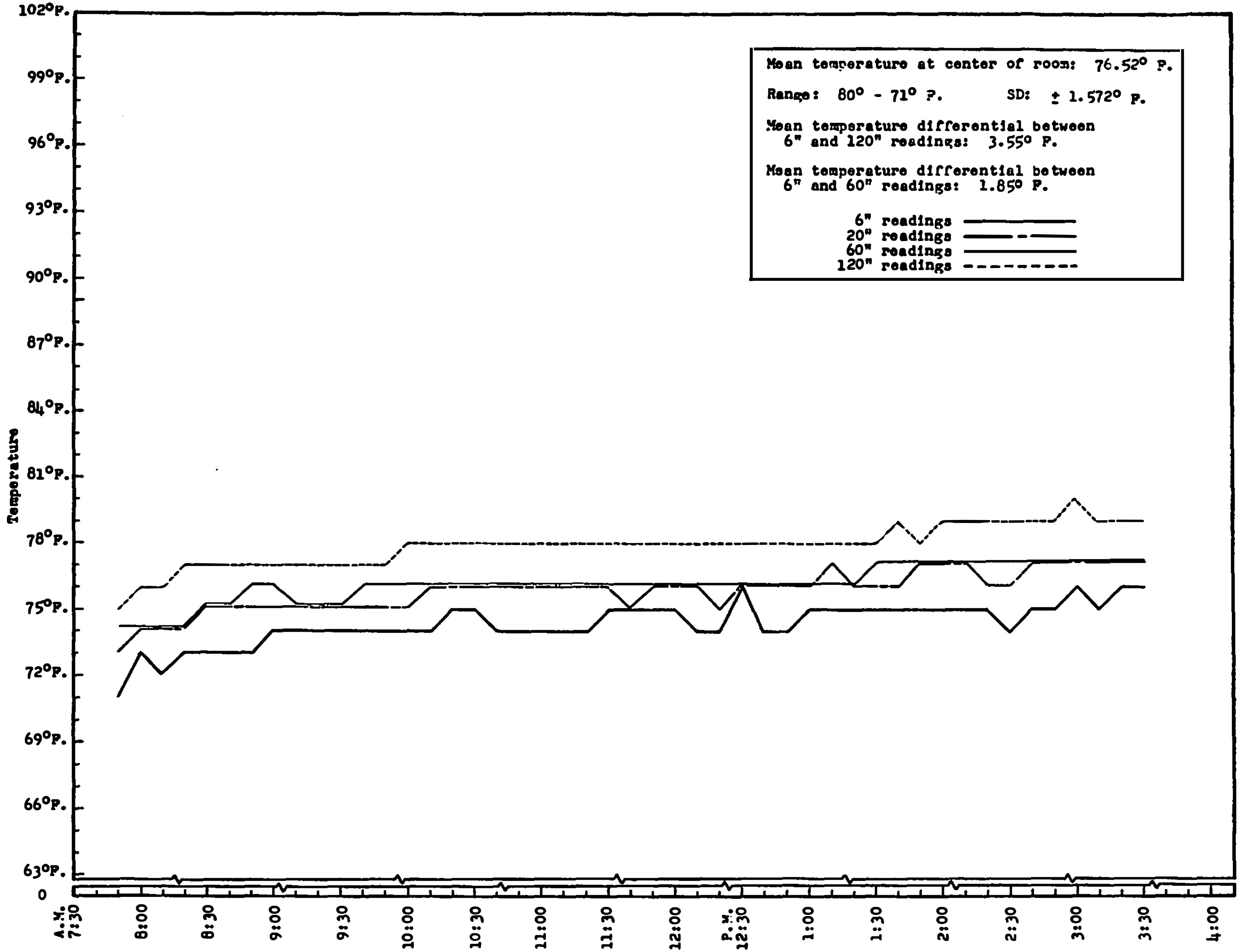


Figure 59. Temperature gradients from floor to ceiling at center of Classroom D-3.

Classroom E-1. Good conditions were evident in Classroom E-1 as depicted in Figure 60. Mean air movement was only about 10 feet per minute, but warm air was constantly escaping into the unheated corridor through the ceiling level opening mentioned in Chapter V. Total differential between floor and ceiling was less than 2 degrees. All data enabled the room to completely meet the criterion.

Classroom E-2. The air movement recorded at the 5-foot level of Zone V, Room E-2, was not perceptible at 8:00 a.m. The results of a strong breeze shortly thereafter resulting from window ventilation are evident in the drop of the 6-inch reading in Figure 61, page 262, illustrating one of the disadvantages of both air movement and ventilation produced by open windows. The total end results were favorable, however, and the criterion was considered to be adequately met.

Classroom E-3. Figure 62, page 263, shows conditions that existed in Classroom E-3. Opening and closing of windows produced some unnecessary temperature wavering, but mean conditions adequately met the criterion.

Classroom F-1. Criterion 5 was considered to have been met adequately in Classroom F-1 because of the gradient situation pictured in Figure 63, page 264. The mean horizontal differential was actually the second worst recorded.

Classroom F-2. Temperature gradients in Classroom F-2 are shown in Figure 64, page 265. Although the reader must recall that there was

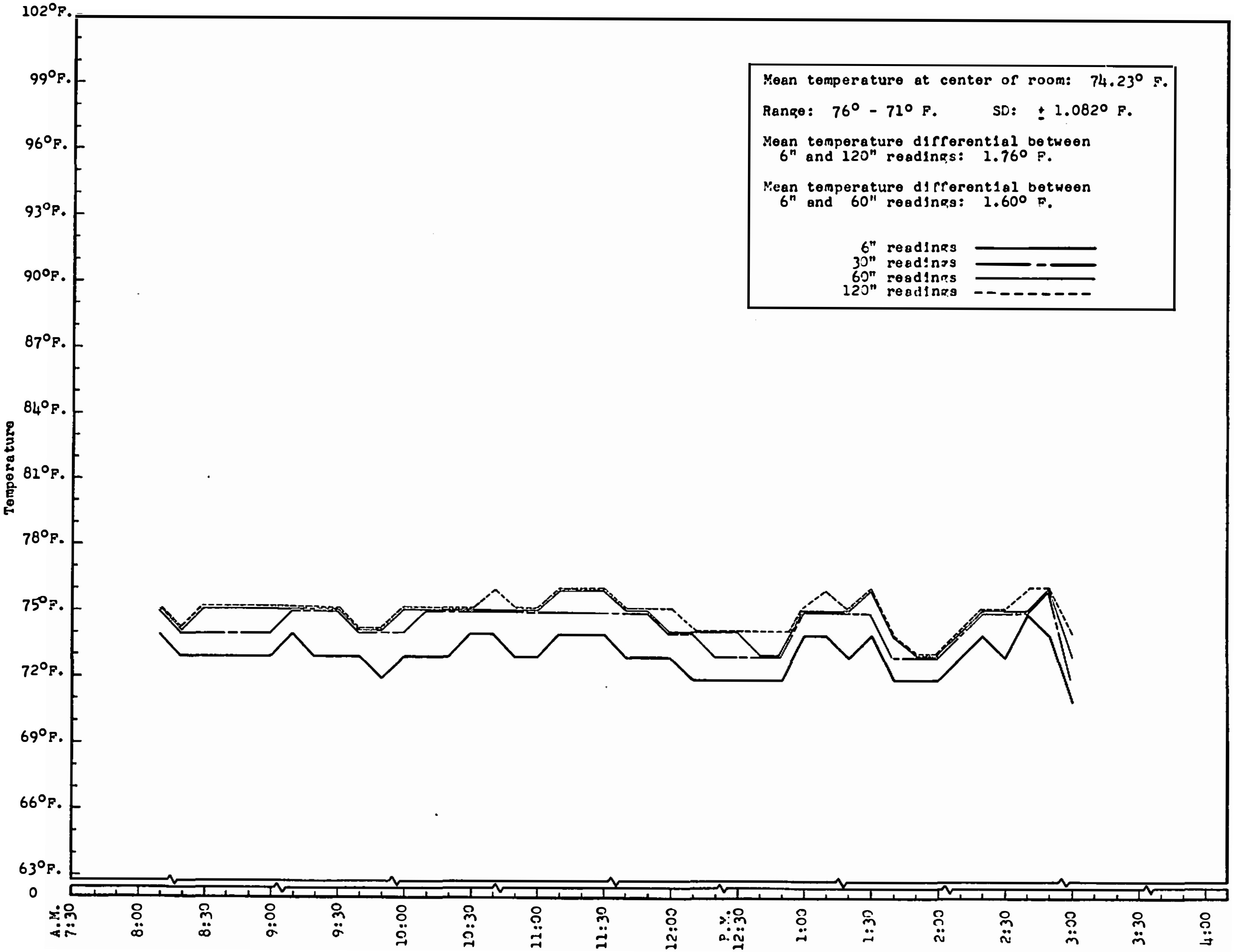


Figure 60. Temperature gradients from floor to ceiling at center of Classroom E-1.

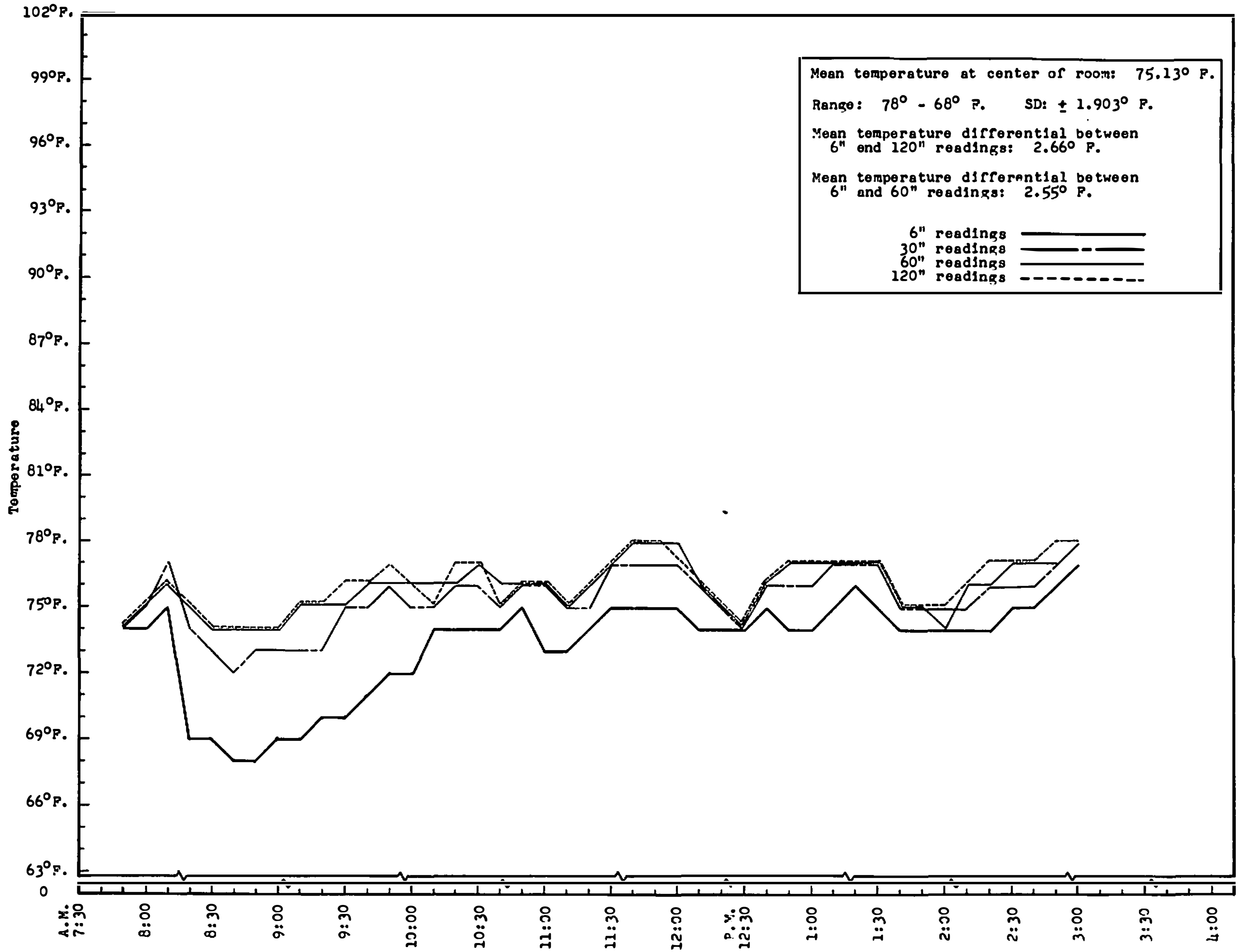


Figure 61. Temperature gradients from floor to ceiling at center of Classroom E-2.

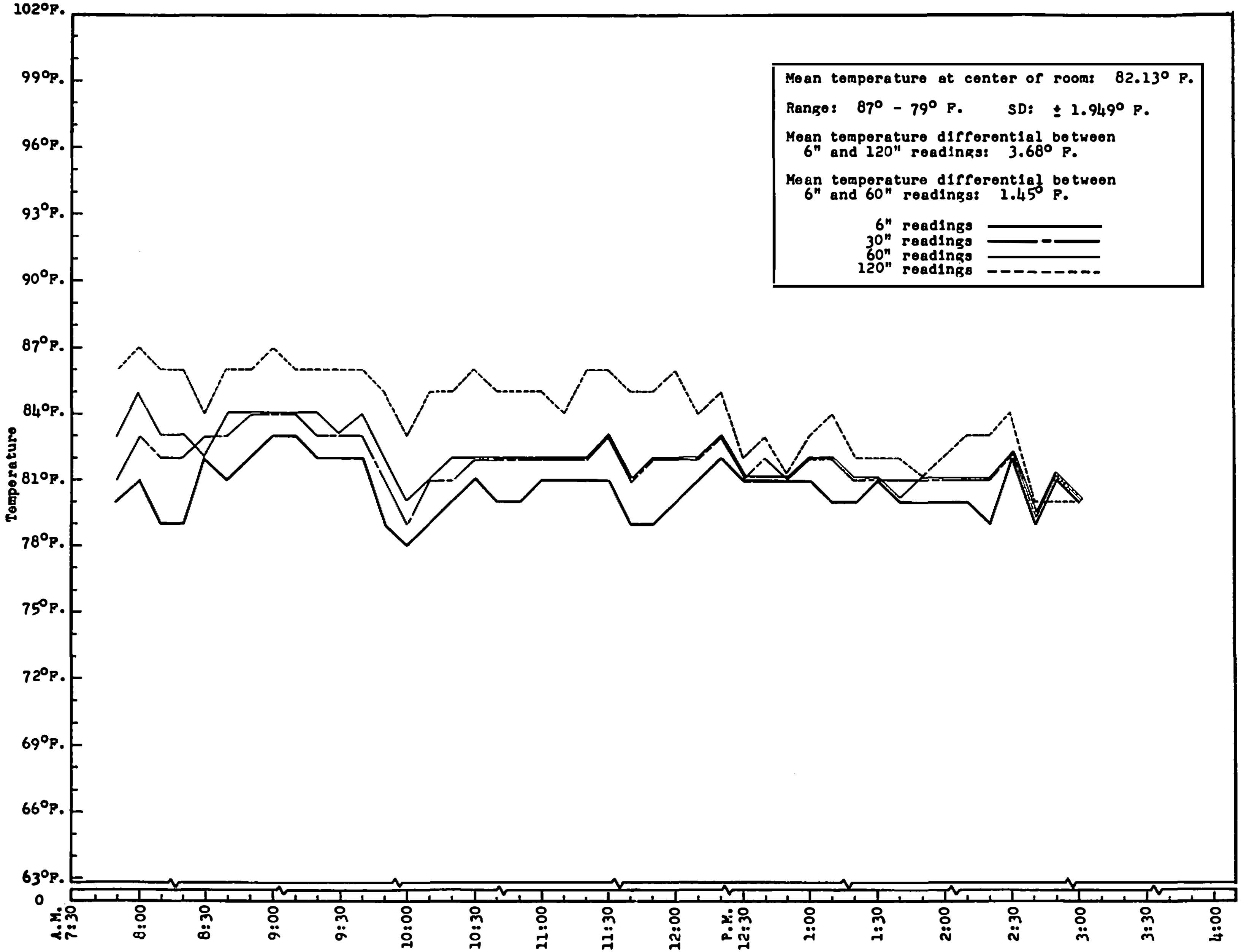


Figure 62. Temperature gradients from floor to ceiling at center of Classroom E-3.

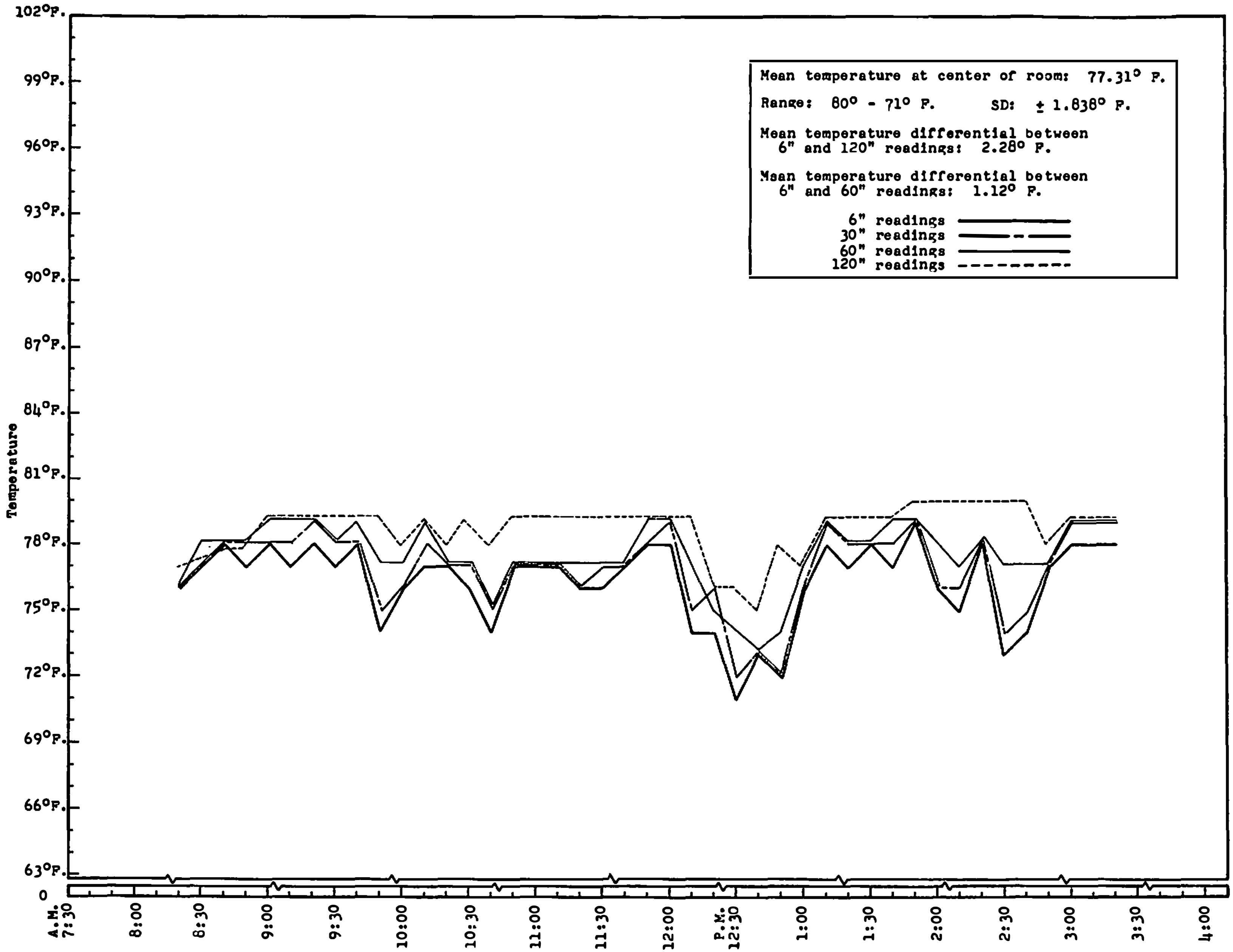


Figure 63. Temperature gradients from floor to ceiling at center of Classroom F-1.

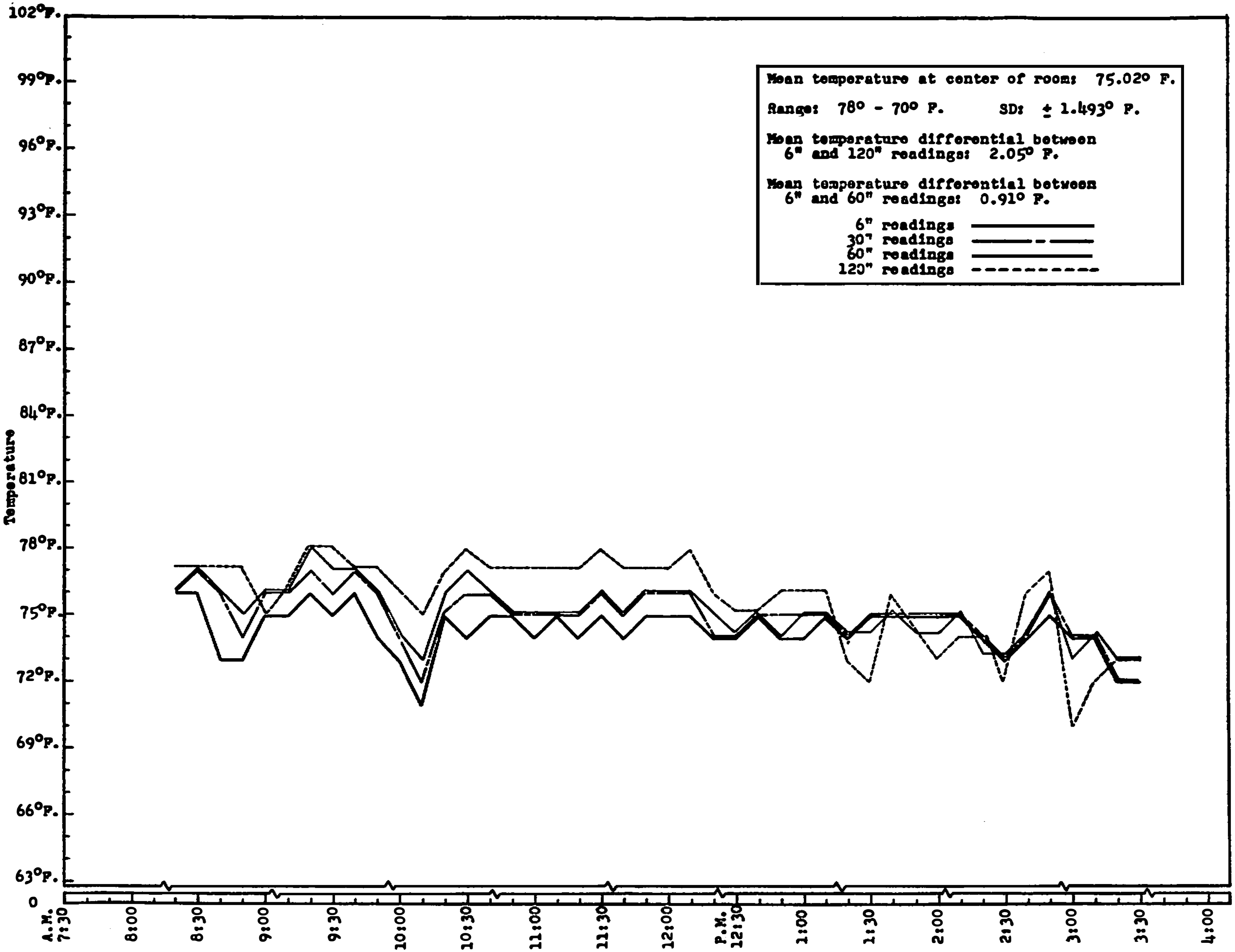


Figure 64. Temperature gradients from floor to ceiling at center of Classroom F-2.

no heat supplied to Classrooms F-1 and F-2 from the heating system because of the high outside temperature. Figure 64, page 265, depicts conditions created by air coming into the room at a rate approaching 100 feet per minute all day. The conditions adequately met Criterion 5.

<u>Classroom</u> <u>F-3</u>. Figure 65 shows some results of downdraft from an unheated window wall. However, the 3.41°F. differential between the 6-inch and the 30-inch reading was offset by the closeness of the other three levels. Classroom F-3 met Criterion 5 adequately.

<u>Classroom</u> <u>G-1</u>. A typical convector-heated room is shown in Figure 66, page 268. The lower two levels probably are closer to each other than normally is true because the room was a second story one, thus affording warmer floors. The conditions in G-1 were considered to have met the criterion adequately because of the low mean temperature difference between the 6-inch and 30-inch level.

<u>Classroom</u> <u>G-2</u>. Although window ventilation was afforded, air movement in Classroom G-2 was very low, at one point in the day not even registering on the Kata thermometer. Conditions pictures in Figure 67, page 269, were quite good, however, and the low mean horizontal gradient of only 0.60°F. enabled Classroom G-2 to completely meet Criterion 5.

<u>Classroom</u> <u>G-3</u>. Conditions in Classroom G-3 were generally good enough for the criterion to be met adequately. Figure 68, page 270, shows the temperature gradients in the room.

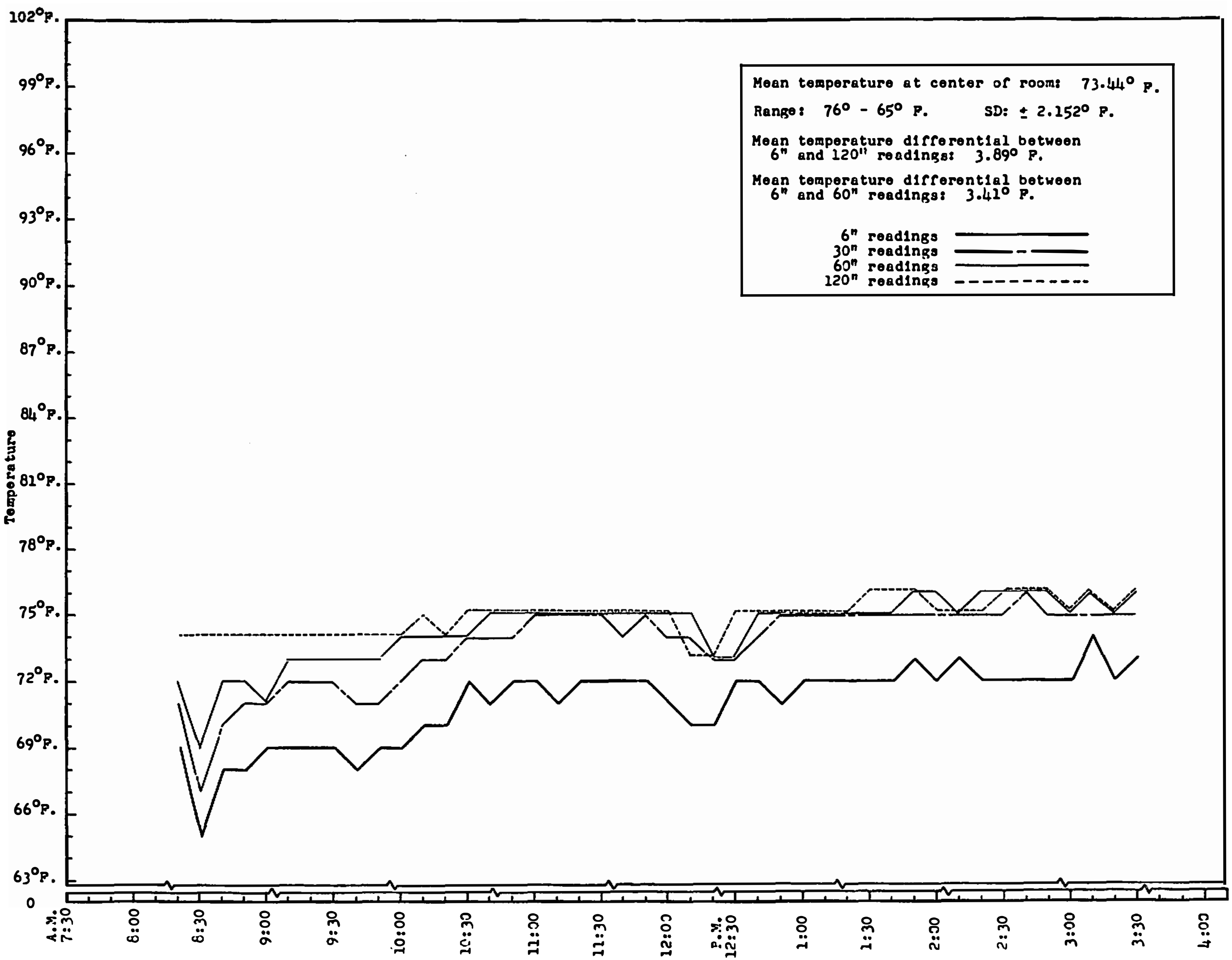


Figure 65. Temperature gradients from floor to ceiling at center of Classroom F-3.

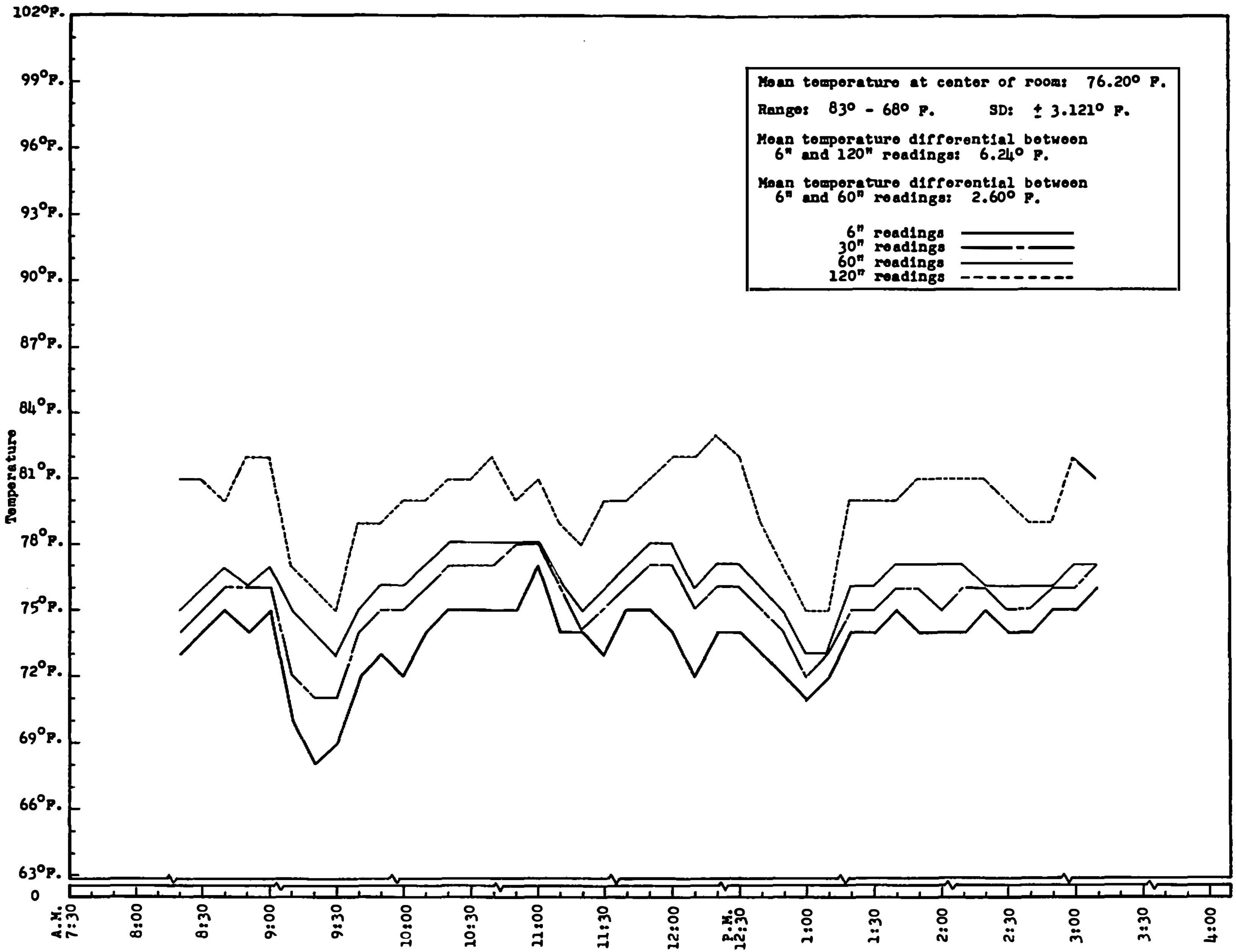


Figure 66. Temperature gradients from floor to ceiling at center of Classroom G-1.

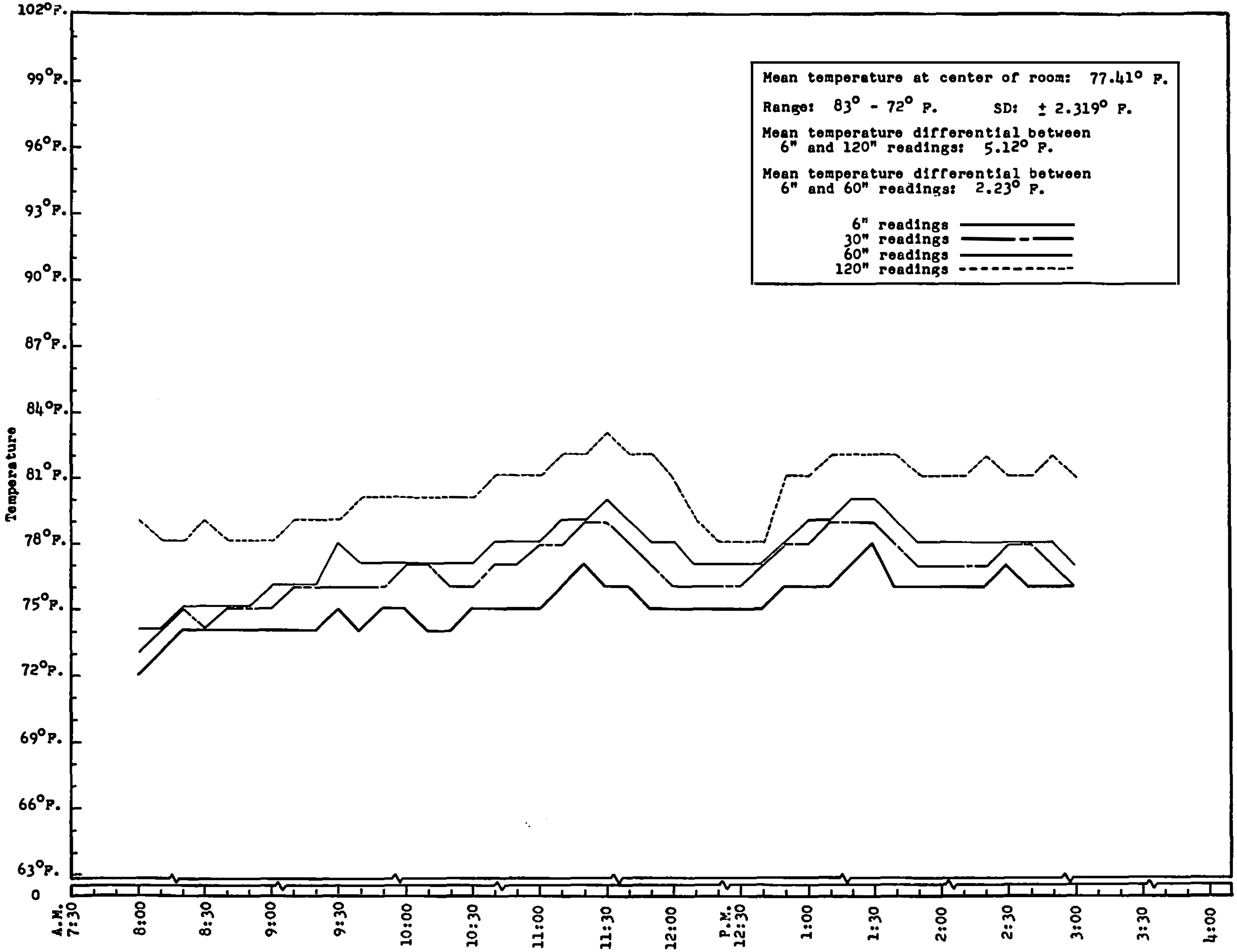


Figure 67. Temperature gradients from floor to ceiling at center of Classroom G-2.

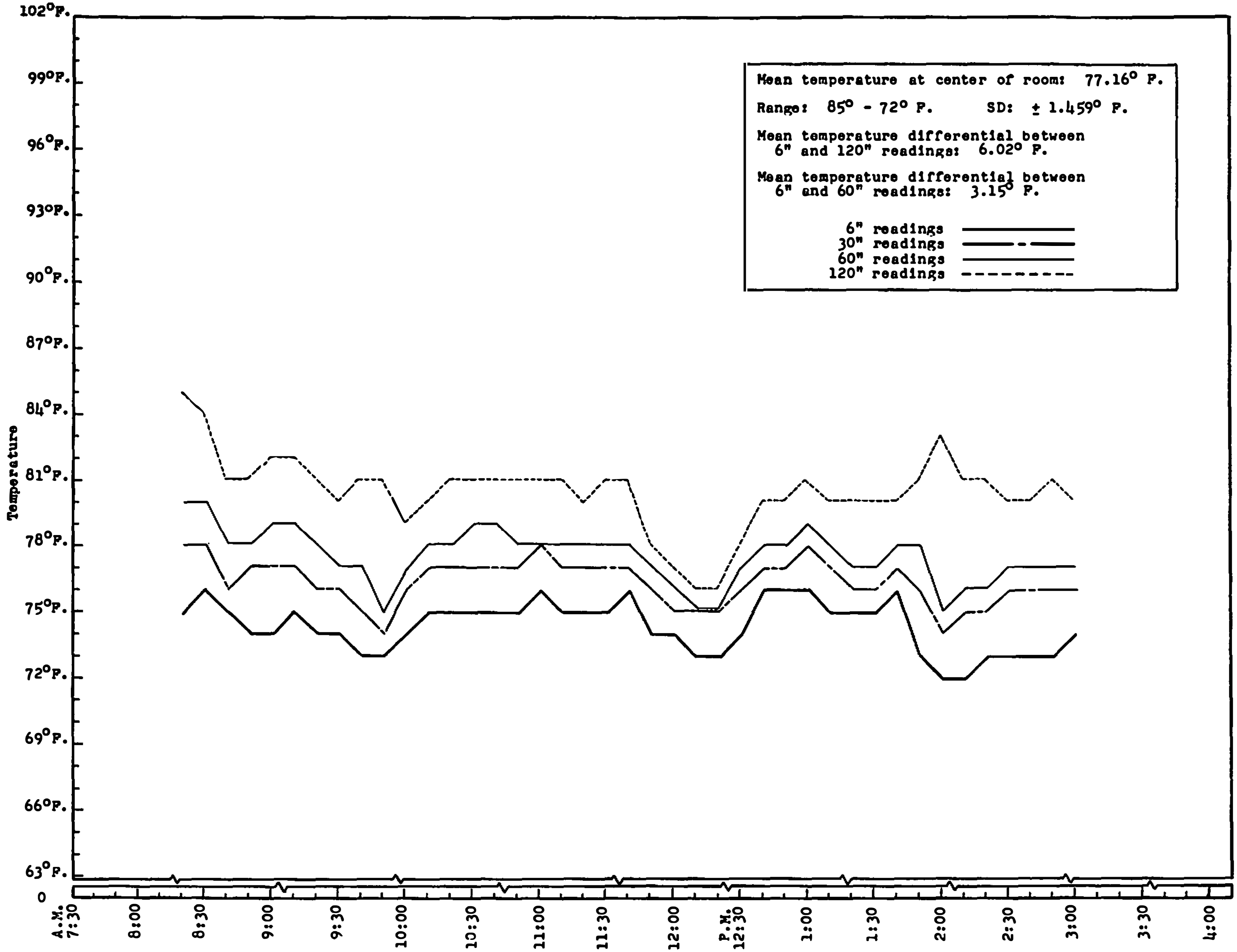


Figure 68. Temperature gradients from floor to ceiling at center of Classroom G-3.

Classroom H-1. Figure 69 graphically illustrates an amazing feat of minimizing excessive gradients from floor to ceiling. The mean temperature differential between the 6-inch and 120-inch level in Classroom H-1 was less than 1 degree with a good air movement throughout the room. A rather unique situation that also existed was that the mean differential between the 6-inch and 120-inch level was actually 0.03°F. less than the differential between the 6-inch and 60-inch level. Because the mean horizontal differential was slightly over 1 degree, however, the criterion was considered to have been met adequately rather than completely.

Classroom H-2. Figure 70, page 273, shows conditions existing in Classroom H-2 similar to those that existed in Classroom H-1. Mean differential between the 6-inch and 120-inch readings was only 1.57°F. Classroom H-2 also was kept from meeting Criterion 5 completely because the mean differential at the horizontal level was slightly over 1 degree. The criterion was met adequately.

Classroom H-3. The lowest differential between the 6-inch and 60-inch reading found in any school was the 0.65°F. differential that existed in Classroom H-3. Figure 71, page 274, also shows that the maximum differential between the highest ceiling reading and the lowest floor reading was only 4 degrees. For some reason, the mean horizontal gradient was the highest recorded, so Classroom H-3 also met the criterion adequately.

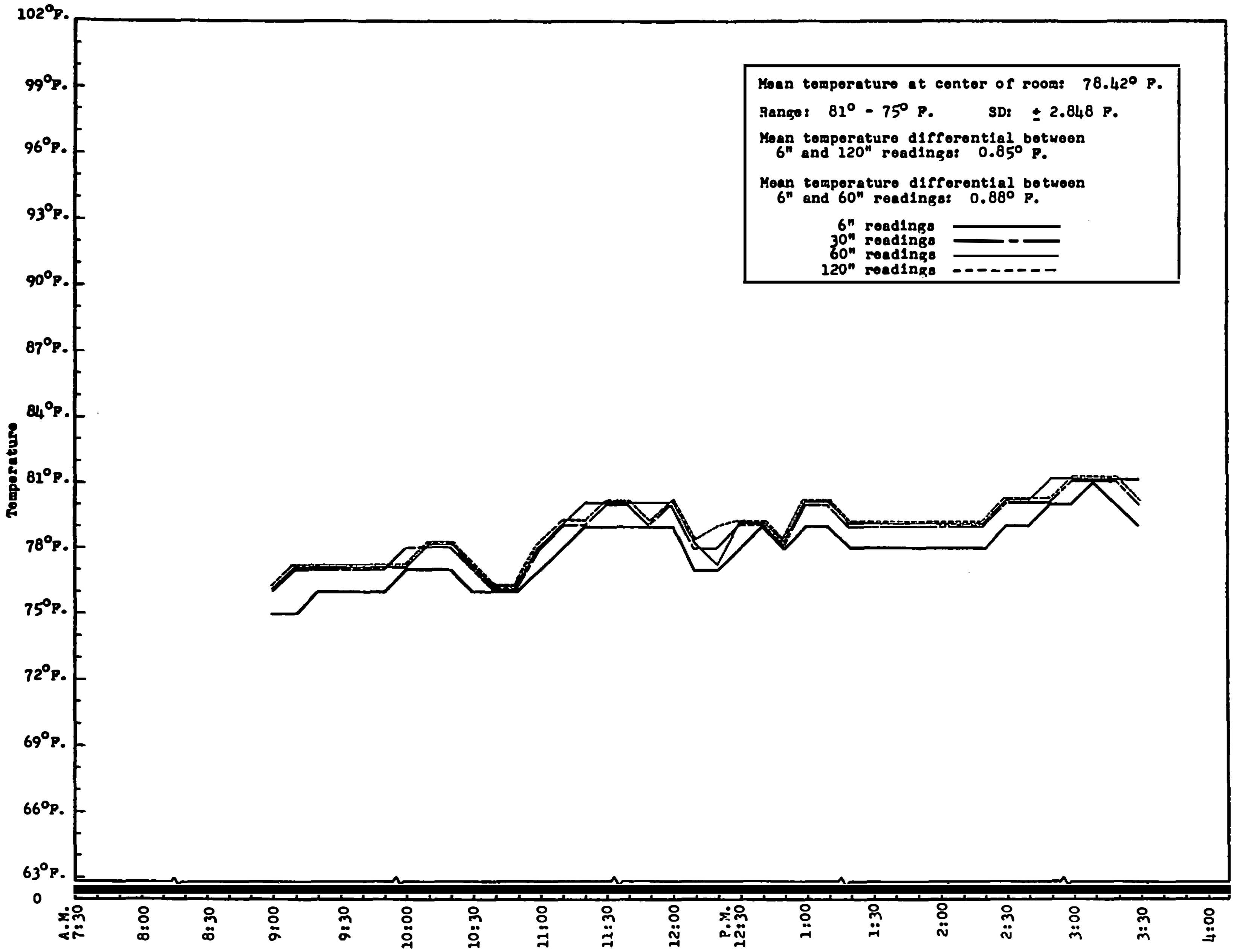


Figure 69. Temperature gradients from floor to ceiling at center of Classroom H-1.

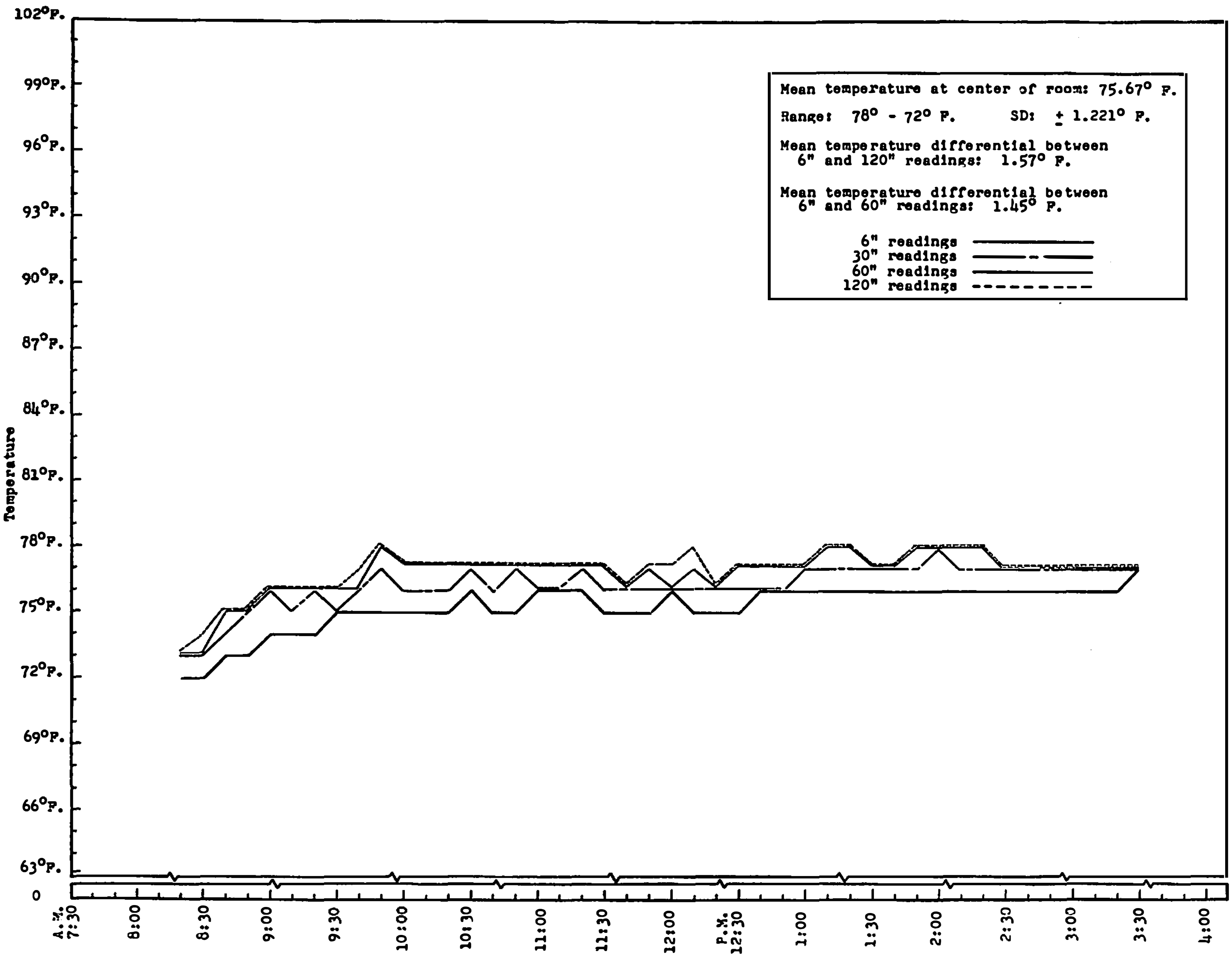


Figure 70. Temperature gradients from floor to ceiling at center of Classroom H-2.

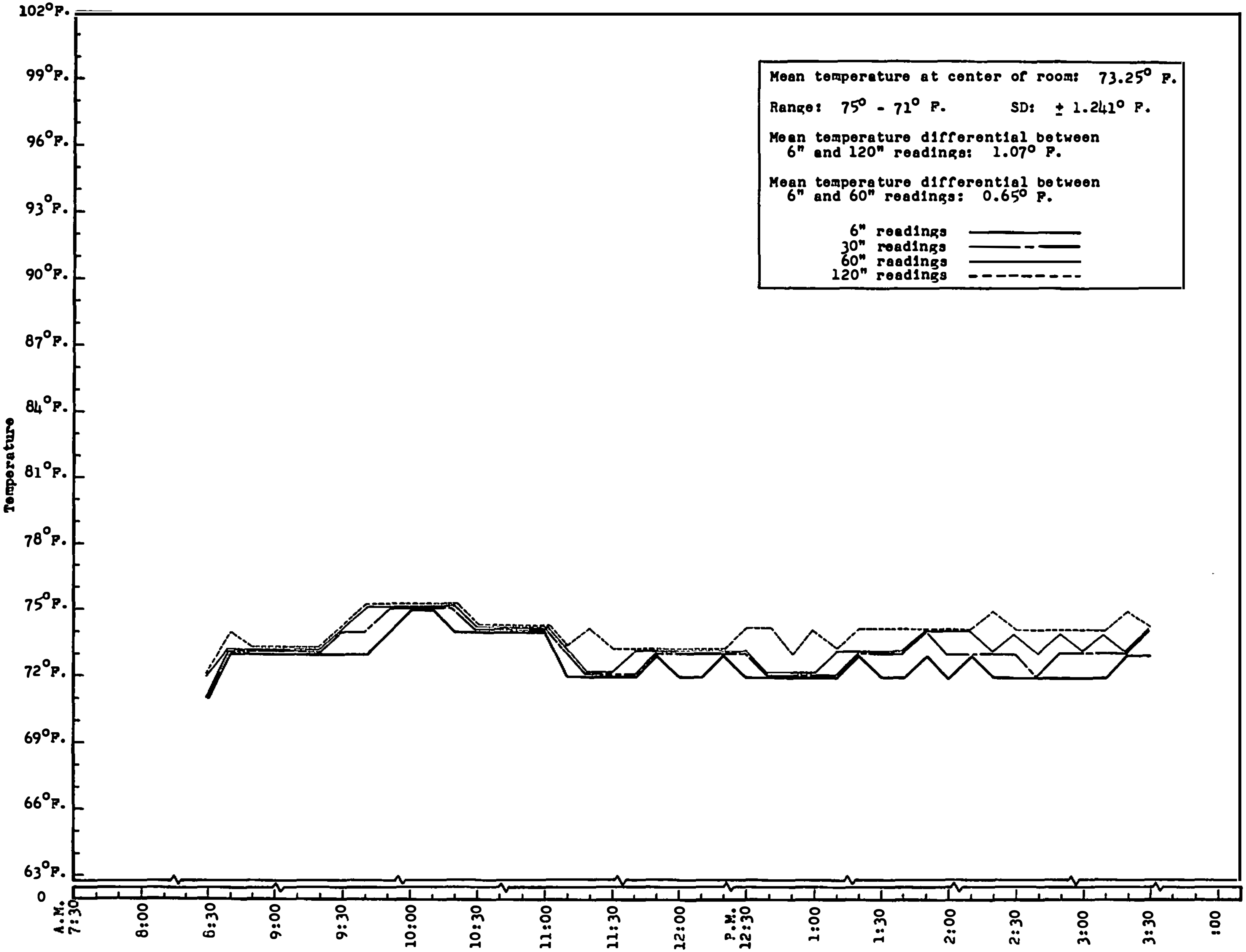


Figure 71. Temperature gradients from floor to ceiling at center of Classroom H-3.

Classroom I-1. Figure 72 presents quite a contrast from Figures 69, 70, and 71. With a mean differential of more than 10 degrees between the floor and ceiling, the criterion was very inadequately met in Classroom I-1.

Classroom I-2. The mean floor to ceiling differential in Classroom I-2, as shown in Figure 73, page 277, was the largest differential found in any classroom examined. The 8-degree mean range from the 60-inch to the 120-inch level was exceptionally high, so the inadequate rating seemed quite appropriate.

Classroom I-3. Classroom I-3 was the only classroom visited by investigator in which the Kata thermometer did not register any air movement at any location within the room. Figure 74, page 278, shows the excess temperature gradients that were produced, thus causing the room to meet the criterion inadequately.

E. SUMMARY

The primary purpose of this chapter has been to present the data relating to relative humidity, ventilation, and air movement found in the twenty-seven selected classrooms investigated.

Fifteen of the twenty-seven classrooms had humidities within the desired criterion range. If coupled with temperatures, however, the resulting effective temperatures were not always at the optimum level because of the many room air temperatures or globe readings outside the optimum range.

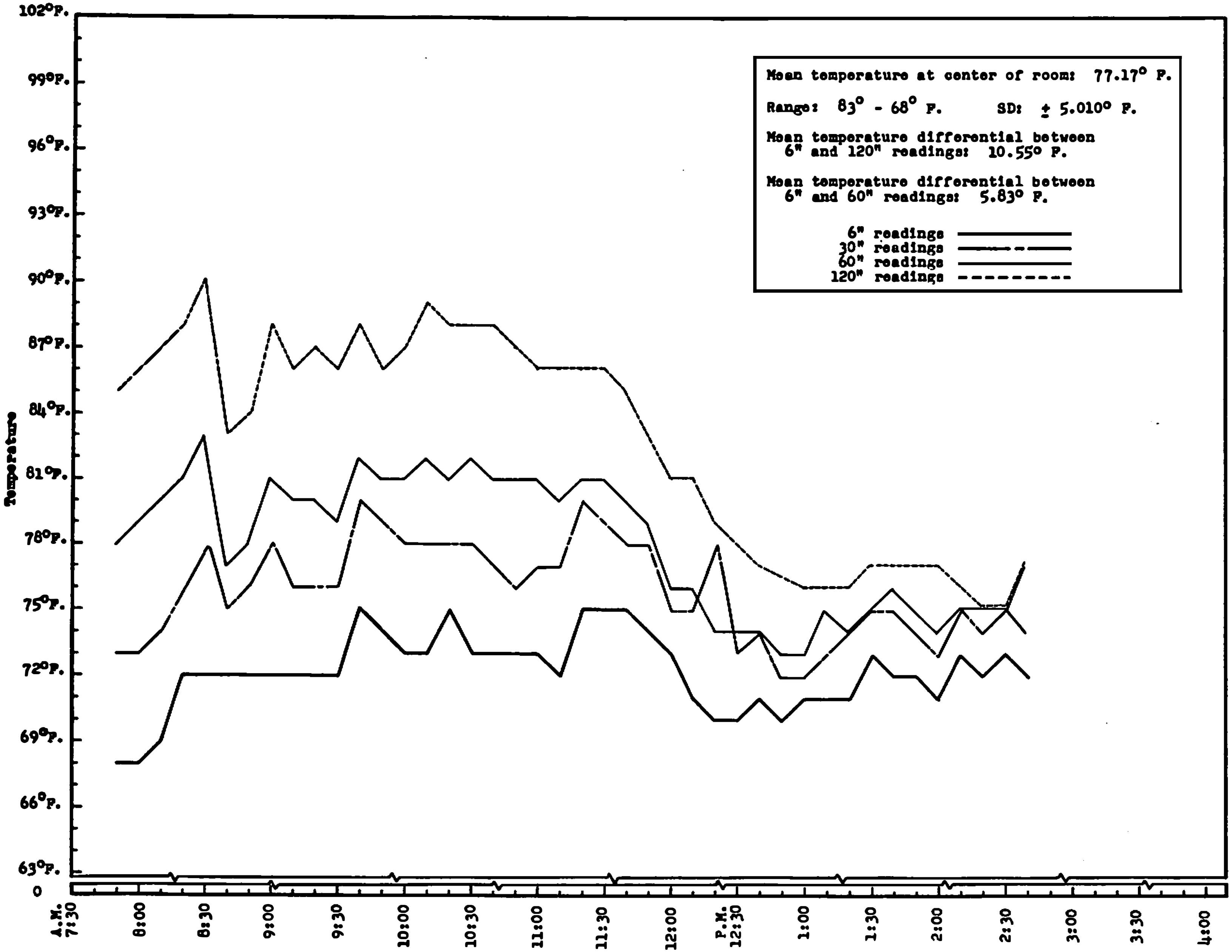


Figure 72. Temperature gradients from floor to ceiling at center of Classroom I-1.

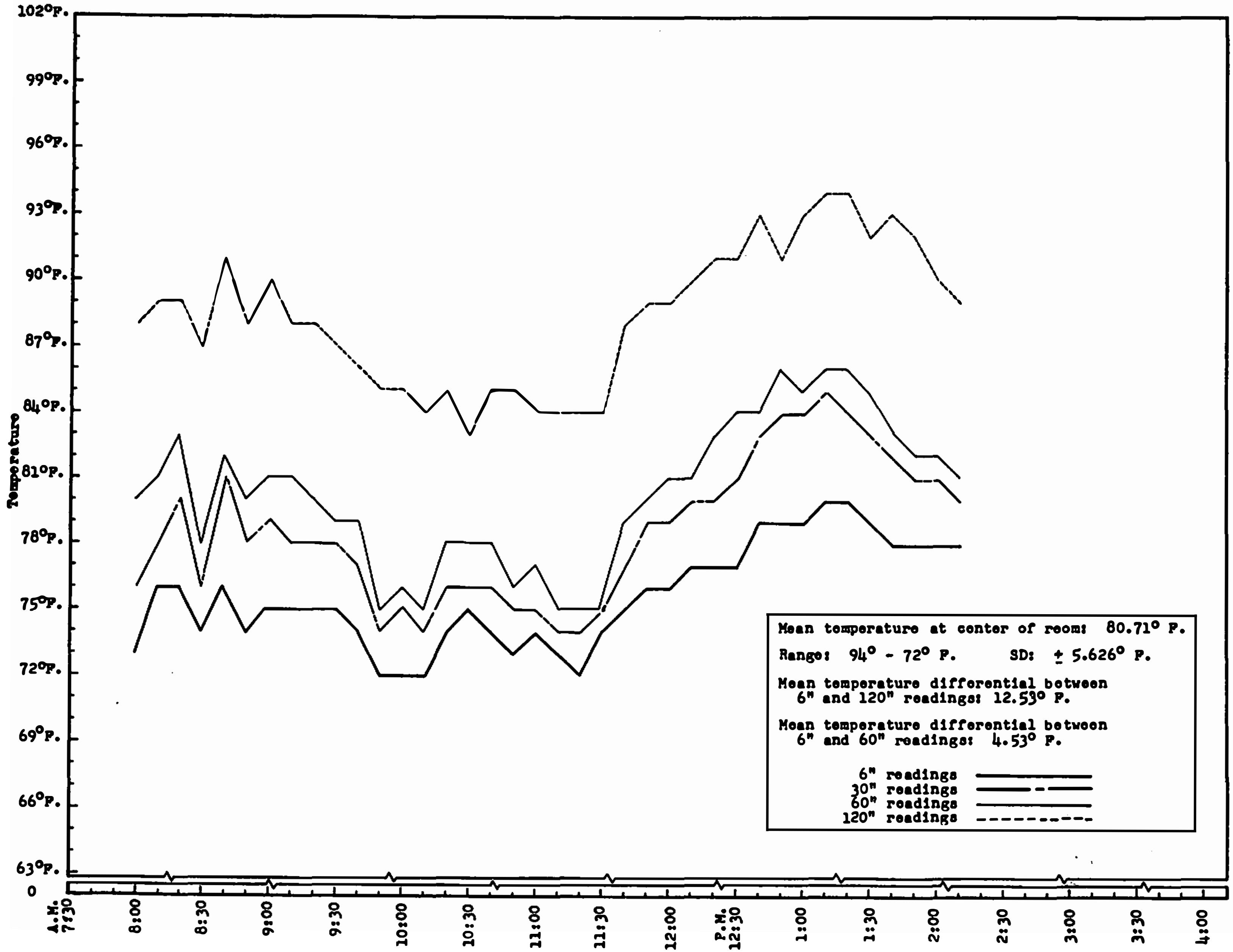


Figure 73. Temperature gradients from floor to ceiling at center of Classroom I-2.

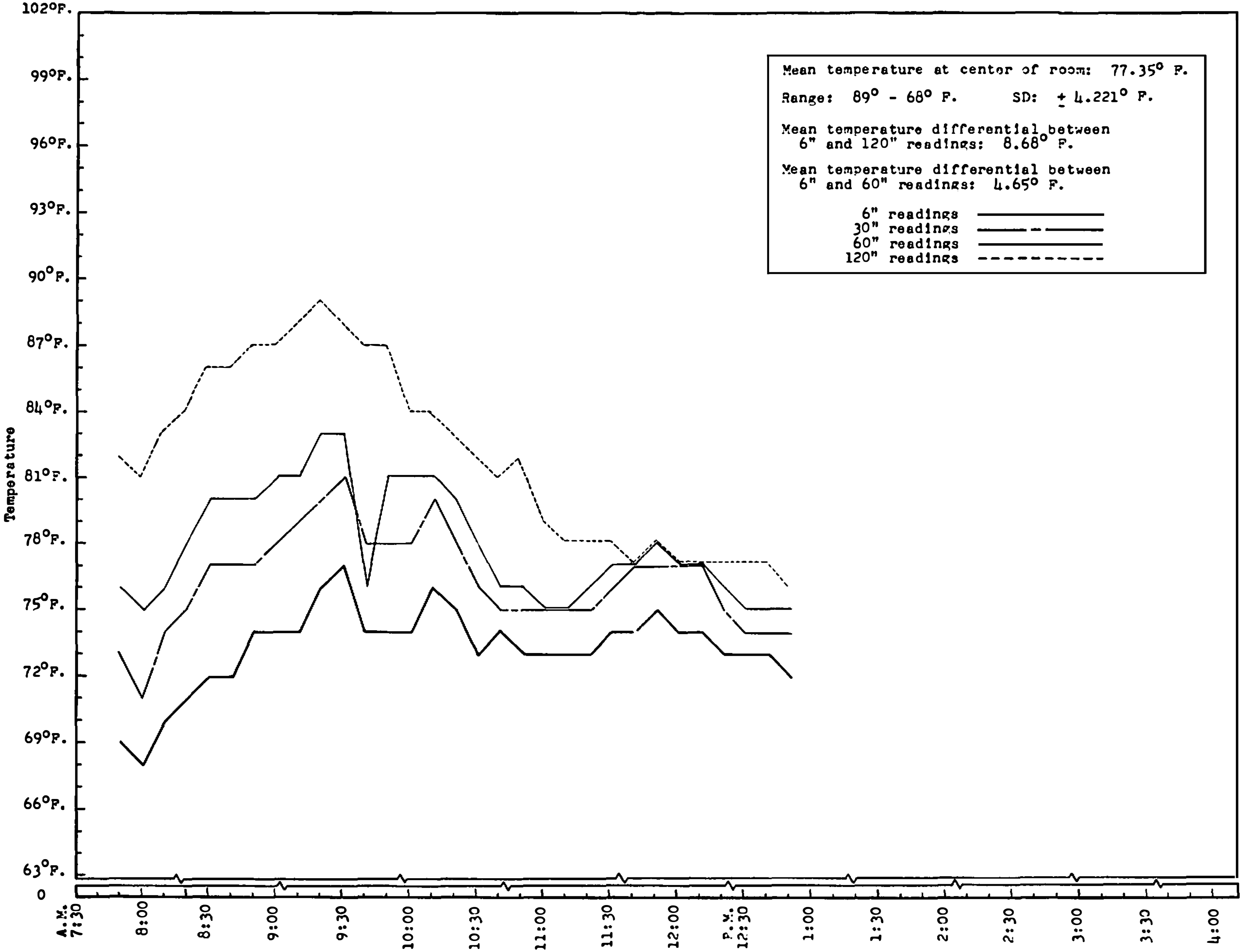


Figure 74. Temperature gradients from floor to ceiling at center of Classroom I-3.

Seven classrooms met Criterion 4 pertaining to ventilation completely, eight met the criterion adequately, eight met the criterion inadequately, and four failed to meet the criterion at all. Odors were not too unpleasant because of the relatively low relative humidities during the heating season, but fourteen of the rooms were overheated.

Air movement within the classroom was found to range from no movement to one hundred feet per minute, while resulting mean vertical differentials from the floor to the ceiling ranged from less than one degree to more than twelve degrees and mean horizontal differentials ranged from less than one degree to nearly three degrees.

CHAPTER VIII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The purpose of this study has been to analyze and appraise conditions relating to thermal environment in the classroom that existed in selected schools. Solution of the problem was effected through the following sub-problems:

<u>Sub-problem 1</u>

<u>To identify criteria related to thermal factors affecting classroom environment.</u>

After establishing a thermal background, attention was given to identification of the best available criteria relating to thermal factors in the classroom environment in order that the criteria could be utilized for the evaluation of the thermal environment in selected classrooms.

The core of the five selected criteria is as follows:

<u>Criterion Number 1</u>. . . . <u>An optimum air temperature for most classroom activity can be found within the range of 70°F. to 75°F.</u> . . . <u>For the optimum desired temperature for any activity, the temperature should not vary more than ±2 degrees</u>.

<u>Criterion Number 2</u>. <u>An ideal classroom temperature exists when both air temperature and mean radiant temperature are identical and</u>

within the optimum range. Since this situation does not always exist, some provision must be made for counteracting or eliminating the heat loss of the body to cold walls and windows.

Criterion Number 3. With air temperature and mean radiant temperature at the optimum level, optimum relative humidity seems to be around 50 per cent ±10 per cent.

Criterion Number 4. Classrooms should be ventilated adequately with clean, fresh, outdoor air to maintain control over overheating and to dissipate odors.

Criterion Number 5. Air movement within the classroom should be continuous and sufficient to distribute heat evenly throughout the working level of the room at the horizontal plane and to minimize excessive temperature gradients from the floor to the ceiling.

Sub-problem 2

To apply criteria identified to a varied selection of classrooms as a means of determining existing conditions relating to thermal environment in the classroom.

Nine schools, with three classrooms from each school were selected for the study. Included were: (1) eight buildings less than ten years of age and one constructed in 1943, constructed from wood, masonry, and curtain wall materials with classroom windows in selected rooms oriented toward every direction; (2) three schools utilizing unit ventilators for heating, three utilizing radiation, and one each

utilizing hot water floor panels, electric baseboards, and a central direct-fired air system; and (3) schools ranging in size from eight rooms and two hundred pupils to twenty-seven rooms and seven hundred fifty pupils.

In order to evaluate thermal conditions in the selected classrooms, the investigator spent a day in each of the selected classrooms during the normal heating season months of February and March, 1961, for the purpose of collecting data that could be utilized in analyzing thermal conditions. Data collected included classroom and outdoor air temperatures, mean radiant temperature, outdoor and indoor relative humidity, air movement readings, and subjective odor ratings.

Instruments that were capable of measuring thermal phenomena with consistent accuracy were used. The instruments included: two Palmer mercurial thermometers, a Wheelco twelve-point thermocouple recorder, a Bristol Thermo-Humidigraph, a Short and Mason Hygro-Thermograph, two Bacharach tempscribe temperature recorders, a homemade globe thermometer with mercurial thermometer inserts, a Taylor sling psychrometer, a Kata thermometer, and a titanium tetrachloride smoke gun.

Sub-problem 3

To analyze the findings in the light of the criteria in order to draw conclusions relating to the present situation regarding thermal environment in classrooms in the area investigated.

Approximately 140,000 temperature readings alone were recorded during the period of the investigation, as well as many other kinds of

data. In order to put the various data into some type of working order, selected random sampling was utilized with various temperature readings, the arithmetic mean was used to describe central tendency, and the range and standard deviation were used to determine dispersion. The organized data were presented in textual, tabular, and graphic forms with analyses by inspection in terms of the criteria.

Forty-four per cent of all classroom working area temperature readings were above 75°F., the upper limit of the optimum range, with 86.2 per cent above 72°F. Only 2.1 per cent of the readings were below 70°F., the lower limit of the optimum range. The maximum single temperature reading for any point within the air space from the floor to the ceiling was a reading of 100°F. recorded at the 120-inch level, while the minimum single temperature reading for any point within the same air space was a 58°F. reading at the 6-inch level.

Only six of the twenty-seven classrooms met Criterion 1 pertaining to air temperature completely, while seven did not meet the criterion in any way. Five of the six completely meeting the air temperature criterion were classrooms using unit ventilators for heating and ventilating.

More classrooms failed to meet Criterion 2, the mean radiant temperature criterion, than any other criterion, owing to the fact that mean radiant temperature often rose above the air temperature and outside the optimum range. Sunshine on window glass was the chief offender, producing high mean radiant temperatures near the window wall of the room.

The mean classroom relative humidity was within the criterion range on fifteen of the twenty-seven days of the investigation. Eleven mean classroom humidities fell below the minimum of 40 per cent, with only one classroom above the upper limits of the optimum range at 61 per cent, a one per cent deviation.

The need for more adequate ventilation was found with fourteen of the twenty-seven classrooms overheated and five rooms containing objectionable odors. No perceptible odors were found in any of the classrooms employing unit ventilators.

Air movement within the selected classrooms ranged from no perceptible movement to one hundred feet per minute as recorded by the Kata thermometer. Mean vertical temperature differentials from the floor to the ceiling ranged from 0.85° to 12.53°F., while mean horizontal temperature differentials at the thirty-inch level of the classroom ranged from 0.45° to 2.67°F.

After applying the thermal data to the rigid yardstick of the criteria, only two classrooms were considered to have met all five criteria completely on the day of investigation. One classroom met all but one criterion completely, while nine met at least four out of the five adequately or better. Five classrooms met at least three of the criteria either completely or adequately. Three or more of the criteria were met inadequately or not at all in ten classrooms.

B. CONCLUSIONS

The following conclusions were derived as a result of this study:

1. The identified criteria represent the best ideas concerning thermal environment and with only slight modification could be used to evaluate classroom thermal conditions in any section of the United States.

2. Too large a percentage of classroom temperatures was above the optimum range, regardless of whether the outside temperature was above or below 60°F.

3. There was no consistent pattern of classroom temperatures for various age groups in the classrooms studied.

4. Outside air utilized for ventilation by unit ventilators can effectively combat overheating until the outside temperature rises above 60°F.

5. Closing down the boiler on days when the outside temperature approached 60°F. contributed favorably to the thermal environment of two schools.

6. The proper maintenance of unit ventilator filters is essential to their efficient operation.

7. Excessive glass seems to have been one of the greatest deterrents to the maintenance of optimum thermal conditions in the classrooms studied.

8. Orientation, roof overhangs, blinds, and drapes should all be used, if necessary, to keep the sun away from the window area. A simpler solution would be to eliminate much of the large amounts of window glass now prevalent in modern school construction.

9. Because of the effect of the sun upon the windows of the classrooms studied, mean radiant temperature presented a slightly different problem than expected, since the mean radiant temperature was seldom below the air temperature, and was always above the air temperature when the sun was shining directly on the window wall.

10. The situation described in Conclusion 9 is not necessarily applicable to the entire United States, or even to the area investigated if colder weather conditions prevail. Outside temperatures during the time of data collection perhaps were not low enough to create cold wall and downdraft problems.

11. Since no serious downdraft problems were encountered except in the two schools that had no positive heat at the window wall, the purchase of special down-draft equipment in the Southeastern Region is perhaps questionable if visual strips are used for windows and the heating unit is located by the window wall.

12. The deviations of relative humidity from the optimum range that were encountered in the study could have been corrected in most instances by lowering the temperature to a point still within the optimum range.

13. The data seemed to indicate the importance of adequate outside air and considerable air movement for the control of odors and overheating.

14. Control of air temperature is the critical issue in maintaining an optimum thermal environment; however, the control of a combination of factors is essential.

15. Those responsible for the provision and maintenance of the thermal environment in the selected schools seemed to be largely unaware of the thermal needs of growing children of different age groups and how to provide for these needs.

16. When unit ventilators were used for heating and ventilating, classrooms with nine-foot ceilings were found to have as good a thermal environment as those having twelve-foot ceilings.

17. Individual automatic room controls are essential for the maintenance of optimum classroom thermal conditions, regardless of the type of heating system utilized.

18. Unit mounted electric controls and pneumatic remote-controls both responded favorably in unit ventilators.

19. The best thermal conditions found in the classrooms investigated on the particular days investigated were those found in schools using unit ventilators for heating and ventilating.

C. RECOMMENDATIONS FOR CLASSROOM THERMAL CONTROL

The following recommendations for thermal control of classrooms now in use are made:

1. All who are in a position of controlling the classroom thermal environment should utilize every available method to maintain a thermal environment that meets the criteria identified in this study.

2. If a change or conversion of the type of heating and ventilating system presently used is contemplated, serious consideration should be given to installation of unit ventilators with individual room controls.

To effect an adequate thermal environment in classrooms constructed in the future, the following recommendations are given:

1. School buildings should be designed for maximum thermal control by incorporating such considerations as minimum window area, covering of window space provided, building orientation, and lowered ceilings.

2. Unit ventilators with individual room controls should be provided for heating and ventilating on days when the outside temperature does not exceed 60°F.

3. Unit ventilators used should be the type that will allow for air conditioning or future air conditioning during periods of the year when the outside temperature consistently rises above 60°F.

D. RECOMMENDATIONS FOR FURTHER RESEARCH

The following recommendations are made for further research:

1. A similar study should be made with collection of data going on simultaneously in a number of selected classrooms rather than one at a time.

2. Material included in the Appendix of this study could be given a more elaborate statistical treatment to determine more fully the differences that existed among the thermal conditions in the different classrooms.

3. A study could be made utilizing materials in the Appendix of this investigation that would integrate all data into some thermal index as the Temperature Humidity Index.

4. Each of the elements included in the criteria should be utilized as a basis for research within a classroom with all other factors controlled at the optimum level and the experimental factor varied to determine its effect upon health, comfort and efficiency of school children.

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APPENDIXES

APPENDIX A

Thermal Environment Data Sheets

SCHOOL DATA SHEET

Name of School____

Address of School______________________________________

Number of Classrooms in Building__________________________

Organization of School:

K-6______; 1-6______; 1-8______; 7-9______.

School Enrollment______________

Ventilation System: Air Supply Method______ Exhaust Method______

Heating and Cooling System ______________

Date of Construction __________________________

Brief Description of Building Construction and Materials____________

____

____

____

____

CLASSROOM THERMAL ENVIRONMENT DATA SHEET

Classroom No.________________

Total Floor Area ____________

Height of Ceiling ____________

Location of Thermostat, if any ________________

Wattage of Classroom Lights ________________

Grade Level, or Subject ________________

Total Window Area at Outside Wall ____________

Directional Orientation of Classroom Windows ________________

Date ________________

Weather ________________

THERMAL DATA

Time							
Degree of Odor or Irritation 0. Imperceptible odor, or irritation. 1. Perceptible odor, or irritation, but not objectionable. 2. Moderate odor, or irritation, little or no objection, acceptable level. 3. Objectionable odor, or irritation, condition regarded with disfavor. 4. Strong odor, or irritation, but endurable. 5. Very strong odor, or irritation, intolerable							
Number of boys present							
Number of girls present							
Number of adults present							
Classroom Activity							
Are lights on?							
Thermostat setting (if heating and cooling system utilizes thermostat)							

THERMAL DATA

Time							
Outside temperature							
Outside relative humidity							
Physical appearance of occupants							
Other pertinent data:							
Relative humidity (within zone of occupancy)							
KATA THERMOMETER READING Zone I 6 inch cooling time							
Reading 1							
Reading 2							
Reading 3							
Average cooling time							
Air temperature							
6 inch level of air movement							
Zone I 5 ft. cooling time							
Reading 1							
Reading 2							
Reading 3							
Average cooling time							
Air temperature							
5 feet level of air movement							
Zone V 6 inch cooling time							
Reading 1							
Reading 2							
Reading 3							
Average cooling time							
Air temperature							
6 inch level of air movement							
Zone V 5 ft. cooling time							
Reading 1							
Reading 2							
Reading 3							
Average cooling time							
Air temperature							
5 ft. level of air movement							

THERMAL DATA

Time							
Globe Thermometer Reading (30 inch level) Zone I							
Zone V							
Mean Radiant Temperature Zone I							
Zone V							

APPENDIX B

Figures 75, 76, 77, 78, 79, and 80

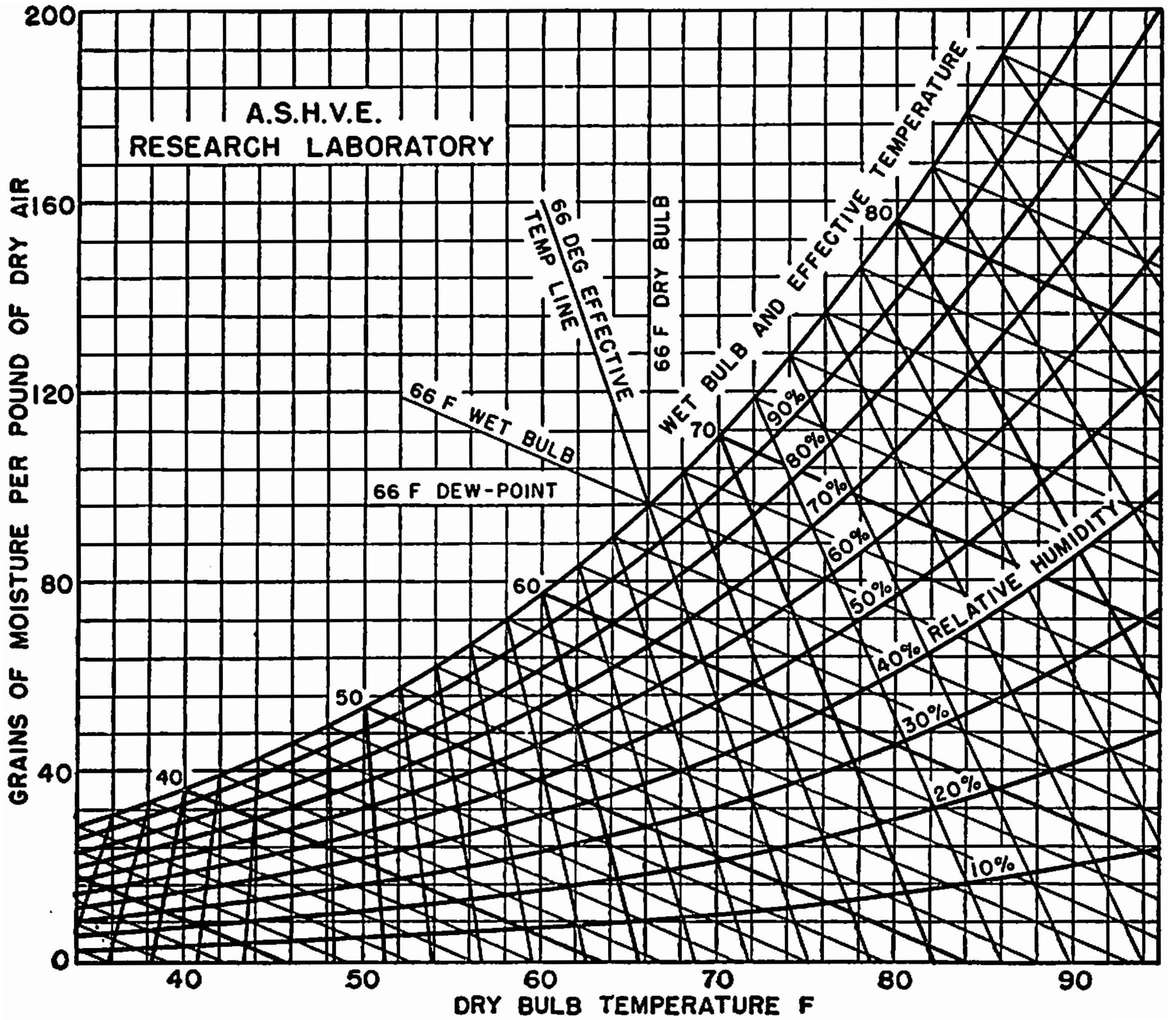


Figure 75. Psychrometric chart, persons at rest, normally clothed, in still air.

Source: American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 68. Used by permission.

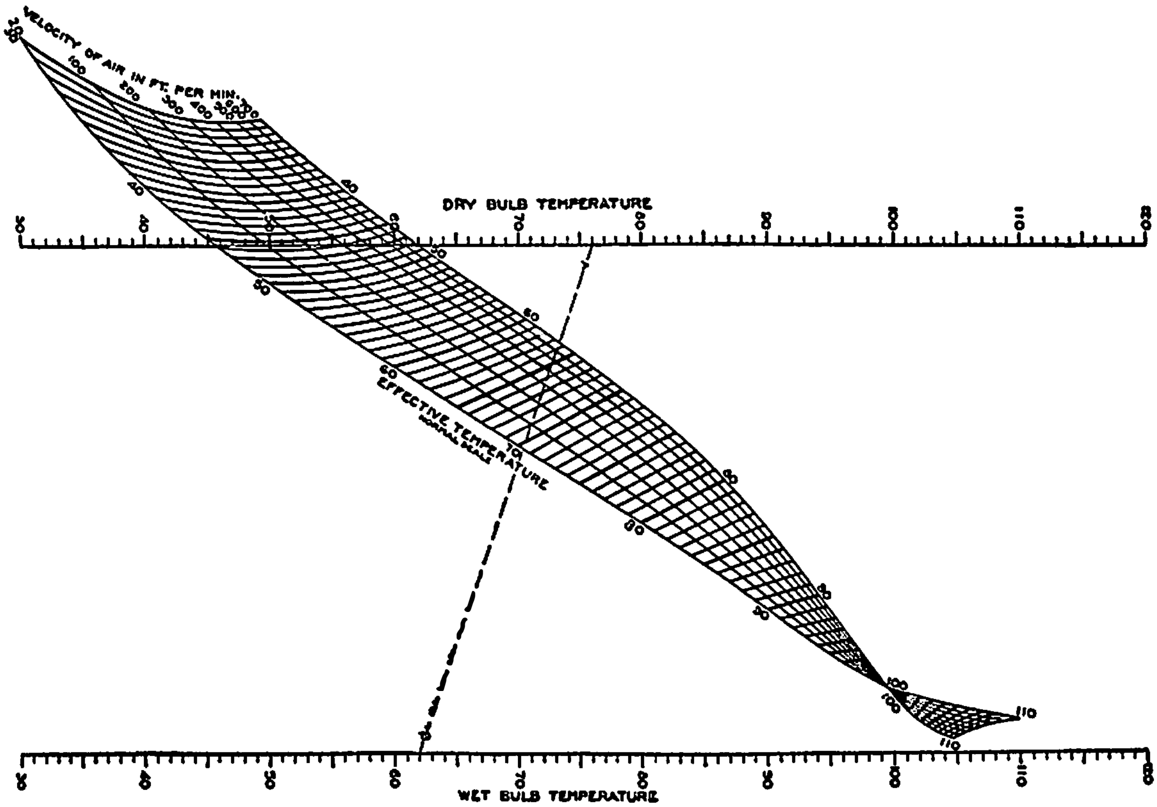
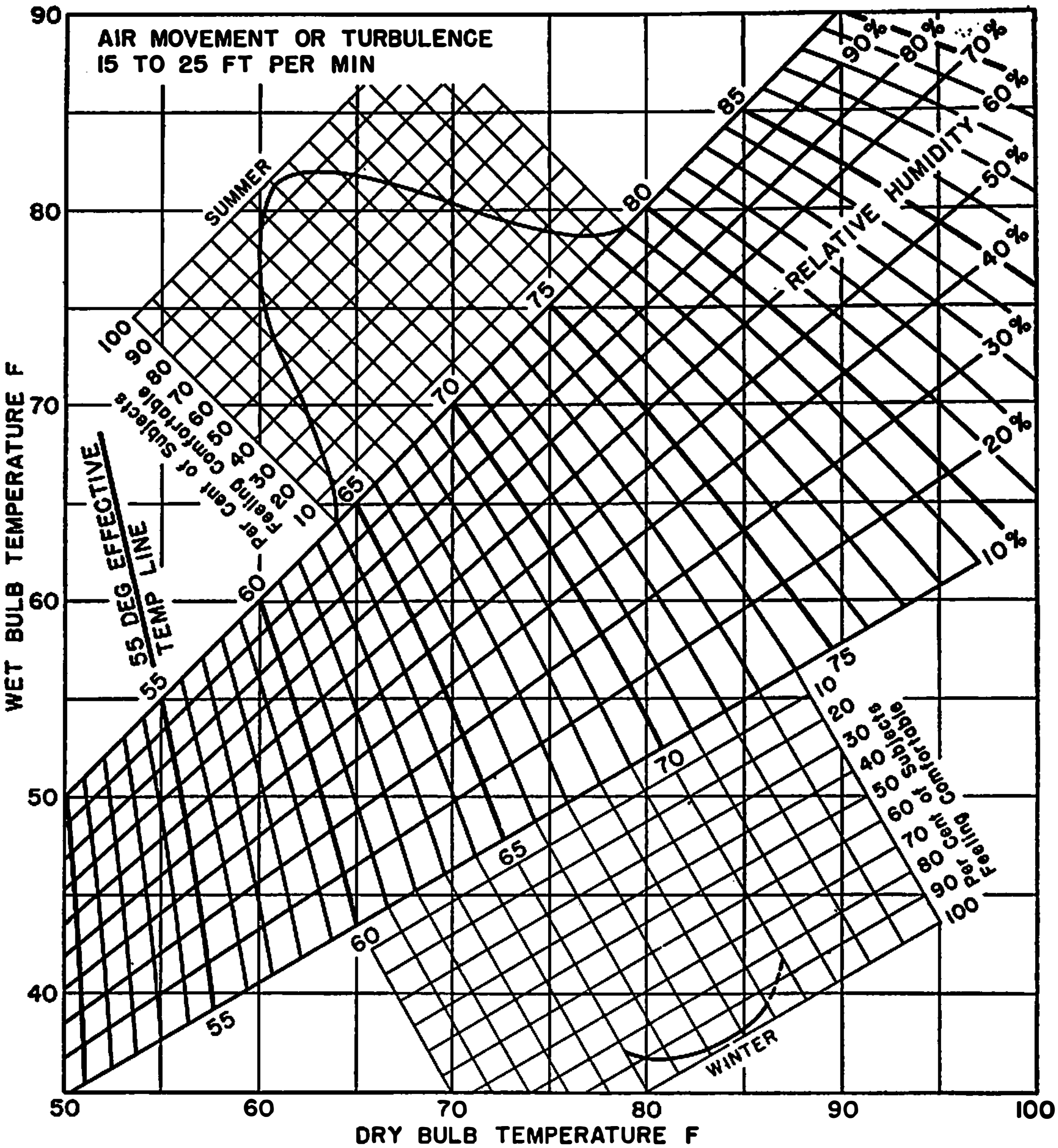


Figure 76. Effective temperature chart showing normal scale of effective temperature, applicable to inhabitants of the United States under the following conditions: (a) Clothing: customary indoor clothing. (b) Activity: sedentary or light muscular work. (c) Heating Methods: convection type, i.e., warm air, direct steam or hot water radiators, plenum systems.

Source: American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 69. Used by permission.



a. Both summer and winter comfort lines apply to inhabitants of the United States only. Application of winter comfort line is further limited to room heated by central system of the convection type. The line does not apply to rooms heated by radiant methods. Application of summer comfort line is limited to homes, offices and the like, where occupants become fully adapted to artificial air conditions. The line does not apply to theaters, department stores, and the like where exposure is less than 3 hours. The summer comfort line shown pertains to Pittsburgh and to other cities in the northern portion of the United States and Southern Canada, and at elevations not in excess of 1,000 feet above sea level. An increase of one degree ET should be made approximately per 5 deg reduction in north latitude.

b. Dotted portion of winter comfort chart was extrapolated beyond test data.

Figure 77. ASHAE comfort chart for still air.[ab]

Source: American Society of Heating and Air-Conditioning Engineers, Inc., Heating Ventilating Air Conditioning Guide 1959 (New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1959), p. 70. Used by permission.

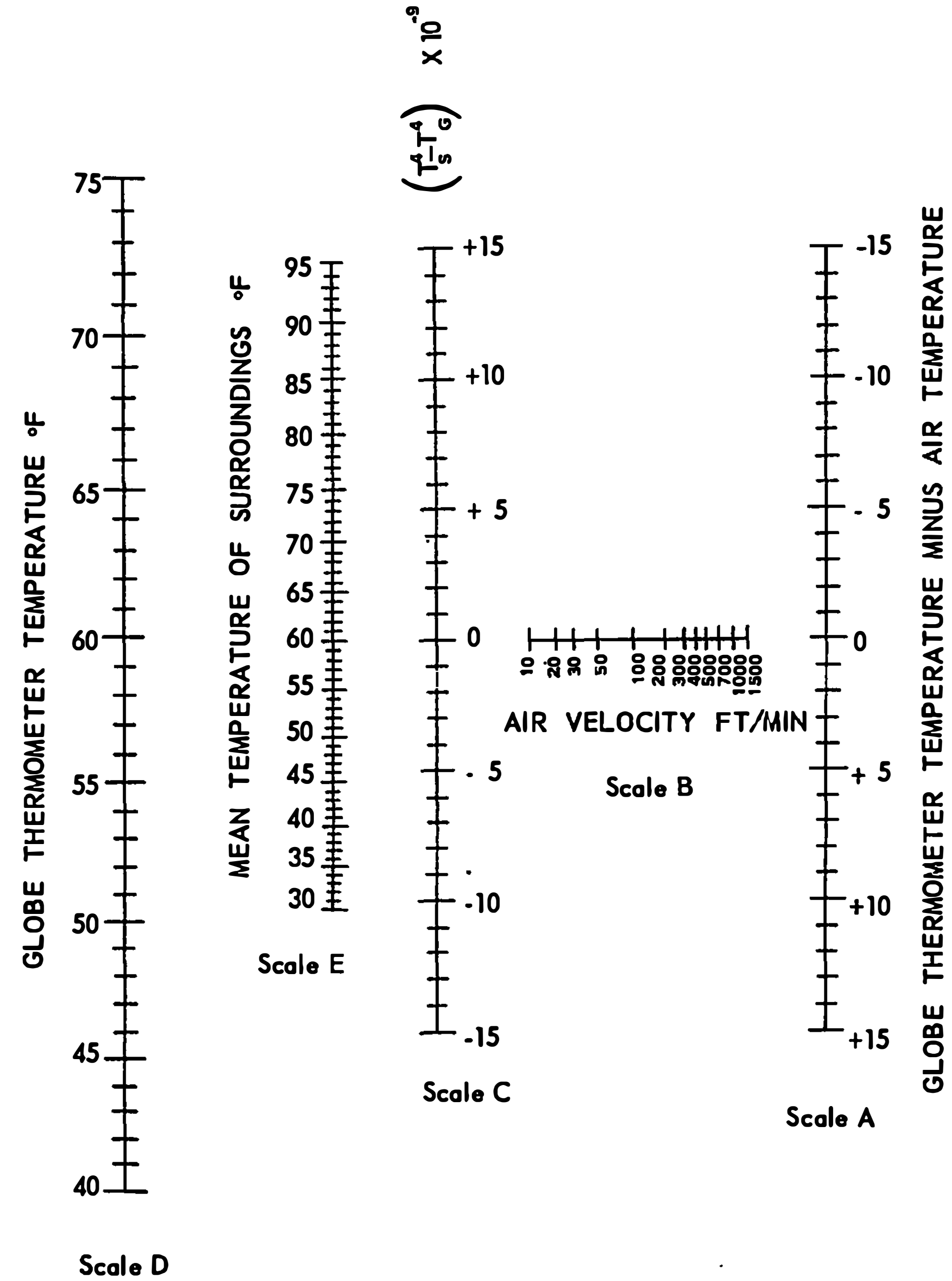


Figure 78. Chart for the estimation of radiation from globe thermometer readings. (Globe thermometer temperature range 40°-75°F.)

Source: "Charts for the Calculation of Environmental Warmth," Supplement to War Memorandum No. 17 (London: Her Majesty's Stationery Office, 1946), Chart 4. Used by permission of the Controller of Her Britannic Majesty's Stationery Office.

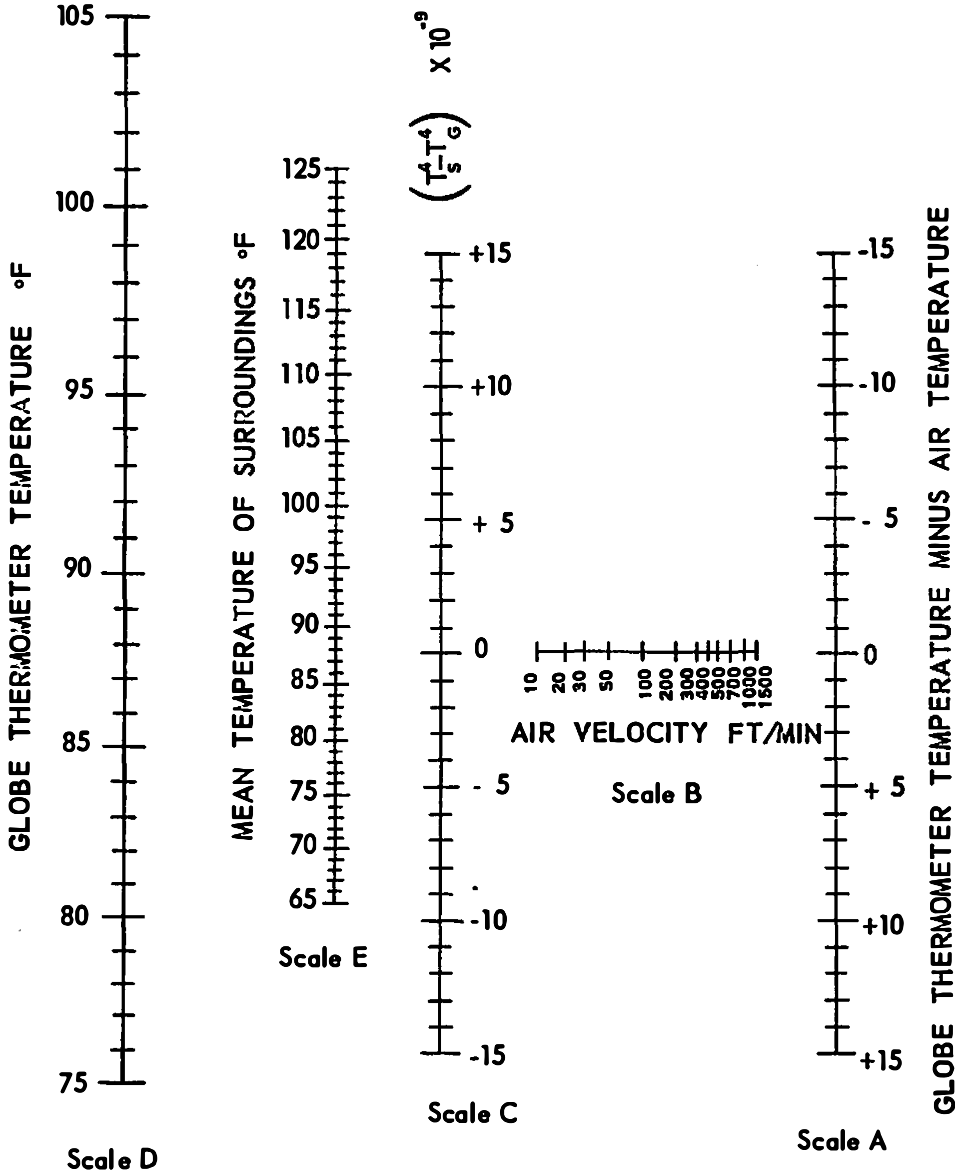


Figure 79. Chart for the estimation of radiation from globe thermometer readings. (Globe thermometer temperature range 75°-105°F.)

Source: "Charts for the Calculation of Environmental Warmth," Supplement to War Memorandum No. 17 (London: Her Majesty's Stationery Office, 1946), Chart 5. Used by permission of the Controller of Her Britannic Majesty's Stationery Office.

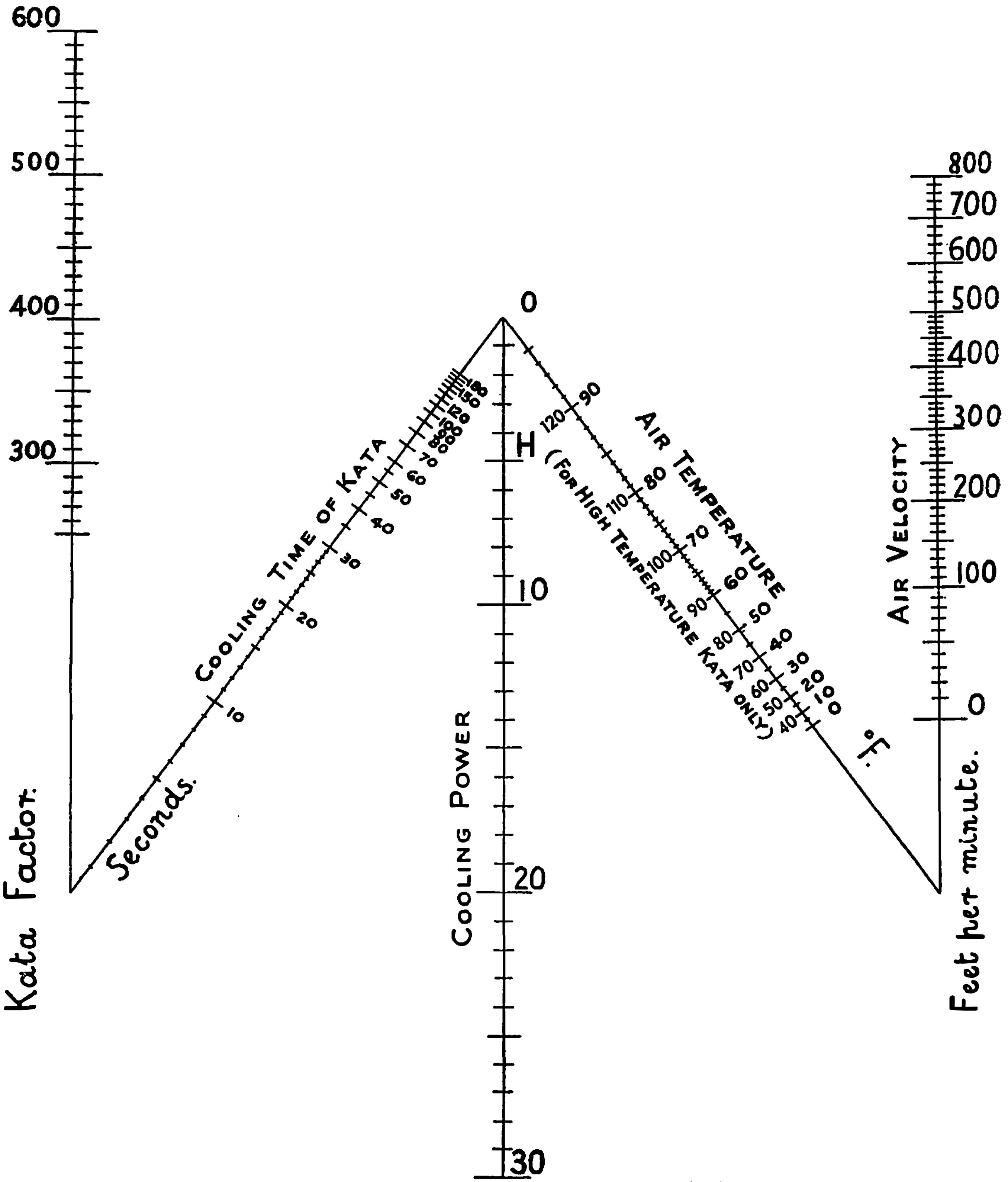


Figure 80. Chart for the computation of air velocities from readings of the dry bulb kata thermometer. (Cooling range 100°-95°F.)

Source: Kata-thermometer direction sheet supplied by James J. Hicks, London, England.

APPENDIX C

Sample Thermal Data Secured from Thermocouple Recordings

THERMOCOUPLE READINGS FOR CLASSROOM A-1

February 7, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	Samp-ling cham-ber	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:50	74	73	74	78	76	74	68	100	69	38	72	72
8:00	75	73	74	77	75	74	68	94	67	38	73	74
8:10	75	74	74	76	75	74	69	91	67	39	71	72
8:20	74	73	73	76	75	74	70	91	66	38	72	73
8:30	74	74	74	77	75	75	70	97	66	39	72	73
8:40	74	74	74	77	75	74	70	93	67	39	73	73
8:50	74	75	75	77	76	75	70	93	67	39	72	73
9:00	74	74	74	76	75	74	70	83	66	39	72	73
9:10	74	74	74	76	75	75	71	90	66	39	73	73
9:20	74	74	74	76	75	75	70	90	67	39	72	73
9:30	74	74	74	75	75	75	71	83	65	39	72	73
9:40	73	73	74	75	75	74	71	84	65	40	73	74
9:50	74	74	74	75	75	75	71	84	66	39	72	73
10:00	74	74	74	76	75	75	71	84	67	39	73	74
10:10	73	73	74	75	74	74	72	83	65	40	72	72
10:20	75	75	75	76	75	75	71	88	67	40	73	74
10:30	75	75	75	76	75	75	72	84	67	39	73	74
10:40	75	75	76	77	76	76	72	84	68	40	73	75
10:50	75	75	76	76	76	75	72	74	66	40	73	74
11:00	75	75	75	76	76	75	72	73	66	40	73	74
11:10	74	74	74	74	74	74	72	80	65	40	73	73
11:20	74	74	75	76	75	75	72	83	66	40	73	74
11:30	74	74	74	75	74	74	72	83	65	40	72	73
11:40	74	74	74	76	75	75	71	86	66	40	73	74
11:50	73	74	74	76	75	75	70	87	65	40	72	73
12:00	73	73	74	76	74	74	69	93	67	40	73	73
12:10	73	73	73	76	75	74	68	93	66	40	71	72
12:20	73	74	73	76	75	74	69	93	67	39	71	72
12:30	74	74	74	76	75	75	71	87	66	40	72	73
12:40	74	74	74	75	74	74	70	85	66	40	72	73

THERMOCOUPLE READINGS FOR CLASSROOM A-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	Samp-ling cham-ber	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:50	74	74	74	76	75	75	71	86	67	40	72	73
1:00	75	74	75	76	75	76	71	84	66	40	73	74
1:10	74	74	74	76	75	74	72	83	66	39	73	74
1:20	74	74	75	76	75	75	72	83	66	40	73	74
1:30	74	74	75	76	75	75	72	83	65	40	73	74
1:40	75	75	75	76	75	75	73	83	67	40	73	74
1:50	74	74	75	75	75	75	72	81	65	40	73	74
2:00	74	74	74	75	75	75	72	82	66	40	73	74
2:10	74	74	74	75	75	75	72	81	66	40	72	73
2:20	73	74	74	76	74	74	71	88	67	40	72	73
2:30	74	73	74	75	74	74	71	88	67	41	72	73
2:40	74	74	74	76	75	75	72	89	67	40	72	73
2:50	75	75	75	76	75	75	72	89	68	40	72	73
3:00	75	75	75	76	75	75	72	88	68	40	72	73
Mean	74.09	73.86	74.30	75.89	74.95	74.66	70.91	86.39	66.36	39.59		73.30

Mean of working area (1,2,3,5,6,7, & 12) = 73.75°F.
Range of working area 76°-68°F. = 8°F. Sample size = 308
Variance = 2.13°F. Standard deviation = ±1.459°F.
Standard error of mean = ±.083°F.

Mean of readings at center of room from floor to ceiling = 74.10°F.
Range 78°-68°F. = 10°F. Sample size = 176
Variance = 4.22°F. Standard deviation = ±2.054°F.
Standard error of mean = ±.155°F.

Mean of all 30" readings = 74.07°F.
Range 76°-72°F. = 4°F. Sample size = 220
Variance = .57°F. Standard deviation = ±.755°F.
Standard error of mean = ±.051°F.

THERMOCOUPLE READINGS FOR CLASSROOM A-2

February 8, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	Samp-ling cham-ber	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:40	71	72	71	74	72	71	66	94	62	37	68	69
7:50	71	71	71	74	72	71	66	94	62	37	68	70
8:00	71	71	71	73	72	71	66	94	62	36	69	70
8:10	72	72	71	74	72	71	66	94	63	37	69	70
8:20	71	71	70	73	72	70	66	94	62	36	68	70
8:30	71	71	71	74	73	70	67	94	63	37	70	71
8:40	73	73	73	75	74	73	69	95	64	37	71	72
8:50	73	73	73	76	74	73	68	94	64	37	70	73
9:00	74	74	74	76	75	74	69	94	66	39	71	74
9:10	74	74	74	76	75	76	69	95	66	37	71	73
9:20	74	74	74	76	75	74	69	94	65	37	71	74
9:30	74	74	74	76	75	74	69	94	65	37	71	74
9:40	74	74	74	76	75	74	69	95	66	38	71	74
9:50	74	74	74	76	75	74	69	94	66	38	71	74
10:00	74	74	74	76	75	74	70	95	67	38	73	74
10:10	74	74	74	76	75	74	70	91	67	39	72	74
10:20	75	75	75	76	75	75	71	89	77	39	72	75
10:30	74	74	75	76	75	75	71	83	63	38	73	74
10:40	73	73	73	74	74	74	70	81	63	37	72	73
10:50	74	74	75	75	75	74	72	82	63	38	73	74
11:00	74	74	74	74	74	74	71	81	63	38	72	74
11:10	73	73	73	74	74	73	71	81	62	37	71	73
11:20	75	74	73	74	74	73	71	81	69	38	72	73
11:30	73	73	72	74	74	73	70	90	63	39	71	72
11:40	73	73	73	74	75	73	69	91	63	39	73	74
11:50	74	74	74	75	75	73	69	91	63	39	71	72
12:00	74	74	72	75	74	73	71	92	65	41	71	73
12:10	75	75	75	76	75	75	71	92	66	40	72	75
12:20	74	74	74	74	74	74	72	76	64	40	73	73
12:30	73	73	73	74	74	74	72	79	65	40	73	74

THERMOCOUPLE READINGS FOR CLASSROOM A-2 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	Samp-ling cham-ber	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:40	73	73	73	74	74	74	72	78	64	40	73	74
12:50	74	73	74	74	74	74	72	79	65	40	72	74
1:00	74	74	74	74	74	74	72	79	66	40	72	74
1:10	74	74	74	74	74	74	72	79	65	41	73	74
1:20	74	74	74	74	74	74	71	80	64	40	72	73
1:30	73	73	74	74	74	74	71	78	65	41	72	74
1:40	74	74	75	74	74	74	71	78	66	40	73	74
1:50	74	74	75	75	75	75	72	79	66	41	73	74
2:00	73	73	74	74	74	74	72	77	65	41	72	73
2:10	73	73	73	74	74	73	71	81	66	41	73	73
2:20	73	73	73	74	73	73	70	80	66	42	71	72
2:30	73	73	73	74	73	73	71	80	64	42	72	72
2:40	73	73	74	74	74	74	71	82	64	41	73	74
2:50	73	73	73	73	73	73	71	78	64	40	72	73
3:00	71	72	72	72	72	72	71	78	64	40	71	71
Mean	73.29	73.29	73.29	74.53	73.98	73.38	69.98	86.22	64.73	83.89		72.98

Mean of working area (1,2,3,5,6,7, & 12) = 72.88°F.
Range of working area 76°-66°F. = 10°F. Sample size = 315
Variance = 3.19°F. Standard deviation = ±1.786°F.
Standard error of mean = ±.101°F.

Mean of readings at center of room from floor to ceiling = 72.97°F.
Range 76°-66°F. = 10°F. Sample size = 180
Variance = 4.94°F. Standard deviation = ±2.223°F.
Standard error of mean = ±.166°F.

Mean of all 30" readings = 73.24°F.
Range 76°-69°F. = 7°F. Sample size = 225
Variance = 1.52°F. Standard deviation = ±1.233°F.
Standard error of mean = ±.082°F.

THERMOCOUPLE READINGS FOR CLASSROOM A-3

February 9, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	Samp-ling cham-ber	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:50	76	75	75	78	76	75	71	102	63	38	73	73
8:00	76	75	75	78	76	75	71	100	63	38	74	74
8:10	75	74	75	78	76	75	72	99	62	38	73	74
8:20	75	75	75	79	76	74	71	106	63	38	75	75
8:30	76	76	75	80	77	76	73	102	62	38	74	75
8:40	76	75	76	78	76	76	72	97	62	37	74	75
8:50	76	76	76	79	77	76	73	96	64	39	75	76
9:00	75	75	75	76	75	75	74	83	61	38	74	75
9:10	76	76	76	77	76	76	74	88	62	38	75	75
9:20	76	76	76	78	76	76	74	89	62	38	75	76
9:30	76	76	76	78	76	76	75	89	62	38	75	76
9:40	76	76	76	78	77	77	75	86	63	39	75	76
9:50	76	76	76	78	76	76	75	86	64	39	75	76
10:00	76	76	76	77	76	76	74	86	63	39	75	76
10:10	76	76	76	77	76	76	75	86	63	39	75	76
10:20	76	76	76	77	76	76	75	86	63	38	75	76
10:30	76	76	76	77	76	76	75	85	63	38	75	76
10:40	76	76	76	77	76	76	75	86	64	39	75	76
10:50	76	76	76	77	76	76	75	85	63	39	75	76
11:00	76	76	76	77	76	76	75	86	63	40	75	76
11:10	76	75	76	76	76	76	74	86	63	40	74	76
11:20	75	76	75	77	75	75	74	85	64	41	74	75
11:30	76	76	76	77	76	76	75	85	65	41	74	75
11:40	76	76	76	77	76	76	75	85	65	41	75	76
11:50	76	75	76	77	76	76	75	85	65	41	75	76
12:00	75	75	75	76	75	75	74	85	63	40	74	75
12:10	75	75	75	76	75	75	73	84	63	40	74	75
12:20	75	75	75	76	75	75	73	85	61	40	73	74
12:30	74	74	74	75	74	74	73	85	62	40	73	74
12:40	72	72	72	73	72	72	71	55	61	41	69	71

THERMOCOUPLE READINGS FOR CLASSROOM A-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	Samp-ling cham-ber	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:50	71	71	71	71	71	71	71	64	60	41	69	70
1:00	72	72	72	72	72	72	71	70	62	41	71	72
1:10	72	72	72	72	72	72	71	66	60	40	70	71
1:20	72	72	72	72	72	72	72	68	61	40	70	71
1:30	72	72	73	72	72	72	72	68	61	40	70	71
1:40	72	72	73	72	72	72	72	70	61	40	70	71
1:50	72	72	72	72	72	72	72	68	61	40	71	72
2:00	76	76	76	79	77	76	74	103	63	40	74	75
2:10	76	77	77	78	77	77	75	85	63	41	75	76
2:20	76	77	77	78	77	77	71	85	65	41	75	77
2:30	77	77	77	78	77	77	71	83	67	43	75	77
2:35	(a)											
2:40	77	77	77	78	77	77	76	84	77	47	76	77
2:50	76	76	76	76	76	76	76	76	80	50	75	81
3:00	75	75	76	75	75	75	75	75	74	50	75	77
Mean	75.07	75.0	75.11	76.34	75.25	75.07	73.41	84.27	63.68	40.16		74.84

Mean of working area (1,2,3,5,6,7, & 12) = 74.82°F.
Range of working area 81°-70°F. = 11°F. Sample size = 308
Variance = 3.38°F. Standard deviation = ±1.838°F.
Standard error of mean = ±.105°F.

Mean of readings at center of room from floor to ceiling = 75.02°F.
Range 80°-71°F. = 9°F. Sample size = 176
Variance = 4.51°F. Standard deviation = ±2.124°F.
Standard error of mean = ±.16°F.

Mean of all 30" readings = 75.02°F.
Range 81°-70°F. = 11°F. Sample size = 220
Variance = 3.09°F. Standard deviation = ±1.758°F.
Standard error of mean = ±.119°F.

(a) Sun came out.

THERMOCOUPLE READINGS FOR CLASSROOM B-1

February 16, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F..	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:50	85	86	85	99	91	86	76	93	89	49	77	78
8:00	(a)											
8:00	85	85	85	100	92	85	76	91	90	46	78	87
8:10	85	85	85	98	91	85	76	96	87	41	77	85
8:18	(b)											
8:20	86	86	85	94	90	86	77	99	78	46	80	88
8:30	84	84	84	91	88	85	78	105	74	56	79	86
8:33	(c)											
8:40	73	73	74	86	81	74	66	90	71	55	68	75
8:50	68	69	70	81	73	69	65	88	70	54	67	71
8:50	(d)											
9:00	73	73	73	81	76	73	71	74	67	56	69	74
9:10	74	74	74	80	75	74	72	70	64	56	71	74
9:20	72	72	72	79	74	72	70	71	63	51	69	72
9:30	72	72	72	79	74	72	70	67	63	52	69	72
9:40	72	71	72	79	73	71	69	68	62	53	68	72
9:50	72	71	72	79	74	72	71	69	63	55	70	72
10:00	(e)											
10:00	70	68	70	73	70	70	68	67	62	54	67	69
10:05	(a)											
10:07	(f)											
10:10	71	71	72	77	72	72	70	70	62	55	70	71
10:20	72	72	73	79	74	73	71	71	64	55	71	73
10:30	72	72	73	79	74	73	72	72	64	56	70	73
10:40	73	73	73	79	75	73	72	70	65	57	71	73
10:50	73	73	73	80	75	73	72	71	65	58	72	73
11:00	74	74	74	80	76	74	73	72	67	59	72	74
11:10	74	74	74	81	76	74	73	75	67	60	73	75
11:16	(g)											
11:20	74	74	74	81	76	75	73	74	68	60	73	75

THERMOCOUPLE READINGS FOR CLASSROOM B-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.
11:30	73	73	74	81	74	73	72	74	68	61	72	73
11:40	74	74	74	81	75	74	73	74	69	62	73	74
11:48	(h)											
11:50	76	76	76	82	77	76	75	76	69	63	74	76
12:00	76	76	76	83	78	76	75	74	70	61	75	76
12:10	76	76	76	84	79	77	75	75	70	63	75	77
12:20	76	76	76	85	79	76	75	74	71	63	75	77
12:28	(i)											
12:30	75	75	76	84	77	75	74	75	71	63	74	75
12:40	75	75	76	85	77	76	74	73	70	63	74	76
12:50	75	75	75	85	76	75	74	76	70	64	74	75
1:00	(j)											
1:00	77	77	77	85	78	77	76	75	71	65	75	77
1:10	76	76	76	86	78	76	75	73	71	65	74	76
1:20	77	77	78	87	80	78	76	76	72	66	75	77
1:30	78	78	78	88	80	78	76	74	72	67	76	78
1:40	78	78	79	88	80	79	76	76	73	68	76	79
1:50	80	80	80	88	81	80	77	77	74	68	77	79
1:56	(k)											
2:00	76	76	76	88	77	76	75	76	73	71	75	76
2:10	77	77	77	88	79	78	75	76	73	70	74	78
2:20	76	76	76	89	78	76	74	76	73	70	74	76
2:30	75	76	76	89	77	76	74	75	73	66	73	75
2:34	(l)											
2:40	75	75	76	88	76	75	74	74	71	67	74	75
2:50	75	75	76	89	77	75	73	76	72	70	73	76
3:00	76	76	76	89	77	76	74	75	72	62	73	75
3:10	77	77	77	88	78	76	75	76	71	68	75	76
Mean	75.62	75.60	75.91	84.78	77.96	75.89	73.29	76.64	70.31	59.78	73.13	75.87

THERMOCOUPLE READINGS FOR CLASSROOM B-1 (continued)

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.41°F.
Range of working area 92°-65°F. = 27°F. Sample size = 360
Variance = 17.40°F. Standard deviation = ±4.171°F.
Standard error of mean = ±.22°F.

Mean of readings at center of room from floor to ceiling = 77.98°F.
Range 100°-65°F. = 35°F. Sample size = 180
Variance = 38.89°F. Standard deviation = ±6.236°F.
Standard error of mean = ±.465°F.

Mean of all 30" readings = 75.78°F.
Range 88°-68°F. = 20°F. Sample size = 225
Variance = 16.02°F. Standard deviation = ±4.002°F.
Standard error of mean = ±.267°F.

(a) Children in room
(b) Windows opened
(c) Outside door opened
(d) Boiler cut off
(e) Morning recess - children out of room
(f) Windows closed
(g) Class went to lunch
(h) Class back from lunch
(i) Class out for play period
(j) Class back from play period
(k) Brief break
(l) Seven students caught early bus

THERMOCOUPLE READINGS FOR CLASSROOM B-2

February 17, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:50	87	86	86	98	92	87	78	161	86	44	80	88
7:53	(a)											
8:00	(b)											
8:00	78	79	80	92	90	84	73	161	74	46	72	81
8:10	84	84	84	92	89	84	77	171	73	46	78	85
8:20	85	85	85	91	89	85	78	167	71	48	79	86
8:30	(c)											
8:30	86	85	85	92	90	86	79	167	72	47	79	87
8:40	86	86	86	91	89	86	79	167	73	48	81	86
8:50	83	83	83	87	86	83	79	122	72	55	80	84
9:00	80	80	80	85	82	80	77	85	69	53	77	80
9:10	78	78	78	84	80	78	76	71	68	53	72	78
9:20	77	78	77	83	80	78	75	71	68	53	72	78
9:30	77	77	77	83	79	77	75	71	68	55	72	78
9:40	77	77	77	83	79	77	74	70	68	54	72	77
9:50	77	77	76	82	78	76	74	69	69	55	72	77
10:00	76	76	76	83	78	77	74	76	70	59	72	77
10:10	77	77	77	82	79	77	75	68	70	58	73	77
10:12	(d)											
10:20	(e)											
10:20	74	74	74	82	75	74	74	74	68	61	72	74
10:30	77	77	77	82	78	77	75	75	69	58	74	77
10:40	77	77	76	82	78	76	74	76	69	60	72	76
10:50	78	78	77	83	79	77	75	75	70		74	77
11:00	78	78	78	83	79	78	75	76	71	59	75	77
11:10	77	77	77	83	79	77	75	74	72	60	74	77
11:19	(f)											
11:20	76	77	76	83	78	77	74	75	70	61	71	73
11:30	74	74	74	79	75	74	72	73	69	61	72	74
11:40	73	73	73	78	73	73	71	73	70	62	71	74

THERMOCOUPLE READINGS FOR CLASSROOM B-2 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
11:49	(g)											
11:50	75	75	75	78	75	75	73	72	70	62	72	74
12:00	75	75	74	80	76	75	73	73	70	63	73	74
12:10	75	77	75	82	77	76	73	75	71	62	72	75
12:20	75	76	75	82	77	76	74	73	73	64	73	75
12:30	75	75	75	82	76	75	74	75	75	66	73	74
12:32	(h)											
12:40	74	74	74	82	75	74	73	74	73	65	72	74
12:50	74	74	74	83	75	75	73	75	74	67	73	75
1:00	74	74	74	83	75	74	73	74	73	68	73	74
1:01	(e)											
1:10	75	75	75	82	75	75	73	75	72	67	73	74
1:20	75	76	75	83	76	76	74	73	71	66	73	75
1:30	76	76	76	83	77	76	75	75	71	65	74	76
1:40	76	76	76	84	77	76	75	75	70	65	74	76
1:50	74	72	73	82	73	73	72	74	69	65	72	72
2:00	74	74	74	81	75	74	74	74	69	65	73	74
2:10	76	76	76	83	77	77	75	74	71	65	74	76
2:20	77	77	76	84	78	77	76	75	73	68	74	77
2:30	77	77	77	84	78	77	76	74	74	70	75	77
2:40	77	77	76	85	78	77	76	76	73	69	76	77
2:42	(i)											
2:50	78	78	78	85	78	78	76	76	74	68	75	77
3:00	78	77	78	85	78	78	76	76	76	68	76	78
3:10	79	79	78	85	79	79	78	77	76	69	76	77
Mean	77.36	77.40	77.18	84.02	79.09	77.58	74.89	87.40	71.49	60.07	74.04	77.29

Mean of working area (1,2,3,5,6,7,11, & 12) = 76.85°F.
Range of working area 92°-71°F. = 21°F. Sample size = 360
Variance = 14.25°F. Standard deviation = ±3.775°F.
Standard error of mean = ±.199°F.

THERMOCOUPLE READINGS FOR CLASSROOM B-2 (continued)

Mean of readings at center of room from floor to ceiling = 78.89°F.
Range 98°-71°F. = 27°F.
Sample size = 180
Variance = 24.71°F.
Standard deviation = ±4.971°F.
Standard error of mean = ±.371°F.

Mean of all 30" readings = 77.36°F.
Range 88°-71°F. = 17°F.
Sample size = 225
Variance = 12.58°F.
Standard deviation = ±3.547°F.
Standard error of mean = ±.236°F.

(a) Windows opened
(b) Children in room
(c) Heat turned off in boiler room
(d) Morning break
(e) Children back in room
(f) Lights turned off - Pupils went to lunch
(g) Class back from lunch - Lights on
(h) Class out to play
(i) Class back in room
(j) Eight students caught early bus

THERMOCOUPLE READINGS FOR CLASSROOM B-3

February 20, 1961

Time	1 30" °F.	2 30" °F.	3 30" °F.	4 120" °F.	5 60" °F.	6 30" °F.	7 6" °F.	8 Temp. of heat °F.	9 Temp. of window glass °F.	10 Out-side air temp. °F.	11 6" °F.	12 30" °F.
7:50	87	87	88	100	93	87	80	158	89	47	80	89
8:00	(a)											
8:00	80	80	80	89	85	80	77	130	75	47	78	82
8:10	78	78	77	84	79	77	75	92	65	49	75	77
8:20	75	75	75	83	77	75	73	73	61	47	71	74
8:30	74	74	74	82	75	73	71	71	60	46	70	72
8:40	72	73	71	81	74	72	71	69	60	47	69	72
8:50	73	73	73	80	74	72	71	65	59	47	69	72
9:00	72	72	71	80	74	72	70	66	59	46	67	71
9:10	72	72	71	79	73	71	70	67	59	47	68	70
9:20	71	72	71	79	73	71	70	64	60	47	68	71
9:30	70	70	69	79	72	70	70	65	59	47	66	70
9:40	71	71	70	79	73	70	69	64	60	47	66	71
9:44	(b)											
9:50	66	64	63	78	66	63	63	62	58	47	58	61
9:55	(c)											
10:00	71	70	70	77	71	70	69	62	59	47	68	70
10:10	72	72	72	78	74	73	71	69	60	48	70	72
10:20	72	72	72	78	73	72	70	65	60	47	69	71
10:30	71	71	71	77	72	72	70	65	60	47	68	70
10:40	71	71	72	78	73	72	71	65	60	47	69	72
10:50	72	72	71	78	73	72	70	65	60	47	70	71
11:00	72	72	71	77	73	72	71	64	60	47	69	71
11:10	71	72	70	77	73	71	70	65	60	47	70	71
11:20	71	71	69	77	71	71	70	64	59	48	68	70
11:24	(d)											
11:30	68	69	67	77	69	68	67	62	58	48	66	68
11:40	68	68	67	76	69	67	67	61	59	48	66	68
11:50	(e)											
11:50	69	68	67	77	69	68	67	65	58	47	65	67

THERMOCOUPLE READINGS FOR CLASSROOM B-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:00	70	70	70	77	71	70	69	64	59	47	66	69
12:10	70	67	69	77	70	69	68	67	59	47	65	66
12:20	70	70	70	77	71	71	70	65	58	48	68	70
12:30	72	71	71	77	72	71	70	65	60	50	69	70
12:40	68	67	66	78	67	68	69	67	60	49	65	65
12:50	70	69	70	78	70	69	69	69	60	49	67	69
1:00	73	73	74	78	74	74	72	71	61	49	70	73
1:10	74	73	74	79	75	74	73	71	62	49	72	73
1:20	74	73	74	79	76	74	73	73	61	49	73	74
1:30	74	74	74	79	76	75	73	72	61	49	72	74
1:40	74	74	74	80	76	75	74	72	61	49	73	75
1:50	74	74	74	79	76	75	73	72	62	49	73	74
2:00	74	74	74	80	75	74	72	73	62	50	72	73
2:10	72	72	72	79	74	72	70	70	61	50	70	72
2:20	73	73	72	79	74	73	71	71	61	49	70	72
2:30	72	72	71	78	73	72	70	70	60	49	69	71
2:40	72	72	72	79	73	73	72	71	60	49	70	72
2:50	(f)											
2:50	71	69	68	78	70	69	70	68	60	49	65	66
3:00	72	71	71	79	73	70	70	70	60	49	66	69
3:10	73	72	72	78	73	72	72	71	61	50	70	71
Mean	72.24	71.98	71.64	79.29	73.49	72.02	70.73	71.33	61.02	47.95	69.07	71.36

Mean of working area (1,2,3,5,6,7,11, & 12) = 71.57°F.
Range of working area 93°-58°F. = 35°F. Sample size = 360
Variance = 14.72°F. Standard deviation = ±3.837°F.
Standard error of mean = ±.020°F.

Mean of readings at center of room from floor to ceiling = 73.88°F.
Range 100°-63°F. = 37°F. Sample size = 180
Variance = 24.58°F. Standard deviation = ±4.958°F.
Standard error of mean = ±.370°F.

THERMOCOUPLE READINGS FOR CLASSROOM B-3 (continued)

Mean of all 30" readings = 71.85°F.
Range 89°-61°F. = 28°F.
Variance = 13.71°F.
Standard error of mean = ±.247°F.
Sample size = 225
Standard deviation = ±3.702°F.

(a) Boiler cut off - Windows opened - Children in room
(b) Morning break
(c) Some windows closed - Children complained about coolness of room
(d) Class went to lunch
(e) Students back from lunch - Heat turned on in boiler room, but off in classroom
(f) Seventeen children caught bus

THERMOCOUPLE READINGS FOR CLASSROOM C-1

February 22, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:35	(a)											
8:40	73	72	72	73	73	73	72	68	66	55	72	73
8:50	73	73	73	75	73	73	72	91	67	55	73	74
9:00	(b)											
9:00	76	77	77	81	77	76	73	107	69	55	74	76
9:10	76	76	76	77	76	76	75	84	69	55	74	76
9:20	75	75	75	75	75	75	73	69	67	55	74	75
9:30	74	74	74	74	74	74	73	68	68	55	73	74
9:40	74	74	74	74	74	74	73	67	67	55	74	74
9:50	(b)											
9:50	74	74	74	74	74	74	73	67	67	55	74	74
10:00	74	74	74	74	74	74	73	67	67	55	74	74
10:10	75	74	74	74	74	74	74	67	67	55	74	75
10:20	75	74	74	74	74	75	74	67	67	55	74	75
10:30	75	74	74	74	74	75	74	67	67	55	74	75
10:40	(b)											
10:40	75	75	75	75	75	75	74	67	67	55	74	75
10:44	(c)											
10:50	74	74	75	74	74	74	74	67	67	55	74	74
10:53	(d)											
11:00	74	74	74	74	75	74	74	66	66	55	74	75
11:10	74	75	75	74	74	75	74	66	67	55	74	75
11:20	74	75	74	74	74	75	74	67	67	55	74	75
11:30	75	75	75	75	75	75	74	66	66	55	74	75
11:40	74	75	75	75	75	75	74	67	67	55	74	75
11:50	75	75	75	74	75	75	74	66	66	55	74	75
12:00	75	75	75	75	75	75	74	66	66	55	74	74
12:10	75	75	75	75	75	75	74	67	67	55	74	74
12:16	(e)											
12:20	74	74	74	74	75	75	74	67	67	55	74	74

THERMOCOUPLE READINGS FOR CLASSROOM C-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:30	74	73	73	73	73	73	73	66	66	55	73	73
12:40	73	73	74	73	73	73	73	66	66	56	73	73
12:50	73	73	73	73	73	73	73	66	65	55	73	73
12:54	(f)											
1:00	73	73	73	73	73	73	72	66	64	55	72	73
1:10	74	74	74	74	74	74	73	67	64	55	73	73
1:13	(g)											
1:20	73	73	73	73	73	73	72	67	64	55	72	72
1:30	72	72	72	72	72	72	72	66	64	55	72	72
1:40	72	72	72	72	72	72	72	67	64	55	72	72
1:50	72	72	72	76	72	72	72	100	65	55	72	72
2:00	74	74	75	79	75	74	73	108	66	55	73	73
2:10	75	75	76	80	77	75	74	86	67	55	74	75
2:20	74	74	74	75	74	74	73	69	67	55	74	74
2:26	(h)											
2:30	74	74	74	74	75	74	74	67	67	55	74	74
2:40	75	75	75	75	75	75	74	66	66	55	74	74
2:50	75	75	75	75	75	75	75	67	68	55	75	75
3:00	75	75	75	75	75	75	74	66	68	56	75	75
3:10	75	75	75	75	75	75	75	66	68	56	74	75
3:20	75	75	75	75	75	75	74	64	67	56	74	75
3:30	75	75	74	78	77	76	74	71	68	56	74	75
Mean	74.19	74.17	74.21	74.71	74.33	74.26	73.45	71.00	66.55	55.12	73.60	74.14

Mean of working area (1,2,3,4,5,6,7,11, & 12) = 74.04°F.
Range of working area 77°-72°F. = 5°F. Sample size = 336
Variance = 1.15°F. Standard deviation = ±1.072°F.
Standard error of mean = ±.058°F.

Mean of readings at center of room from floor to ceiling = 74.19°F.
Range 81°-72°F. = 9°F. Sample size = 168
Variance = 1.86°F. Standard deviation = ±1.364°F.
Standard error of mean = ±.105°F.

THERMOCOUPLE READINGS FOR CLASSROOM C-1 (continued)

Mean of all 30" readings = 74.2°F.

Range 77°-72°F. = 9°F.

Variance = 1.12°F.

Standard error of mean = ±.073°F.

Sample size = 210

Standard deviation = ±1.058°F.

(a) Children coming into room - Hall door opened
(b) Classes changed
(c) Class left room
(d) Class back in room
(e) Lunch
(f) Class back from lunch
(g) Class gone to art room
(h) Class back from art

THERMOCOUPLE READINGS FOR CLASSROOM C-2

February 23, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Outside air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:30	(a)											
8:30	73	74	74	79	75	73	72	100	64	52	71	74
8:40	73	73	74	77	74	73	72	78	64	52	72	74
8:50	73	73	75	76	74	74	72	69	64	51	72	74
9:00	(b)											
9:00	73	73	73	76	74	73	72	65	64	52	72	73
9:10	73	73	74	76	74	73	72	64	64	52	72	74
9:20	73	73	73	76	74	74	73	63	64	53	72	74
9:30	73	73	74	76	74	74	73	63	64	53	73	75
9:40	73	73	74	77	75	74	73	63	64	54	73	74
9:50	(b)											
9:50	74	74	74	77	75	74	73	63	65	54	73	74
10:00	74	73	74	77	74	74	73	63	65	54	72	74
10:10	74	73	74	77	75	74	73	63	65	55	73	74
10:20	74	74	74	77	75	74	73	64	66	56	73	74
10:30	74	74	74	77	75	74	74	64	66	56	72	74
10:40	74	74	75	77	75	75	73	64	67	57	73	75
10:50	74	74	75	77	75	75	74	64	67	57	73	75
11:00	(c)											
11:00	74	74	75	78	75	75	74	65	67	57	73	74
11:10	73	73	73	77	74	74	73	65	67	58	72	73
11:20	73	73	73	77	73	73	72	65	68	59	73	73
11:30	73	73	73	77	73	73	73	65	68	59	72	73
11:40	73	73	73	77	73	73	73	65	69	60	72	73
11:47	(d)											
11:50	73	73	73	77	73	73	73	66	69	60	72	73
12:00	73	72	73	77	73	73	72	66	69	62	72	73
12:10	73	72	73	77	73	73	72	66	69	61	72	73
12:13	(e)											
12:20	74	74	74	77	75	74	73	66	70	61	73	74

THERMOCOUPLE READINGS FOR CLASSROOM C-2 (continued)

Time	1	2	3	4	5	6	7	8	9	10	11	12
	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:27	(f)											
12:30	74	73	74	77	75	74	73	67	70	67	73	74
12:40	73	73	73	78	73	73	73	68	71	68	73	74
12:50	74	74	74	78	74	74	73	68	77	68	73	74
1:00	(g)											
1:00	74	74	74	78	74	74	73	69	79	68	73	74
1:07	(h)											
1:10	75	75	75	78	75	75	74	70	82	71	74	75
1:20	75	75	75	79	76	75	74	71	83	68	74	75
	(i)											
1:30	75	75	75	79	76	75	74	72	85	68	74	76
1:40	76	76	76	80	77	76	75	73	86	69	75	76
1:50	76	76	77	80	77	77	76	73	88	70	78	77
1:52	(j)											
2:00	78	78	78	81	79	78	75	72	91	70	75	78
2:10	79	78	79	82	80	79	76	73	91	72	76	79
2:20	79	79	79	83	80	79	76	72	92	72	76	80
2:30	80	80	80	84	81	80	77	72	93	71	77	80
2:40	79	79	80	85	81	80	76	72	94	72	77	80
2:50	80	80	80	86	82	80	76	72	94	71	78	80
3:00	81	81	81	86	82	81	78	73	94	70	80	81
3:10	83	83	83	89	84	83	79	74	97	73	81	84
3:20	84	84	84	90	85	84	80	75	97	71	83	85
3:30	85	85	86	91	86	85	82	75	98	72	84	86
Mean	75.37	75.26	75.67	79.30	76.21	75.60	74.12	68.84	75.60	63.58	74.21	75.79

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.28°F.

Range of working area 86°-71°F. = 15°F. Sample size = 344

Variance = 10.37°F. Standard deviation = ±3.220°F.

Standard error of mean = ±.174°F.

THERMOCOUPLE READINGS FOR CLASSROOM C-2 (continued)

Mean of readings at center of room from floor to ceiling = 76.31°F.
Range 91°-72°F. = 19°F. Sample size = 172
Variance = 14.47°F. Standard deviation = ±3.804°F.
Standard error of mean = ±.290°F.

Mean of all 30" readings = 75.54°F.
Range 86°-73°F. = 13°F. Sample size = 215
Variance = 10.53°F. Standard deviation = ±3.245°F.
Standard error of mean = ±.221°F.

(a) Children started coming into room - Boiler cut off
(b) Classes changed
(c) Children out of room for play practice
(d) Corridor door opened
(e) Class back in room - Corridor door still open
(f) Lunch - Class out of room
(g) Class back from lunch
(h) Class gone to play practice - Sun shining in room
(i) Rise in discharge temperature perhaps caused by sun shining in window by discharge grille
(j) Blinds closed - Children back in room

THERMOCOUPLE READINGS FOR CLASSROOM C-3

February 24, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:30	76	77	76	81	78	76	71	103	65	50	71	76
8:40	73	73	73	75	74	73	71	68	64	50	71	73
8:50	73	72	72	75	73	73	71	74	64	52	72	73
9:00	75	76	75	80	77	76	72	114	66	53	72	76
9:08	(a)											
9:10	78	78	78	82	79	77	75	108	68	55	75	78
9:15	(b)											
9:20	76	77	76	78	77	76	74	70	68	55	75	76
9:30	75	76	75	77	76	75	74	66	68	56	75	76
9:40	75	76	75	77	76	75	74	65	68	56	75	75
9:50	(a)											
9:50	75	75	75	77	75	75	74	64	68	57	74	75
10:00	74	75	74	76	75	74	73	64	68	58	74	74
10:10	74	75	75	76	75	74	73	64	68	59	74	74
10:20	74	75	75	77	75	74	74	64	69	59	74	75
10:30	75	75	76	77	76	75	74	65	70	61	74	75
10:40	75	76	75	77	76	75	75	66	71	62	75	76
10:41	(c)											
10:50	77	75	76	77	76	76	75	66	72	62	75	76
11:03	(d)											
11:04	75	75	75	76	75	75	74	67	73	64	75	75
11:10	74	74	74	75	74	74	73	63	72	64	74	74
11:20	74	74	74	74	74	73	73	67	72	64	74	74
11:30	73	73	73	74	73	73	73	67	72	64	73	73
11:31	(e)											
11:36	(f)											
11:40	75	75	75	76	75	75	74	68	73	65	75	76
11:50	75	75	76	77	76	76	76	69	73	65	76	76
12:03	(g)											
12:04	76	76	77	78	77	77	76	69	74	66	77	77

THERMOCOUPLE READINGS FOR CLASSROOM C-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
								Temp. of heat	Temp. of window glass	Out-side air temp.		
Time	30"	30"	30"	120"	60"	30"	6"				6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:10	76	76	77	78	77	77	76	69	73	65	77	77
12:20	76	76	77	78	77	76	75	69	73	66	76	77
12:30	75	75	75	77	75	75	74	69	73	67	75	75
12:40	75	75	76	75	75	75	75	70	74	68	76	75
12:41	(h)											
12:50	75	75	75	75	75	75	74	70	76	68	75	75
1:00	74	74	75	75	75	75	74	70	77	69	74	75
1:10	75	75	75	75	75	75	74	71	76	67	75	75
1:20	75	75	75	76	75	75	75	71	77	68	76	76
1:30	76	76	76	77	77	76	75	71	75	68	76	77
1:40	77	77	77	78	77	77	76	72	75	68	77	77
1:50	77	78	77	79	78	78	76	72	76	69	78	78
1:57	(i)											
2:00	76	77	76	79	77	77	75	72	75	68	76	77
2:10	76	76	76	78	76	76	75	72	74	68	76	76
2:20	76	76	76	79	76	76	75	71	72	67	76	76
2:30	75	75	75	78	75	75	75	69	72	66	75	75
2:39	(j)											
2:40	75	75	75	78	75	75	75	69	71	66	75	75
2:50	76	76	76	78	76	76	75	69	71	66	76	76
3:00	76	77	76	79	77	77	76	70	72	66	76	76
3:10	77	77	76	79	77	77	76	70	72	65	76	77
3:20	77	77	77	79	77	77	76	69	72	65	76	77
3:30	77	77	77	79	77	77	77	72	72	65	76	77
Mean	75.33	75.56	75.47	77.23	75.84	75.44	74.37	71.35	71.49	62.84	74.93	75.69

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.32°F.

Range of working area 79°-71°F. = 80°F. Sample size = 344

Variance = 1.83°F. Standard deviation = ±1.353°F.

Standard error of mean = ±.073°F.

THERMOCOUPLE READINGS FOR CLASSROOM C-3 (continued)

Mean of readings at center of room from flor to ceiling = 75.72°F.
Range 81°-71°F. = 10°F. Sample size = 172
Variance = 3.15°F. Standard deviation = ±1.775°F.
Standard error of mean = ±.135°F.

Mean of all 30" readings = 75.48°F.
Range 78°-72°F. = 6°F. Sample size = 215
Variance = 1.48°F. Standard deviation = ±1.217°F.
Standard error of mean = ±.083°F.

(a) Classes changed
(b) Boilers cut off
(c) Classes changed - Break taken in room
(d) Recorder off approximately 11 minutes with blown fuse. Pupils gone to Spanish - Lights off - Sky becoming a little overcase
(e) Class back from Spanish
(f) A few children complained about being too cold.
(g) Fuse had been blown approximately 7 minutes
(h) Lunch
(i) Class gone for physical education
(j) Class back from physical education

THERMOCOUPLE READINGS FOR CLASSROOM D-1

February 27, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:20	(a)											
8:20	72	72	72	81	73	72	69	121	62	36	70	71
8:30	73	72	73	84	75	73	70	122	63	37	70	73
8:40	74	74	74	82	76	74	71	100	64	38	71	74
8:50	75	74	75	78	76	75	71	87	64	39	71	75
9:00	75	74	75	77	76	75	71	86	64	40	71	74
9:10	75	75	75	77	76	75	72	85	64	42	72	75
9:20	75	75	76	76	76	75	72	84	64	43	72	75
9:30	75	75	75	77	76	75	73	86	65	45	72	75
9:40	75	75	75	77	76	75	72	85	66	46	72	75
9:50	75	76	75	77	77	75	72	85	66	48	72	75
10:00	75	76	75	77	77	75	73	85	67	48	73	75
10:10	76	76	76	77	77	77	73	85	68	50	73	76
10:04	(b)											
10:20	76	76	75	78	76	76	73	85	68	51	73	75
10:30	75	75	75	78	76	75	73	84	68	52	73	75
10:34	(c)											
10:40	76	77	76	78	77	76	74	84	69	53	73	76
10:50	77	77	77	80	78	77	74	86	70	56	74	77
11:00	77	78	78	80	79	77	74	86	71	56	74	77
11:10	78	78	78	80	79	78	75	86	71	58	74	78
11:20	78	78	78	81	79	78	75	85	72	58	75	78
11:30	78	78	78	80	79	78	75	81	72	60	75	78
11:40	78	78	78	80	79	78	75	79	72	61	75	78
11:50	(d)											
11:50	78	78	78	81	79	78	75	79	72	61	76	78
12:00	78	77	77	81	78	77	76	78	72	62	75	77
12:10	77	77	77	81	78	77	74	78	72	62	74	77
12:20	77	77	77	82	78	77	74	76	72	61	74	77
12:30	77	76	77	81	77	77	75	73	72	63	75	77

THERMOCOUPLE READINGS FOR CLASSROOM D-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:32	(e)											
12:40	77	77	77	81	78	77	75	73	72	64	75	77
12:50	77	78	78	82	78	78	76	73	72	64	75	77
1:00	78	78	78	82	79	78	75	73	73	64	75	78
1:10	78	78	78	82	79	78	76	73	73	64	76	78
1:20	79	79	79	84	80	79	76	77	74	65	76	79
1:30	80	80	81	84	82	81	76	86	75	66	76	81
1:40	81	81	81	85	82	81	76	88	77	67	77	81
1:50	81	81	81	86	83	81	77	88	76	66	77	81
2:00	(f)											
2:00	81	81	81	86	83	82	78	89	76	65	78	81
2:10	80	80	80	86	82	81	76	89	77	67	76	80
2:20	80	80	80	86	82	80	76	89	77	67	75	80
2:30	79	79	80	86	81	80	76	82	77	67	76	79
2:40	80	80	80	86	81	81	77	78	76	68	77	80
2:50	80	80	80	85	81	81	78	77	76	67	77	80
3:00	(g)											
3:00	81	80	80	85	81	81	79	76	75	68	78	80
3:06	(h)											
3:10	78	78	78	82	79	79	76	75	75	68	75	78
3:20	78	78	78	80	79	78	76	75	74	67	75	77
3:30	78	77	78	80	78	78	76	75	74	68	75	76
Mean	77.29	77.25	77.34	81.10	78.43	77.48	74.45	84.79	70.89	57.23	74.27	77.14

Mean of working area (1,2,3,5,6,7,11, & 12) = 76.70°F.
Range of working area 83°-69°F. = 14°F. Sample size = 352
Variance = 7.01°F. Standard deviation = ±2.648°F.
Standard error of mean = ±.141°F.

Mean of readings at center of room from floor to ceiling = 77.87°F.
Range 86°-69°F. = 17°F. Sample size = 176
Variance = 11.77°F. Standard deviation = ±3.431°F.
Standard error of mean = ±.259°F.

THERMOCOUPLE READINGS FOR CLASSROOM D-1 (continued)

Mean of all 30" readings = 77.30°F.
Range 82°-71°F. = 11°F.
Variance = 5.21°F.
Standard error of mean = ±.154°F.
Sample size = 220
Standard deviation = ±2.283°F.

(a) Children coming into room - Lights on
(b) Recess begins
(c) Recess over
(d) Lunch
(e) Children back from lunch
(f) Recess
(g) End of school day - Pupils out
(h) Lights off

THERMOCOUPLE READINGS FOR CLASSROOM D-2

February 28, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:00	(a)											
8:00	75	75	75	79	75	75	74	94	64	54	74	75
8:10	76	75	75	79	76	76	74	95	64	54	75	75
8:20	76	76	77	79	77	77	76	91	65	57	75	77
8:29	(b)											
8:30	77	77	77	78	77	77	76	87	66	58	76	76
8:40	77	77	78	78	78	78	77	84	66	59	77	78
8:49	(c)											
8:50	78	77	78	78	78	78	77	84	67	59	77	78
9:00	78	77	78	79	78	78	77	83	67	60	77	78
9:10	78	77	78	79	78	78	77	82	68	62	78	79
9:20	78	78	79	80	79	79	77	82	68	61	78	79
9:30	78	78	79	79	79	78	77	82	68	61	77	78
9:40	78	78	78	79	79	79	77	83	69	63	78	79
9:50	79	79	80	80	79	79	78	80	70	63	78	79
10:00	80	80	80	81	80	80	78	83	71	64	79	80
10:10	80	80	80	81	80	80	78	83	71	63	80	81
10:17	(d)											
10:20	80	79	80	81	80	80	78	83	71	65	79	80
10:30	79	78	79	80	79	79	78	83	70	62	77	78
10:33	(e)											
10:40	79	79	79	80	80	80	78	82	70	62	79	80
10:50	80	80	81	81	80	80	78	83	70	62	79	80
11:00	81	80	81	81	81	80	79	83	71	65	80	81
11:10	81	81	81	82	82	81	79	84	72	64	80	81
11:20	82	81	82	83	82	81	80	82	72	64	80	82
11:30	82	81	82	83	82	81	79	79	72	63	80	81
11:38	(f)											
11:40	81	81	81	81	81	81	79	78	73	64	81	81
11:46	(g)											

THERMOCOUPLE READINGS FOR CLASSROOM D-2 (continued

Time	1	2	3	4	5	6	7	8	9	10	11	12
								Temp. of heat	Temp. of window glass	Out-side air temp.		
	30" °F.	30" °F.	30" °F.	120" °F.	60" °F.	30" °F.	6" °F.	°F.	°F.	°F.	6" °F.	30" °F.
11:50	81	81	81	82	81	81	79	77	74	67	85	77
11:55	(h)											
12:00	80	80	80	81	80	80	78	77	75	70	85	81
12:10	79	79	79	79	79	79	78	77	75	68	84	80
12:20	79	79	80	79	79	79	78	82	76	69	85	80
12:30	(i)											
12:30	80	81	80	80	80	79	79	83	77	70	83	82
12:40	80	80	81	81	81	81	79	80	77	71	85	82
12:50	80	80	79	80	80	80	79	75	76	66	81	81
1:00	79	80	78	80	80	80	79	73	77	72	85	81
1:10	80	80	78	80	80	80	79	74	76	72	84	81
1:20	81	80	78	81	81	81	79	74	77	73	82	82
1:30	81	80	78	81	80	80	79	73	76	68	81	81
1:40	81	81	79	83	81	81	80	73	78	73	85	82
1:50	81	81	79	83	82	82	80	76	76	67	82	82
2:00	(j)											
2:00	81	82	80	84	82	82	80	77	78	71	83	84
2:10	82	82	80	84	82	82	80	77	79	74	84	84
2:20	81	81	80	83	81	81	79	77	79	71	82	83
2:30	(k)											
2:30	82	81	81	82	82	82	80	83	79	74	84	84
2:40	83	83	82	83	83	83	81	84	80	72	83	84
2:50	83	83	82	83	83	83	81	80	79	73	83	85
3:00	(l)											
3:00	82	82	81	83	82	82	81	77	79	76	83	87
3:10	81	81	81	82	81	80	80	75	79	78	81	85
3:20	80	80	80	81	81	81	79	75	79	80	81	82
3:30	81	81	80	81	80	80	79	74	78	76	81	84
Mean	79.80	79.61	79.46	81.02	80.02	79.87	78.41	80.50	73.13	66.52	80.57	80.65

THERMOCOUPLE READINGS FOR CLASSROOM D-2 (continued)

Mean of working area (1,2,3,5,6,7,11 & 12) = 79.79°
Range of working area 87°-74°F. = 13°F. Sample size = 368
Variance = 4.71°F. Standard deviation = ±2.170°F.
Standard error of mean = ±.113°F.

Mean of readings at center of room from floor to ceiling = 79.78°F.
Range 87°-74°F. = 10°F. Sample size = 184
Variance = 3.52°F. Standard deviation = ±1.876°F.
Standard error of mean = ±.138°F.

Mean of all 30" readings = 79.88°F.
Range 87°-75°F. = 12°F. Sample size = 230
Variance = 4.06°F. Standard deviation = ±2.015°F.
Standard error of mean = ±.133°F.

(a) Children coming into room
(b) Bell
(c) One-third of venetian blinds pulled
(d) Recess
(e) Recess over - Fifth grade coming in for demonstration of equipment
(f) Fifth grade class left room
(g) Sun shining on floor
(h) Class gone to lunch
(i) Class back from lunch
(j) Recess begins
(k) Recess over
(l) Windows opened

THERMOCOUPLE READINGS FOR CLASSROOM D-3

March 1, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:50	73	73	72	75	74	73	71	82	65	47	71	75
8:00	(a)											
8:00	74	74	73	76	74	74	73	83	66	48	72	75
8:10	75	74	73	76	74	74	72	84	65	47	72	75
8:20	74	74	73	77	74	74	73	83	66	48	73	75
8:30	75	75	75	77	75	75	73	83	66	48	73	76
8:40	75	75	75	77	75	75	73	83	65	48	74	76
8:50	75	75	75	77	76	75	73	83	66	48	74	76
9:00	76	75	75	77	76	75	74	84	65	48	74	76
9:10	75	75	75	77	75	75	74	83	65	48	74	76
9:20	75	75	75	77	75	75	74	83	65	48	74	76
9:30	75	75	75	77	75	75	74	83	65	47	74	76
9:40	75	75	75	77	76	75	74	83	65	48	75	77
9:50	75	75	75	77	76	75	74	82	66	48	75	76
10:00	75	75	75	78	76	75	74	82	66	48	75	77
10:10	75	75	75	78	76	76	74	83	65	47	75	77
10:15	(b)											
10:20	75	76	76	78	76	76	75	83	66	47	75	76
10:30	(c)											
10:30	76	76	74	78	76	76	75	83	65	47	74	77
10:40	75	75	75	78	76	76	74	83	65	47	75	76
10:50	75	75	75	78	76	76	74	83	66	47	75	77
11:00	76	75	76	78	76	76	74	83	67	48	75	77
11:10	76	75	75	78	76	76	74	82	67	48	75	77
11:20	76	76	76	78	76	76	74	82	67	48	75	77
11:30	76	75	75	78	76	76	75	83	66	48	75	77
11:40	75	75	75	78	76	75	75	83	65	48	75	77
11:50	75	75	75	78	76	76	75	83	65	47	75	77
12:00	76	75	75	78	76	76	75	83	66	48	76	77
12:10	76	76	75	78	76	76	74	83	66	48	75	77

THERMOCOUPLE READINGS FOR CLASSROOM D-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:20	75	75	75	78	76	75	74	82	66	47	75	77
12:30	76	76	76	78	76	76	76	82	66	48	75	76
12:40	76	76	76	78	76	76	74	82	65	48	75	77
12:50	76	76	75	78	76	76	74	82	65	48	75	77
1:00	76	76	75	78	76	76	75	82	66	49	75	77
1:10	76	76	76	78	76	77	75	82	66	49	76	77
1:20	76	76	76	78	76	76	75	83	66	49	76	77
1:30	76	75	76	78	76	76	75	83	66	49	75	77
1:40	76	76	76	79	77	76	75	83	68	50	76	77
1:50	77	76	76	78	77	77	75	83	68	50	75	77
2:00	(d)											
2:00	77	76	77	79	77	77	75	83	69	51	75	78
2:10	77	76	77	79	77	77	75	83	69	51	75	77
2:20	76	76	76	79	77	76	75	83	68	51	75	75
2:30	76	76	76	79	77	76	74	83	68	52	74	77
2:32	(e)											
2:40	77	76	76	79	77	77	75	83	68	51	75	78
2:50	77	76	77	79	77	77	75	83	68	51	75	78
3:00	77	77	77	80	77	77	76	83	68	51	76	78
3:10	77	77	77	79	77	77	75	83	68	51	76	78
3:20	77	77	78	79	77	77	76	83	67	51	77	78
3:30	77	77	77	79	77	77	76	83	67	51	77	78
Mean	75.67	75.45	75.39	77.89	75.98	75.77	74.32	83.02	66.26	48.62	74.74	77.26

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.31°F.
Range of working area 78°-71°F. = 7°F. Sample size = 376
Variance = 1.39°F. Standard deviation = ±1.179°F.
Standard error of mean = ±.061°F.

Mean of readings at center of room from floor to ceiling = 76.52°F.
Range 80°-71°F. = 9°F. Sample size = 188
Variance = 2.47°F. Standard deviation = ±1.572°F.
Standard error of mean = ±.115°F.

THERMOCOUPLE READINGS FOR CLASSROOM D-3 (continued

Mean of all 30" readings = 75.51°F.
Range 78°-72°F. = 6°F.
Variance = 1.53°F.
Standard error of mean = ±.081°F.

Sample size = 235
Standard deviation = ±1.237°F.

(a) Children coming into room
(b) Recess - Games in room
(c) End of recess
(d) Recess begins
(e) Recess over

THERMOCOUPLE READINGS FOR CLASSROOM E-1

March 2, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:04	(a)											
8:10	74	75	74	75	75	75	74	95	58	38	74	75
8:20	74	74	74	74	74	74	73	78	56	35	73	74
8:30	74	74	74	75	75	74	73	78	56	37	72	74
8:40	73	74	74	75	75	74	73	78	57	38	72	74
8:50	74	73	74	75	75	74	73	77	57	39	72	74
9:00	74	74	74	75	75	74	73	76	58	40	72	74
9:10	74	74	75	75	75	75	74	77	59	42	73	74
9:20	74	74	75	75	75	75	73	76	59	43	73	75
9:30	74	74	74	75	75	75	73	77	59	43	73	75
9:37	(b)											
9:40	74	74	74	74	74	74	73	76	59	45	74	75
9:41	(c)											
9:45	(d)											
9:50	73	74	74	74	74	74	72	75	59	45	73	74
10:00	74	74	74	75	75	74	73	76	59	45	73	75
10:10	74	74	74	75	75	75	73	75	60	45	73	74
10:20	74	74	75	75	75	75	73	75	60	46	73	74
10:30	75	75	75	75	75	75	74	75	60	47	73	75
10:40	75	75	75	76	75	75	74	76	61	48	73	75
10:50	74	75	75	75	75	75	73	75	60	47	73	75
11:00	74	75	75	75	75	75	73	75	61	48	73	75
11:10	75	75	75	76	76	75	74	76	61	50	73	75
11:20	75	75	75	76	76	75	74	76	62	49	74	75
11:30	75	75	75	76	76	75	74	74	62	50	73	75
11:40	74	75	74	75	75	75	73	73	62	49	72	74
11:42	(e)											
11:50	74	74	74	75	75	75	73	73	62	50	72	74
12:00	74	74	74	75	74	74	73	75	62	51	72	74
12:10	73	73	73	74	74	74	72	74	62	50	72	73

THERMOCOUPLE READINGS FOR CLASSROOM E-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:20	73	73	73	74	74	73	72	74	62	52	72	73
12:30	73	73	73	74	74	73	72	74	63	52	72	73
12:40	73	72	73	74	73	73	72	73	62	52	71	72
12:50	(f)											
12:50	73	73	73	74	73	73	72	74	63	53	72	73
1:00	73	73	73	75	75	75	74	74	64	53	73	75
1:10	75	75	75	76	75	75	74	72	64	54	73	75
1:20	74	74	74	75	75	75	73	72	64	52	72	75
1:30	75	75	75	76	76	75	74	73	65	54	74	75
1:34	(g)											
1:40	73	73	73	74	74	73	72	71	64	54	72	73
1:50	72	72	73	73	73	73	72	71	64	54	72	73
2:00	72	72	73	73	73	73	72	70	64	56	73	83
2:10	(h)											
2:10	73	74	73	74	74	74	73	72	65	54	71	73
2:20	74	74	75	75	75	75	74	72	65	56	73	74
2:30	73	74	75	75	75	75	73	72	65	56	74	75
2:40	75	75	75	76	75	75	75	73	66	59	74	76
2:50	75	75	75	76	76	76	74	70	66	57	71	75
3:00	72	72	72	74	73	72	71	70	64	55	70	72
Mean	71.43	71.57	71.71	72.45	74.67	74.36	73.07	74.71	61.45	48.64	72.59	74.19

Mean of working area (1,2,3,5,6,7,11, & 12) = 73.84°F.
Range of working area 76°-70°F. = 6°F. Sample size = 336
Variance = 1.18°F. Standard deviation = ±1.086°F.
Standard error of mean = ±.059°F.

Mean of readings at center of room from floor to ceiling = 74.23°F.
Range 76°-71°F. = 5°F. Sample size = 168
Variance = 1.17°F. Standard deviation = ±1.082°F.
Standard error of mean = ±.083°F.

THERMOCOUPLE READINGS FOR CLASSROOM E-1 (continued)

Mean of all 30" readings = 74.08°F.
Range 76°-72°F. = 4°F.
Variance = .82°F.
Standard error of mean = ±.020°F.

Sample size = 210
Standard deviation = ±.286°F.

(a) Class in progress - Recorder on
(b) Morning break
(c) Window open slightly
(d) Class back from break
(e) Class going to music and then lunch
(f) Class returned from lunch
(g) Class out for play period
(h) Class involved in group work

THERMOCOUPLE READINGS FOR CLASSROOM E-2

March 3, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:45	(a)											
7:50	74	74	74	74	74	74	74	93	69	46	74	74
8:00	75	75	76	75	75	75	74	87	72	47	74	75
8:10	76	76	76	76	76	77	75	86	75	51	75	76
8:16	(b)											
8:20	72	71	73	75	75	74	69	80	77	50	67	72
8:30	72	72	73	74	74	73	69	74	78	50	68	72
8:40	71	71	74	74	74	72	68	73	79	49	68	72
8:50	71	72	76	74	74	73	68	72	80	51	67	71
9:00	73	72	73	74	74	73	69	73	80	52	69	73
9:10	72	72	73	75	75	73	69	73	82	53	69	72
9:20	72	72	73	75	75	73	70	73	82	56	69	73
9:30	74	73	74	76	75	75	70	76	85	60	69	74
9:40	75	75	75	76	76	75	71	76	86	57	71	75
9:50	75	75	75	77	76	76	72	78	87	61	71	76
10:00	75	75	75	76	76	75	72	78	87	58	71	76
10:04	(c)											
10:10	75	75	75	75	76	75	74	79	85	60	73	76
10:20	75	75	76	77	76	76	74	80	95	61	72	76
10:30	75	75	76	77	77	76	74	80	90	60	73	76
10:40	75	75	75	75	76	75	74	78	96	58	73	76
10:49	(d)											
10:50	75	75	76	76	76	76	75	78	71	59	75	76
11:00	76	75	76	76	76	76	73	76	70	57	73	75
11:10	74	74	75	75	75	75	73	75	69	57	72	74
11:20	75	75	75	76	76	75	74	76	72	60	73	76
11:30	76	76	76	77	77	77	75	78	79	62	75	81
11:40	77	77	77	78	78	77	75	79	87	61	75	78
11:50	77	77	77	78	78	77	75	77	82	62	74	77
12:00	77	76	77	77	78	77	75	76	79	61	75	76

THERMOCOUPLE READINGS FOR CLASSROOM E-2 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:07	(e)											
12:10	75	75	75	76	76	76	74	75	77	61	74	75
12:20	75	74	75	75	75	75	74	75	74	60	74	75
12:26	(f)											
12:30	74	74	74	74	74	74	74	76	76	64	74	75
12:40	75	75	76	76	76	76	75	76	74	62	74	75
12:50	76	76	77	77	77	76	74	76	73	63	74	76
1:00	76	76	77	77	77	76	74	77	73	64	74	76
1:10	77	76	77	77	77	77	75	77	75	64	75	76
1:20	77	77	78	77	77	77	76	78	75	64	76	77
1:30	77	76	77	77	77	77	75	76	73	63	74	76
1:31	(g)											
1:40	75	75	75	75	75	75	74	77	72	65	74	75
1:50	75	75	75	75	75	75	74	77	72	64	74	75
2:00	74	74	75	75	74	75	74	77	71	65	74	74
2:10	75	75	76	76	76	75	74	75	71	65	74	77
2:20	76	75	77	77	76	76	74	76	72	64	74	76
2:30	76	75	76	77	77	76	75	76	71	62	74	77
2:40	76	75	77	77	77	76	75	76	71	64	75	77
2:42	(h)											
2:50	77	77	78	78	77	77	76	78	72	64	76	77
3:00	77	76	78	78	78	78	77	77	72	64	75	77
Mean	74.93	74.68	75.55	75.95	75.89	75.39	73.30	77.25	77.45	59.11	72.82	75.34

Mean of working area (1,2,3,5,6,7,11, & 12) = 74.74°F.
Range of working area 81°-67°F. = 14°F. Sample size = 352
Variance = 4.18°F. Standard deviation = ±2.045°F.
Standard error of mean = ±.109°F.

Mean of readings at center of room from floor to ceiling = 75.13°F.
Range 78°-68°F. = 10°F. Sample size = 176
Variance = 3.62°F. Standard deviation = ±1.903°F.
Standard error of mean = ±.143°F.

THERMOCOUPLE READINGS FOR CLASSROOM E-2 (continued)

Mean of all 30" readings = 75.45°F.
Range 81°-71°F. = 10°F.
Variance = 2.55°F.
Standard error of mean = ±.171°F.
Sample size = 220
Standard deviation = ±2.629°F.

(a) Drapes drawn - Children coming into room
(b) Windows opened
(c) Drapes opened
(d) Drapes opened - Sky somewhat overcast
(e) Class gone to lunch
(f) Class back from lunch
(g) Class out to play - Lights out
(h) Committee work in class

THERMOCOUPLE READINGS FOR CLASSROOM E-3

March 6, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:42	(a)											
7:50	82	81	81	86	83	81	80	134	77	65	81	83
8:00	(b)											
8:00	83	83	83	87	85	83	81	136	77	65	83	84
8:10	83	81	82	86	83	82	79	142	76	66	80	82
8:20	82	82	81	86	83	82	79	138	75	66	80	82
8:30	82	82	82	84	82	83	82	114	75	65	83	84
8:40	83	83	83	86	84	83	81	124	74	64	82	82
8:50	83	83	83	86	84	84	82	130	74	65	84	84
9:00	83	83	84	87	84	84	83	132	74	65	83	84
9:10	83	83	83	86	84	84	83	129	74	65	84	84
9:20	82	83	83	86	84	83	82	127	75	64	83	83
9:30	83	83	83	86	83	83	82	126	74	64	82	83
9:40	85	83	83	86	84	83	82	127	75	64	82	83
9:43	(c)											
9:50	80	80	81	85	82	81	79	132	74	65	80	81
10:00	79	79	79	83	80	79	78	122	73	64	78	79
10:10	81	80	81	85	81	81	79	134	75	65	81	81
10:18	(d)											
10:20	81	81	81	85	82	81	80	132	74	65	80	80
10:30	82	82	81	86	82	82	81	131	75	65	80	81
10:40	81	81	81	85	82	82	80	130	75	66	81	82
10:50	82	81	81	85	82	82	80	125	75	66	82	82
11:00	82	82	82	85	82	82	81	126	76	66	81	82
11:10	82	82	82	84	82	82	81	123	75	67	82	82
11:20	82	82	82	86	82	82	81	114	75	67	83	83
11:28	(e)											
11:30	83	82	82	86	83	83	81	125	75	67	83	83
11:33	(f)											
11:40	81	80	81	85	81	81	79	124	76	68	82	82

THERMOCOUPLE READINGS FOR CLASSROOM E-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
11:50	81	81	82	85	82	82	79	128	76	69	82	82
12:00	81	81	81	86	82	82	80	128	77	69	82	83
12:03	(g)											
12:10	81	81	82	84	82	82	81	127	76	68	82	83
12:20	83	82	82	85	83	83	82	124	76	69	82	82
12:30	81	81	81	82	81	81	81	102	76	69	82	80
12:40	81	81	81	83	81	82	81	92	78	69	81	83
12:50	81	81	81	81	81	81	81	88	79	71	83	82
1:00	81	82	82	83	82	82	81	89	80	72	83	83
1:10	82	81	81	84	82	82	80	87	78	71	81	81
1:20	81	81	80	82	81	81	80	87	78	72	81	82
1:30	82	81	81	82	81	81	81	87	77	71	81	81
1:40	81	81	80	82	80	81	80	85	77	72	81	81
1:50	81	81	80	81	81	81	80	86	77	71	82	82
2:00	81	80	81	82	81	81	80	85	78	73	81	81
2:10	82	81	81	83	81	81	80	85	77	71	81	81
2:20	82	81	80	83	81	81	79	86	77	72	81	81
2:30	83	82	83	84	82	82	82	83	76	71	82	82
2:40	79	77	79	80	79	79	79	81	75	69	80	79
2:50	81	81	81	80	81	81	81	82	75	69	81	81
3:00	81	81	80	80	80	80	80	82	73	66	81	81
Mean	81.73	81.36	81.45	84.18	82.00	81.80	80.55	110.70	75.77	67.57	81.59	81.98

Mean of working area (1,2,3,5,6,7,11, & 12) = 81.56°F.
Range of working area 85°-77°F. = 8°F. Sample size = 352
Variance = 1.79°F. Standard deviation = ±1.338°F.
Standard error of mean = ±.071°F.

Mean of readings at center of room from floor to ceiling = 82.13°F.
Range 87°-79°F. = 8°F. Sample size = 176
Variance = 3.80°F. Standard deviation = ±1.949°F.
Standard error of mean = ±.147°F.

THERMOCOUPLE READINGS FOR CLASSROOM E-3 (continued)

Mean of all 30" readings = 77.12°F.
Range 85°-77°F. = 8°F.
Variance = 1.38°F.
Standard error of mean = ±.079°F.

Sample size = 220
Standard deviation = ±1.175°F.

(a) Children coming into room
(b) Three windows opened
(c) Class out of room for music
(d) Class back from music
(e) Class gone to lunch
(f) Thermostat setting changed to 65°F. by principal
(g) Class back from lunch

THERMOCOUPLE READINGS FOR CLASSROOM F-1

March 7, 1961

Time	1	2	3	4	5	6	7	8	9	10	11	12
	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:20	76	77	76	77	76	76	76	71	69	60	74	75
8:30	77	78	78	77	78	77	77	71	69	60	75	76
8:34	(a)											
8:40	78	77	78	78	78	78	78	71	70	62	72	77
8:50	77	77	78	78	78	78	77	71	71	64	76	77
9:00	77	77	78	79	79	78	78	71	71	63	76	77
9:10	78	77	79	79	79	78	77	71	71	65	75	77
9:20	78	77	79	79	79	79	78	71	71	70	76	77
9:30	77	76	77	79	78	78	77	71	71	64	72	75
9:40	78	77	78	79	79	78	78	73	73	70	76	77
9:50	76	75	77	79	77	75	74	71	72	65	72	74
10:00	77	75	77	78	77	76	76	72	72	67	74	75
10:10	77	77	78	79	79	78	77	72	72	68	75	76
10:20	77	75	77	78	77	77	77	71	71	66	74	75
10:30	77	76	76	79	77	77	76	71	71	64	73	73
10:31	(b)											
10:40	74	74	74	78	75	75	74	72	71	66	74	74
10:46	(c)											
10:50	77	77	77	79	77	77	77	72	72	66	75	75
11:00	77	77	77	79	77	77	77	72	72	66	76	76
11:10	77	77	77	79	77	77	77	73	73	69	74	76
11:20	76	76	77	79	77	76	76	72	72	65	75	76
11:30	76	76	76	79	77	77	76	72	72	67	75	76
11:40	77	76	77	79	77	77	77	72	72	68	76	76
11:45	(d)											
11:50	78	78	79	79	79	78	78	72	72	71	76	77
12:00	78	78	78	79	79	79	78	72	73	70	76	77
12:10	75	73	75	79	77	75	74	71	72	65	71	76
12:19	(e)											
12:20	74	72	74	76	75	76	74	71	72	65	70	73

THERMOCOUPLE READINGS FOR CLASSROOM F-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:30	73	72	72	76	74	72	71	71	71	65	70	73
12:40	73	72	73	75	73	73	73	71	70	65	71	71
12:48	(f)											
12:50	73	71	73	78	74	72	72	71	70	64	71	72
1:00	76	76	78	77	77	76	76	71	71	66	74	74
1:10	79	79	79	79	79	79	78	72	72	70	76	76
1:20	77	77	79	79	78	78	77	72	73	70	75	77
1:30	78	79	79	79	78	78	78	72	73	70	77	78
1:40	78	78	80	79	79	78	77	72	74	70	76	78
1:50	79	78	79	80	79	79	79	73	74	70	78	79
2:00	77	77	77	80	78	76	76	72	73	67	73	75
2:10	77	77	78	80	77	76	75	71	72	68	72	74
2:20	78	77	79	80	78	78	78	72	73	68	72	76
2:30	75	74	75	80	77	74	73	71	72	65	72	73
2:40	76	74	75	80	77	75	74	71	72	65	71	72
2:44	(g)											
2:50	77	77	79	78	77	77	77	72	72	72	75	75
3:00	78	78	79	79	79	79	78	72	73	77	77	77
3:10	78	78	79	79	79	79	78	72	73	75	77	77
3:20	79	80	79	79	79	79	78	72	73	74	77	78
Mean	76.74	76.26	77.19	78.60	77.44	76.86	76.33	71.60	71.58	67.14	74.23	75.55

Mean of working area (1,2,3,5,6,7,11, & 12) = 76.33°F.
Range of working area 80°-70°F. = 10°F. Sample size = 344
Variance = 4.35°F. Standard deviation = ±2.086°F.
Standard error of mean = ±.112°F.

Mean of readings at center of room from floor to ceiling = 77.31°F.
Range 80°-71°F. = 9°F. Sample size = 172
Variance = 3.38°F. Standard deviation = ±1.838°F.
Standard error of mean = ±.140°F.

THERMOCOUPLE READINGS FOR CLASSROOM F-1 (continued)

Mean of all 30" readings = 76.51°F.
Range 80°-71°F. = 9°F.
Variance = 3.61°F.
Standard error of mean = ±.130°F.

Sample size = 215
Standard deviation = ±1.900°F.

(a) Window open
(b) Milk break
(c) Class out of room
(d) Students coming into room
(e) Lunch period
(f) Class in room
(g) Classes changed

THERMOCOUPLE READINGS FOR CLASSROOM F-2

March 8, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:15	(a)											
8:20	76	76	76	77	76	76	76	77	69	63	75	76
8:24	(b)											
8:30	77	77	77	77	77	77	76	77	70	64	75	77
8:40	75	74	75	77	76	76	73	77	70	69	71	74
8:50	75	74	74	77	75	74	73	77	70	71	72	75
9:00	75	75	75	75	76	76	75	78	71	72	74	75
9:10	75	75	76	76	76	76	75	78	71	72	74	77
9:20	77	77	78	78	78	77	76	78	72	71	75	77
9:30	76	76	76	78	77	76	75	78	72	72	74	76
9:40	77	76	77	77	77	77	76	80	73	73	77	77
9:50	76	75	76	77	76	76	74	80	71	72	74	75
10:00	74	73	73	76	74	74	73	78	68	66	72	74
10:10	72	71	72	75	73	72	71	77	66	65	69	71
10:20	75	75	76	77	76	75	75	77	67	65	72	75
10:30	76	76	76	78	77	76	74	77	69	65	72	75
10:40	75	75	76	77	76	76	75	77	70	67	72	74
10:46	(c)											
10:50	75	75	75	77	75	75	75	78	72	69	75	76
11:00	75	74	75	77	75	75	74	78	71	68	73	75
11:10	75	74	74	77	75	75	75	78	72	70	75	75
11:18	(d)											
11:20	75	74	75	77	75	75	74	77	70	72	74	75
11:30	76	75	76	78	76	76	75	78	72	70	75	75
11:40	76	75	76	77	75	75	74	77	71	68	73	75
11:50	75	75	76	77	76	76	75	77	71	69	73	75
12:00	76	75	76	77	76	76	75	77	72	70	75	75
12:03	(e)											
12:10	76	75	76	78	76	76	75	77	72	70	75	75
12:20	74	74	74	76	75	74	74	77	72	71	73	74

THERMOCOUPLE READINGS FOR CLASSROOM F-2 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:30	74	74	74	75	74	74	74	77	72	69	72	73
12:38	(f)											
12:40	75	75	76	75	75	75	75	77	73	71	73	74
12:50	75	74	75	76	74	75	74	77	72	70	72	73
1:00	(g)											
1:00	76	75	75	76	75	75	74	77	72	70	73	74
1:10	75	75	75	76	75	75	75	77	73	70	74	74
1:20	73	73	74	73	74	74	74	77	71	69	73	73
1:30	73	72	73	72	74	75	75	77	70	66	73	73
1:40	75	75	75	76	75	75	75	77	72	69	74	74
1:50	74	73	75	74	74	75	75	77	73	69	73	74
2:00	74	73	75	73	74	75	75	77	72	69	73	73
2:10	74	74	75	74	75	75	75	77	72	69	73	73
2:12	(h)											
2:20	73	73	75	74	73	74	74	77	72	68	73	73
2:30	(i)											
2:30	72	72	73	72	73	73	73	77	72	69	73	73
2:40	75	74	75	76	74	74	74	77	72	68	73	74
2:50	75	75	76	77	76	76	75	77	72	67	74	75
3:00	72	72	73	70	73	74	74	76	70	66	71	72
3:10	72	72	72	72	74	74	74	77	70	66	71	72
3:20	71	71	73	73	73	72	72	76	68	64	70	70
3:30	72	71	73	73	73	72	72	75	69	65	70	71
Mean	74.63	74.18	74.95	75.68	75.05	74.98	74.36	77.25	70.93	70.02	73.11	74.23

Mean of working area (1,2,3,5,6,7,11, & 12) = 74.44°F.

Range of working area 78°-69°F. = 9°F. Sample size = 352

Variance = 2.46°F. Standard deviation = ±1.568°F.

Standard error of mean = ±.084°F.

THERMOCOUPLE READINGS FOR CLASSROOM F-2 (continued)

Mean of readings at center of room from floor to ceiling = 75.02°F.
Range 78°-70°F. = 8°F. Sample size = 176
Variance = 2.23°F. Standard deviation = ±1.493°F.
Standard error of mean = ±.113°F.

Mean of all 30" readings = 74.60°F.
Range 78°-70°F. = 8°F. Sample size = 220
Variance = 2.50°F. Standard deviation = ±1.581°F.
Standard error of mean = ±.107°F.

(a) Students coming into room
(b) Sun partially shining - Some windows open - Drapes closed
(c) Class gone to music room
(d) Class returns
(e) Lunch - Lights off
(f) Class back from lunch - Lights on
(g) Drapes open
(h) Play period
(i) Play period over

THERMOCOUPLE READINGS FOR CLASSROOM F-3

March 9, 1961

Time	1	2	3	4	5	6	7	8	9	10	11	12
	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Outside air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:20	71	71	71	74	72	71	69	72	50	34	67	70
8:22	(a)											
8:30	68	66	66	74	69	67	65	71	50	34	64	66
8:32	(b)											
8:40	70	70	70	74	72	70	68	72	50	34	66	70
8:50	70	70	71	74	72	71	68	72	50	34	66	69
9:00	(c)											
9:00	71	70	70	74	71	71	69	72	50	34	67	70
9:10	71	72	71	74	73	72	69	73	50	35	67	70
9:20	71	71	72	74	73	72	69	73	50	35	67	70
9:30	71	71	71	74	73	72	69	73	49	35	67	71
9:40	70	71	71	74	73	71	68	73	50	36	66	68
9:50	71	71	71	74	73	71	69	73	50	36	68	71
10:00	72	73	73	74	74	72	69	73	50	35	69	72
10:10	72	73	73	75	74	73	70	73	51	36	69	72
10:20	73	73	73	74	74	73	70	73	50	37	69	73
10:30	74	74	74	75	74	74	72	73	52	36	70	73
10:40	73	74	74	75	75	74	71	73	50	36	70	73
10:50	73	74	74	75	75	74	72	73	51	36	70	74
11:00	74	74	74	75	75	75	72	73	51	36	70	74
11:10	74	74	74	75	75	75	71	73	52	36	70	74
11:20	74	75	75	75	75	75	72	73	51	36	70	74
11:30	74	74	75	75	75	75	72	74	52	36	71	74
11:40	74	74	74	75	75	74	72	73	51	37	71	74
11:50	74	75	75	75	75	75	72	74	51	37	71	74
11:57	(d)											
12:00	74	74	74	75	75	74	71	73	51	36	70	73
12:10	72	72	72	73	75	74	70	73	51	36	70	72
12:20	72	72	72	73	73	73	70	73	51	36	69	72
12:30	73	73	75	75	73	73	72	73	51	36	70	72

THERMOCOUPLE READINGS FOR CLASSROOM F-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.
12:31	(e)											
12:40	74	74	74	75	75	74	72	73	52	36	71	73
12:50	74	74	74	75	75	75	71	73	53	38	70	74
1:00	74	75	75	75	75	75	72	74	51	37	71	74
1:10	74	75	75	75	75	75	72	74	51	37	71	75
1:20	75	75	75	75	75	75	72	74	52	37	72	74
1:30	74	75	75	76	75	75	72	74	52	37	71	75
1:40	74	75	75	76	75	75	72	74	52	37	72	74
1:50	75	75	75	76	76	75	73	74	53	38	72	75
2:00	75	75	75	75	76	75	72	74	54	39	71	75
2:10	75	75	74	75	75	75	73	74	53	38	71	75
2:20	75	75	75	75	76	75	72	74	54	39	72	75
2:30	75	75	75	76	76	75	72	74	53	38	72	75
2:40	75	75	75	76	76	76	72	74	54	38	72	75
2:50	75	75	75	76	76	75	72	74	54	38	72	74
3:00	74	75	75	75	75	75	72	74	53	38	72	74
3:10	76	76	75	76	76	75	74	74	54	39	72	74
3:20	74	75	75	75	75	75	72	74	54	39	71	75
3:30	76	75	75	76	76	75	73	74	53	39	72	75
Mean	73.18	73.41	73.45	74.82	74.34	73.66	70.93	73.27	51.52	36.52	69.79	72.86

Mean of working area (1,2,3,5,6,7,11, & 12) = 72.70°F.
Range of working area 76°-64°F. = 12°F. Sample size = 352
Variance = 5.68°F. Standard deviation = ±2.383°F.
Standard error of mean = ±.127°F.

Mean of readings at center of room from floor to ceiling = 73.44°F.
Range 76°-65°F. = 11°F. Sample size = 176
Variance = 4.63°F. Standard deviation = ±2.152°F.
Standard error of mean = ±.162°F.

THERMOCOUPLE READINGS FOR CLASSROOM F-3 (continued)

Mean of all 30" readings = 73.31°F.
Range 76°-66°F. = 10°F.
Variance = 3.93°F.
Standard error of mean = ±.134°F.

Sample size = 220
Standard deviation = ±1.982°F.

(a) Window opened slightly
(b) Class gone to gymnasium
(c) Class back from gym
(d) Class gone to lunch
(e) Class returned from lunch

THERMOCOUPLE READINGS FOR CLASSROOM G-1

March 17, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Outside air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:15	(a)											
8:20	74	74	74	81	75	74	73	80	58	41	73	73
8:30	75	75	75	81	76	75	74	81	58	42	74	74
8:40	76	76	76	80	77	76	75	81	59	43	75	75
8:43	(b)											
8:50	(c)											
8:50	76	75	76	82	76	76	74	82	59	43	74	74
9:00	(d)											
9:00	76	76	76	82	77	76	75	82	60	45	75	76
9:05	(e)											
9:10	72	71	73	77	75	72	70	79	59	45	66	68
9:20	72	70	72	76	74	71	68	78	59	45	65	68
9:30	71	69	71	75	73	71	69	76	58	45	69	71
9:32	(f)											
9:40	73	73	74	79	75	74	72	78	59	46	73	73
9:50	75	74	75	79	76	75	73	79	61	46	73	74
10:00	75	74	75	80	76	75	72	80	60	46	73	74
10:10	76	75	76	80	77	76	74	81	62	47	75	75
10:20	77	77	77	81	78	77	75	82	63	49	75	76
10:30	77	76	77	81	78	77	75	82	62	48	75	76
10:40	77	76	77	82	78	77	75	83	63	49	75	77
10:50	78	77	78	80	78	78	75	83	64	50	75	76
11:00	(g)											
11:00	78	78	78	81	78	78	77	84	65	50	71	73
11:10	75	75	76	79	76	76	74	84	64	51	74	75
11:20	74	74	74	78	75	74	74	83	63	50	73	74
11:26	(h)											
11:30	76	74	76	80	76	75	73	82	63	50	74	75
11:40	76	76	76	80	77	76	75	82	65	52	75	76
11:50	77	76	77	81	78	77	75	83	65	52	76	76

THERMOCOUPLE READINGS FOR CLASSROOM G-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:00	(i)											
12:00	77	76	77	82	78	77	74	83	66	54	75	76
12:10	75	74	75	82	76	75	72	81	65	53	73	74
12:20	76	76	76	83	77	76	74	81	66	54	74	76
12:30	76	75	76	82	77	76	74	81	67	53	73	74
12:40	74	74	75	79	76	75	73	80	66	55	71	73
12:40	(j)											
12:50	73	73	74	77	75	74	72	80	66	54	70	73
1:00	73	72	73	75	73	72	71	79	65	55	70	71
1:09	(k)											
1:10	73	72	73	75	73	73	72	78	65	56	71	72
1:20	75	74	75	80	76	75	74	79	67	57	74	75
1:30	75	75	76	80	76	75	74	80	67	56	72	75
1:40	76	76	76	80	77	76	75	80	68	57	74	76
1:50	76	75	76	81	77	76	74	80	68	59	74	76
2:00	75	75	76	81	77	75	74	80	68	57	72	73
2:10	75	75	75	81	77	76	74	80	68	57	72	73
2:20	76	76	76	81	76	76	75	80	68	58	74	75
2:30	75	74	75	80	76	75	74	80	68	58	72	74
2:40	75	74	75	79	76	75	74	80	68	59	71	74
2:50	75	75	75	79	76	76	75	81	69	59	74	75
3:00	76	76	76	82	77	76	75	81	69	61	75	76
3:01	(l)											
3:10	77	77	77	81	77	77	76	81	70	61	76	76
Mean	75.21	74.64	75.38	79.88	76.24	75.29	73.64	80.71	64.12	51.62	72.98	74.19

Mean of working area (1,2,3,5,6,7,11, & 12) = 74.70°F.

Range of working area 78°-65°F. = 13°F. Sample size = 336

Variance = 4.11°F. Standard deviation = ±2.027°F.

Standard error of mean = ±.111°F.

THERMOCOUPLE READINGS FOR CLASSROOM G-1 (continued)

Mean of readings at center of room from floor to ceiling = 76.20°F.
Range 83°-68°F. = 15°F. Sample size = 168
Variance = 9.74°F. Standard deviation = ±3.121°F.
Standard error of mean = ±.241°F.

Mean of all 30" readings = 74.94°F.
Range 78°-68°F. = 10°F. Sample size = 210
Variance = 3.14°F. Standard deviation = ±1.772°F.
Standard error of mean = ±.122°F.

(a) Bell - Children coming into room
(b) Class left room to get milk
(c) Class returned from milk break
(d) Light off - T.V. period
(e) Windows opened for ventilation
(f) T.V. class over - Lights on
(g) Class gone to gym - Two rows of lights off
(h) Class returned - Lights on
(i) More windows open
(j) Class gone to lunch
(k) Class back from lunch
(l) Most of class gone

THERMOCOUPLE READINGS FOR CLASSROOM G-2

March 20, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:00	73	73	73	79	74	73	72	89	66	54	72	73
8:10	74	74	74	78	74	74	73	85	66	56	73	74
8:20	74	74	74	78	75	75	74	83	67	56	73	75
8:30	(a)											
8:30	74	74	74	79	75	74	74	81	66	55	73	75
8:40	(b)											
8:40	75	74	75	78	75	75	74	80	67	56	73	75
8:50	75	75	75	78	75	75	74	79	67	58	73	75
9:00	75	75	75	78	76	75	74	79	67	60	74	75
9:10	76	76	76	79	76	76	74	79	68	58	74	76
9:20	76	77	76	79	76	76	74	78	70	63	74	76
9:30	76	76	76	79	78	76	75	79	70	57	75	76
9:40	76	76	77	80	77	76	74	79	69	60	75	76
9:50	76	76	76	80	77	76	75	79	71	64	75	77
10:00	(c)											
10:00	76	76	77	80	77	77	75	79	70	62	74	76
10:06	(d)											
10:10	76	75	75	80	77	77	74	79	71	61	74	76
10:20	76	76	76	80	77	76	74	79	71	62	74	76
10:30	76	76	76	80	77	76	75	79	71	61	75	76
10:40	77	77	77	81	78	77	75	79	74	63	75	77
10:50	77	77	77	81	78	77	75	79	73	60	75	77
11:00	78	78	77	81	78	78	75	80	74	65	76	78
11:10	77	77	78	82	79	78	76	80	74	61	75	78
11:20	78	78	79	82	79	79	77	80	77	63	76	79
11:30	78	78	79	83	80	79	76	81	78	67	77	79
11:40	77	77	77	82	79	78	76	81	77	64	76	78
11:50	77	77	77	82	78	77	75	80	79	67	75	77
12:00	(e)											
12:00	76	76	76	81	78	76	75	81	80	72	75	77

THERMOCOUPLE READINGS FOR CLASSROOM G-2 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.	oF.
12:10	76	76	76	79	77	76	75	81	80	67	75	76
12:20	76	76	76	78	77	76	75	81	80	68	75	76
12:30	76	76	76	78	77	76	75	81	80	71	75	76
12:38	(f)											
12:40	76	76	77	78	77	77	75	80	80	72	75	77
12:50	78	77	78	81	78	78	76	81	81	69	76	78
1:00	78	78	79	81	79	78	76	81	81	71	76	78
1:10	79	78	78	82	79	79	76	81	81	72	77	79
1:20	78	78	79	82	80	79	77	81	81	71	77	79
1:30	79	79	79	82	80	79	78	82	82	71	77	79
1:35	(g)											
1:40	77	77	78	82	79	78	76	82	82	74	76	77
1:50	77	77	77	81	78	77	76	82	82	73	76	77
2:00	(h)											
2:00	77	77	77	81	78	77	76	82	82	72	76	77
2:10	78	77	78	81	78	77	76	82	81	71	76	78
2:20	77	77	77	82	78	77	76	82	82	72	76	77
2:30	77	77	78	81	78	78	77	82	79	70	76	78
2:40	77	77	77	81	78	78	76	82	82	73	76	78
2:50	77	77	77	82	78	77	76	82	80	76	76	77
3:00	77	77	77	81	77	76	76	82	81	73	76	77
Mean	76.49	76.39	76.65	80.30	77.42	76.72	75.19	80.79	75.35	65.37	75.07	76.77

Mean of working area (1,2,3,5,6,7,11, & 12) = 76.34°F.
Range of working area 80°-72°F. = 8°F. Sample size = 344
Variance = 2.35°F. Standard deviation = ±1.533°F.
Standard error of mean = ±.083°F.

Mean of readings at center of room from floor to ceiling = 77.41°F.
Range 83°-72°F. = 11°F. Sample size = 172
Variance = 5.38°F. Standard deviation = ±2.319°F.
Standard error of mean = ±.177°F.

THERMOCOUPLE READINGS FOR CLASSROOM G-2 (continued)

Mean of all 30" readings = 76.60°F.
Range 79°-73°F. = 6°F.
Variance = 1.87°F.
Standard error of mean = ±.093°F.

Sample size = 215
Standard deviation = ±1.367°F.

(a) Class gone to get milk - Blinds drawn
(b) Class returned
(c) Break - Children gone to rest room
(d) Children back in room
(e) Lunch - Lights off
(f) Class back from lunch - Lights on
(g) Class gone to physical education
(h) Class back from physical education

THERMOCOUPLE READINGS FOR CLASSROOM G-3

March 21, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:13	(a)											
8:20	76	76	77	85	80	78	75	186	70	57	75	77
8:28	(b)											
8:30	77	77	77	84	80	78	76	180	69	56	74	77
8:31	(c)											
8:38	(d)											
8:40	76	76	76	81	78	76	75	163	67	55	74	76
8:50	77	77	77	81	78	77	74	152	67	55	75	77
9:00	77	77	76	82	79	77	74	143	67	55	74	77
9:10	77	77	77	82	79	77	75	133	68	54	74	77
9:20	75	75	76	81	78	76	74	124	67	54	73	76
9:30	76	76	76	80	77	76	74	117	66	54	73	76
9:40	75	75	75	81	77	75	73	111	66	54	72	74
9:41	(e)											
9:45	(f)											
9:50	74	73	74	81	75	74	73	110	65	54	70	73
9:55	(g)											
10:00	75	75	76	79	77	76	74	110	65	53	73	76
10:10	77	77	77	80	78	77	75	107	66	54	75	76
10:20	77	77	77	81	78	77	75	105	66	54	75	77
10:30	77	77	77	81	79	77	75	102	66	54	75	78
10:40	77	77	78	81	79	77	75	100	66	53	75	77
10:50	77	77	77	81	78	77	75	98	66	55	75	76
11:00	77	77	77	81	78	78	76	96	66	55	75	76
11:10	77	77	76	81	78	77	75	95	66	54	74	77
11:20	77	77	77	80	78	77	75	93	66	55	76	77
11:30	77	77	77	81	78	77	75	92	67	54	74	77
11:40	77	77	77	81	78	77	76	92	67	55	74	77
11:45	(h)											
11:50	75	75	75	78	77	76	74	91	67	57	74	76

THERMOCOUPLE READINGS FOR CLASSROOM G-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F..	°F.	°F.	°F.
12:00	75	74	75	77	76	75	74	89	66	55	72	74
12:10	74	74	74	76	75	75	73	88	66	55	71	73
12:17	(i)											
12:20	75	75	75	76	75	75	73	87	65	56	72	75
12:30	76	76	76	78	77	76	74	87	66	55	74	76
12:40	77	77	77	80	78	77	76	88	67	56	75	77
12:50	78	78	78	80	78	77	76	90	67	56	75	77
1:00	77	77	78	81	79	78	76	91	68	56	76	78
1:02	(j)											
1:10	77	76	76	80	78	77	75	91	68	55	75	77
1:20	76	76	76	80	77	76	75	90	67	56	74	76
1:30	76	76	76	80	77	76	75	89	67	56	75	76
1:32	(k)											
1:40	78	77	77	80	78	77	76	88	68	57	76	78
1:48	(l)											
1:50	76	76	76	81	78	76	73	87	68	57	71	72
2:00	73	73	74	83	75	74	72	86	67	60	71	74
2:10	74	74	75	81	76	75	72	85	68	58	70	74
2:13	(m)											
2:20	74	75	75	81	76	75	73	84	68	64	73	75
2:30	75	75	75	80	77	76	73	83	68	58	73	75
2:40	75	75	75	80	77	76	73	82	68	57	71	74
2:50	75	75	76	81	77	76	73	82	68	56	70	74
3:00	76	76	77	80	77	76	74	81	68	59	73	76
Mean	76.02	75.95	71.29	80.44	77.51	71.46	74.37	103.61	66.93	55.68	73.56	75.88

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.73°F.
Range of working area 80°-70°F. = 10°F. Sample size = 328
Variance = 2.14°F. Standard deviation = ±1.463°F.
Standard error of mean = ±.081°F.

THERMOCOUPLE READINGS FOR CLASSROOM G-3 (continued)

Mean of readings at center of room from floor to ceiling = 77.16°F.
Range 85°-72°F. = 13°F.
Sample size = 164
Variance = 2.13°F.
Standard deviation = ±1.459°F.
Standard error of mean = ±.114°F.

Mean of all 30" readings = 76.07°F.
Range 78°-72°F. = 6°F.
Sample size = 205
Variance = 2.04°F.
Standard deviation = ±1.428°F.
Standard error of mean = ±.099°F.

(a) Thermocouple for position 8 raised slightly above convector because the temperature of the convector was above 200°F. causing Number 8 not to print.
(b) Windows opened
(c) Class gone for milk
(d) Class returned
(e) Break - Class out of room
(f) Break over - Class back in room
(g) Windows closed
(h) Lights off - Class gone to lunch
(i) Class back from lunch - Lights on
(j) Class gone to physical education class
(k) Class back from physical education
(l) Windows opened (upon suggestion from principal)
(m) Some windows closed (children complained about being cold)

THERMOCOUPLE READINGS FOR CLASSROOM H-1

March 22, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:51	(a)											
9:00	75	76	76	76	76	76	75	68	65	50	75	75
9:10	75	75	76	77	77	77	75	69	66	50	75	76
9:20	76	76	77	77	77	77	76	70	66	51	76	76
9:28	(b)											
9:30	76	77	77	77	77	77	76	69	67	50	76	76
9:40	77	77	76	77	77	77	76	69	66	51	76	77
9:48	(c)											
9:50	77	77	76	77	77	77	76	73	66	52	77	76
10:00	77	77	77	77	77	78	77	77	67	52	77	77
10:10	78	78	76	78	78	78	77	76	68	52	77	77
10:20	77	77	78	78	78	78	77	77	69	54	77	77
10:23	(d)											
10:30	77	77	77	77	77	77	76	74	69	54	76	76
10:40	76	76	75	76	76	76	76	74	71	56	76	76
10:50	(e)											
10:50	76	76	76	76	76	76	76	73	69	54	76	75
11:00	77	77	77	78	78	78	77	74	72	56	77	77
11:10	78	78	78	79	79	79	78	75	74	59	78	79
11:20	79	79	79	79	80	79	79	75	73	56	79	79
11:30	79	79	79	80	80	80	79	75	72	56	79	79
11:40	79	79	79	80	80	80	79	75	72	57	78	79
11:50	(b)											
11:50	79	79	79	79	80	79	79	75	71	56	78	78
12:00.	79	79	79	80	80	80	79	75	72	57	79	79
12:01	(f)											
12:10	77	77	77	78	78	78	77	75	73	58	77	77
12:20	77	77	77	79	77	78	77	76	73	59	77	77
12:27	(g)											
12:30	78	78	78	79	79	79	78	75	74	56	78	78

THERMOCOUPLE READINGS FOR CLASSROOM H-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:40	78	78	79	79	79	79	79	75	73	59	78	78
12:50	78	78	78	78	78	78	78	74	71	58	77	78
1:00	79	79	79	80	80	80	79	75	71	56	78	78
1:10	79	79	79	80	80	80	79	75	71	57	78	78
1:18	(h)											
1:20	78	78	79	79	79	79	78	75	70	56	78	78
1:30	78	78	78	79	79	79	78	74	69	56	77	77
1:40	78	78	77	79	79	79	78	74	68	55	77	77
1:50	78	78	78	79	79	79	78	73	68	56	76	76
2:00	78	78	78	79	79	79	78	74	70	57	76	77
2:10	78	78	79	79	79	79	78	75	69	57	76	77
2:19	(h)											
2:20	78	78	78	79	79	79	78	75	69	57	77	78
2:30	79	79	80	80	80	80	79	75	71	58	78	78
2:40	80	80	79	80	80	80	79	76	73	61	79	80
2:50	80	80	80	80	81	80	80	77	73	60	79	80
3:00	80	80	81	81	81	81	80	78	74	61	80	80
3:10	80	80	80	81	81	81	81	78	74	61	80	80
3:20	81	81	81	81	81	81	80	77	74	61	75	75
3:30	80	80	80	80	81	80	79	73	72	63	79	79
Mean	77.98	78.02	78.05	78.68	78.72	78.68	77.85	74.30	70.37	56.12	77.30	77.50

Mean of working area (1,2,3,5,6,7,11, & 12) = 78.01°F.

Range of working area 81°-75°F. = 6°F. Sample size = 320

Variance = 3.00°F. Standard deviation = ±1.732°F.

Standard error of mean = ±.097°F.

Mean of readings at center of room from floor to ceiling = 78.42°F.

Range 81°-75°F. = 6°F. Sample size = 160

Variance = 8.12°F. Standard deviation = ±2.848°F.

Standard error of mean = ±.225°F.

THERMOCOUPLE READINGS FOR CLASSROOM H-1 (continued)

Mean of all 30" readings = 78.04°F.
Range 81°-75°F. = 6°F.
Variance = 1.51°F.
Standard error of mean = ±.087°F.

Sample size = 200
Standard deviation = ±1.229°F.

(a) Class already in progress - Adjusting recorder
(b) Change of classes
(c) Change of position for number 8 wire
(d) End of class period - Room vacant
(e) Thermostat setting changed from 70°F. to 64°F. to determine if the 6°F. lag is due to faulty calibration of the thermostat
(f) Class gone to lunch
(g) Class back in room
(h) Classes changed

THERMOCOUPLE READINGS FOR CLASSROOM H-2

March 23, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:20	72	72	73	73	73	73	72	105	58	46	70	72
8:30	(a)											
8:30	73	73	73	74	73	73	72	103	57	46	71	72
8:40	74	74	74	75	75	74	73	101	59	47	71	73
8:50	74	74	75	75	75	75	73	90	61	47	72	74
9:00	75	75	75	76	76	76	74	85	61	47	72	74
9:10	75	75	75	76	76	75	74	82	62	48	72	74
9:20	75	75	75	76	76	76	74	82	63	49	73	74
9:30	75	75	76	76	76	75	75	81	62	49	73	74
9:32	(b)											
9:40	75	75	76	77	76	76	75	78	63	50	73	75
9:50	77	76	77	78	78	77	75	79	63	49	74	75
10:00	76	76	76	77	77	76	75	80	63	49	73	75
10:10	76	76	76	77	77	76	75	81	63	50	74	75
10:20	76	75	76	77	77	76	75	81	63	50	74	76
10:22	(b)											
10:30	76	76	76	77	77	77	76	81	63	50	74	76
10:40	75	76	75	77	77	76	75	81	63	51	73	75
10:50	76	76	76	77	77	77	75	81	63	51	74	75
11:00	(b)											
11:00	76	76	77	77	77	76	76	81	64	51	74	75
11:10	76	76	77	77	77	76	76	81	64	51	74	75
11:20	76	76	76	77	77	77	76	81	63	51	74	76
11:30	76	76	76	77	77	76	75	80	62	49	74	76
11:40	76	76	76	76	76	76	75	80	61	50	74	76
11:50	76	76	76	77	77	76	75	80	63	50	74	76
11:51	(b)											
12:00	(c)											
12:00	76	76	76	77	76	76	76	80	65	51	75	76
12:10	76	76	76	78	77	76	75	80	64	51	74	75

THERMOCOUPLE READINGS FOR CLASSROOM H-2 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:20	75	75	76	76	76	76	75	73	66	52	74	74
12:21	(d)											
12:30	76	76	77	77	77	76	75	72	64	51	74	75
12:40	76	76	76	77	77	76	76	72	65	52	74	75
12:50	76	76	76	77	77	76	76	72	66	54	74	76
1:00	77	76	77	77	77	77	76	71	67	52	75	76
1:10	78	76	78	78	78	77	76	73	68	54	75	76
1:16	(b)											
1:20	77	77	78	78	78	77	76	72	67	53	75	75
1:30	77	76	77	77	77	77	76	72	64	52	74	75
1:40	76	76	77	77	77	77	76	72	64	53	75	76
1:50	76	76	77	78	78	77	76	73	66	54	75	76
2:00	77	77	78	78	78	78	76	73	67	53	75	76
2:10	77	77	77	78	78	77	76	72	67	53	75	75
2:20	76	77	78	78	78	77	76	71	64	52	75	75
2:30	77	76	77	77	77	77	76	72	64	52	75	75
2:40	76	76	77	77	77	77	76	72	64	52	75	75
2:50	77	77	77	77	77	77	76	72	65	53	74	75
3:00	77	77	77	77	77	77	76	73	67	55	75	75
3:10	77	76	77	77	77	77	76	72	67	54	75	75
3:20	(b)											
3:20	77	77	77	77	77	77	76	72	66	54	75	75
3:30	77	77	77	77	77	77	77	73	66	54	75	75
Mean	75.91	75.77	76.25	76.79	76.70	76.23	75.25	78.59	64.00	50.95	73.86	74.98

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.62°F.
Range of working area 78°-70°F. = 8°F.
Sample size = 352
Variance = 1.88°F.
Standard deviation = ±1.371°F.
Standard error of mean = ±.073°F.

THERMOCOUPLE READINGS FOR CLASSROOM H-2 (continued)

Mean of readings at center of room from floor to ceiling = 75.67°F.
Range 78°-72°F. = 6°F.
Sample size = 176
Variance = 1.49°F.
Standard deviation = ±1.221°F.
Standard error of mean = ±.092°F.

Mean of all 30" readings = 75.83°F.
Range 78°-72°F. = 6°F.
Sample size = 220
Variance = 1.33°F.
Standard deviation = ±1.153°F.
Standard error of mean = ±.078°F.

(a) Students coming into room
(b) Classes changed
(c) Lunch
(d) Students coming back from lunch

THERMOCOUPLE READINGS FOR CLASSROOM H-3

March 24, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:30	(a)											
8:30	72	71	71	72	72	71	71	69	59	45	69	70
8:32	(b)											
8:40	73	73	73	74	73	73	73	72	61	45	71	72
8:43	(c)											
8:50	73	72	73	73	73	73	73	69	60	45	70	70
9:00	73	72	72	73	73	73	73	69	59	46	70	70
9:10	73	72	72	73	73	73	73	69	60	45	70	71
9:20	74	73	73	73	73	73	73	73	61	45	71	71
9:28	(d)											
9:30	74	73	73	74	74	74	73	73	61	46	71	71
9:40	74	74	74	75	75	74	73	73	62	46	71	72
9:50	75	75	74	75	75	75	74	74	63	47	72	73
10:00	74	74	75	75	75	75	75	75	64	48	72	73
10:10	75	75	75	75	75	75	75	75	62	47	72	73
10:20	75	75	75	75	75	75	74	70	62	47	72	73
10:24	(e)											
10:30	74	74	74	74	74	74	74	70	64	47	72	73
10:40	74	74	74	74	74	74	74	70	65	48	72	72
10:50	74	74	74	74	74	74	74	70	63	48	72	72
11:00	(f)											
11:00	75	74	74	74	74	74	74	64	63	48	71	71
11:10	73	72	73	73	73	73	72	61	59	47	69	70
11:20	73	72	73	74	72	72	72	61	61	48	69	69
11:30	73	72	72	73	72	72	72	61	62	49	70	70
11:39	(g)											
11:40	73	72	73	73	73	72	72	62	69	50	71	71
11:50	(d)											
11:50	73	73	73	73	73	73	73	74	64	49	71	71
12:00	73	72	73	73	73	73	72	61	61	48	70	70

THERMOCOUPLE READINGS FOR CLASSROOM H-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
12:10	73	72	72	73	73	73	72	61	67	51	70	70
12:20	73	72	73	73	73	73	73	61	73	55	70	71
12:30	73	72	73	74	73	73	72	62	66	51	70	70
12:34	(h)											
12:40	73	72	73	74	72	72	72	61	63	49	70	70
12:50	72	71	72	73	72	72	72	62	64	51	70	70
1:00	72	71	71	74	72	72	72	61	63	50	69	69
1:04	(f)											
1:10	73	72	72	73	73	72	72	62	64	51	69	70
1:13	(i)											
1:20	(d)											
1:20	73	72	73	74	73	73	73	62	66	50	70	70
1:30	73	72	73	74	73	73	72	62	67	57	71	71
1:40	74	72	73	74	73	73	72	62	66	55	70	70
1:50	74	73	74	74	74	74	73	63	67	57	71	71
2:00	74	73	73	74	74	73	72	62	64	51	70	70
2:10	74	73	73	74	74	73	73	61	62	50	70	70
2:18	(d)											
2:20	73	73	73	75	73	73	72	61	61	49	70	70
2:30	74	72	73	74	74	73	72	62	62	51	70	70
2:40	74	72	73	74	73	72	72	62	64	51	70	70
2:50	73	72	73	74	74	73	72	61	62	50	70	70
3:00	74	72	73	74	73	73	72	62	62	52	70	70
3:10	74	72	73	74	74	73	72	63	65	57	70	70
3:20	74	72	74	75	73	73	73	63	65	54	71	71
3:30	74	73	74	74	74	74	73	63	64	51	71	71
Mean	73.51	72.63	73.12	73.81	73.37	73.14	72.72	65.44	63.30	49.47	70.47	70.14

Mean of working area (1,2,3,5,6,7,11, & 12) = 72.46°F.
Range of working area 75°-69°F. = 6°F. Sample size = 344
Variance = 2.42°F. Standard deviation = ±1.556°F.
Standard error of mean = ±.084°F.

THERMOCOUPLE READINGS FOR CLASSROOM H-3 (continued)

Mean of readings at center of room from floor to ceiling = 73.25°F.
Range 75°-71°F. = 4°F. Sample size = 172
Variance = 1.54°F. Standard deviation = ±1.241°F.
Standard error of mean = ±.095°F.

Mean of all 30" readings = 72.63°F.
Range 75°-69°F. = 6°F. Sample size = 215
Variance = 2.39°F. Standard deviation = ±1.546°F.
Standard error of mean = ±.105°F.

(a) Class coming into room
(b) Custodians changing filter
(c) Filter cleaned - Class in room
(d) Classes changed
(e) Change of classes - Room vacant
(f) Class back in room
(g) Sun shining
(h) Class gone to lunch
(i) Girls complained about being too cold

THERMOCOUPLE READINGS FOR CLASSROOM I-1

March 27, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:50	(a)											
7:50	72	72	73	85	78	73	68	133	70	51	68	73
8:00	73	73	74	86	79	73	68	159	72	53	69	74
8:10	74	74	74	87	80	74	69	164	72	54	70	75
8:20	(b)											
8:20	75	76	77	88	81	76	72	163	74	55	72	77
8:30	78	78	78	90	83	78	72	164	75	55	73	78
8:32	(c)											
8:40	75	75	76	83	77	75	72	163	73	56	73	76
8:50	75	76	76	84	78	76	72	165	73	58	72	77
9:00	78	78	78	88	81	78	72	166	74	58	73	78
9:04	(d)											
9:10	79	77	76	86	80	76	72	143	75	60	72	76
9:16	(e)											
9:20	76	77	76	87	80	76	72	179	75	59	72	77
9:30	(f)											
9:30	76	76	75	86	79	76	72	179	75	60	72	76
9:40	80	80	80	88	82	80	75	185	76	61	76	80
9:48	(g)											
9:50	79	79	78	86	81	79	74	182	76	61	74	79
10:00	(h)											
10:00	77	78	78	87	81	78	73	184	75	63	74	78
10:10	78	79	78	89	82	78	73	188	76	60	74	79
10:20	(i)											
10:20	77	79	78	88	81	78	75	187	76	60	75	78
10:25	(j)											
10:30	(k)											
10:30	78	79	78	88	82	78	73	188	75	61	74	78
10:40	77	78	77	88	81	77	73	182	76	61	73	77
10:50	76	77	76	87	81	76	73	173	77	63	73	76

THERMOCOUPLE READINGS FOR CLASSROOM I-1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Outside air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
11:00	77	77	76	86	81	77	73	170	77	63	73	76
11:10	(l)											
11:10	76	77	77	86	80	77	72	162	76	61	73	76
11:20	80	80	80	86	81	80	75	155	76	61	75	80
11:30	(m)											
11:30	78	79	79	86	81	79	75	155	75	61	76	79
11:40	78	80	78	85	80	78	75	155	75	62	75	79
11:46	(n)											
11:50	77	78	77	83	79	78	74	101	75	63	75	78
12:00	75	75	75	81	76	75	73	83	73	63	73	75
12:03	(o)											
12:08	(p)											
12:10	74	74	74	81	76	75	71	80	71	63	70	73
12:20	72	72	73	79	74	78	70	78	70	62	68	71
12:30	72	73	72	78	74	73	70	77	69	62	69	72
12:34	(q)											
12:40	73	74	73	77	74	74	71	76	69	62	70	73
12:50	72	72	72	75	73	72	70	76	68	61	70	72
1:00	72	72	72	76	73	72	71	75	70	62	71	72
1:10	73	73	73	76	75	73	71	75	73	64	71	73
1:20	73	74	73	76	74	74	71	75	75	65	71	73
1:30	74	75	74	77	75	75	73	74	76	66	72	75
1:40	75	75	74	77	76	75	72	75	78	68	71	74
1:42	(r)											
1:50	74	74	74	77	75	74	72	75	79	69	72	74
2:00	(s)											
2:00	73	73	73	77	74	73	71	74	79	69	71	73
2:10	74	75	74	76	75	75	73	74	79	68	73	74
2:20	74	74	73	75	74	74	72	74	79	69	72	73
2:30	75	76	75	75	75	75	73	74	79	69	73	74
2:40	74	75	74	77	75	74	72	74	78	68	71	74
Mean	75.43	75.90	75.50	82.69	78.02	75.83	72.14	129.38	72.21	61.67	72.24	75.62

THERMOCOUPLE READINGS FOR CLASSROOM I-1 (continued)

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.09°F.
Range of working area 83°-68°F. = 15°F. Sample size = 336
Variance = 8.85°F. Standard deviation = ±2.975°F.
Standard error of mean = ±.162°F.

Mean of readings at center of room from floor to ceiling = 77.17°F.
Range 83°-68°F. = 15°F. Sample size = 168
Variance = 25.10°F. Standard deviation = ±5.010°F.
Standard error of mean = ±.387°F.

Mean of all 30" readings = 75.18°F.
Range 80°-71°F. = 8°F. Sample size = 210
Variance = 5.49°F. Standard deviation = ±2.343°F.
Standard error of mean = ±.162°F.

(a) No windows opened - Children not in room
(b) Children in room
(c) Windows opened for ventilation
(d) Number eight wire slipped - Temperature of pipe actually above 200°F.
(e) Number eight wire adjusted but still slightly above hot water pipe
(f) Door to corridor closed
(g) Corridor door opened
(h) Recess - Class out of room - Corridor door still opened
(i) Class back in room
(j) Class out of room to reading club
(k) Thermostat in office completely turned off
(l) Class back in room - Door closed
(m) Thirteen glee club members left the room
(n) Boiler off
(o) Glee club members back
(p) Lunch - Door left open
(q) Class back from lunch
(r) Recess - Part of class out of room
(s) End of recess

THERMOCOUPLE READINGS FOR CLASSROOM I-2
March 28, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
8:00	(a)											
8:00	76	76	76	88	80	76	73	198	71	58	73	77
8:09	(b)											
8:10	78	78	78	89	81	78	76	181	70	57	75	78
8:18	(c)											
8:20	80	80	80	89	83	80	76	173	69	57	75	81
8:22	(d)											
8:30	(e)											
8:30	76	76	76	87	78	76	74	173	66	56	73	76
8:40	80	80	80	91	82	81	76	175	68	57	75	81
8:43	(f)											
8:50	76	76	76	88	80	78	74	185	66	56	74	78
9:00	79	79	79	90	81	79	75	180	69	57	76	79
9:10	78	78	78	88	81	78	75	174	69	57	75	78
9:20	78	78	78	88	80	78	75	172	68	57	76	78
9:29	(g)											
9:30	77	77	76	87	79	78	75	160	68	58	75	78
9:40	76	76	76	86	79	77	74	122	71	58	73	76
9:50	74	74	74	85	75	74	72	106	70	58	70	72
9:51	(h)											
10:00	74	74	74	85	76	75	72	94	67	58	71	75
10:10	74	73	74	84	75	74	72	87	65	58	70	72
10:12	(i)											
10:20	76	76	76	85	78	76	74	89	68	58	73	75
10:30	77	76	77	83	78	76	75	83	68	58	74	75
10:40	75	75	76	85	78	76	74	81	68	58	74	75
10:50	75	74	75	85	76	75	73	78	68	58	73	74
11:00	75	75	75	84	77	75	74	77	68	58	73	76
11:10	(j)											
11:10	74	74	74	84	75	74	73	77	67	59	73	74

THERMOCOUPLE READINGS FOR CLASSROOM I-2 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
11:16	(k)											
11:20	73	74	74	84	75	74	72	80	67	59	72	74
11:30	74	74	74	84	75	75	74	145	68	60	73	75
11:39	(l)											
11:40	(m)											
11:40	77	77	77	88	79	77	75	162	71	60	75	78
11:41	(n)											
11:50	79	79	79	89	80	79	76	176	74	63	76	79
11:57	(o)											
11:59	(p)											
12:00	79	79	79	89	81	79	76	179	75	63	76	80
12:10	79	79	79	90	81	80	77	172	76	63	76	80
12:20	80	80	80	91	83	80	77	167	77	64	76	80
12:30	81	81	81	91	84	81	77	175	79	65	76	81
12:33	(q)											
12:40	83	83	83	93	84	83	79	182	80	65	80	83
12:50	84	84	84	91	86	84	79	163	83	68	79	84
1:00	84	84	83	93	85	84	79	165	84	69	79	83
1:05	(r)											
1:10	84	84	84	94	86	85	80	153	82	67	80	84
1:20	84	84	83	94	86	84	80	159	82	67	81	84
1:30	(s)											
1:30	81	81	81	92	85	83	79	162	82	69	80	83
1:31	(t)											
1:40	81	81	81	93	83	82	78	117	84	70	78	81
1:50	81	81	81	92	82	81	78	101	84	71	78	81
2:00	80	80	80	90	82	81	78	98	83	71	78	81
2:10	80	80	79	89	81	80	78	90	83	69	78	80
Mean	78.21	78.16	78.16	88.37	80.26	78.58	75.63	139.76	72.84	61.43	75.32	78.39

THERMOCOUPLE READINGS FOR CLASSROOM I-2 (continued)

Mean of working area (1,2,3,5,6,7,11, & 12) = 77.84°F.
Range of working area 86°-72°F. = 14°F. Sample size = 304
Variance = 11.71°F. Standard deviation = ±3.422°F.
Standard error of mean = ±.196°F.

Mean of readings at center of room from floor to ceiling = 80.71°F.
Range 94°-72°F. = 22°F. Sample size = 152
Variance = 31.66°F. Standard deviation = ±5.626°F.
Standard error of mean = ±.456°F.

Mean of all 30" readings = 78.30°F.
Range 85°-72°F. = 13°F. Sample size = 190
Variance = 10.26°F. Standard deviation = ±3.203°F.
Standard error of mean = ±.232°F.

(a) Children coming into room - Wire number 8 located above fins - Heat above 200°F.
(b) Some windows opened for ventilation - Door closed
(c) Hand valve turned nearly off
(d) Class gone to get drink - Door opened
(e) Class back
(f) Transoms opened
(g) Recess - Some children out of room - Some activity in room
(h) Class back - Recess ended
(i) Some outside windows closed
(j) Children gone to lunch - All windows closed but one
(k) Thermostat in office turned to maximum setting
(l) Class back from lunch
(m) Windows opened for ventilation
(n) Door closed again - Lights off - Rest period
(o) Rest period over - Lights on
(p) Class gone to library
(q) Class back in room
(r) Recess - Door opened
(s) Recess over - Thermostat in office completely off
(t) Door left opened - More windows opened

THERMOCOUPLE READINGS FOR CLASSROOM I-3

March 29, 1961

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7:50	72	72	73	82	76	73	69	95	67	46	69	72
8:00	(a)											
8:00	70	72	73	81	75	71	68	109	68	47	68	71
8:10	73	73	73	83	76	74	70	115	68	48	70	73
8:20	75	75	75	84	78	75	71	104	69	50	71	75
8:30	77	77	77	86	80	77	72	114	71	52	72	77
8:40	76	76	76	86	80	77	72	107	72	53	72	77
8:50	77	77	77	87	80	77	74	123	73	53	73	78
9:00	(b)											
9:00	78	78	78	87	81	78	74	115	74	55	73	78
9:10	78	78	78	88	81	79	74	114	75	58	73	79
9:20	80	80	81	89	83	80	76	119	76	59	75	80
9:30	80	79	80	88	83	81	77	106	77	58	76	80
9:31	(c)											
9:40	77	77	78	87	76	78	74	121	76	60	73	77
9:50	77	78	77	87	81	78	74	109	78	62	74	77
10:00	77	77	78	84	81	78	74	111	77	63	74	77
10:03	(d)											
10:10	80	80	79	84	81	80	76	95	78	64	75	80
10:20	79	79	79	83	80	78	75	94	77	64	75	78
10:22	(e)											
10:30	76	76	76	82	78	76	73	89	76	64	73	76
10:40	75	75	75	81	76	75	74	87	76	64	73	75
10:43	(f)											
10:50	74	74	74	82	76	75	73	83	76	64	72	74
11:00	74	74	74	79	75	75	73	82	74	64	73	74
11:08	(g)											
11:10	74	74	74	78	75	75	73	81	73	64	73	75
11:20	74	74	75	78	76	75	73	81	74	65	72	74
11:30	76	76	76	78	77	76	74	81	75	66	73	76

THERMOCOUPLE READINGS FOR CLASSROOM I-3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Time	30"	30"	30"	120"	60"	30"	6"	Temp. of heat	Temp. of window glass	Out-side air temp.	6"	30"
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
11:40	76	76	76	77	77	77	74	80	74	66	74	76
11:50	78	77	77	78	78	77	75	80	76	67	74	77
12:00	77	77	77	77	77	77	74	79	75	67	74	77
12:10	77	77	77	77	77	77	74	80	75	67	74	77
12:14	(h)											
12:20	75	75	74	77	76	75	73	79	77	68	73	75
12:30	74	74	74	77	75	74	73	78	76	67	73	74
12:40	74	74	74	77	75	74	73	77	76	68	72	74
12:50	73	73	73	76	75	74	72	78	76	67	72	74
Mean	75.90	75.94	76.06	81.94	77.90	76.32	73.26	95.68	74.35	60.65	72.84	76.03

Mean of working area (1,2,3,5,6,7,11, & 12) = 75.53°F.
Range of working area 83°-68°F. = 15°F. Sample size = 248
Variance = 7.13°F. Standard deviation = ±2.670°F.
Standard error of mean = ±.17°F.

Mean of readings at center of room from floor to ceiling = 77.35°F.
Range 89°-68°F. = 21°F. Sample size = 124
Variance = 17.82°F. Standard deviation = ±4.221°F.
Standard error of mean = ±.379°F.

Mean of all 30" readings = 76.05°F.
Range 81°-68°F. = 13°F. Sample size = 155
Variance = 4.98°F. Standard deviation = ±2.232°F.
Standard error of mean = ±.179°F.

(a) Class coming into room - Hand valve half on
(b) Thermostat in office completely off
(c) Class out for recess - Door open
(d) Class back from recess - Door closed
(e) Class gone to music - Lights off - Door opened
(f) Some of class came in room for their lunch - Lights on
(g) Class back from lunch - Rest period - Door closed
(h) Class leaving for day - B.I.E. Day