

A COMPARATIVE STUDY OF THE PHYSIOLOGICAL EFFECTS ON CHILDREN OF SCHOOL HEATING BY HOT-WATER RADIATORS AND BY RADIANT HEAT FROM ELECTRIC CEILING AND WALL PANELS.

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(With 6 Figures in the Text.)

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INTRODUCTION.

THE introduction of new systems of heating and ventilating school buildings of necessity demands experimental trials on a large scale before any authoritative opinion for or against any particular system or installation can be given.

A few years ago an urban authority in London built a school adjoining a newly developed housing estate, and installed in this school a system of electric heating by radiant heat emitted from panels, at a temperature not exceeding 550° F., suspended from the ceilings and walls in the school classrooms. Architecturally, the school is very different from the ordinary two- or three-storied type, for the majority of rooms are on the ground floor, with outside walls on at least two sides. Moreover, each room is fitted on two sides with large fan windows, which can be thrown wide open, an ideal arrangement for hot summer weather.

If physiological and educational considerations demand that the air in school classrooms should be maintained within a certain range of cooling power and temperature during cold weather, then the window area and number of outside walls in such a school must demand a greater capacity for heating from any heating system than would be needed in a school of the ordinary type.

Whether or not the heating of a schoolroom is adequate or suitable for

school children for the ordinary elementary school routine is a physiological as well as a psychological problem, and with a view to its elucidation the investigation dealt with below was undertaken.

METHOD OF INVESTIGATION.

In order to evaluate the effectiveness of the electrically heated panel installation, it was necessary to have a physiological standard with which the reactions of children in the electrically heated classrooms could be compared. Hence the educational authorities were asked to name a school which was regarded locally as both well heated and well ventilated.

The control school, which for the purpose of this report we will call School A, is a large three-storied school of the ordinary type, heated by hot-water radiators and pipes. In ground-floor classrooms in this school, classes of children of approximately the same age, and doing the same school work as similar children in School B, the electrically heated school, were selected to form the group whose physiological reactions were to furnish the standard for comparison.

It is clear that if the relative efficiency of two systems of heating are to be compared in their physiological effects, then it is necessary to observe the effect of such systems on the occupants of the rooms at a time when both systems are called upon to cope with the same climatic conditions, as regards external temperature and wind. Hence, during a spell of cold weather in February, 1932, investigations on the children were carried out in the classrooms of these two schools.

External and internal temperature conditions.

On February 12th, both the schools were visited, and a general survey made of internal and external temperature conditions. In the case of School A, the one heated by hot-water pipes and radiators, the temperature readings were taken between 11.45 a.m. and 12.15 p.m. In two rooms on the ground floor which appeared to be typical, wet- and dry-bulb readings were taken with a sling psychrometer. One room with closed windows had a dry-bulb temperature of 65° F., and a wet-bulb temperature of 55° F., the second room with two sash windows open had a dry-bulb of 59° F., and wet-bulb of 55° F.

School B, heated by electric panels, was then visited, and a tour of the classrooms began at 1.45 p.m. This school is divided into two sections: the "Boys'" side and the "Infants'" side. Both sides of the school are heated by electric ceiling and wall panels, controlled in the majority of the rooms by air thermostats, which are set at 60° F. on the "Boys'" side, and 65° F. on the "Infants'" side. It should be noted that these thermostats installed in the classrooms are influenced by the actual temperature of the air, and not by radiant heat. Moreover, they are fixed to the wall about 7 ft. above floor level, *i.e.* about 4 ft. higher than the bodies of the children sitting at the desks. Table I gives the range of wet- and dry-bulb temperatures, and the cooling

powers of the air in the classrooms on both "sides" of School B. The photograph in Fig. 1 shows one of the electric wall panels in position.

In one room on the "Infants'" side, in which a dry-bulb temperature of 48° F., a wet-bulb of 39° F., and cooling power of 11.5 were observed, two radiators had failed, unknown to the teacher. The children, particularly on the "Infants'" side, gave the impression of being cold. Their hands were often blue and cold to the touch. A large number were sitting on their hands



Fig. 1. Photograph of a classroom heated by radiant heat from electric wall panels, one of which is seen in the corner at a height of 7 feet 3 inches above floor level.

Table I. *School B. Electric panel heating. Outside and inside conditions of temperature and cooling power.*

	Date	Time p.m.	Outside conditions		Conditions inside classrooms			No. of class- rooms
			Dry bulb ° F.	Wet bulb ° F.	Dry bulb ° F.	Wet bulb ° F.	Kata cooling power	
"Boys'" side	12. ii. 1932	1.45-3.0	35	35	54-59	45-51	5.7- 9	7
"Infants'" side	12. ii. 1932	3-4	36	35	48-55	39-46	7.5-11.5	13

or had their arms folded. Incidentally, it is worthy of note that the external temperature conditions were actually slightly less severe at the time the observations were made at School B than when the control observations were made at School A, the hot-water heated school.

On Monday, February 15th, a more detailed investigation was made at the electrically heated school. A typical ground-floor room was selected on the "Boys'" side. Windows on both sides of the room were open. Wet- and dry-bulb readings and dry kata cooling powers were taken at intervals throughout the period. The finger temperatures of the children were measured by the Moll radiation thermopile, as described by Vernon^{1,2}, and forehead temperatures were taken in a similar way as a control. A summary of the results of this investigation, and also of one on February 17th, when both schools were

Table II. *Summary of observations.*

School	...	...	...	School B, electrically heated panels	School A, hot-water radiators	School B, electrically heated panels
Date	...	...	...	15. ii, 1932	17. ii, 1932	17. ii, 1932
Time	...	...	...	10.55-11.30 a.m.	10.30-11 a.m.	11.30 a.m.-12 noon
Outside weather conditions	Dry bulb			41° F.	39° F.	46° F.
	Wet bulb			39° F.	37° F.	42° F.
	Dry kata cooling power			18	17.7	18
	Air velocity			170 ft. per min.	150 ft. per min.	210 ft. per min.
Classroom	...	...	...	Room C, "Boys'" side	Room 2 C	Room C, "Infants'" side
Type of heating	...	...	...	Five electric wall panels at 7 ft. height above floor	One hot-water radiator under window	Five electric wall panels at 7 ft. height above floor
Inside conditions	Dry bulb			58-60° F.	59-64° F.	55° F.
	Wet bulb			50-52° F.	51-54° F.	49.5° F.
	Dry kata cooling power			7-7.2	6.2	8.7
	Air velocity			21-25 ft. per min.	5-20 ft. per min.	36 ft. per min.
Number of children examined	...	...	...	30	37	51
Sex and age	...	...	...	Girls 11-12	Mixed 11-12	Mixed 8-9
Occupation of children	...	...	...	Writing	Writing	Writing, rather restless
Skin tempera- ture observa- tions	Mean tempera- ture of right fingers			65.4° F.	71.4° F.	68.0° F.
	Mean tempera- ture of left fingers			66.3° F.	71.9° F.	67.4° F.

visited, is shown in Table II, while Tables III, IV and V give the actual finger and forehead temperatures of the children recorded. It should be noted that the dimensions of the classroom in the hot-water heated school were 24 ft. 6 in. by 24 ft. 6 in. floor space and 14 ft. 2 in. high. Both classrooms in the electric panel heated school were of the same size, namely 22 ft. 6 in. by 21 ft. 4 in. floor space with a height of 11 ft.

¹ Vernon, H. M., Vernon, M. D. and Lorrain Smith, I. (1928). A physiological investigation of the radiant heating in various buildings. *Report No. 46 of Industrial Fatigue Research Board.*

² Vernon, H. M. and Bedford, T. (1930) (assisted by C. G. Warner). A study of heating and ventilation in schools. *Report No. 58 of Industrial Health Research Board.*

Observations on school children.

Table II shows that the mean skin temperature of the fingers of the children in the hot-water heated school was 71.4° F. for the right hands, and 71.9° F. for the left. It is apparent, however, from Table IV, which gives the actual temperatures recorded, and from Fig. 2, which shows the position of each child in the classroom, that the children seated at the desks nearest the

Table III. *School B. Electric-panel heated school. Skin temperatures of 30 children in ground-floor classroom C.*

Girls aged 11-12, writing.

Date, 15. ii. 32. Time, 10.55-11.30 a.m.

Outside weather conditions: cold day; 41° F. dry bulb, 39° F. wet bulb.

Position	Skin temperature readings		
	Right fingers ° F.	Left fingers ° F.	Forehead ° F.
1	61.0	66.0	93.7
2	73.8	70.7	92.5
3	61.3	61.7	95.2
4	77.0	81.0	94.3
5	64.6	64.6	92.3
6	63.1	64.0	93.4
7	64.6	61.7	92.7
8	61.3	61.7	91.6
9	59.9	61.7	93.2
10	62.2	62.6	94.6
11	62.2	62.2	93.7
12	60.8	61.3	94.3
13	63.3	62.2	94.6
14	62.2	63.1	92.8
15	65.1	65.5	96.1
16	60.8	60.8	95.0
17	62.6	63.5	96.1
18	64.4	66.4	95.2
19	67.3	68.2	96.1
20	75.6	69.1	100.4
21	64.9	66.4	96.4
22	64.0	66.4	95.5
23	68.7	70.5	96.4
24	72.0	81.9	96.4
25	66.0	66.4	95.5
26	63.5	64.4	95.2
27	64.4	66.0	96.4
28	66.9	68.7	93.0
29	61.7	63.5	94.6
30	74.7	76.5	95.3
Average	65.4	66.3	94.7

windows were on the average much colder than those in other parts of the room. In fact out of 16 children sitting in the two rows nearest the windows, 12 had finger temperatures below 70° F., the mean temperatures for the 16 being 68.8° F. for the right hands and 67.2° F. for the left. Of the 21 children sitting in other parts of the room only 7 had finger temperatures below 70° F., the mean temperatures for the whole group being 73.8° F. for the right hand and 75.5° F. for the left.

In the case of the school with classrooms heated by radiant heat from

electric wall panels, the distribution of children with chilled hands was found to be practically uniform throughout the rooms, as shown in Figs. 3 and 4. The mean finger temperatures of these children ranged from 65.4 to 68.0° F., *i.e.* from 6.3 to 3.7° F. below 71.7° F., the mean finger temperature of the whole group of children examined in the hot-water heated school.

Table IV. *School A. Heated by hot-water radiators. Skin temperatures of 37 children in ground-floor classroom 2 C.*

Mixed class aged 11-12, writing.

Date, 17. ii. 32. Time, 10.30-11 a.m.

Outside weather conditions: cold day; 39° F. dry bulb, 37° F. wet bulb.

Position	Skin temperature readings		
	Right fingers ° F.	Left fingers ° F.	Forehead ° F.
2	61.7	62.2	92.5
3	62.8	63.1	90.5
4	83.7	75.2	90.9
5	61.7	60.3	90.5
6	61.7	61.0	91.8
7	58.5	60.8	84.6
8	65.8	65.3	91.8
9	81.1	80.6	91.8
10	69.1	68.7	91.8
11	74.7	68.2	90.5
12	63.1	63.1	91.4
13	62.2	62.6	91.4
15	74.3	77.0	93.9
16	66.4	63.5	93.4
17	64.0	66.9	91.4
18	81.1	76.5	93.9
19	70.5	74.7	91.4
20	65.3	66.9	93.0
21	75.2	76.5	92.3
22	75.2	77.4	91.4
23	70.5	70.5	88.7
24	68.7	69.1	90.5
27	76.1	82.4	93.4
28	65.3	66.9	92.7
29	75.2	76.5	93.0
30	84.6	86.4	95.0
31	74.7	73.8	93.0
32	78.3	81.1	91.4
33	66.4	66.4	91.4
34	72.5	72.0	93.4
35	68.7	66.9	90.3
38	69.1	74.7	89.6
39	75.2	77.0	91.4
40	89.1	89.6	93.9
41	68.7	68.7	91.4
42	75.6	82.4	91.4
43	86.0	85.1	92.3
Average	71.4	71.9	91.7

As will appear below, there is some justification for the opinion that the mean finger temperature should not be below 75.0° F., although, of course, owing to individual variation, temperatures lower than this may be encountered in cold weather whatever the heating arrangements may be. Actually the mean finger temperature of the 21 children in the warmer parts of the hot-water heated classroom was 74.7° F., and when the finger tem-

Table V. *School B. Electric-panel heated school. Skin temperatures of 51 children in ground-floor classroom C.*

Mixed class. Infants aged 8-9, writing.

Date, 17. ii. 32. Time, 11.30 a.m.-12 noon.

Outside weather conditions: cold day; 46° F. dry bulb, 42° F. wet bulb.

Position	Skin temperature readings		
	Right fingers ° F.	Left fingers ° F.	Forehead ° F.
1	77.0	74.3	94.6
2	69.1	36.4	96.4
3	66.9	64.9	95.9
4	66.4	63.1	96.4
5	76.1	70.9	95.9
6	72.9	72.9	94.6
7	65.8	66.9	95.5
8	61.7	62.6	94.6
9	61.3	61.7	93.0
10	75.2	75.6	95.0
11	62.6	61.7	92.3
12	81.1	82.4	92.7
13	64.4	64.0	93.0
14	64.9	64.4	92.7
15	66.9	65.3	92.3
16	68.7	66.9	93.0
17	64.0	65.8	93.9
18	63.1	64.0	95.5
19	62.6	64.4	93.0
20	68.7	61.7	93.9
21	68.2	69.1	93.0
22	65.8	67.3	92.7
23	67.3	66.9	91.8
24	74.3	75.2	93.9
25	64.4	64.0	93.9
26	66.9	70.5	93.4
27	66.4	65.3	94.3
28	64.9	64.4	93.4
28 A	63.5	64.9	94.3
29	64.4	64.0	94.6
30	69.1	69.1	94.6
31	69.6	70.9	94.6
32	65.8	68.2	94.3
33	65.3	67.3	95.0
34	70.0	69.1	96.1
35	72.5	74.7	94.6
36	67.3	67.3	94.6
37	63.5	63.5	93.7
38	67.8	67.3	93.0
39	72.0	70.9	92.3
40	77.9	68.7	94.6
41	68.2	64.0	95.5
42	66.4	63.1	94.6
43	69.6	70.5	93.0
44	64.4	63.1	94.6
45	70.5	66.4	94.6
46	65.8	68.7	94.3
47	65.3	66.4	94.3
48	67.8	65.8	93.0
49	69.1	67.3	93.9
50	74.3	76.1	93.0
Average	68.0	67.4	94.1

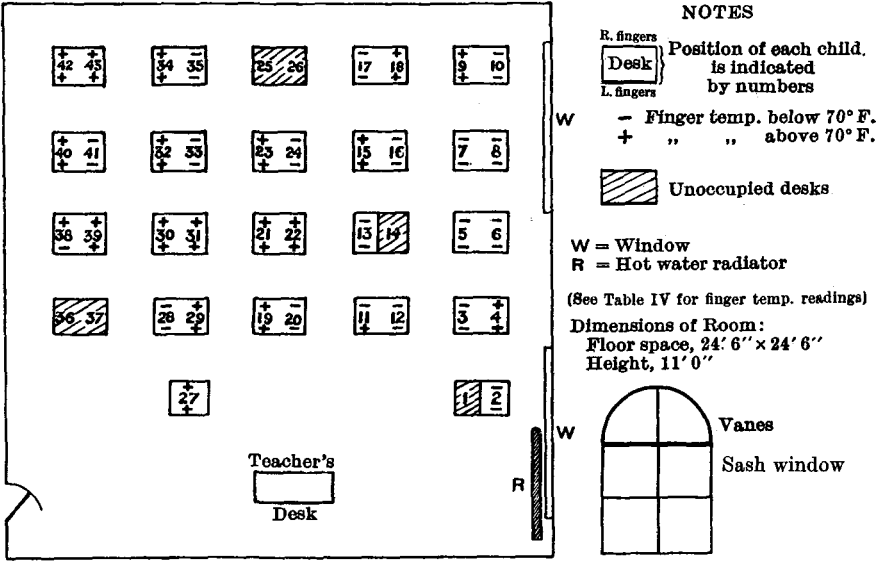


Fig. 2. School A: Classroom heated by hot-water radiator. A mixed Class. Age 11-12. Writing. Feb. 17, 1932.

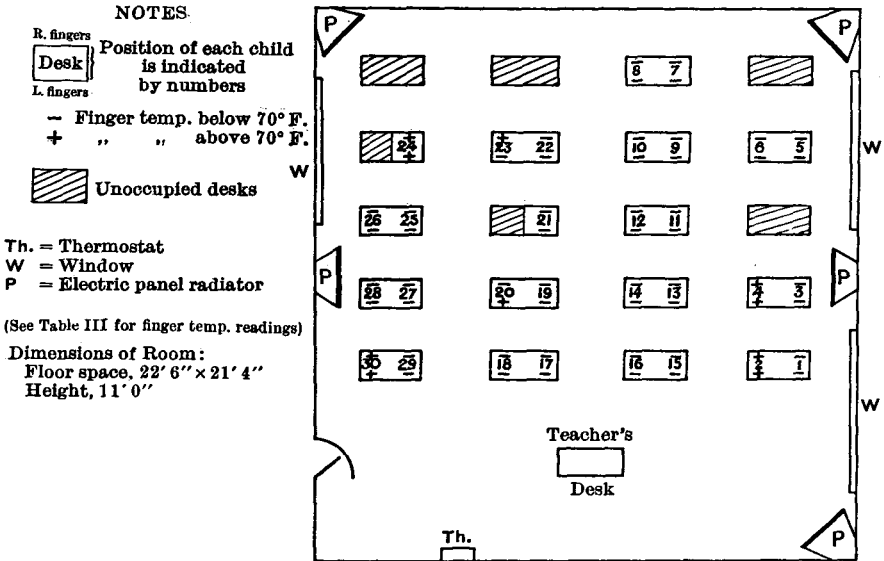


Fig. 3. School B: Classroom "C," Boys' side. Heated by radiant heat from five electric wall panels. Girls aged 11-12. Writing. Feb. 15, 1932.

peratures recorded in the electric-panel heated rooms are compared with this figure they are found to be from 9.3 to 6.7° F. lower.

According to Lewis¹, hands showing cyanosis on exposure to atmospheric air during the cold months of the year are usually found to have a temperature between 68.0 and 77.0° F. Moreover, from considerations of oxygen supply, Lewis holds that if the skin temperature falls within the range 59.0–77.0° F. the blood flow through the skin tends to be insufficient to meet its full needs. It may be of interest to mention here that a superficial examination of the

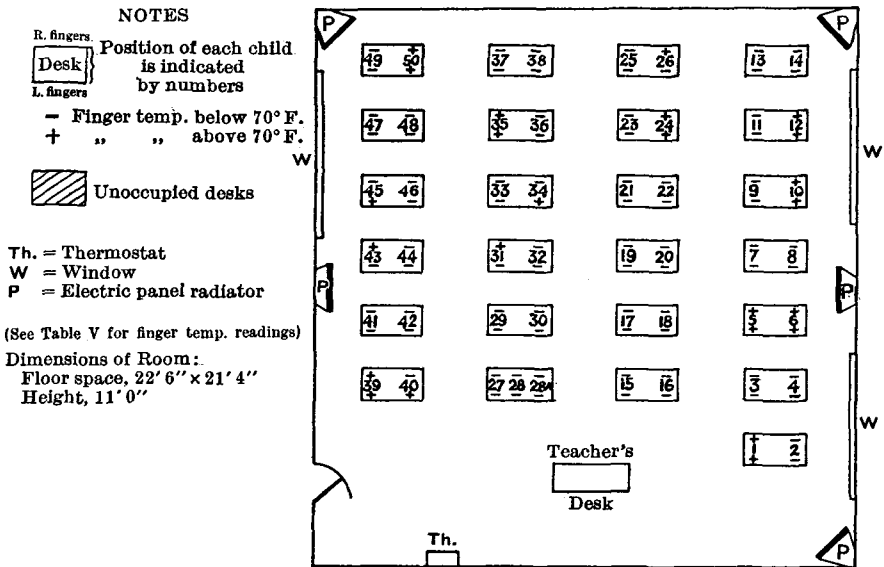


Fig. 4. School B: Classroom "C," Infants' side. Heated by radiant heat from five electric wall panels. Mixed Class. Age 8–9. Writing. Feb. 17, 1932.

children's hands in the electric-panel heated school revealed many which were "blue with cold."

Vernon and Bedford² examined a very large number of children's hands in open air and other schools in which different forms of heating were employed. They carried out dexterity tests on themselves and on some of the children, and established the fact that when the hand temperature falls to 70.0° F., then there is a distinct and measurable falling off in manual dexterity in school children. Vernon's actual observations on children led him to the conclusion that hands with a temperature between 75 and 79° F. are probably warm enough. This conclusion, viewed in the light of Lewis's opinion as stated above, appears to indicate that the minimum desirable skin temperature is in the region of 77.0° F. However, for the purposes of this investigation, in

¹ Lewis, T. (1927). *The Blood Vessels of the Human Skin and their Responses*. London: Shaw and Sons.

² Vernon, H. M. and Bedford, T. (1930) (assisted by C. G. Warner). A study of heating and ventilation in schools. *Report No. 58 of Industrial Health Research Board*.

which the actual state of children in the electric-panel heated classrooms is being compared with that of children in a hot-water heated school, we take the skin temperatures actually recorded in the latter school as the control standard for comparison. Suffice it to say that were we to adopt the higher figure of 77.0° F., the chilling experienced by the children in the classrooms heated by radiant heat from the electric wall panels would appear to be much more severe.

The charts in Figs. 5 and 6, compiled from Table VI, give a graphic comparison of the finger temperatures of the children in the two schools. The number of hands in each temperature group are expressed as percentages of the total number of hands examined. It is evident from these charts and Table VI that the hands of the children in the classrooms heated by radiant heat from the electric panels were markedly colder than the hands of the children in the hot-water heated classrooms of School A under equally severe external weather conditions. From 83 to 76 per cent. of the children in the classrooms heated by radiant heat from electric wall panels showed finger temperatures below 70° F.

Table VI. *Finger temperatures expressed in percentage of number of hands examined.*

	Electric-panel heated school, 15. ii. 1932	Control school, hot-water heated, 17. ii. 1932	Electric-panel heated school, 17. ii. 1932
Under 60° F.	1.7	1.3*	0
60-65° F.	56.7	20.3*	32.3
65-70° F.	25.0	27.0	44.1
70-75° F.	8.3	14.9	14.7
75-80° F.	5.0	18.9	6.9
80-85° F.	3.3	10.8	2.0
85-90° F.	0	6.8	0

* All the children in these two groups were sitting near the open windows.

In regard to forehead temperature, Tables III, IV and V show that the foreheads of the children in the classrooms warmed by radiant heat from the electric wall panels were, on the average, approximately 3° F. warmer than those of children in the hot-water heated classrooms. This is no doubt accounted for by the fact that the heads of the children were directly and continuously exposed to radiant heat from the electric wall panels, which are fixed at a height of 7 ft. 3 in. above floor level. However, that the heat imparted to the upper part of their bodies was insufficient to provide adequate general warmth, or, rather, to prevent excessive heat loss, was shown both by the appearance and behaviour of the children, and the finger temperatures actually recorded at the same time as the forehead temperatures were taken.

DISCUSSION.

The question of importance is whether the degree of chilling to which the children in the electric-panel heated classrooms were subjected is harmful to the child or a hindrance to educational progress. Certainly the children in

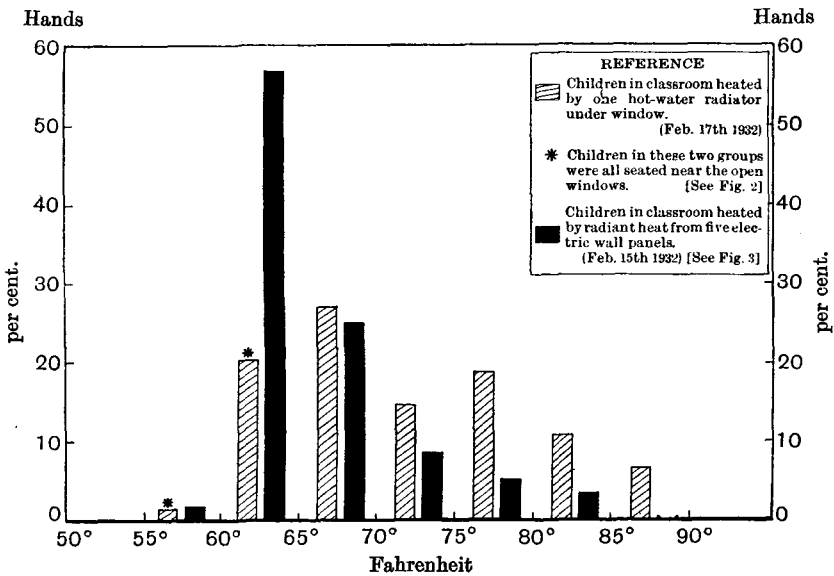


Fig. 5. Finger temperatures of children in hot-water heated classroom and in classroom heated by radiant heat from electric wall panels.

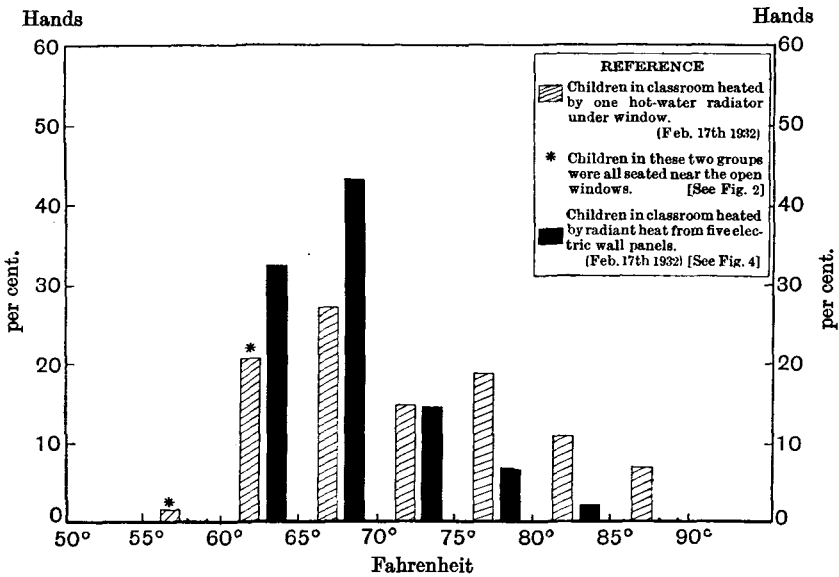


Fig. 6. Finger temperatures of children in hot-water heated classroom and in classroom heated by radiant heat from electric wall panels.

the hot-water heated school were not handicapped by being warmer than the children in the electrically heated school. As already noted, many of the children in the latter were restless, and a large number of them, particularly on the "Infants'" side, looked cold. Their hands were blue and felt cold to the touch, and that the children themselves felt cold was proved by the fact that many of them were sitting on their hands or had their arms folded. These observations, supported by the actual temperature measurements taken, led us to the conclusion that the cold experienced by the children in the electric-panel heated school caused a good deal of discomfort and handicapped the children in the performance of their school work.

The observations of temperature and cooling power of the air showed that the conditions in the electrically heated school were much colder than the usually accepted standards for comfort of 60–65° F. air temperature with a cooling power of 6–7 dry katathermometer units. In none of the nineteen classrooms in the school did we find a temperature as high as 60° F. at the level of the desks where the children were sitting. In fifteen out of the nineteen classrooms visited the temperature was below 55° F. on the "Infants'" side. These temperature observations are in complete accord with those made by Vernon in semi open-air schools, and it should be noted that an air temperature of 55° F. was regarded by Vernon, as a result of his extensive observations, to be the lowest limit compatible with full efficiency in the performance of the school curriculum. In regard to cooling power it should be noted that Vernon and Bedford¹ formed the opinion that "for the attainment of full efficiency at work, school children ought not, as a rule, to be subjected to air with a cooling power much above 7, and in any case, not above 9." In our observation we found that out of nineteen classrooms in the electrically heated school only two showed a cooling power below 7, and in these either the windows were closed or bright sunshine was pouring into the room. Of the remaining seventeen classrooms, five had a cooling power between 7–8, five between 8–9, six between 9–10, and one in which two electric panels had fused as high a cooling power as 11.5. Vernon and Bedford found that there was some falling off in manual dexterity if the cooling power was as high as 7.2, and, moreover, it is now recognised that a cooling power between 6–7 dry katathermometer units is compatible with comfort and efficiency for sedentary work, comparable in nature to the elementary school routine. It is not, therefore, surprising that the children in the electrically heated school looked cold, behaved as if they were cold, and were found by skin temperature measurements to be unduly chilled.

Whether or not this chilling by cold air to which the children were subjected is a disadvantage from the point of view of health depends on whether the children are properly fed, and whether the school routine enables them to warm themselves by exercise at frequent intervals during school hours. It should be noted that this electric-panel heated school is not a special school

¹ See ref. 2, foot of p. 159.

for sick and ailing children, whose nutrition as well as education demand and receive special care. The children in it were required to carry out the same routine as those in the water-heated school, and we understand that the authorities have no control whatever over their daily intake of food.

Vernon and Bedford found that the hand and finger temperatures of children in certain open air schools were actually higher than those of children in other schools. But we did not find this to be the case in the panel-heated school when compared with the control school. The children in Vernon's open-air schools were specially fed, and had frequent intervals for exercise during school work. Both these factors would increase their metabolism, and enable them to keep up their body heat in spite of a colder environment.

In regard to the health of the children attending the electric-panel heated school and the hot-water heated school, enquiries were made as to the number of absentees during the month of February, 1932. Although we publish this data in Table VII, we wish to say that, without more extensive enquiry in

Table VII. *Absentees from Schools A and B during month of February, 1932.*

School	No. on roll	Average absentees	% absentees
A. Heated by hot-water radiators	460 seniors	47.7	10.4
	172 infants	18.4	10.6
B. Electric-panel heating	521 seniors	51.9	9.9
	566 juniors and infants	80.9	14.1

regard to sickness incidence and absenteeism in several schools, it would not be possible to decide whether the difference between the data for the infants in the two schools could be ascribed to the cooler conditions met with in the classrooms of the electric-panel heated school.

SUMMARY AND CONCLUSIONS.

1. An attempt has been made to ascertain by physiological observations on school children whether the radiant heat from a heating installation comprising electric panels suspended from the ceilings and walls of the classrooms, in a semi open-air school, was sufficient to impart adequate warmth to children while performing the ordinary curriculum of an elementary school.

2. During identical cold weather conditions, observations were made on children in two schools in the same area, the one heated by electric ceiling and wall panels and the other, the control school, heated by hot-water radiators and pipes.

3. The children in classrooms heated by radiant heat from electric ceiling and wall panels were found to be attempting to perform ordinary elementary school work under conditions of chilling incompatible with comfort and efficiency, and without such compensating factors as frequent exercise and controlled nutrition, neither of which are possible in such a school.

4. The observations made on the children in the semi open-air electric-panel heated school, the air temperatures and cooling powers encountered in the classrooms, and the control observations made in the hot-water heated school under similar weather conditions prove that the radiant heat emitted from the electric ceiling and wall panels was insufficient to impart adequate warmth to the children, and that the heating system as at present installed and controlled, is unable adequately to cope with such cold conditions as are commonly met with during the winter months of the year.

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