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UNIVERSITY OF LOUISVILLE

A CLASSROOM ILLUMINATION STUDY

OF

THE PUBLIC SCHOOL SYSTEM

OF

JEFFERSONVILLE, INDIANA

A Dissertation

Submitted to the Faculty

Of the Graduate School of the University of Louisville

In Partial Fulfillment of the

Requirements for the Degree

Of Master of Arts

Department of Education

By

Ross Graham

June, 1939

Name: _____

Title: A CLASSROOM ILLUMINATION STUDY
OF
THE PUBLIC SCHOOL SYSTEM
OF
JEFFERSONVILLE, INDIANA

Director: _____

Approved by a reading committee
composed of the following members:

Representative of the English Department:

Date: _____ *June 1 1939*

TABLE OF CONTENTS

CHAPTER	PAGE
I. THE PROBLEM AND DEFINITIONS OF TERMS USED.....	1
The problem.....	2
Definitions of terms used.....	4
II. PHOTOMETRICS USED IN THE SURVEY.....	8
Instruments.....	9
III. DIGEST OF PERTINENT LITERATURE.....	22
IV. SOURCES AND TREATMENT OF DATA.....	42
V. STATISTICAL AND GRAPHICAL ANALYSIS OF FINDINGS	51
VI. CONCLUSIONS AND RECOMMENDATIONS.....	82
Conclusions.....	83
Recommendations.....	85
BIBLIOGRAPHY.....	89
APPENDIX.....	97

LIST OF TABLES

TABLE	PAGE
A. Statistical Data for Illumination Curves	
I. Spring Hill Elementary School.....	57
II. Chestnut Street Elementary School.....	60
III. Rose Hill Elementary School.....	63
IV. Port Fulton Elementary School.....	66
V. Ingramville Elementary School.....	69
VI. Taylor Colored School.....	72
VII. Junior High School.....	75
VIII. Senior High School.....	78
B. Statistical Analysis of Data	
IX. Spring Hill: Bright Days.....	58
X. Spring Hill: Dull Days.....	59
XI. Chestnut Street: Bright Days.....	61
XII. Chestnut Street: Dull Days.....	62
XIII. Rose Hill: Bright Days.....	64
XIV. Rose Hill: Dull Days.....	65
XV. Port Fulton: Bright Days.....	67
XVI. Port Fulton: Dull Days.....	68
XVII. Ingramville: Bright Days.....	70
XVIII. Ingramville: Dull Days.....	71
XIX. Taylor Colored: Bright Days.....	73
XX. Taylor Colored: Dull Days.....	74

TABLE

PAGE

XXI. Junior High School: Bright Days.....	76
XXII. Junior High School: Dull Days.....	77
XXIII. Senior High School: Bright Days.....	79
XXIV. Senior High School: Dull Days.....	80
XXV. Summary of Calculations.....	81

LIST OF FIGURES

FIGURE	PAGE
1. Weston Foot-candle Meter.....	15
2. Intercepting Screens and Masks.....	15
3. Light Meter and Additional Photo-Electric Cells..	17
4. Special Foot-candle Meter.....	17
5. Schematic Wiring Diagram of Special Light Meter..	18
6. Unassembled Parts for Special Meter.....	21
7. Common Experiences in Light and Vision.....	21
8. Societies Approving Adoption of I. E. S. Code....	30
9. Recommended Code of School Lighting.....	30
10. Physiological Reactions Under Different Illumination Intensities.....	30
11. Time and Light Required for Discrimination.....	36
12. Time and Light Required for Perception.....	36
13. Time and Light Required for Reading.....	36
22. Illumination Survey Record Form.....	50
44. Form Sheet for Collection of Physical Data.....	111
45. Characteristics of Photronic Cells.....	112
PHOTOGRAPHS OF BUILDINGS SURVEYED	
14. Spring Hill.....	47
15. Chestnut Street.....	47
16. Rose Hill.....	47
17. Port Fulton.....	48

FIGURE	PAGE
18. Ingramville.....	48
19. Taylor Colored.....	48
20. Junior High School.....	49
21. Senior High School.....	49
ILLUMINATION LEVEL DISTRIBUTION GRAPHS	
23. Spring Hill.....	57
24. Chestnut Street.....	60
25. Rose Hill.....	63
26. Port Fulton.....	66
27. Ingramville.....	69
28. Taylor Colored.....	72
29. Junior High School.....	75
30. Senior High School.....	78
FLOOR PLANS OF BUILDINGS SURVEYED	
31. Spring Hill: Second Floor.....	98
32. Chestnut Street: First Floor.....	99
33. Chestnut Street: Second Floor.....	100
34. Rose Hill: First Floor.....	101
35. Rose Hill: Second Floor.....	102
36. Port Fulton: First Floor.....	103
37. Port Fulton: Second Floor.....	104
38. Ingramville: First Floor.....	105
39. Taylor Colored: First Floor.....	106

FIGURE	PAGE
40. Taylor Colored: Second Floor.....	107
41. Junior High School: First and Second Floors...	108
42. Senior High School: First Floor.....	109
43. Senior High School: Second Floor.....	110

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R. G.

CHAPTER I

THE PROBLEM AND DEFINITION OF TERMS USED

THE PROBLEM AND DEFINITIONS OF TERMS USED

Purpose. The purpose of this investigation is (1) to obtain, digest, and analyze the data relative to representative classroom illumination in the public school system of Jeffersonville, Indiana; (2) to present statistical and graphical analyses of these findings; and (3) to compare the results with standard norms.

Validation. The importance of any step in the direction of discovery and correction of illumination inadequacy can be appreciated only when viewed from the perspective of its concomitant results. There is evidence to support the belief that improper light can (1) influence scholarship; (2) cause nearsightedness and other refractive defects of vision; (3) alter dispositions; and (4) produce drowsiness, indigestion, and headaches.¹

A procedure that contributes towards the elimination of any of these undesirable conditions should be considered important. On the basis that discovery of faults must precede correction, this investigation becomes fundamentally worth-while.

¹ Cf. post. pp. 27 et. sqq.

Delimitations. The scope of this study is restricted to classroom illumination as it actually existed. No attempt was made to improve the conditions encountered before the raw data was collected.

Furthermore, the conclusions and deductions from this inquiry apply exclusively to the specimen rooms. No comparison to rooms not examined is intended.

DEFINITION OF TERMS

The field of illuminating engineering contains many terms that are completely confusing to the uninitiated. In the literature of the physics of light alone, efficiency in description has demanded the frequent use of specialized vocabulary, technical terminology, and scientific definitions. Many common words that are used rather loosely in ordinary conversation have connotations that are definitely peculiar to this branch of science. To clarify and integrate this lack of verbal articulation, the following important definitions and explanations are offered.

International candle. For several generations the common artificial illumination was provided by candles. These were often home-made, and therefore not standardized in their ability to produce light. When new light sources began to supersede the candle, it was most natural that the illuminating power of these new luminants should be expressed in terms of the candle familiar to all. The standard international candle, as finally agreed upon, was a sperm candle seven-eighths of an inch in diameter and burning at the rate of 120 grains per hour.¹ Such a

¹ R. A. Millikan, and H. G. Gale, New Elementary Physics, (Boston: Ginn and Company, 1936), p. 494.

source is said to emit light at the rate of one candle power. Hence, it is readily seen that the international candle is an arbitrary unit for measuring luminous intensity.

Foot-candle. While the intensity of any light source is measured in terms of candle power, the intensity of illumination is usually measured in foot-candles. Intensity of a source is a cause, and intensity of illumination the effect or result. Thus, to measure the illumination on a newspaper, book, desk, or other working plane, the unit called a foot-candle would be used.

A foot-candle represents the amount of illumination equal to that produced at a point on a plane one foot distant from a source of one candle power.¹ Since Kepler's law of the propagation of light states that the intensity of illumination of a surface varies inversely as the square of the distance of the surface from the source of light, the foot-candles of illumination for any given condition are determined by the mathematical formula;²
$$\text{foot-candles} = \frac{\text{candle power}}{\text{feet}^2}$$
 For example, a source of thirty-two candles at a distance of four

1 Ibid. pp. 493-494.

2 Ward Harrison and K. A. Staley, Fundamentals of Illumination, (Cleveland, Ohio: General Electric Research Department, 1931), pp. 11-12.

feet from a plane would illuminate that surface with two foot-candles. This law assumes that the surface is perpendicular to the incident rays of light. In other cases of oblique lighting the foot-candles vary directly as the cosine of the angle of incidence.¹

Reflection--Factor and Brightness. Although two objects may receive the identical number of foot-candles of illumination, one may not appear as bright as the other. This phenomenon is explained by the fact that the two objects absorb different amounts of light. The eye sees them only by the reflected light. The percentage of light reflected by a surface determines its reflection-factor. If an object reflects all of the light that falls upon it, its reflection-factor is taken at unity. Any amount of reflection less than perfect reflection is so designated by decimal fractions of unity indicating the degree of reflection.² White blotting paper, which has a reflection factor of .8, would, therefore, reflect eighty per cent of the light that fell upon it. Likewise, so-called black cloth with a reflection factor of .05 reflects only five

1 Ibid. p. 10.

2 M. Luckiesh, Seeing, (Baltimore, The Williams and Wilkins Company, 1931) pp. 57-60.

per cent of its illumination. Therefore, brightness is determined both by the number of foot-candles of illumination and by the reflection-factor inherent in the material itself.

Contrast. This term may be defined as the difference in brightness between an object and its background. The mathematical formula for this relation is as follows:¹

$$\text{Per cent Contrast} = \frac{\text{Background brightness} - \text{Object brightness}}{\text{Background brightness}}.$$

Glare. Any brightness within the field of vision of such a character as to cause annoyance, discomfort, interference with vision, or eye fatigue is called glare.² Just as dirt has sometimes been defined as matter out of place, so may glare be defined as light out of place; that is, it may come directly from the light source to the eye, or it may be reflected brightness such as that from a desk top, polished machine parts, or glazed paper. The extent to which glare is objectionable is partially dependent upon the contrast in brightness between the light source and the background. Automobile headlights on an unlighted highway, for instance, may be so glaring as to be blinding to the

¹ Ibid. p. 46.

² Harrison, op. cit., pp. 40-41.

eye: the same lights in the daytime or on a well lighted street would scarcely be noticed. The presence of glare is probably one of the most common and serious faults of lighting.

Photometers. Meters designed to measure quantitatively the amount of illumination in foot-candles are called photometers. A detailed description of the types used in this survey is given in the following chapter.

CHAPTER II
PHOTOMETRICS USED IN THE SURVEY

PHOTOMETRICS USED IN THE SURVEY

Instruments

The early types of photometers used for measuring foot-candles of illumination were entirely unsuitable for an extensive survey of light conditions in which many variables were existent. These instruments were handicapped by bulk, weight, and length of time necessary for a single reading. Although they were quite accurate for laboratory experiments verifying the fundamental laws of light propagation, these instruments were definitely inadequate for field work.

Direct reading photometers of the portable type made their appearance practically simultaneously with the comparatively recent invention of the photo-electric cell, sometimes referred to as the "electric eye."

The Weston Electric Instrument Corporation of Newark, New Jersey, manufactures one of the accepted standard photometers of the electric cell type. This apparatus consists of a Photronic cell of the photo-emissive classification coupled electrically to a very sensitive galvanometer. The galvanometer is graduated directly in foot-candles. The design of the electric eye is such that 1.4 micro-amperes of current represents one foot-candle of illumination.

Most of the commercial light and power companies use this instrument which is known as the model #703 Weston Light Meter.

Although the device just described was used as the basic instrument for this survey, it possessed certain limitations which necessitated the use of special auxiliary accessories and the design of a photometer which was more flexible and versatile for the purposes of this study than the regular model #703.

The standard Weston meter has a calibrated range from 0 to 50 foot-candles. A range of this limit is quite satisfactory for most indoor determinations when the illumination is supplied by artificial means.

However, an understanding of the wide variations of illumination intensity levels encountered in any survey of this sort is essential to an appreciation of the necessity for apparatus of diverse ranges. As mentioned in more detail elsewhere in this treatise, the amount of light supplied outdoors by bright sunshine often attains values as high as ten thousand foot-candles. Under the shade of a tree or porch on such a day, the value is in the neighborhood of one thousand to three thousand foot-candles. Indoors this value drops so rapidly it is almost beyond human conception to realize that, even under good conditions,

natural daylighting often falls as low as twelve or fifteen units. Although most illuminating engineers strive to obtain as much intensity as possible, commensurate with cost under artificial illumination, yet this value rarely exceeds ten foot-candles even in library reading rooms.

Hence, in consideration of these facts, it is easily seen that for a complete collection of data pertinent to the subject, meters are necessary that can accurately determine values between the extreme limits of zero and several hundred light units.

In order to extend the range of the basic meter #703, metallic masks were machined to precision tolerances. These masks intercepted the light on a predetermined portion of the sensitized area and thus made it possible within certain limits to use an integral conversion factor as a multiplier of the meter readings throughout the entire scale. The first mask was made after determining by micrometer measurement the diameter of the sensitized surface of the light cell. This dimension must not be assumed to be that of the glass cover, since the cell is active only to the phosphor bronze contact ring. The diameter to this ring measures 1.483 inches. By multiplying this constant by .707 a diameter of 1.048 inches was obtained. The internal diameter of the mask was machined to this size. Since this

opening admitted light to only one-half of the active area, the range of the meter was exactly doubled throughout the entire scale.

Similarly, by making the next mask with a circular opening of .7415 inches diameter, its factor of conversion became four, thereby increasing the range of the meter to a maximum reading of 200 foot-candles. It will be noticed from the diagrams and photographs that the metal thickness was beveled to a knife edge at the inner opening, in order to prevent tiny shadows at this point from introducing an uncontrollable deviation in readings.

Although these two masks, which respectively doubled and quadrupled the range of the light meter, were found to be valuable accessories, other masks which were designed to multiply the readings of the instrument by ten or more were found quite unsatisfactory. Any interception of this nature which obstructed more than 75 per cent of the active area of the Photronic cell was found to be very irregular in its multiplying factor. For rays of light normal to the plane of the meter, a constant multiplier could be used with accuracy, but when these rays became markedly oblique to the surface no prediction could be made as to the proper multiplier to use.

Other forms of partial interception in the nature of

filters were considered, but rejected, because of the fact that filters not only reduce the intensity of light, but rob the light of some of its spectral quality. Colored filters of gelatin film, cellophane, and glass were discarded on account of this fact. The only acceptable interceptors of this nature were found to be ground glass, opal glass, and the quite expensive Polaroid discs recently placed on the open market. By developing a photographic negative to a uniform density, an additional substitute was investigated and found quite satisfactory except for the difficulty in handling. A lack of durability, together with a definite susceptibility to scratches and finger prints made this photographic emulsion poorly adapted to repeated usage.

To supplement the basic instrument and its accessories, a special auxiliary photometer was assembled according to the following description. The foundation of this special meter was composed of two electric eyes instead of just one. Two standard Photronic units were mounted flush in a one-sixteenth inch thick aluminum panel which also carried a Jewell micro-ammeter of high sensitivity and an accuracy of less than two per cent error. "Pattern number 51" commercially identifies this indicating device. The particular scale and range of the meter selected were respectively, "center scale zero," and 500 micro-amperes in either direction.

FIGURE 1
WESTON FOOT-CANDLE METER

FIGURE 2
INTERCEPTING SCREENS AND MASKS

The panel was shaped closely to the outline of the assembled units and then placed in a conforming wood supporting base. Two toggle switches were included, one mounted in the top and the other on the side of the instrument. A standard 500 ohm resistance placed within the housing completed the construction. The wiring diagram, Figure 5, describes the electrical circuits possible.

It will be readily seen by tracing the sketch and at the same time considering the laws of mathematical combinations when using the two different intercepting masks previously described, that a total of fourteen different arrangements is possible. These are obtained by proper switching of circuits in conjunction with the use of the proper masks. The combinations that are most important and easiest to use are indicated in the following classification:

1. One Photronic cell connected direct to meter.
2. Two cells connected directly in parallel to meter.
3. One cell connected to meter through the 500 ohm series resistance.
4. Two cells connected in multiple and the pair connected in series to the meter and resistance.
5. The metallic masks applied to any of the above situations, singly or in combination with each other.

FIGURE 3
LIGHT METER AND ADDITIONAL PHOTO-ELECTRIC CELLS

FIGURE 4
SPECIAL FOOT-CANDLE METER

Fig. 5. Schematic Wiring Diagram
Of
Special Light Meter

The choice offered by these widely divergent arrangements made possible, as the condition demanded, the reading of extremely low light values or extremely high intensities.

The calibration of the instrument in any case was accomplished by considering the amount of exposed sensitive cell area connected to the micro-ammeter. To convert these current readings into foot-candles, it was necessary to prepare a table of conversion factors which were obtained from the manufacturers' specifications for these cells. These constants are contained in the graphs shown in Figure 45, on page 112 of the appendix.

To guarantee a reasonable degree of accuracy, both instruments were tested separately on an optical bench with both a standard sixteen candle-power and a thirty candle-power light at varying distances. The meters were checked against each other, and also compared to the values mathematically determined by measurement on the optical bench. As a still further check, they were compared in a given situation to the readings of the meters used by the Indiana Northern Power and Light Company as well as those used by the Indiana Public Service Company. In all cases, the accuracy was found to be well within the limit of human observational error.

Although the above equipment functioned quite satisfactorily under all conditions encountered, the only serious objection was found in the total cost. The special meter, with its two electric eyes at ten dollars each, plus the micro-ammeter at fifteen dollars, ran the price for these three major parts alone to thirty-five dollars. The basic foot-candle meter was listed at nineteen and a half dollars. To these costs must be added incidental outlays for switches, metal, and labor costs for machine tool operations upon the various parts of the construction.

FIGURE 6
UNASSEMBLED PARTS FOR SPECIAL METER

FIGURE 7
COMPARISONS OF ILLUMINATION LEVELS UNDER DIFFERENT CONDITIONS

CHAPTER III

DIGEST OF PERTINENT LITERATURE

DIGEST OF PERTINENT LITERATURE

The results of any illumination survey can be viewed critically only with knowledge of the major studies in the realm of vision. The outstanding researches in this field have been promoted and financed, for the most part, by private corporations and professional societies. Perhaps the most prolific contributions have originated in organizations sponsored by General Electric Company, Westinghouse Corporation, Illuminating Engineering Society, or the American Institute of Architects. Apparently the individual most frequently quoted in periodical literature, as well as the author of the greatest number of textbooks on the subject is Matthew Luckiesh, the Director of Research of the General Electric Lighting Laboratory.

The complexity of the problems involved in indoor illumination has for its foundation the history of the development of the human eye. Until comparatively recent generations, man was for centuries distinctly an outdoor animal. Through the prehistoric period to the modern period, this type of life evolved the sense of sight that was best adapted for functioning in sunlight. Only after present-day conditions had brought man indoors, did widespread vision difficulties arise. Two factors are

responsible for the increased demand upon vision brought about by this transition. One was the greatly reduced amount of illumination and the other was the greater seriousness and more detailed minuteness of the tasks constituting the indoor work. In this connection, Hillyer states that the present generation use their eyes thirty per cent more than the last generation.¹

Differences between outdoor and indoor illumination on the same day are almost unbelievable. In bright sunshine the intensity of illumination often attains values as high as ten-thousand foot-candles. Even in the shade, values range from one-thousand to three-thousand light units. When daylight outdoors becomes as low as five-hundred, it is a very dull and dark day, indeed. On the other hand, there are few buildings in which the level of illumination reaches more than ten foot-candles, except at locations near the windows.² In many rooms, points removed from the windows by more than twenty feet have less than three foot-candles. At first thought, this disparity seems impossible. However, if one has ever attempted to take a photograph indoors, either

1 E. Hillyer, "Good Light Saves Wear and Tear on Eyes, Nerves, and Dispositions," Delineator, 130:4, February 1937.

2 M. Luckiesh, Light and Work, (New York: D. Van Nostrand Company, 1924) pp. 52-53.

he has realized the light difference, or he has experienced failure. For example, on a clear day outside, a lens setting of f16 at one-fiftieth of a second will ordinarily produce a normal negative. However, an indoor exposure to procure the same negative density will require an approximate setting of f3.5 at one second. Dividing one exposure by the other produces the ratio of 1600 to 1. This figure agrees favorably with the corresponding light values given above. An interpretation of this ratio means that the illumination level outdoors was 1600 times as great as that indoors.

In regard to the nature of indoor work, it is common knowledge that clerical, professional, and skillful activities are much more exacting than those performed outside. In fact, a study by Luckiesh shows that defects in vision are not nearly so common among farmers, policemen, and other outdoor workers as among machinists, moulders and factory laborers.¹

Cobb states that twenty per cent of the grade school population have impaired vision.² This figure advanced to

¹ M. Luckiesh, The Science of Seeing, (New York: D. Van Nostrand Company, 1937), p. 21.

² Percy W. Cobb, Lighting for the Conservation of Vision, (New York: National Society for Prevention of Blindness, Publication #123, 1933) pp. 13-14.

forty per cent when college students were considered, and ultimately reached the startling proportions of ninety-five per cent for people over sixty years of age. These data agree favorably with the statistics of Luckiesh and Moss, who assert that forty per cent of the general public have defective vision. In close agreement with the above results, the Scientific American published findings purporting to show that twenty-five per cent of school children and fifty per cent of the adults were handicapped by impaired vision either corrected or uncorrected.¹ The conclusion to these astounding percentages impresses us with the fact that we are living in a half-seeing world.

Since seeing is a partnership of lighting and vision, attention should be concentrated not only upon correction of refractive errors, but also upon sight-saving illumination. Luckiesh says, "Nearsightedness is commonly caused by inadequate intensity of illumination for seeing of reading matter."² The same authority still further states that children are most susceptible to harm in this respect.

1 "Too Much Illumination," editorial, Scientific American, 151:8, July, 1934.

2 M. Luckiesh, Seeing, (Baltimore: The Williams and Wilkins Company, 1931) p. 7.

Writing from the angle of physiological reaction, Hillyer states that inadequate and improper light can cause headaches, nervousness and even indigestion.¹ To Hillyer, heavy muscular energy drain as well as increased nervous tension and irritability can, in many instances, be attributed directly to a slight continuous eye strain, which the victim himself cannot detect. The same discussion incorporated a table of recommended intensities that are considerably higher than even those of the Illuminating Engineering Society. In these recommendations, Hillyer advocates fifty to one hundred foot-candles for reading and similar tasks, while intensities below five foot-candles are declared the danger zone for any type of prolonged task.

The insidious deception involved in poor lighting is due to the fact that the human eye, on account of its adaptation ability, is a very poor light meter. Rosa says that the eyes as photometric instruments are utterly useless.² He also elaborates this statement by saying, "The human eye, by itself, is entirely incapable of determining with any

1 E. Hillyer, op. cit., p. 4 ff.

2 Ed. B. Rosa, Lectures on Illuminating Engineering, (Baltimore: The Johns Hopkins Press, 1911) p. 386.

accuracy the intensity of a source of light, or the intensity of illumination upon any object. The eye is also incapable of making any correct estimate of how many times one light is brighter than another."

Ability of the eye to adapt itself to various adverse conditions of illumination often causes needless fatigue. In fact, we "see with our whole body." That is, eye work alone, with no other physical activity, consumes energy. Luckiesh states that twenty-five per cent of the consumption of bodily energy is dissipated by seeing. Still further, seventy per cent of muscular activity is due to impulses received through the eyes. Most adults use their eyes about sixteen hours per day.¹ And yet, in view of these facts, very little is done to lessen the burden of the priceless eyes.

Eye fatigue has defied, for the most part, exact quantitative measurement. Unlike the test for muscular response, complete fatigue is not indicated by failure to react. One machine, designed to measure eye fatigue, revolves a spot of light which is made to coincide with stationary spots of light by the control of patient under test. Even after hours of application to this test, the performance of the individual is just about as good as at

¹ Luckiesh, op. cit., pp. 11-16.

the beginning. However, the eyes show signs of strain by the inflammation of the membranes, by watering, and by appearing bloodshot. In addition, the subject usually complains of tiredness. And yet, as far as quantitative measurement of fatigue is concerned, the efficiency of performance has not decreased. Hence, any lighting appraised by the ability to see is quite inadequate.

In order to provide some measure of protection against the different eye abuses, The Illuminating Engineering Society, in collaboration with other learned organizations, has attempted to recommend minimum illumination levels best adapted to particular tasks. One of their most recent publications was released in March, 1938, and accordingly contains recommendations based on the latest research. This code, called American Recommended Practice of School Lighting, was approved by the American Standards Association. Although this code was sponsored by the Illuminating Engineering Society and the American Institute of Architects, there were fifteen other reputable organizations that voted for the new standards. A list of these organizations is contained on the following page. A reproduction of recommended foot-candles for school lighting offered by the report is also contained on the following page.

The code specified a minimum of fifteen foot-candles for class rooms and offices. This amount practically doubles

AMERICAN INSTITUTE OF ARCHITECTS: Theodore Irving Coe, Technical Secretary, Structural Service Department, American Institute of Architects, The Octagon, 1741 New York Avenue, Washington, D. C. Succeeding F. Leo Smith.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS: G. H. Stickney, General Electric Company, Nela Park, Cleveland, Ohio.

AMERICAN MEDICAL ASSOCIATION: Dr. Edward Jackson, 700 Madison Street, Denver, Colorado.

AMERICAN PUBLIC HEALTH ASSOCIATION: Leonard Greenburg, Ph.D., Ex-Dir., Division of Industrial Hygiene, New York Department of Labor, 80 Center Street, New York, N. Y. Alternate: Joel I. Connolly, Chief, Bureau of Sanitary Engineering, Department of Health, Chicago, Illinois.

ELECTRIC LIGHT AND POWER GROUP: J. C. Fisher, Consolidated Gas Electric Light and Power Company, Baltimore, Maryland. Alternate: Alexander Maxwell, Edison Electric Institute, 420 Lexington Avenue, New York, N. Y.

ILLUMINATING ENGINEERING SOCIETY: H. B. Dates, Sectional Committee Chairman, Case School of Applied Science, Cleveland, Ohio. Alternate: Willard C. Brown, Sectional Committee Secretary, General Electric Company, Nela Park, Cleveland, Ohio.

NATIONAL ASSOCIATION OF PUBLIC SCHOOL BUSINESS OFFICIALS: C. E. Dyson, Architect, Board of Education, Toronto, Canada.

NATIONAL BUREAU OF CASUALTY AND SURETY UNDERWRITERS: Roger T. Waite, Engineering and Inspection Department, Aetna Casualty and Surety Company, Hartford, Conn. Alternate: W. M. Graff, Manager, Conservation Department, National Bureau of Casualty and Surety Underwriters, 1 Park Ave., New York, N. Y.

NATIONAL COUNCIL ON SCHOOLHOUSE CONSTRUCTION: R. H. F. Halsey, Deputy Supt. of Buildings, Board of Education, New York, N. Y.

NATIONAL SAFETY COUNCIL: G. H. Stickney, General Electric Company, Nela Park, Cleveland, Ohio.

NATIONAL SOCIETY FOR THE PREVENTION OF BLINDNESS: Mrs. Winifred Hathaway, Associate Director, National Society for the Prevention of Blindness, 50 West 50th Street, New York, N. Y. Alternate: Lewis H. Carris, Managing Director, National Society for the Prevention of Blindness, 50 West 50th Street, New York, N. Y.

U. S. DEPARTMENT OF COMMERCE, NATIONAL BUREAU OF STANDARDS: Dr. M. G. Lloyd, National Bureau of Standards, Washington, D. C.

U. S. DEPARTMENT OF THE INTERIOR, OFFICE OF EDUCATION: Miss Alice Barrows, Office of Education, U. S. Department of the Interior, Washington, D. C.

U. S. DEPARTMENT OF LABOR, WOMEN'S BUREAU: Miss Bertha Nienburg, Assistant Director, Women's Bureau, U. S. Department of Labor, Washington, D. C.

U. S. TREASURY DEPARTMENT, BUREAU OF PUBLIC HEALTH SERVICE: Dr. Richard Lee, U. S. Public Health Service, Washington, D. C.

MEMBER AT-LARGE: Dr. LeGrand H. Hardy, 30 East 40th Street, New York, N. Y.

RECOMMENDED PRACTICE OF SCHOOL LIGHTING

11

TABLE I

Location	Minimum Operating Foot-candles of General Illumination
Classrooms—on desks and blackboards; study halls, lecture rooms, libraries—on desks and tables.....	15
Offices—on desks.....	15
Sewing rooms, drafting rooms, art rooms and other rooms where fine detail work is to be done—on the work.....	25
Shops, laboratories—on the work.....	15
Gymnasiums—main exercising floor, wrestling, playrooms, swimming pools, basketball, handball, boxing.....	15
Auditoriums, assembly rooms, cafeterias and other similar rooms not used for study.....	6
Locker rooms, corridors, stairs, passageways, toilets and all indoor areas traversed by students.....	4
Sight-saving classrooms—on desks and blackboards.....	30

RECOMMENDED PRACTICE OF SCHOOL LIGHTING

9

FIG. 1—A summary of results of extensive researches which reveal the influence of illumination upon important aspects of visual efficiency and upon even more important effects of seeing.

Figures 8, 9, 10.

the eight foot-candle level recommended by the same groups in 1932. The objection to the increase apparently lies in the increased cost alone. One current article says, "To put fifteen foot-candles on every pupil's desk would cost United States schools untold millions (\$1,000,000 a year in New York City alone)."¹

Because glare is extremely harmful, the report also advised that special attention be given to the elimination of such reflecting surfaces as glossy finish on desk tops, and glass tops on desks. Any of these, it is said, can produce severe optical strain when the eyes are exposed to the reflections for long periods of time.

Most researches on illumination emphasize the importance of the elimination of both the reflected glare of the type previously mentioned and the direct glare. The most common source of direct glare is occasioned by some light source in the line of vision. This is usually caused by unshaded tungsten bulbs that are not sufficiently high overhead. Although the actual intensity level of illumination can be greatly increased, in accordance with the inverse square law, on a given working plane by lowering the overhead light sources, this procedure is not advisable because of the

¹ "Light and Heat," editorial, Time, 31:13.

glare encountered. For the same reason, all incandescent filaments should be enclosed in translucent diffusing globes.

Although there is general prejudice among those not familiar with the facts against too much light for certain seeing tasks, this attitude is altogether unfounded scientifically. Whenever the objection is offered that too much illumination exists, the analysis of the situation usually reveals not too much illumination, but too much glare.¹

In cases where the glare and reflection-factors have been practically nil, experiments have shown that the greatest efficiency has been obtained in such tasks as sewing with black thread on black cloth when the intensity level has been increased to as high as ten-thousand foot-candles. Lagerstrom is authority for the statement that "All researches indicate that seeing becomes easier as the illumination is increased apparently without bound, as long as the element of glare does not enter."²

Another experiment reported by Moss verifies the folly of the belief that too much illumination is harmful

1 "Too Much Illumination," editorial, Scientific American, 151:8 July, 1934.

2 Personal letter R. E. Lagerstrom to Ross Graham. February 23, 1938.

and uncomfortable. In this research each subject was seated under an ordinary floor lamp equipped to deliver about eight foot-candles upon reading matter in the hands of the subject. All subjects believed that the amount of light was quite adequate for the purpose. The next step in the procedure moved the individual to a specially constructed booth in which the quantity of illumination could be controlled by the subject in accordance with his own desires and likes. He was then told to adjust the illumination to the optimum level. After this had been done, a reading of the foot-candles was taken and recorded. The mean of this controlled illumination in several hundred cases averaged 370 foot-candles.

Since dense shadows contribute to the degree of contrast, and hence indirectly aggravate the attendant glare, localized lighting alone, at or near the working plane, is not sanctioned. All localized lighting should be supplemented by general lighting. One investigator says that the general lighting should provide at least ten per cent of the illumination of the localized light source.¹ This recommendation is also justified by the fact that the eyes, in being diverted from a brilliantly illuminated

¹ M. Luckiesh, The Science of Seeing, (New York: D. Van Nostrand Company, 1937), p. 334.

working surface to darkened surroundings, are required to adapt themselves to the change by iris dilation. This requirement introduces a new muscular strain upon the eye, since adaptation from a higher to a lower level of illumination requires considerably more time and strain than adaptation for the reverse condition, even when the light differential remains the same. It requires about sixty times as long for the pupil of the eye to dilate as it does for it to contract. This means that if looking from a darkened area to a brighter area required a few seconds for proper adjustment, then looking back again from the brighter area to the darker area will require the same number of minutes, not seconds, for proper adjustment.

Inasmuch as the eyes are required to shift about, change focus, and provide adaptation, the muscles and nerve centers demand an enormous amount of energy during prolonged working periods. To alleviate this burden, it becomes important to provide lighting capable of creating the most effective retinal impression with the minimum amount of strain and effort.

Under higher levels of illumination, the eye has been shown to respond accordingly, by: (1) increased ability of perception as shown by Figure 12; (2) increased speed of discrimination, or rapidity with which the eye is able to

identify a difference, or differences, in objects, as shown by Figure 11; (3) increased accommodation, or ability of the eye to focus upon objects at different distances; (4) improvement in sustained vision, or the ability of the eye to keep a clear view of all details of an object under continuous observation; and (5) increased speed of vision, or speed of reading, as shown by Figure 13.

Luckiesh gives data in this respect to show that an increase in speed of vision of four-hundred per cent was brought about by an increase from two foot-candles to twelve foot-candles.¹ However, Tinker states that his own studies have shown no gain in speed of reading in light stronger than three foot-candles.² No data other than this conclusion was reported, however.

Likewise, Halsey, who is Superintendent of School Buildings in New York City, is definitely antagonistic toward increased illumination in the school room. One of his published articles charges that the researches in favor of increased light are financed by the utility companies,

1 M. Luckiesh, Light and Work, (New York: D. Van Nostrand Company, 1924) p. 182.

2 "Light and Heat," editorial, Time, 31:13, March 1938.

QUANTITY OF ILLUMINATION

Fig. 46—Normal eyes increase in speed of discrimination $3\frac{1}{2}$ to 1 between 1 and 12 foot-candles; astigmatic eyes show even more pronounced improvement.

Fig. 45—It takes $3\frac{1}{2}$ times as long for the eye to perceive a small test object under 2 foot-candles as it does under 100 foot-candles

When the illumination is of a low order, these impressions will be inadequate, the eye muscles have extra work thrown upon them and they become rapidly exhausted; work is consequently retarded and mistakes are frequent.

Fig. 47—Speed of reading indicates the time it takes to see; even when conditions for reading are best, i.e., black and white contrast, the eye can see 20% more quickly under good illumination.

and hence are colored by disguised salesmanship. Halsey does not offer definite scientific reasons for his belief that six to eight foot-candles are sufficient for reading. His conclusions are based solely on the fact that under such illumination he, himself, has noticed no ill effects from reading for time intervals as high as three hours. An additional argument offered by Halsey reminds us that Abraham Lincoln never received twenty foot-candles from his fireplace.¹

One of the most outstanding studies showing increased scholarship on account of better lighting was conducted by Allphin.² In this investigation, two identical rooms were chosen, teachers were alternated, and the pupils were divided into two equal groups. One room was then arranged to be illuminated by photo-electric controls set to maintain a minimum level of twenty foot-candles on the desks. No change was made in the lighting equipment of the other room. The results of the test, which covered one-hundred thirty-five school days, show, with statistical accuracy, that the gain

¹ R. H. F. Halsey, "How Much Light for Schoolrooms," American School Board Jr., 96: 27-8 January, 1938.

² Williard Allphin, Does School Lighting Influence Scholarship, (Buffalo: Trans. Illuminating Engineering Society, September 1936) pp. 1-12.

in reading age of the pupils in the better lighted room was twenty-eight per cent higher than those in the poorly lighted room. Furthermore, the educational age also showed a ten per cent increase with a probable error of .71.

Substantiating the foregoing findings, there are other tests conducted by Albert, and reported in his treatise, Scholarship Improved by Light.¹ Johnston's survey still further verifies the benefits received by improved classroom illumination.² Of 4316 school children in Syracuse, 50.6 per cent of those repeating a school grade had defective vision, whereas only 14.6 per cent of those making normal progress had refractive errors.

A parallel case at Baltimore revealed that of 7122 children, those who possessed defective vision were more often chronologically over-age, with respect to school age, than they were chronologically under-age.

If these studies are considered reliable, inadequate illumination, and its concomitant corollary of abnormality of vision are conclusively proved to be closely related to

1 E. C. Albert, "Scholarship Improved by Light," Trans. Illuminating Engineering Society, 28:866, 1933.

2 H. L. Johnston, "Better School Lighting Pays," Electrical World, 104:1078 July, 1934.

retardation in educational progress of school children.

Measurements of intensities of illumination before and after cleaning glass areas yield startling results. In many cases, the increase in light value is as much as five to ten times, and it is not uncommon to increase the illumination intensity from an average of one foot-candle with dirty glass to as high as fifteen foot-candles with clean glass.

Hibben, of Westinghouse, states, as an authority, that one billion dollars were spent one year (1932) for artificial light.¹ The same authority estimated that proper maintenance in the form of frequent cleaning of bulbs, fixtures, luminaires, and glass areas could have saved three hundred million dollars of the total. In the same discourse, emphasizing that "water is cheaper than watts," Hibben concludes, "I would say that if all our lighting installations and their immediate surroundings could be cleaned and reconditioned today, then the illumination that this nation enjoyed last night would be well-nigh doubled tonight."

Cleanliness is also considered paramount by Cady, who goes still further in his recommendations for the

¹ "Dirt Adds Millions To Light Costs," editorial, Literary Digest, 115:26, March 4, 1933.

maintenance of light colored walls and ceilings for proper schoolroom lighting. The specific recommendations concern the reflection-factors of walls which should range between .30 and .50. The preferred colors are light warm gray, light buff, dark cream, and light olive green. Ceilings should have reflection-factors of sixty-five per cent. Ceiling colors should be limited to white or light cream. Desk tops should have a reflection-factor not exceeding twenty-five per cent, in order to eliminate the possibility of glare from this source.¹

In consideration of the gradual depreciation of light as the result of the accumulation of opaque dirt, and in view of the fact that the human eye is an extremely unreliable light meter, the ideal solution of the classroom lighting problem is one that completely removes the human element in the control of artificial illumination. Automatic control has been successfully installed and operated in many school units including laboratory schools, sight-saving classes, and ultra-modern public school buildings. In such installations, adjustable photo-electric relays are set to turn on the artificial illumination whenever the natural

¹ F. E. Cady and Dates, H. B., Illuminating Engineering, (New York: John Wiley and Sons, Inc., 1925) pp. 357-358.

light falls to a predetermined minimum. Similarly, when the total foot-candles reach a given level, the artificial luminaires are automatically switched off. An arrangement of this sort provides optimum lighting conditions coupled with minimum current consumption.

It is, indeed, unfortunate that most school systems cannot enjoy the benefits of these photo-electric relays. Although quantity production in their manufacture has reduced the initial cost of these units to the extent that the price is no longer prohibitive for any school system of sound financial status, yet school executives are reluctant to adopt such improvements. This attitude in some cases takes the form of definite antagonism towards any "new-fangled frills." In other instances, a possible explanation is found in the fact that few lay school board members are thoroughly conversant with the need for adequate and proper illumination.

In this age of mechanization and idolatry of efficiency in all other lines of activity, it is very strange that more attention has not been devoted towards the perfection of the conditions of seeing.

CHAPTER IV
SOURCES AND TREATMENT OF DATA

SOURCES AND TREATMENT OF DATA

This classroom illumination study included the examination of one room from each of the eight buildings comprising the entire Jeffersonville, Indiana, public school system. These buildings are known as: Rose Hill; Chestnut Street; Spring Hill; Port Fulton; Junior High School; Senior High School; Ingramville; and Taylor Colored.¹

In each of these buildings, after a preliminary determination of light values, a room was chosen which would best represent the average conditions of illumination for the building. This choice of the particular room to be examined included such considerations as; direction of light exposure; window area; reflection factors of the interior wall surfaces; and the type of artificial light sources. Every attempt was made to be sure that the room chosen for study was not exceptional in any of the above mentioned characteristics.

It is not to be assumed that the room selected was intended to serve as a typical unit from which general conclusions could be drawn for the entire building. This study does not, in any respect, purport to establish the

¹ Cf. post. pp. 47-49

existence of identical and similar illumination conditions between the rooms studied and those not studied. The rooms examined were merely units for specimen sampling.

The raw data upon which this work was based consisted of more than 2,000 separate foot-candle determinations. The actual readings, for purposes of classification and systematization, were recorded on printed file cards three by five inches in size. This card provided space for the entry data for the various positions in any of the seat rows. The form of this primary record card, which included all the more important facts concerning the conditions of illumination, is reproduced on the following page.

The actual collection of data and various meter readings was carried on throughout the school year ending 1938. A much more complete sampling was obtained by extending the period of observation over an interval which included different seasons. To guarantee still further a random cross-section of the illumination conditions as they actually existed, the time of day at which the readings were taken was varied as much as possible.

No attempt was made to improve the light conditions in any room, before the readings were taken, by such procedure as adjusting the window shades or by turning on the artificial lights. Thus, the results obtained are indicative of the actual conditions encountered in the

classrooms.

After these readings were separated according to the building involved, the type of natural light conditions, and the location of the desk rows, a frequency distribution was tabulated for each group. This procedure resulted in forty-eight such arrangements. Then for each of these groups, the mean illumination, the sigma of the distribution, and the probable error of the average were calculated for each of the forty-eight tabulations. Thus, the accepted standard measures of central tendency, variability, and reliability were obtained.

Interpretation of these last two measures in terms of probability defines the sigma of the distribution as setting the upper and lower limit of variation from the average within which 68.26 per cent of all cases will fall. The probable error of the average indicates the limits in which fifty per cent of all cases would fall if a frequency distribution were made of an infinite number of averages obtained in similar manner.

With the mean illumination on the desk tops, and position of the desk rows as the co-ordinates, curves for each representative room were drawn representing the illumination level distribution for both the bright and the dull days. The graph representing the bright day conditions was represented in all drawings by the red line, while the

dull day conditions were indicated by the black line. The green line represented the desirable recommended minimum light level.

In order to give the proper identification of the rooms studied, their location in the building with reference to other rooms, their directional orientation, and their window position and number, complete floor plans for both first and second floors of all eight buildings are given in the appendix of this thesis.¹

Also given elsewhere herein are the tables containing the statistical analysis, the form sheet used for collection and recording the physical properties of the rooms, and a summary of all calculated results.²

1 Cf. post. Appendix, pp. 98-110.

2 Cf. post. Appendix, pp. 110.

SPRING HILL ELEMENTARY

CHESTNUT STREET ELEMENTARY

ROSE HILL ELEMENTARY

Figures 14, 15, 16.

PORT FULTON ELEMENTARY

INGRAMVILLE ELEMENTARY

TAYLOR COLORED

Figures, 17, 18, 19.

BUILDINGS SURVEYED

JUNIOR HIGH SCHOOL

SENIOR HIGH SCHOOL

Illumination Survey Data			
<u>Bldg.</u>	<u>Rm.</u>	<u>Date</u>	<u>Time</u>
Light Conditions			
Natural		Artificial	
Bright		Incandescent-on	
Clear		" -off	
Cloudy		Interception	
Dull			
Meter Readings		Foot-candles Micro-Amps.	
<div style="border: 1px solid black; width: 250px; height: 150px; margin: 10px auto;"></div>			

Figure 22

CHAPTER V

STATISTICAL AND GRAPHICAL ANALYSIS OF FINDINGS

STATISTICAL AND GRAPHICAL ANALYSIS
OF FINDINGS

Although different foot-candle measurements showed that the illumination in the different rooms varied considerably over a rather wide range of values, yet when the statistical reliability was computed, it was found to be high.

An authority, previously quoted, predicted this possible result when he said:

"Visual data taken under identical conditions insofar as is possible are often in wide variance. If sufficient observations are taken, the average value for a given condition can be shown to be of a high degree of reliability. These are not the ordinary averages of arithmetical means."¹

The same author then gives the customary approved formulae for the determination of mean probable errors.

The curves that follow, showing the decrease across the rooms of illumination level are, for the most part, entirely self-explanatory.

It will be noted that the entire length of these curves does not follow Kepler's inverse square law of light propagation. This apparent irregularity was fully anticipated,

¹ M. Luckiesh, *Seeing*, (Baltimore: The Williams and Wilkins Company, 1931) p. 50.

because the "inverse square law does not hold unless the distance between source and object is at least ten times the maximum dimension of the source."¹

The important facts revealed by these curves are two-fold. First, the drop is rapid for all curves throughout the extremely short distance represented by the first two rows of desks. This rapid initial drop is as outstanding as the small amount of relative difference between the curves for the bright days and for the dull days. The curves indicate that, although the weather conditions may produce a great difference in illumination near the windows, large differences fail to exist more than a few feet from the windows.

In fact, the only irregularity of any note in any of the curves occurs in the graph for Taylor Colored School, Figure 28. The intersection of the red line with the black line reveals the fact that for certain room areas the light on dull days was of higher order than the light values in the same area for bright days.

The nature of this discrepancy would suggest some fundamental errors either in the tabulation of data or the

¹ M. Luckiesh, Light and Work, (New York: D. Van Nostrand Company, 1924) p. 109.

calculation of the results for this one particular room. To eliminate this possibility, all figures and calculations were carefully rechecked, and were found to be correct as listed. Although the writer has no explanation for this one exception, it should be pointed out that this one room was architecturally different from all others surveyed. As shown by the floor plans, this is the only room studied which had the major window area located at the rear of the room.

To read the various graphs and to interpret correctly the related data that follows, a detailed description is warranted. Since the several series of graphs and data analyses are similar, with the exception of their application and numerical magnitude, only one of each kind will be discussed. An understanding of the remaining tables and figures will be obtained by extending the analogous explanation.

For example, Figure 23 shows the decrease in illumination by desk rows across room #1 of Spring Hill elementary school. The conditions for both the bright days and the dull days are indicated by different colored curves plotted on the same coordinate axes.

The ordinates of the vertical axis represent the amount of illumination in foot-candles. The abscissas of the

horizontal axis indicate the various positions of desk rows. The left-hand extremity of the horizontal axis locates the desk row adjacent to the windows of the room. Likewise, the right-hand extremity indicates the desk row nearest the wall opposite the windows. The vertical lines between these two extremes represent the positions of the intervening desk rows.

The contour of the red curve reveals that for bright days the illumination received by the desk row adjacent to the windows was approximately eighty-six foot-candles. This mean value progressively decreased to twenty foot-candles for the center desk row and finally became nine foot-candles for the desk row most remotely removed from the windows. For dull days, the black curve shows values of forty-three, ten, and five for the same corresponding positions mentioned above. The green line indicates the uniform illumination level of fifteen foot-candles, which is the minimum recommended by the Illuminating Engineering Society.

Table I supplies, in the first column, the values upon which the curves of Figure 23 were plotted. In addition, Table I not only furnished the variability of the frequency tabulation in terms of the sigma of the distribution, but also provides the figures for the reliability of the calculations in terms of the probable error of the average. The interpre-

tations of these last two statistical terms have been given previously in this study.

Tables IX and X apply respectively to the bright and dull day conditions for the room treated in Figure 23. Each table is in reality three separate tables. These separate parts are devoted respectively to the desk row adjacent to windows, the desk row at the center of the room, and the desk row most remotely removed from the windows. Each of the three subdivisions of these tables is merely the standardized form for the calculation of statistical constants by the "short-method." All results are labeled by the customary symbols peculiar to this branch of investigation.

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #1, SPRING HILL SCHOOL

FIGURE 23
Illumination Level Distribution Curves

TABLE I
Statistical Data for Curves Above

	Mean Illumination Foot-Candles Desk - Top.	Variability $\sigma_{\text{dist.}} = \left(\frac{\sum F D^2}{N} \right)^{1/2}$	Reliability $PE = \frac{.6745 \sigma_{\text{dist.}}}{\sqrt{N}}$
Bright Day	85.97	39.99	4.32
	19.78	6.27	.62
	9.26	3.17	.32
Dull Day	42.50	18.40	2.10
	9.82	4.02	.40
	4.65	2.33	.22

TABLE IX

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall					
Step	Mid Pt.	F	D	FD	FD ²	Step	Mid Pt.	F	D	FD	FD ²	Step	Mid Pt.	F	D	FD	FD ²
145-150	147.5	2	11	22	242	29-30	29.5	4	12	48	576	29-30	29.5				
140-145	142.5	2	10	20	200	28-29	28.5	0	11			28-29	28.5				
135-140	137.5	1	9	9	81	27-28	27.5	0	10			27-28	27.5				
130-135	132.5	0	8			26-27	26.5	1	9	9	81	26-27	26.5				
125-130	127.5	2	7	14	98	25-26	25.5	9	8	72	576	25-26	25.5				
120-125	122.5	6	6	36	216	24-25	24.5	3	7	21	147	24-25	24.5				
115-120	117.5	0	5			23-24	23.5	0	6			23-24	23.5				
110-115	112.5	0	4			22-23	22.5	1	5	5	25	22-23	22.5				
105-110	107.5	0	3			21-22	21.5	1	4	4	16	21-22	21.5				
100-105	102.5	4	2	8 ¹⁰⁹	16	20-21	20.5	10	3	30	90	20-21	20.5				
95-100	97.5	0	1			19-20	19.5	0	2			19-20	19.5				
90-95	92.5	0	0	0	0	18-19	18.5	1	1	1 ¹¹⁰	1	18-19	18.5				
85-90	87.5	2	-1	-2	2	17-18	17.5	2	0	0	0	17-18	17.5				
80-85	82.5	5	-2	-10	20	16-17	16.5	1	-1	-1	1	16-17	16.5				
75-80	77.5	0	-3			15-16	15.5	3	-2	-6	12	15-16	15.5	4	6	24	144
70-75	72.5	0	-4			14-15	14.5	0	-3			14-15	14.5	0	5		
65-70	67.5	1	-5	-5	25	13-14	13.5	0	-4			13-14	13.5	2	4	8	32
60-65	62.5	3	-6	-18	108	12-13	12.5	5	-5	-25	125	12-13	12.5	2	3	6	18
55-60	57.5	0	-7			11-12	11.5	0	-6			11-12	11.5	1	2	2	4
50-55	52.5	1	-8	-8	64	10-11	10.5	1	-7	-7	49	10-11	10.5	12	1	12 ¹⁵²	12
45-50	47.5	3	-9	-27	243	9-10	9.5	2	-8	-16	128	9-10	9.5	5	0	0	0
40-45	42.5	2	-10	-20	200	8-9	8.5	2	-9	-18	162	8-9	8.5	7	-1	-7	7
35-40	37.5	0	-11			7-8	7.5	1	-10	-10 ⁹³	100	7-8	7.5	0	-2		
30-35	32.5	1	-12	-12	144	6-7	6.5					6-7	6.5	1	-3	-3	9
25-30	27.5	0	-13			5-6	5.5					5-6	5.5	8	-4	-32	128
20-25	22.5	1	-14	-14	196	4-5	4.5					4-5	4.5	3	-5	-15	75
15-20	17.5	2	-15	-30	450	3-4	3.5					3-4	3.5	1	-6	-6 ⁶³	36
10-15	12.5	1	-16	-16 ¹⁶²	256	2-3	2.5					2-3	2.5				
5-10	7.5					1-2	1.5					1-2	1.5				
0-5	2.5					0-1	0.5					0-1	0.5				
C = -1.307	39			-51	2561	C = 2.276	47			+107	2089	C = -2.339	46			-11	465
C ² = 1.708	Av. dist. = 85.97		Std. dist. = 39.98		C ² = 5.180	Av. dist. = 19.78		Std. dist. = 6.27		C ² = .057	Av. dist. = 9.26		Std. dist. = 3.17				
C = -6.54	PE av. = 4.319				PE av. = .617						PE av. = .315						
Statistical Analysis of Data								Building: Spring Hill				Room: 2		Conditions: Bright + Clear			

TABULATION OF ILLUMINATION
FOR
BRIGHT DAYS IN ROOM #1, SPRING HILL SCHOOL

TABLE X

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall					
Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²
145-150	147.5					29-30	29.5					29-30	29.5				
140-145	142.5					28-29	28.5					28-29	28.5				
135-140	137.5					27-28	27.5					27-28	27.5				
130-135	132.5					26-27	26.5					26-27	26.5				
125-130	127.5					25-26	25.5					25-26	25.5				
120-125	122.5					24-25	24.5					24-25	24.5				
115-120	117.5					23-24	23.5					23-24	23.5				
110-115	112.5					22-23	22.5					22-23	22.5				
105-110	107.5					21-22	21.5					21-22	21.5				
100-105	102.5					20-21	20.5					20-21	20.5				
95-100	97.5					19-20	19.5	1	10	10	100	19-20	19.5				
90-95	92.5	1	10	10	100	18-19	18.5	0	9			18-19	18.5				
85-90	87.5	0	9			17-18	17.5	0	8			17-18	17.5				
80-85	82.5	1	8	8	64	16-17	16.5	1	7	7	49	16-17	16.5				
75-80	77.5	1	7	7	49	15-16	15.5	3	6	18	108	15-16	15.5				
70-75	72.5	1	6	6	36	14-15	14.5	1	5	5	25	14-15	14.5				
65-70	67.5	0	5			13-14	13.5	4	4	16	64	13-14	13.5				
60-65	62.5	2	4	8	32	12-13	12.5	6	3	18	54	12-13	12.5	1	9	9	81
55-60	57.5	0	3			11-12	11.5	2	2	4	8	11-12	11.5	0	8		
50-55	52.5	3	2	6	12	10-11	10.5	8	1	8	8	10-11	10.5	2	7	14	98
45-50	47.5	5	1	5+50	5	9-10	9.5	3	0	0+36	0	9-10	9.5	1	6	6	36
40-45	42.5	3	0	0	0	8-9	8.5	3	-1	-3	4	8-9	8.5	2	5	10	50
35-40	37.5	3	-1	-3	3	7-8	7.5	1	-2	-2	4	7-8	7.5	0	4		
30-35	32.5	7	-2	-14	28	6-7	6.5	4	-3	-12	36	6-7	6.5	5	3	15	45
25-30	27.5	3	-3	-9	27	5-6	5.5	3	-4	-12	48	5-6	5.5	6	2	12	24
20-25	22.5	2	-4	-8	32	4-5	4.5	2	-5	-10	50	4-5	4.5	10	1	10+76	10
15-20	17.5	2	-5	-10	50	3-4	3.5	3	-6	-18	108	3-4	3.5	11	0	0	0
10-15	12.5	1	-6	-6-50	36	2-3	2.5	2	-7	-14-71	98	2-3	2.5	15	-1	-15-15	15
5-10	7.5					1-2	1.5					1-2	1.5				
0-5	2.5					0-1	0.5					0-1	0.5				
C = 0		35		0	474	C = .319		47		+15	764	C = 1.15		53		+61	359
C ² = 0		Av. dist. = 42.5 $\sigma_{dist.}$ = 18.4				C ² = .102		Av. dist. = 9.82 $\sigma_{dist.}$ = 4.02				C ² = 1.323		Av. dist. = 4.65 $\sigma_{dist.}$ = 2.33			
C = 0																	
		PE _{av.} = 2.098						PE _{av.} = .395						PE _(av.) = .216			

Statistical Analysis of Data

Building: Spring Hill

Room: 1

Conditions: Dull + Cloudy

TABULATION OF ILLUMINATION
FOR
DULL DAYS IN ROOM #1, SPRING HILL SCHOOL

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #2, CHESTNUT STREET SCHOOL

FIGURE 24
Illumination Level Distribution Curves

TABLE II
Statistical Data for Curves Above

	Mean Illumination Foot-Candles on Desk - Top.	Variability $\sigma = \left(\frac{\sum FD^2 - c}{N} \right)^{1/2}$ dist.	Reliability $PE = \frac{.6745}{\sigma \sqrt{N}} \sqrt{(dist.)}$
Bright Day	42.89	33.06	4.37
	12.35	4.56	.59
	12.65	6.63	.86
Dull Day	38.75	27.43	2.67
	9.67	5.86	.52
	10.13	7.63	.72

TABLE XI

Seats Adjacent to Windows						Seats of Center						Seats Adjacent to Opposite Wall					
Step	M.I.Pt.	F	D	FD	FD ²	Step	M.I.Pt.	F	D	FD	FD ²	Step	M.I.Pt.	F	D	FD	FD ²
145-150	147.5					29-30	29.5					29-30	29.5				
140-145	142.5	1	20	20	400	28-29	28.5					28-29	28.5				
135-140	137.5	0	19			27-28	27.5					27-28	27.5	1	15	15	225
130-135	132.5	0	18			26-27	26.5					26-27	26.5	0	14		
125-130	127.5	0	17			25-26	25.5					25-26	25.5	2	13	26	338
120-125	122.5	1	16	16	256	24-25	24.5					24-25	24.5	0	12		
115-120	117.5	0	15			23-24	23.5					23-24	23.5	0	11		
110-115	112.5	0	14			22-23	22.5	1	11	11	121	22-23	22.5	0	10		
105-110	107.5	0	13			21-22	21.5	0	10			21-22	21.5	1	9	9	81
100-105	102.5	1	12	12	144	20-21	20.5	1	9	9	81	20-21	20.5	2	8	16	128
95-100	97.5	0	11			19-20	19.5	1	8	8	64	19-20	19.5	0	7		
90-95	92.5	0	10			18-19	18.5	2	7	14	98	18-19	18.5	0	6		
85-90	87.5	0	9			17-18	17.5	0	6			17-18	17.5	0	5		
80-85	82.5	1	8	8	64	16-17	16.5	0	5			16-17	16.5	0	4		
75-80	77.5	0	7			15-16	15.5	2	4	8	32	15-16	15.5	2	3	6+72	18
70-75	72.5	0	6			14-15	14.5	1	3	3	9	14-15	14.5	0	2		
65-70	67.5	0	5			13-14	13.5	2	2	4	8	13-14	13.5	0	1		
60-65	62.5	1	4	5	20	12-13	12.5	3	1	3+60	3	12-13	12.5	4	0	0	0
55-60	57.5	0	3			11-12	11.5	2	0	0	0	11-12	11.5	1	-1	-1	1
50-55	52.5	0	2			10-11	10.5	5	-1	-5	5	10-11	10.5	4	-2	-8	16
45-50	47.5	2	1	2+63	2	9-10	9.5	1	-2	-2	4	9-10	9.5	1	-3	-3	9
40-45	42.5	2	0	0	0	8-9	8.5	1	-3	-3	9	8-9	8.5	2	-4	-8	32
35-40	37.5	2	-1	-2	2	7-8	7.5	0	-4			7-8	7.5	0	-5		
30-35	32.5	1	-2	-2	4	6-7	6.5	3	-5	-15	75	6-7	6.5	4	-6	-24	144
25-30	27.5	5	-3	-15	45	5-6	5.5	2	-6	-12-37	72	5-6	5.5	1	-7	-7	49
20-25	22.5	4	-4	-16	64	4-5	4.5					4-5	4.5	1	-8	-8	64
15-20	17.5	4	-5	-20	100	3-4	3.5					3-4	3.5	1	-9	-9-68	81
10-15	12.5	1	-6	-6-61	36	2-3	2.5					2-3	2.5				
5-10	7.5					1-2	1.5					1-2	1.5				
0-5	2.5					0-1	0.5					0-1	0.5				
c = .077		26		+2	1137	c = .851		27		+23	581	c = .148		27		+4	1186
c ² = .0059		Av. dist. = 42.89		$\sigma_{dist.} = 33.06$		c ² = .724		Av. dist. = 12.35		$\sigma_{dist.} = 4.56$		c ² = .022		Av. dist. = 12.65		$\sigma_{dist.} = 6.63$	
C = .385																	
		PE _{av.} = 4.37						PE _{av.} = .592						PE _(av.) = .860			
Statistical Analysis of Data								Building: Chestnut Street				Room: 2		Conditions: Bright and Clear			

TABULATION OF ILLUMINATION
FOR

BRIGHT DAYS IN ROOM #2, CHESTNUT STREET SCHOOL

TABLE XII

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall						
Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	
145-150	147.5					29-30	29.5					29-30	29.5	3	20	60	1200	
140-145	142.5					28-29	28.5					28-29	28.5	0	19			
135-140	137.5					27-28	27.5	1	19	19	361	27-28	27.5	0	18			
130-135	132.5					26-27	26.5	0	18			26-27	26.5	0	17			
125-130	127.5					25-26	25.5	0	17			25-26	25.5	2	16	32	512	
120-125	122.5	1	18	18	324	24-25	24.5	0	16			24-25	24.5	0	15			
115-120	117.5	0	17			23-24	23.5	1	15	15	225	23-24	23.5	0	14			
110-115	112.5	0	16			22-23	22.5	1	14	14	196	22-23	22.5	0	13			
105-110	107.5	0	15			21-22	21.5	0	13			21-22	21.5	2	12	24	288	
100-105	102.5	2	14	28	392	20-21	20.5	1	12	12	144	20-21	20.5	0	11			
95-100	97.5	0	13			19-20	19.5	2	11	22	242	19-20	19.5	0	10			
90-95	92.5	0	12			18-19	18.5	0	10			18-19	18.5	2	9	18	162	
85-90	87.5	1	11	11	121	17-18	17.5	0	9			17-18	17.5	0	8			
80-85	82.5	3	10	30	300	16-17	16.5	3	8	24	192	16-17	16.5	0	7			
75-80	77.5	0	9			15-16	15.5	3	7	21	147	15-16	15.5	2	6	12	72	
70-75	72.5	2	8	16	128	14-15	14.5	1	6	6	36	14-15	14.5	1	5	5	25	
65-70	67.5	0	7			13-14	13.5	1	5	5	25	13-14	13.5	1	4	4	16	
60-65	62.5	1	6	6	36	12-13	12.5	3	4	12	48	12-13	12.5	1	3	3	9	
55-60	57.5	0	5			11-12	11.5	1	3	3	9	11-12	11.5	0	2			
50-55	52.5	0	4			10-11	10.5	4	2	8	16	10-11	10.5	4	1	4+162	4	
45-50	47.5	2	3	6	18	9-10	9.5	4	1	4+165	4	9-10	9.5	2	0	0	0	
40-45	42.5	2	2	4	8	8-9	8.5	7	0	0	0	8-9	8.5	6	-1	-6	6	
35-40	37.5	3	1	3+122	3	7-8	7.5	1	-1	-1	1	7-8	7.5	3	-2	-6	12	
30-35	32.5	6	0	0	0	6-7	6.5	2	-2	-4	8	6-7	6.5	3	-3	-9	27	
25-30	27.5	6	-1	-6	6	5-6	5.5	9	-3	-27	81	5-6	5.5	5	-4	-20	80	
20-25	22.5	9	-2	-18	36	4-5	4.5	4	-4	-16	64	4-5	4.5	3	-5	-15	75	
15-20	17.5	3	-3	-9	27	3-4	3.5	5	-5	-25	125	3-4	3.5	3	-6	-18	108	
10-15	12.5	6	-4	-24	96	2-3	2.5	4	-6	-24-97	144	2-3	2.5	8	-7	-56-130	392	
5-10	7.5	1	-5	-5-62	25	1-2	1.5					1-2	1.5					
0-5	2.5					0-1	0.5					0-1	0.5					
C = 1.25		48			+60	1520	C = 1.17		58		+68	2068	C = .627		51		+32	2908
C ² = 1.563		Av. dist. = 38.75 σ _{dist} = 27.43				C ² = 1.37	Av. dist. = 9.67 σ _{dist} = 5.86				C ² = .393	Av. dist. = 10.13 σ _{dist} = 7.63				PE _{av.} = .724		
C = 6.25																		
		PE _{av.} = 2.671				PE _{av.} = .5186												

Statistical Analysis of Data

Building: Chestnut Street

Room: 2

Conditions: Dull and Cloudy

TABULATION OF ILLUMINATION
FOR
DULL DAYS IN ROOM #2, CHESTNUT STREET SCHOOL

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #3, ROSE HILL SCHOOL

FIGURE 25
Illumination Level Distribution Curves

TABLE III
Statistical Data for Curves Above

	Mean Illumination Foot-Candles Desk - Top.	Variability $\sigma_{\text{dist.}} = \left(\frac{\sum F D^2}{N} \right)^{1/2}$	Reliability $PE = \frac{.6745 \sigma_{\text{dist.}}}{\sqrt{N}}$
Bright Day	56.64	23.59	2.69
	11.61	4.33	.49
	8.06	3.85	.41
Dull Day	34.50	18.29	2.25
	8.67	4.27	.48
	5.98	4.56	.62

TABLE XIII

Seats Adjacent to Windows						Seats of Center						Seats Adjacent to Opposite Wall									
Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²				
145-150	147.5					29-30	29.5					29-30	29.5								
140-145	142.5					28-29	28.5					28-29	28.5								
135-140	137.5					27-28	27.5					27-28	27.5								
130-135	132.5					26-27	26.5					26-27	26.5								
125-130	127.5					25-26	25.5					25-26	25.5								
120-125	122.5					24-25	24.5					24-25	24.5								
115-120	117.5					23-24	23.5					23-24	23.5								
110-115	112.5					22-23	22.5					22-23	22.5								
105-110	107.5					21-22	21.5	1	10	10	100	21-22	21.5								
100-105	102.5	2	10	20	200	20-21	20.5	1	9	9	81	20-21	20.5	1	13	13	169				
95-100	97.5	1	9	9	81	19-20	19.5		8			19-20	19.5		12						
90-95	92.5	1	8	8	64	18-19	18.5	1	7	7	49	18-19	18.5	1	11	11	121				
85-90	87.5	1	7	7	49	17-18	17.5	1	6	6	36	17-18	17.5		10						
80-85	82.5	3	6	18	108	16-17	16.5	2	5	10	50	16-17	16.5	1	9	9	81				
75-80	77.5		5			15-16	15.5	1	4	4	16	15-16	15.5		8						
70-75	72.5	1	4	4	16	14-15	14.5	1	3	3	9	14-15	14.5		7						
65-70	67.5	1	3	3	9	13-14	13.5	2	2	4	8	13-14	13.5	1	6	6	36				
60-65	62.5	3	2	6	12	12-13	12.5	4	1	4+57	4	12-13	12.5	1	5	5	25				
55-60	57.5	5	1	5+80	5	11-12	11.5	8	0	0	0	11-12	11.5	1	4	4	16				
50-55	52.5	4	0	0	0	10-11	10.5	3	-1	-3	3	10-11	10.5	2	3	6	18				
45-50	47.5	2	-1	-2	2	9-10	9.5	2	-2	-4	8	9-10	9.5	3	2	6	12				
40-45	42.5	2	-2	-4	8	8-9	8.5	2	-3	-6	18	8-9	8.5	8	1	8+68	8				
35-40	37.5	2	-3	-6	18	7-8	7.5		-4			7-8	7.5	4	0	0	0				
30-35	32.5	2	-4	-8	32	6-7	6.5	1	-5	-5	25	6-7	6.5	4	-1	-4	4				
25-30	27.5	2	-5	-10	50	5-6	5.5	2	-6	-12	72	5-6	5.5	5	-2	-10	20				
20-25	22.5	1	-6	-6	36	4-5	4.5	1	-7	-7	49	4-5	4.5	6	-3	-18	54				
15-20	17.5	1	-7	-7	49	3-4	3.5	2	-8	-16-53	128	3-4	3.5	2	-4	-8	32				
10-15	12.5	1	-8	-8-51	64	2-3	2.5					2-3	2.5	1	-5	-5-45	25				
5-10	7.5					1-2	1.5					1-2	1.5								
0-5	2.5					0-1	0.5					0-1	0.5								
C = .828		35			+29	803	c = .114		35			+4	656	c = .561		41		+23	621		
C ² = .686		Av. dist. = 56.64		σ _{dist.} = 23.59			c ² = .013		Av. dist. = 11.61		σ _{dist.} = 4.33		c ² = .315		Av. dist. = 8.06		σ _{dist.} = 3.85				
C = 4.14																					
		PE _{av.} = 2.69								PE _{av.} = .493								PE _{av.} = .406			

Statistical Analysis of Data

Building: Rose Hill

Room: 3

Conditions: Bright

TABULATION OF ILLUMINATION
FOR
BRIGHT DAYS IN ROOM #3, ROSE HILL SCHOOL

TABLE XIV

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall					
Step	M.d.Pk.	F	D	FD	FD ²	Step	M.d.Pk.	F	D	FD	FD ²	Step	M.d.Pk.	F	D	FD	FD ²
145-150	147.5					29-30	29.5					29-30	29.5				
140-145	142.5					28-29	28.5					28-29	28.5				
135-140	137.5					27-28	27.5					27-28	27.5				
130-135	132.5					26-27	26.5					26-27	26.5				
125-130	127.5					25-26	25.5					25-26	25.5				
120-125	122.5					24-25	24.5					24-25	24.5				
115-120	117.5					23-24	23.5					23-24	23.5				
110-115	112.5					22-23	22.5					22-23	22.5				
105-110	107.5					21-22	21.5					21-22	21.5				
100-105	102.5					20-21	20.5	1	12	12	144	20-21	20.5	2	14	28	392
95-100	97.5					19-20	19.5		11			19-20	19.5		13		
90-95	92.5					18-19	18.5		10			18-19	18.5		12		
85-90	87.5					17-18	17.5		9			17-18	17.5		11		
80-85	82.5	1	11	11	121	16-17	16.5	1	8	8	64	16-17	16.5		10		
75-80	77.5		10			15-16	15.5	1	7	7	49	15-16	15.5		9		
70-75	72.5	1	9	9	81	14-15	14.5	2	6	12	72	14-15	14.5		8		
65-70	67.5		8			13-14	13.5	2	5	10	50	13-14	13.5		7		
60-65	62.5	1	7	7	49	12-13	12.5	1	4	4	16	12-13	12.5		6		
55-60	57.5	2	6	12	72	11-12	11.5		3			11-12	11.5		5		
50-55	52.5	1	5	5	25	10-11	10.5	3	2	6	12	10-11	10.5		4		
45-50	47.5	1	4	4	16	9-10	9.5	3	1	3+62	3	9-10	9.5		3		
40-45	42.5	3	3	9	27	8-9	8.5	8	0	0	0	8-9	8.5	1	2	2	4
35-40	37.5	2	2	4	8	7-8	7.5		-1			7-8	7.5	1	1	1+31	1
30-35	32.5	4	1	4+65	4	6-7	6.5	2	-2	-4	8	6-7	6.5	2	0	0	0
25-30	27.5	3	0	0	0	5-6	5.5	3	-3	-9	27	5-6	5.5	7	-1	-7	7
20-25	22.5	4	-1	-4	4	4-5	4.5	4	-4	-16	64	4-5	4.5	3	-2	-6	12
15-20	17.5	2	-2	-4	8	3-4	3.5	3	-5	-15	75	3-4	3.5	6	-3	-18	54
10-15	12.5	5	-3	-15-23	45	2-3	2.5	2	-6	-12-56	72	2-3	2.5	2	-4	-8	32
5-10	7.5					1-2	1.5					1-2	1.5	1	-5	-5-44	25
0-5	2.5					0-1	0.5					0-1	0.5				
c = 1.40		30		+42	460	c = .116		36		+6	656	c = -.52		25		-13	527
c ² = 1.96		Av. dist. = 34.5 σ _{dist.} = 18.29				c ² = .028		Av. dist. = 8.67 σ _{dist.} = 4.27				c ² = .270		Av. dist. = 5.98 σ _{dist.} = 4.56			
C = 7.00																	
		PE _{av.} = 2.252						PE _{av.} = .479						PE _{av.} = .6153			
Statistical Analysis of Data								Building: Rose Hill				Room: 3		Conditions: Dull.			

TABULATION OF ILLUMINATION
FOR
DULL DAYS IN ROOM #3, ROSE HILL SCHOOL

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #4, PORT FULTON SCHOOL

FIGURE 26

Illumination Level Distribution Curves

TABLE IV

Statistical Data for Curves Above

	Mean Illumination Foot-Candles Desk-Top	Variability $\sigma_{dist} = \left(\frac{\sum FD^2 - \bar{D}^2}{N} \right)^{1/2}$	Reliability $PE = \frac{.6745 \sigma_{dist}}{\text{av. } \sqrt{N}}$
Bright Day	44.30	17.54	2.37
	14.80	4.65	.55
	11.83	3.77	.46
Dull Day	34.91	17.92	2.33
	12.90	6.16	.76
	8.02	3.60	.44

TABLE XV

Seats Adjacent to Windows						Seats of Center						Seats Adjacent to Opposite Wall						
Step	M.I.Pt.	F	D	FD	FD ²	Step	M.I.Pt.	F	D	FD	FD ²	Step	M.I.Pt.	F	D	FD	FD ²	
145-150	147.5					29-30	29.5					29-30	29.5	1	18	18	324	
140-145	142.5					28-29	28.5					28-29	28.5		17			
135-140	137.5					27-28	27.5					27-28	27.5		16			
130-135	132.5					26-27	26.5					26-27	26.5		15			
125-130	127.5					25-26	25.5	2	11	22	242	25-26	25.5		14			
120-125	122.5					24-25	24.5		10			24-25	24.5		13			
115-120	117.5					23-24	23.5		9			23-24	23.5		12			
110-115	112.5					22-23	22.5		8			22-23	22.5		11			
105-110	107.5					21-22	21.5	1	7	7	49	21-22	21.5		10			
100-105	102.5	1	14	14	196	20-21	20.5	3	6	18	108	20-21	20.5	2	9	18	162	
95-100	97.5		13			19-20	19.5	1	5	5	25	19-20	19.5		8			
90-95	92.5		12			18-19	18.5		4			18-19	18.5	1	7	7	49	
85-90	87.5		11			17-18	17.5	1	3	3	9	17-18	17.5		6			
80-85	82.5		10			16-17	16.5	2	2	4	8	16-17	16.5		5			
75-80	77.5		9			15-16	15.5	3	1	3+62	3	15-16	15.5	1	4	4	16	
70-75	72.5		8			14-15	14.5	6	0	0	0	14-15	14.5	2	3	6	18	
65-70	67.5	1	7	7	49	13-14	13.5	4	-1	-4	4	13-14	13.5	4	2	8	16	
60-65	62.5	1	6	6	36	12-13	12.5		-2			12-13	12.5	3	1	3+46	3	
55-60	57.5	2	5	10	50	11-12	11.5	2	-3	-6	18	11-12	11.5	5	0	0	0	
50-55	52.5	3	4	12	48	10-11	10.5	5	-4	-20	80	10-11	10.5	4	-1	-4	4	
45-50	47.5	4	3	12	36	9-10	9.5	1	-5	-5	25	9-10	9.5		-2			
40-45	42.5	2	2	4	8	8-9	8.5		-6			8-9	8.5	3	-3	-9	27	
35-40	37.5	2	1	2+67	2	7-8	7.5		-7			7-8	7.5		-4			
30-35	32.5	5	0	0	0	6-7	6.5	1	-8	-8	64	6-7	6.5	1	-5	-5	25	
25-30	27.5	2	-1	-2	2	5-6	5.5	1	-9	-9-52	81	5-6	5.5	3	-6	-18-36	108	
20-25	22.5	1	-2	-2	4	4-5	4.5					4-5	4.5					
15-20	17.5		-3			3-4	3.5					3-4	3.5					
10-15	12.5	1	-4	-4-8	16	2-3	2.5					2-3	2.5					
5-10	7.5					1-2	1.5					1-2	1.5					
0-5	2.5					0-1	0.5					0-1	0.5					
C = 2.36		25			159	447	C = .303		33		+10	716	C = .333		30		+10	428
C ² = 5.570		Av. dist. = 44.30 σ _{dist} = 17.54				C ² = .092		Av. dist. = 14.80 σ _{dist} = 4.65				C ² = .111		Av. dist. = 11.83 σ _{dist} = 3.76				
C = 11.8																		
PE _{av.} = 2.366						PE _{av.} = .5458						PE _{av.} = .4633						
Statistical Analysis of Data										Building: Port Fulton		Room: 4		Conditions: Bright.				

TABULATION OF ILLUMINATION
FOR
BRIGHT DAYS IN ROOM #4, PORT FULTON SCHOOL

TABLE XVI

Seats Adjacent to Windows						Seats of Center						Seats Adjacent to Opposite Wall					
Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²
145-150	147.5					29-30	29.5					29-30	29.5	1	22	22	484
140-145	142.5					28-29	28.5					28-29	28.5		21		
135-140	137.5					27-28	27.5					27-28	27.5		20		
130-135	132.5					26-27	26.5					26-27	26.5		19		
125-130	127.5					25-26	25.5	3	13	39		25-26	25.5		18		
120-125	122.5					24-25	24.5		12			24-25	24.5		17		
115-120	117.5					23-24	23.5	1	11	11	121	23-24	23.5		16		
110-115	112.5					22-23	22.5	2	10	20	200	22-23	22.5		15		
105-110	107.5					21-22	21.5		9			21-22	21.5		14		
100-105	102.5					20-21	20.5	2	8	16	108	20-21	20.5		13		
95-100	97.5					19-20	19.5		7			19-20	19.5		12		
90-95	92.5					18-19	18.5		6			18-19	18.5		11		
85-90	87.5					17-18	17.5		5			17-18	17.5		10		
80-85	82.5	1	9	9	81	16-17	16.5		4			16-17	16.5		9		
75-80	77.5		8			15-16	15.5	3	3	9	27	15-16	15.5	1	8	8	64
70-75	72.5	1	7	7	49	14-15	14.5	1	2	2	4	14-15	14.5		7		
65-70	67.5		6			13-14	13.5	1	1	1+98	1	13-14	13.5		6		
60-65	62.5	1	5	5	25	12-13	12.5	4	0	0	0	12-13	12.5	3	5	15	75
55-60	57.5		4			11-12	11.5	1	-1	-1	1	11-12	11.5	3	4	12	48
50-55	52.5	1	3	3	9	10-11	10.5	1	-2	-2	4	10-11	10.5	2	3	6	18
45-50	47.5	2	2	4	8	9-10	9.5	1	-3	-3	9	9-10	9.5		2		
40-45	42.5	3	1	3+31	3	8-9	8.5		-4			8-9	8.5	3	1	3+66	3
35-40	37.5	4	0	0	0	7-8	7.5	1	-5	-5	25	7-8	7.5	3	0	0	0
30-35	32.5	3	-1	-3	3	6-7	6.5		-6			6-7	6.5	2	-1	-2	2
25-30	27.5	2	-2	-4	8	5-6	5.5	4	-7	-28	196	5-6	5.5	4	-2	-8	16
20-25	22.5	3	-3	-9	27	4-5	4.5	1	-8	-8	64	4-5	4.5	2	-3	-6	18
15-20	17.5	1	-4	-4	16	3-4	3.5	2	-9	-18	162	3-4	3.5	1	-4	-4	16
10-15	12.5	5	-5	-25-45	125	2-3	2.5	1	-10	-10	100	2-3	2.5	6	-5	-30-50	150
5-10	7.5					1-2	1.5	1	-11	-11-86	121	1-2	1.5				
0-5	2.5					0-1	0.5					0-1	0.5				
C = -.518		27		-14	354	C = .4		30		+12	1143	C = .516		31		+16	410
C ² = .268		Av. dist. = 34.91 σ _{dist.} = 17.92				C ² = .16		Av. dist. = 12.90 σ _{dist.} = 6.16				C ² = .266		Av. dist. = 8.02 σ _{dist.} = 3.60			
C = -2.59																	
PE _{av} = 2.326					PE _{av} = .7585					PE _{av} = .4361							

Statistical Analysis of Data

Building: Port Fulton

Room: 4

Conditions: Dull

TABULATION OF ILLUMINATION
FOR

DULL DAYS IN ROOM #4, PORT FULTON SCHOOL

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #5, INGRAMVILLE SCHOOL

FIGURE 27
Illumination Level Distribution Curves

TABLE VI
Statistical Data for Curves Above

	Mean Illumination Foot-Candles on Desk-Top	Variability $\sigma_{\text{dist.}} = \left(\frac{\sum F D^2 - \bar{F}^2}{N} \right)^{1/2}$	Reliability $PE = \frac{.6745 \sqrt{\text{dist.}}}{\text{av. } \sqrt{N}}$
Bright Day	64.25	35.71	3.67
	19.05	7.12	.76
	11.08	6.71	.79
Dull Day	32.64	12.60	1.39
	10.11	4.28	.48
	5.38	2.60	.30

TABLE XVII

Seats Adjacent to Windows						Seats of Center						Seats Adjacent to Opposite Wall						
Step	M.d.P.	F	D	FD	FD ²	Step	M.d.P.	F	D	FD	FD ²	Step	M.d.P.	F	D	FD	FD ²	
145-150	147.5	1	12	12	144	29-30	29.5	1	6	6	36	29-30	29.5	1	19	19	361	
140-145	142.5	1	11	11	121	28-29	28.5		5			28-29	28.5		18			
135-140	137.5		10			27-28	27.5	2	4	8	32	27-28	27.5		17			
130-135	132.5		9			26-27	26.5	3	3	9	27	26-27	26.5		16			
125-130	127.5		8			25-26	25.5	2	2	4	8	25-26	25.5	1	15	15	225	
120-125	122.5	1	7	7	49	24-25	24.5	4	1	4+31	4	24-25	24.5		14			
115-120	117.5		6			23-24	23.5	6	0	0	0	23-24	23.5		13			
110-115	112.5		5			22-23	22.5	3	-1	-3	4	22-23	22.5	1	12	12	144	
105-110	107.5	1	4	4	16	21-22	21.5	2	-2	-4	8	21-22	21.5	1	11	11	121	
100-105	102.5	2	3	6	18	20-21	20.5	1	-3	-3	9	20-21	20.5	1	10	10	100	
95-100	97.5		2			19-20	19.5		-4			19-20	19.5	1	9	9	81	
90-95	92.5	4	1	4	4	18-19	18.5	1	-5	-5	25	18-19	18.5		8			
85-90	87.5	6	0	0+44	0	17-18	17.5		-6			17-18	17.5		7			
80-85	82.5	2	-1	-2	2	16-17	16.5	1	-7	-7	49	16-17	16.5		6			
75-80	77.5	1	-2	-2	4	15-16	15.5	1	-8	-8	64	15-16	15.5	2	5	10	50	
70-75	72.5	3	-3	-9	27	14-15	14.5	1	-9	-9	81	14-15	14.5		4			
65-70	67.5	2	-4	-8	32	13-14	13.5	1	-10	-10	100	13-14	13.5	1	3	3	9	
60-65	62.5	1	-5	-5	25	12-13	12.5	1	-11	-11	121	12-13	12.5	2	2	4	8	
55-60	57.5		-6			11-12	11.5		-12			11-12	11.5	3	1	3+96	3	
50-55	52.5		-7			10-11	10.5	2	-13	-26	338	10-11	10.5	3	0	0	0	
45-50	47.5		-8			9-10	9.5	3	-14	-42	588	9-10	9.5		-1			
40-45	42.5		-9			8-9	8.5	3	-15	-45	675	8-9	8.5	1	-2	-2	4	
35-40	37.5	3	-10	-30	300	7-8	7.5		-16			7-8	7.5	1	-3	-3	9	
30-35	32.5	4	-11	-44	484	6-7	6.5	1	-17	-17	289	6-7	6.5	4	-4	-16	64	
25-30	27.5	4	-12	-48	576	5-6	5.5		-18			5-6	5.5	5	-5	-25	125	
20-25	22.5	5	-13	-65	845	4-5	4.5	1	-19	-19-209	361	4-5	4.5	4	-6	-24	144	
15-20	17.5		-14			3-4	3.5					3-4	3.5	1	-7	-7-77	49	
10-15	12.5	1	-15	-15	225	2-3	2.5					2-3	2.5					
5-10	7.5	1	-16	-16-24	256	1-2	1.5					1-2	1.5					
0-5	2.5					0-1	0.5					0-1	0.5					
C = -4.651	43			-200	3128	C = -4.45	40			-178	2819	C = .575	33			+19	1497	
C ² = 21.632	Av. dist. = 64.25					σ _{dist.} = 35.71	C ² = 19.80	Av. dist. = 19.05				σ _{dist.} = 7.12	C ² = .331	Av. dist. = 11.08				σ _{dist.} = 6.71
C = -23.26	PE _{av.} = 3.67						PE _{av.} = .7591						PE _{av.} = .7879					
Statistical Analysis of Data						Building: Ingramville						Room: 5		Conditions: Bright				

TABULATION OF ILLUMINATION
FOR
BRIGHT DAYS IN ROOM #5, INGRAMVILLE SCHOOL

TABLE XVIII

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall						
Step	M.d.P.	F	D	FD	FD ²	Step	M.d.P.	F	D	FD	FD ²	Step	M.d.P.	F	D	FD	FD ²	
145-150	147.5					29-30	29.5					29-30	29.5					
140-145	142.5					28-29	28.5					28-29	28.5					
135-140	137.5					27-28	27.5					27-28	27.5					
130-135	132.5					26-27	26.5					26-27	26.5					
125-130	127.5					25-26	25.5					25-26	25.5					
120-125	122.5					24-25	24.5					24-25	24.5					
115-120	117.5					23-24	23.5					23-24	23.5					
110-115	112.5					22-23	22.5					22-23	22.5					
105-110	107.5					21-22	21.5					21-22	21.5					
100-105	102.5					20-21	20.5	2	10	20	200	20-21	20.5					
95-100	97.5					19-20	19.5		9			19-20	19.5					
90-95	92.5					18-19	18.5	1	8	8	64	18-19	18.5					
85-90	87.5					17-18	17.5		7			17-18	17.5					
80-85	82.5					16-17	16.5		6			16-17	16.5					
75-80	77.5					15-16	15.5	1	5	5	25	15-16	15.5	1	11	11	121	
70-75	72.5					14-15	14.5	2	4	8	32	14-15	14.5		10			
65-70	67.5	1	7	7	49	13-14	13.5	2	3	6	18	13-14	13.5		9			
60-65	62.5	1	6	6	36	12-13	12.5	1	2	2	4	12-13	12.5		8			
55-60	57.5		5			11-12	11.5	4	1	4+53	4	11-12	11.5		7			
50-55	52.5		4			10-11	10.5	5	0	0	0	10-11	10.5		6			
45-50	47.5	2	3	6	18	9-10	9.5	2	-1	-2	2	9-10	9.5	1	5	5	25	
40-45	42.5	4	2	8	16	8-9	8.5	4	-2	-8	16	8-9	8.5	2	4	8	32	
35-40	37.5	8	1	8+35	8	7-8	7.5	4	-3	-12	36	7-8	7.5	4	3	12	36	
30-35	32.5	7	0	0	0	6-7	6.5	2	-4	-8	32	6-7	6.5	2	2	4	8	
25-30	27.5	5	-1	-5	5	5-6	5.5	2	-5	-10	50	5-6	5.5	4	1	4+44	4	
20-25	22.5	3	-2	-6	12	4-5	4.5	2	-6	-12	72	4-5	4.5	12	0	0	0	
15-20	17.5	2	-3	-6	18	3-4	3.5	1	-7	-7	49	3-4	3.5	4	-1	-4	4	
10-15	12.5	3	-4	-12	48	2-3	2.5	1	-8	-8-61	64	2-3	2.5	2	-2	-4	8	
5-10	7.5	1	-5	-5-34	25	1-2	1.5					1-2	1.5	2	-3	-6-14	18	
0-5	2.5					0-1	0.5					0-1	0.5					
C = .027		37			+1	235	C = .388		36		-14	668	C = .882		34		+30	256
C ² = .00073		Av. dist. = 32.64		$\sigma_{dist.} = 12.60$		C ² = .151		Av. dist. = 10.11		$\sigma_{dist.} = 4.29$		C ² = .778		Av. dist. = 5.38		$\sigma_{dist.} = 2.60$		
C = .135																		
PE _{av} = 1.397						PE _{av} = .4822						PE _{av} = .3005						

Statistical Analysis of Data

Building: Ingramville

Room: 5

Conditions: Dull.

TABULATION OF ILLUMINATION
FOR
DULL DAYS IN ROOM #5, INGRAMVILLE SCHOOL

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #6, TAYLOR SCHOOL

FIGURE 28
Illumination Level Distribution Curves

TABLE VII
Statistical Data for Curves Above

	Mean Illumination Foot-Candles on Desk-Top	Variability $\sigma = \frac{(\sum F D^2 - \bar{F}^2)}{N}^{1/2}$	Reliability $PE = \frac{.6745 \sigma_{(dist)}}{\bar{F}}$
Bright Day	49.50	21.78	2.68
	18.65	5.56	.72
	16.32	5.55	.71
Dull Day	62.15	13.69	1.43
	12.62	6.18	.71
	9.47	5.44	.68

TABLE XIX

Seats Adjacent to Windows						Seats of Center						Seats Adjacent to Opposite Wall					
Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²
145-150	147.5					29-30	29.5	2	14	28	392	29-30	29.5	2	12	24	288
140-145	142.5					28-29	28.5		13			28-29	28.5		11		
135-140	137.5					27-28	27.5		12			27-28	27.5		10		
130-135	132.5					26-27	26.5		11			26-27	26.5		9		
125-130	127.5					25-26	25.5	1	10	10	100	25-26	25.5	1	8	8	64
120-125	122.5	1	15	15	225	24-25	24.5		9			24-25	24.5		7		
115-120	117.5		14			23-24	23.5		8			23-24	23.5		6		
110-115	112.5		13			22-23	22.5	5	7	35	245	22-23	22.5		5		
105-110	107.5		12			21-22	21.5	3	6	18	108	21-22	21.5	2	4	8	32
100-105	102.5		11			20-21	20.5	2	5	10	50	20-21	20.5	3	3	9+9	27
95-100	97.5		10			19-20	19.5	2	4	8	32	19-20	19.5		2		
90-95	92.5		9			18-19	18.5		3			18-19	18.5		1		
85-90	87.5	1	8	8	64	17-18	17.5	1	2	2	4	17-18	17.5	4	0	0	0
80-85	82.5	1	7	7	49	16-17	16.5	2	1	2+13	2	16-17	16.5	1	-1	-1	1
75-80	77.5		6			15-16	15.5	3	0	0	0	15-16	15.5	2	-2	-4	8
70-75	72.5	2	5	10	50	14-15	14.5	1	-1	-1	1	14-15	14.5	1	-3	-3	9
65-70	67.5		4			13-14	13.5	1	-2	-2	4	13-14	13.5	1	-4	-4	16
60-65	62.5	1	3	3	9	12-13	12.5		-3			12-13	12.5	3	-5	-15	75
55-60	57.5	2	2	4	8	11-12	11.5		-4			11-12	11.5	2	-6	-12	72
50-55	52.5	6	1	6+53	6	10-11	10.5	2	-5	-10	50	10-11	10.5	5	-7	-35	245
45-50	47.5	4	0	0	0	9-10	9.5		-6			9-10	9.5	1	-8	-8-82	64
40-45	42.5	1	-1	-1	1	8-9	8.5	1	-7	-7	49	8-9	8.5				
35-40	37.5	2	-2	-4	8	7-8	7.5	1	-8	-8-28	64	7-8	7.5				
30-35	32.5	4	-3	-12	36	6-7	6.5					6-7	6.5				
25-30	27.5	2	-4	-8	32	5-6	5.5					5-6	5.5				
20-25	22.5	2	-5	-10	50	4-5	4.5					4-5	4.5				
15-20	17.5	1	-6	-6-41	36	3-4	3.5					3-4	3.5				
10-15	12.5					2-3	2.5					2-3	2.5				
5-10	7.5					1-2	1.5					1-2	1.5				
0-5	2.5					0-1	0.5					0-1	0.5				
C = .4	30			+12	574	C = 3.148	27			+85	1101	C = -1.178	28			-33	901
C ² = .16	Av. dist. = 49.50 $\sigma_{dist.} = 21.78$					C ² = 9.91	Av. dist. = 18.65 $\sigma_{dist.} = 5.56$					C ² = 1.388	Av. dist. = 16.32 $\sigma_{dist.} = 5.55$				
C = 2.0																	
PE _{av.} = 2.682					PE _{av.} = .7211					PE _{av.} = .7073							

Statistical Analysis of Data

Building: Taylor

Room: 6

Conditions: Bright

TABULATION OF ILLUMINATION
FOR
BRIGHT DAYS IN ROOM #6, TAYLOR SCHOOL

TABLE XX

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall					
Step	M.I.P.	F	D	FD	FD ²	Step	M.I.P.	F	D	FD	FD ²	Step	M.I.P.	F	D	FD	FD ²
145-150	147.5	1	16	16	256	29-30	29.5	1	19	19	361	29-30	29.5				
140-145	142.5	2	15	30	450	28-29	28.5		18			28-29	28.5				
135-140	137.5		14			27-28	27.5		17			27-28	27.5				
130-135	132.5		13			26-27	26.5		16			26-27	26.5				
125-130	127.5		12			25-26	25.5		15			25-26	25.5				
120-125	122.5		11			24-25	24.5		14			24-25	24.5				
115-120	117.5		10			23-24	23.5		13			23-24	23.5				
110-115	112.5		9			22-23	22.5	1	12	12	144	22-23	22.5	1	12	12	144
105-110	107.5		8			21-22	21.5	3	11	33	363	21-22	21.5	1	11	11	121
100-105	102.5	1	7	7	49	20-21	20.5	1	10	10	100	20-21	20.5	1	10	10	100
95-100	97.5		6			19-20	19.5	1	9	9	81	19-20	19.5		9		
90-95	92.5	1	5	5	25	18-19	18.5	2	8	16	128	18-19	18.5	1	8	8	64
85-90	87.5		4			17-18	17.5		7			17-18	17.5		7		
80-85	82.5	2	3	6	18	16-17	16.5	1	6	6	36	16-17	16.5		6		
75-80	77.5	3	2	6	12	15-16	15.5		5			15-16	15.5		5		
70-75	72.5	1	1	1	1	14-15	14.5		4			14-15	14.5	1	4	4	16
65-70	67.5	6	0	0	0	13-14	13.5	1	3	3	9	13-14	13.5		3		
60-65	62.5	5	-1	-5	5	12-13	12.5	3	2	6	12	12-13	12.5	1	2	2	4
55-60	57.5	4	-2	-8	16	11-12	11.5	2	1	2	2	11-12	11.5		1		
50-55	52.5	4	-3	-12	36	10-11	10.5	5	0	0	0	10-11	10.5	4	0	0	0
45-50	47.5	2	-4	-8	32	9-10	9.5	4	-1	-4	4	9-10	9.5	4	-1	-4	4
40-45	42.5	1	-5	-5	25	8-9	8.5	3	-2	-6	12	8-9	8.5	3	-2	-6	12
35-40	37.5		-6			7-8	7.5		-3			7-8	7.5	2	-3	-6	18
30-35	32.5	3	-7	-21	147	6-7	6.5	1	-4	-4	16	6-7	6.5	3	-4	-12	48
25-30	27.5	2	-8	-16	128	5-6	5.5	2	-5	-10	50	5-6	5.5	2	-5	-10	50
20-25	22.5	1	-9	-9	81	4-5	4.5	1	-6	-6	36	4-5	4.5		-6		
15-20	17.5	1	-10	-10	100	3-4	3.5	2	-7	-14	98	3-4	3.5	2	-7	-14	98
10-15	12.5	2	-11	-22	242	2-3	2.5					2-3	2.5	2	-8	-16	128
5-10	7.5					1-2	1.5					1-2	1.5	1	-9	-9	81
0-5	2.5					0-1	0.5					0-1	0.5				
C = -1.07		42		-45	1623	c = 2.117		34		+72	1452	c = -1.034		29		-30	888
c ² = 1.145		Av. dist. = 62.15 σ _{dist.} = 13.69				c ² = 4.482		Av. dist. = 12.62 σ _{dist.} = 6.18				c ² = 1.069		Av. dist. = 9.47 σ _{dist.} = 5.44			
C = -5.35																	
		PE _{av.} = 1.425						PE _{av.} = .7151						PE _{av.} = .6809			
Statistical Analysis of Data								Building: Taylor				Room: 6		Conditions: Dull			

TABULATION OF ILLUMINATION
FOR
DULL DAYS IN ROOM #6, TAYLOR SCHOOL

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #7, JUNIOR HIGH SCHOOL

FIGURE 29

Illumination Level Distribution Curves

TABLE VII

Statistical Data for Curves Above

	Mean Illumination Foot-Candles on Desk-Top.	Variability $\sigma = \left(\frac{\sum FD^2}{N} - \bar{c}^2 \right)^{1/2}$ dist.	Reliability $PE = \frac{.6745 \sigma_{(dist)}}{\sqrt{N}}$
Bright Day	49.69	19.08	2.27
	13.03	3.13	.36
	7.41	3.21	.37
Dull Day	33.15	12.75	1.54
	8.47	2.97	.37
	7.24	3.02	.36

TABLE XXI

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall					
Step	M.d.M.	F	D	FD	FD ²	Step	M.d.M.	F	D	FD	FD ²	Step	M.d.M.	F	D	FD	FD ²
145-150	147.5					29-30	29.5					29-30	29.5				
140-145	142.5					28-29	28.5					28-29	28.5				
135-140	137.5					27-28	27.5					27-28	27.5				
130-135	132.5					26-27	26.5					26-27	26.5				
125-130	127.5					25-26	25.5					25-26	25.5				
120-125	122.5					24-25	24.5					24-25	24.5				
115-120	117.5	1	14	14	196	23-24	23.5					23-24	23.5				
110-115	112.5		13			22-23	22.5	1	10	10	100	22-23	22.5				
105-110	107.5		12			21-22	21.5		9			21-22	21.5				
100-105	102.5		11			20-21	20.5		8			20-21	20.5				
95-100	97.5		10			19-20	19.5		7			19-20	19.5				
90-95	92.5		9			18-19	18.5	1	6	6	36	18-19	18.5				
85-90	87.5		8			17-18	17.5		5			17-18	17.5				
80-85	82.5		7			16-17	16.5	3	4	12	48	16-17	16.5	1	10	10	100
75-80	77.5		6			15-16	15.5	1	3	3	9	15-16	15.5	1	9	9	81
70-75	72.5	2	5	10	50	14-15	14.5	4	2	8	16	14-15	14.5		8		
65-70	67.5	2	4	8	32	13-14	13.5	7	1	7+46	7	13-14	13.5		7		
60-65	62.5	2	3	6	18	12-13	12.5	8	0	0	0	12-13	12.5	1	6	6	36
55-60	57.5	4	2	8	16	11-12	11.5	4	-1	-4	4	11-12	11.5	1	5	5	25
50-55	52.5	3	1	3+49	3	10-11	10.5		-2			10-11	10.5	1	4	4	16
45-50	47.5	8	0	0	0	9-10	9.5	1	-3	-3	9	9-10	9.5	3	3	9	27
40-45	42.5	2	-1	-2	2	8-9	8.5	1	-4	-4	16	8-9	8.5	3	2	6	12
35-40	37.5	2	-2	-4	8	7-8	7.5	1	-5	-5	25	7-8	7.5	6	1	6+55	6
30-35	32.5	1	-3	-3	9	6-7	6.5	2	-6	-12-28	72	6-7	6.5	8	0	0	0
25-30	27.5	1	-4	-4	16	5-6	5.5					5-6	5.5	2	-1	-2	2
20-25	22.5	2	-5	-10	50	4-5	4.5					4-5	4.5	2	-2	-4	8
15-20	17.5	2	-6	-12-35	72	3-4	3.5					3-4	3.5	2	-3	-6	18
10-15	12.5					2-3	2.5					2-3	2.5	3	-4	-12-24	48
5-10	7.5					1-2	1.5					1-2	1.5				
0-5	2.5					0-1	0.5					0-1	0.5				
c = .437	32			+14	472	c = .529	34			+18	342	c = .911	34			+31	379
c ² = .191	Av. dist = 49.69		σ _{dist.} = 19.08			c ² = .280	Av. dist = 13.03		σ _{dist.} = 3.13			c ² = .830	Av. dist = 7.41		σ _{dist.} = 3.21		
C = 2.185	PE _{av.} = 2.27						PE _{av.} = .3617						PE _{av.} = .3715				

Statistical Analysis of Data

Building: Junior H.S.

Room: 7

Conditions: Bright.

TABULATION OF ILLUMINATION
FOR

BRIGHT DAYS IN ROOM #7 JUNIOR. HIGH SCHOOL

TABLE XXII

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall					
Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²
145-150	147.5					29-30	29.5					29-30	29.5				
140-145	142.5					28-29	28.5					28-29	28.5				
135-140	137.5					27-28	27.5					27-28	27.5				
130-135	132.5					26-27	26.5					26-27	26.5				
125-130	127.5					25-26	25.5					25-26	25.5				
120-125	122.5					24-25	24.5					24-25	24.5				
115-120	117.5					23-24	23.5					23-24	23.5				
110-115	112.5					22-23	22.5					22-23	22.5				
105-110	107.5					21-22	21.5					21-22	21.5				
100-105	102.5					20-21	20.5					20-21	20.5				
95-100	97.5					19-20	19.5					19-20	19.5				
90-95	92.5					18-19	18.5					18-19	18.5				
85-90	87.5					17-18	17.5					17-18	17.5				
80-85	82.5					16-17	16.5					16-17	16.5				
75-80	77.5					15-16	15.5	1	6	6	36	15-16	15.5				
70-75	72.5					14-15	14.5		5			14-15	14.5	1	7	7	49
65-70	67.5					13-14	13.5		4			13-14	13.5	1	6	6	36
60-65	62.5	1	6	6	36	12-13	12.5	2	3	6	18	12-13	12.5		5		
55-60	57.5		5			11-12	11.5	1	2	2	4	11-12	11.5		4		
50-55	52.5	2	4	8	32	10-11	10.5	4	1	4+18	4	10-11	10.5	4	3	12	36
45-50	47.5	1	3	3	9	9-10	9.5	7	0	0	0	9-10	9.5	1	2	2	4
40-45	42.5	4	2	8	16	8-9	8.5	4	-1	-4	4	8-9	8.5	3	1	3+30	3
35-40	37.5	8	1	8+33	8	7-8	7.5	1	-2	-2	4	7-8	7.5	9	0	0	0
30-35	32.5	5	0	0	0	6-7	6.5	2	-3	-6	18	6-7	6.5	3	-1	-3	3
25-30	27.5	1	-1	-1	1	5-6	5.5	3	-4	-12	48	5-6	5.5	1	-2	-2	4
20-25	22.5	3	-2	-6	12	4-5	4.5	2	-5	-10	50	4-5	4.5	3	-3	-9	27
15-20	17.5	4	-3	-12	36	3-4	3.5	1	-6	-6	36	3-4	3.5	3	-4	-12	48
10-15	12.5	1	-4	-4	16	2-3	2.5		-7			2-3	2.5	1	-5	-5	25
5-10	7.5		-5			1-2	1.5	1	-8	-8-48	64	1-2	1.5		-6		
0-5	2.5	1	-6	-6-29	36	0-1	0.5					0-1	0.5	1	-7	-7-38	49
$c = .129$		31		+4	202	$c = -1.034$		29		-30	286	$c = -.258$		31		-8	284
$c^2 = .0166$		$Av_{(dist)} = 33.15$				$c^2 = 1.069$		$Av_{(dist)} = 8.47$				$c^2 = .0666$		$Av_{(dist)} = 7.24$			
$C = .645$		$\sigma_{dist} = 12.75$						$\sigma_{dist} = 2.97$						$\sigma_{dist} = 3.02$			
		$PE_{(av)} = 1.544$						$PE_{(av)} = .3714$						$PE_{(av)} = .3652$			

Statistical Analysis of Data

Building: Junior H.S.

Room: 7

Conditions: Dull

TABULATION OF ILLUMINATION
FOR
DULL DAYS IN ROOM #7, JUNIOR HIGH SCHOOL

DECREASE IN ILLUMINATION BY DESK ROWS
ACROSS ROOM #8, SENIOR HIGH SCHOOL

FIGURE 30

Illumination Level Distribution Curves

TABLE VIII

Statistical Data for Curves Above

	Mean Illumination Foot-Candles Desk-Top	Variability $\sigma_{\text{dist.}} = \left(\frac{\sum F D^2}{N} \right)^{1/2}$	Reliability $PE = \frac{.6745}{\sqrt{N}} (\sigma_{\text{dist.}})$
Bright Day	81.09	35.91	4.28
	12.73	6.23	.77
	7.74	2.93	.34
Dull Day	38.54	20.06	2.51
	5.64	2.60	.33
	3.63	2.53	.32

79

79

Building: Senior
H.S.

Conditions: Bright

TABULATION OF ILLUMINATION
FOR
BRIGHT DAYS IN ROOM #8, SENIOR HIGH SCHOOL

TABLE XXIV

Seats Adjacent to Windows						Seats at Center						Seats Adjacent to Opposite Wall					
Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²	Step	M.d.Pt.	F	D	FD	FD ²
145-150	147.5					29-30	29.5					29-30	29.5				
140-145	142.5					28-29	28.5					28-29	28.5				
135-140	137.5					27-28	27.5					27-28	27.5				
130-135	132.5					26-27	26.5					26-27	26.5				
125-130	127.5					25-26	25.5					25-26	25.5				
120-125	122.5					24-25	24.5					24-25	24.5				
115-120	117.5					23-24	23.5					23-24	23.5				
110-115	112.5					22-23	22.5					22-23	22.5				
105-110	107.5					21-22	21.5					21-22	21.5				
100-105	102.5	1	12	12	144	20-21	20.5					20-21	20.5				
95-100	97.5		11			19-20	19.5					19-20	19.5				
90-95	92.5		10			18-19	18.5					18-19	18.5				
85-90	87.5		9			17-18	17.5					17-18	17.5				
80-85	82.5		8			16-17	16.5					16-17	16.5				
75-80	77.5		7			15-16	15.5					15-16	15.5				
70-75	72.5		6			14-15	14.5					14-15	14.5				
65-70	67.5		5			13-14	13.5					13-14	13.5				
60-65	62.5	2	4	8	32	12-13	12.5	1	7	7	49	12-13	12.5				
55-60	57.5	1	3	3	9	11-12	11.5		6			11-12	11.5				
50-55	52.5	3	2	6	12	10-11	10.5		5			10-11	10.5	2	8	16	128
45-50	47.5	4	1	4+33	4	9-10	9.5	1	4	4	16	9-10	9.5		7		
40-45	42.5	4	0	0	0	8-9	8.5	4	3	12	36	8-9	8.5		6		
35-40	37.5	1	-1	-1	1	7-8	7.5	3	2	6	12	7-8	7.5	1	5	5	25
30-35	32.5	4	-2	-8	16	6-7	6.5	1	1	1+30	1	6-7	6.5	2	4	8	32
25-30	27.5	1	-3	-3	9	5-6	5.5	7	0	0	0	5-6	5.5		3		
20-25	22.5	3	-4	-12	48	4-5	4.5	4	-1	-4	4	4-5	4.5	5	2	10	20
15-20	17.5	1	-5	-5	25	3-4	3.5	1	-2	-2	4	3-4	3.5	4	1	4+43	4
10-15	12.5	2	-6	-12	72	2-3	2.5	4	-3	-12	36	2-3	2.5	7	0	0	0
5-10	7.5	1	-7	-7	49	1-2	1.5	2	-4	-8-26	32	1-2	1.5	6	-1	-6	6
0-5	2.5	1	-8	-8-56	64	0-1	0.5					0-1	0.5	2	-2	-4-10	8
C = -.793	29			-23	485	C = .142	28			+4	190	C = .113	29			+33	223
C ² = .629	Av. dist. = 38.54 σ _{dist.} = 20.06					C ² = .0202	Av. dist. = 5.64 σ _{dist.} = 2.60					C ² = .1277	Av. dist. = 3.63 σ _{dist.} = 2.53				
C = -3.965																	
PE _{av.} = 2.512					PE _{av.} = .3315					PE _(av.) = .3171							

Statistical Analysis of Data

Building: Senior H.S.

Room: 8

Conditions: Dull.

TABULATION OF ILLUMINATION
FOR
DULL DAYS IN ROOM #8, SENIOR HIGH SCHOOL

TABLE XXV

Building.		Seats Adjacent to Windows						Seats at Center						Seats Near Opposite Wall					
		c	c ²	C	Av. dist.	Σ dist.	PE _{av.}	c	c ²		Av. dist.	Σ dist.	PE _{av.}	c	c ²		Av. dist.	Σ dist.	PE _{av.}
Rose Hill	Brt.	.828	.686	4.140	56.64	23.585	2.689	.114	.013		11.614	4.327	.4933	.561	.315		8.061	3.851	.4057
	D	1.40	1.96	7.00	34.5	18.285	2.252	.116	.0276		8.666	4.265	.4795	.52	.270		5.98	4.561	.6153
Chestnut Street	Brt.	.077	.0059	.385	42.89	33.060	4.373	.851	.724		12.351	4.560	.5919	.148	.0219		12.648	6.626	.8601
	D	1.25	1.563	6.25	38.75	27.43	2.6705	1.172	1.373		9.672	5.855	.5186	.627	.393		10.127	7.628	.7241
Spring Hill	Brt.	-1.307	1.708	-6.54	85.97	39.985	4.319	2.276	5.180		19.776	6.266	.6165	-.239	.057		9.261	3.170	.3153
	D	0	0	0	42.5	18.40	2.0977	.319	.102		9.819	4.019	.3954	1.15	1.323		4.65	2.334	.2162
Port Fulton	Brt.	2.36	5.570	11.8	44.3	17.54	2.366	.303	.092		14.803	4.648	.5458	.333	.111		11.833	3.762	.4633
	D	-.518	.268	-2.59	34.91	17.915	2.326	.4	.16		12.90	6.159	.7585	.516	.266		8.016	3.600	.4361
Junior H.S.	Brt.	.437	.191	2.185	49.69	19.075	2.274	.529	.280		13.029	3.127	.3617	.911	.830		7.411	3.212	.3715
	D	.129	.0166	.645	33.15	12.745	1.544	-1.034	1.069		8.466	2.965	.3714	-.258	.0666		7.242	3.015	.3652
Senior H.S.	Brt.	.718	.516	3.59	81.09	35.905	4.281	.233	.0543		12.733	6.232	.7675	-.764	.584		7.736	2.931	.3390
	D	-.793	.629	-3.965	38.54	20.055	2.512	.142	.0202		5.642	2.601	.3315	1.13	1.277		3.63	2.532	.3171
Ingramville	Brt.	-4.651	21.632	-23.26	64.25	35.710	3.673	-4.45	19.803		19.05	7.118	.7591	.575	.331		11.075	6.711	.7819
	D	.027	.00073	.135	32.64	12.595	1.397	-.388	.151		10.112	4.289	.4822	.882	.778		5.382	2.598	.3005
Taylor	Brt.	.4	.16	2.0	49.50	21.775	2.6815	3.148	9.910		18.648	5.555	.7211	-1.178	1.388		16.322	5.549	.7073
	D	-1.07	1.145	-5.35	62.15	13.690	1.425	2.117	4.482		12.617	6.182	.7151	-1.034	1.069		9.466	5.436	.6809

Summary of Calculations

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS AND RECOMMENDATIONS

Since two of the three initial purposes of analyzing and graphically representing the illumination conditions have been fulfilled, there yet remains the third original intention of comparing the findings with the accepted norms.

The green horizontal line on each of the illumination level distribution curves represents the Illuminating Engineering Society's recommended minimum for classroom lighting practice. Although this norm is set at fifteen foot-candles, it must be thoroughly understood that higher values are not only unobjectionable, but highly desirable.

From a consideration of the curves, it is obvious that the light on dull days, in all instances, falls to or below the recommended minimum at a distance no more remotely removed than the row of desks which is second from the windows. Even on bright days this minimum is reached at a point about midway between the windows and the opposite wall. In rounded fractions, this means that the rooms, on dull days, are inadequately lighted for about two-thirds of their area. On bright days, about one-half of the desks receive illumination that is below the recommended minimum standard.

An additional conclusion, evident from the calculations, relates to the statistical reliability of the data. In all cases, the least reliable measures were those obtained

adjacent to the windows. The probable error of the average in these locations indicates that the chances are even that the true average may differ from the obtained average by an amount varying from slightly more than one foot-candle to an amount as large as four foot-candles. However, since the light values near the windows are large, this probable error, ranging from one to four foot-candles, becomes insignificant when considered on a percentage basis. The probable error of all other measurements taken at points removed from the windows indicates a considerably higher reliability. In each of these cases, it is possible to predict that the chances are even that the true average differs from the obtained average by an amount considerably less than one foot-candle. This error is entirely within the limitations of the instruments used, especially since no attempt was made to read the meters in terms of fractions of a foot-candle.

A few recommendations are indicated in connection with any further study in the field of illumination. After this study had been completed, the General Electric Company announced a new light meter, which, according to specifications, is superior in its versatility to those used in this survey. Since this new instrument has a maximum range of seven-hundred foot-candles, it could replace both of the instruments used in this survey at approximately one-fourth of the cost.

Precision tolerances to the nearest thousandth part of an inch would not have been necessary in making the special masks used in this study, if a simpler perforated type had been calibrated by trial and error.

Recommendations for the improvement of the lighting conditions would entail, for the most part, structural alterations in the physical properties of the rooms. The most important of these would involve the repositioning of the incandescent luminaires, in order to increase the inadequate illumination near the wall opposite the windows. The best practice in this respect seems to sanction the placing of two parallel rows of artificial lights, energized by independently controlled circuits. Often the inner-most row contains lights of higher wattage than those rows nearer the windows. The lowering of the luminaires to increase the illumination is not to be recommended because of the high probability of attendant glare in the line of vision. All artificial light sources should, for the same reason, be enclosed in diffusing translucent globes.

Many improvements in the lighting conditions could be made without involving any additional expense, if attention were given to the details. Increased illumination efficiency can be effected by the maintenance of both window areas that are clean and lighting fixtures that have not accumulated

opaque dirt. When replacement is necessary, opaque window shades should be superseded by those that are translucent. Likewise, when the occasion demands, repainting should be done in the colors that are high in their reflection-factors.

Specifically, if one were charged with improving the general illumination of classrooms within a given system, a definite procedure would be expedient. A time schedule for the collection of the raw data for all rooms concerned should be carefully planned. All teachers in the system should be acquainted with the importance of adequate lighting in order that the observations would be taken under the optimum conditions. This step could be economically profitable in many situations by reducing the expense of unnecessary electrical installations.

Next, a comprehensive integration of the observed facts should be synthesized by the use of some technique similar to that employed in this particular study.

If the actual survey were made after proper attention was given to the previously mentioned recommendations concerning cleanliness and reflection-factors of wall surfaces, then a competent illumination engineer should be asked for an estimate and specifications for the required corrections.

In consideration of the natural variations encountered in this particular inquiry, too much emphasis cannot be placed

upon the necessity of avoiding fallacious results derived from a paucity of meter readings.

Perhaps much improvement could be made, in any school system, by the frequent use of a light meter. The psychological effect of the light meter upon the teacher, who usually controls the adjustment of window shades and the use of the artificial lights, can cause this individual to become light conscious. Since the human eye is a very poor light meter, the value of some device that is accurate cannot be overestimated.

Although, on the surface, it may seem apparent that this survey reveals deplorable inadequacy in classroom illumination, it should be borne in mind that the modern standards are exceptionally high. Our educational institutions have not always been primarily concerned with the high standards of illumination. However, a description by Williard Samuel of the provisions for light in the early schoolhouses is illustrative of the general practice until as late as 1835, and in some sections of the country until much later. He said that: "On at least one side of the schoolhouse, the space between two logs would be left open to admit light; and this window would be closed by greased paper

to exclude rain and snow."¹

The progress made in classroom illumination in the past one hundred years has been remarkable, indeed.

¹ F. R. Noffsinger, "A Century of Progress in Schoolroom Lighting," American School Board Journal, 96:75 April, 1938.

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APPENDIX

Symbols
 Direction of Seating
 Room Surveyed
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Figure 31

FLOOR PLAN OF SECOND FLOOR
 SPRING HILL ELEMENTARY SCHOOL

Figure 32

Symbols
 ← Direction of Seating
 ○ Room Surveyed

FLOOR PLAN OF FIRST FLOOR
 CHESTNUT STREET SCHOOL.

Figure 33

FLOOR PLAN OF SECOND FLOOR
CHESTNUT STREET ELEM. SCHOOL.

← Direction of Seating
○ Room Surveyed.

Figure 34

Symbols
 Direction of Seating
 Room Surveyed

FLOOR PLAN OF FIRST FLOOR
 ROSE HILL ELEMENTARY SCHOOL

Figure 35

Symbols

Direction of Seating
Room Surveyed

FLOOR PLAN OF SECOND FLOOR
ROSE HILL ELEMENTARY SCHOOL

Figure 36

Symbols
 Direction of Seating
 Room Surveyed

FLOOR PLAN OF FIRST FLOOR
 PORT FULTON ELEMENTARY SCHOOL

Figure 37.
 Symbols
 Direction of Seating
 Room Surveyed

FLOOR PLAN OF SECOND FLOOR
 PORT FULTON ELEMENTARY SCHOOL

Figure 38

Symbols
 ← Direction of Seating
 (5) Room Surveyed

FLOOR PLAN OF FIRST FLOOR
 INGRAMVILLE ELEMENTARY SCHOOL

Figure 39

FLOOR PLAN OF FIRST FLOOR
 TAYLOR COLORED SCHOOL

Figure 40

Symbols
 — Direction of Seating
 ○ Room Surveyed

FLOOR PLAN OF SECOND FLOOR
 TAYLOR COLORED SCHOOL

Figure 41.

FLOOR PLAN OF FIRST AND SECOND FLOORS
JUNIOR HIGH SCHOOL BUILDING

← ^{Symbols} Direction of Seating
○ Room Surveyed

Figure 42.

Symbols

← Direction of Seating
○ Room Surveyed

FLOOR PLAN OF FIRST FLOOR
SENIOR HIGH SCHOOL BUILDING

Figure 43

Symbols
 Direction of Seating
 Room Surveyed

FLOOR PLAN OF SECOND FLOOR
SENIOR HIGH SCHOOL BUILDING

Characteristic Curves of Typical Cells

Figure 45.