J. Hyg., Camb. (1969), **67**, 59
Printed in Great Britain

Thermal requirements of secondary schoolchildren in winter

By A. AULICIEMS
Department of Geography, University of Reading

(*Received* 18 *June* 1968)

INTRODUCTION

Although winter thermal comfort requirements in Great Britain have been investigated for adults in light industry (Bedford, 1936), offices (Black, 1954), and lecture halls (Angus & Brown, 1957), no inquiry appears to have been conducted with respect to schoolchildren.

Suggestions for desirable classroom temperatures have been largely based on considerations of the relatively higher metabolic rate of children and in consequence recommended temperatures have been appreciably lower than those considered optimum for adults. Clay (1929) advocated air temperatures of 55–60° F., Vernon, Bedford & Warner (1930) 'not much below 60° F.', and Seymour (1939) 55–57° F. equivalent temperature. However, Post War Building Studies No. 27, on heating and ventilating of schools (1947), suggested somewhat higher values with 57–60° F. equivalent temperature, while the Building Bulletin No. 2 (1950) specified an air temperature of 62° F. This is the present legal requirement (Statutary Instruments 1954), which stipulates 62° F. air temperature with six air changes per hour (20–40 ft./min. air movement).

Although the latter is regarded by the Institute of Heating and Ventilating Engineers (The Heating and Ventilation of Schools, 1951) as the minimum requirement, the reasons for and indeed the desirability of this temperature may be open to question since no experimental data have yet been presented. The present investigation was designed to determine the optimum conditions and limits for the thermal comfort of secondary schoolchildren.

METHOD

Data were collected from twenty-three classes of children drawn from nineteen secondary schools in the Reading area. The sample included Secondary Modern, Grammar and Public Schools from which 624 children (378 boys and 246 girls), aged approximately 11–16 years, acted as subjects.

Usual school clothing was worn and measurements were taken following tests of performance with the children seated as usual at their desks. Air temperature and humidity were measured by an Assmann psychrometer (a radiation-shielded dry- and wet-bulb thermometer combination aspirated by means of a clockwork or electric fan), thermal radiation was estimated by two 6 in. globe thermometers (an instrument in which the thermometer is inserted with the bulb at the centre of a blackened hollow copper sphere), and the rate of air movement was determined from a silvered Kata thermometer (this is a large-bulbed alcohol thermometer which is heated by immersion in hot water, dried and allowed to cool: the time required for cooling over a final temperature range is proportional to the air velocity). The instruments were located in two central positions on desks at sitting head height, readings were averaged and equivalent temperature (T_{eq}) and corrected effective temperature (C.E.T.) determined. These indices facilitate description and assessment of the thermal environment since they combine several atmospheric factors into *single* numerical values, which are conveniently derived by reference to charts. T_{eq} integrates air temperature, radiation and air velocity and C.E.T. combines radiation, humidity and air velocity. (For further description of instruments and indices see Macpherson, 1962.)

Subjective impressions of warmth were recorded on the seven-point scale as used by Bedford (1936). The scale was printed on the blackboard and the children were asked to consider individually their sensations and enter the corresponding numeral in appropriate spaces on their performance test papers. The arbitrary units 1–7 were considered to be the most simple for the children, but for statistical analysis were altered to those as shown in Table 1.

Table 1. *Scale of thermal sensations*

Sensation	Numerical value used by children	Numerical value used in analysis
Much too warm	1	+3
Too warm	2	+2
Comfortably warm	3	+1
Comfortable	4	0
Comfortably cool	5	−1
Too cool	6	−2
Much too cool	7	−3

Most assessments were made 40–70 min. after the children had entered the room, but on seven occasions after 25–30 min. The data relate to both the mornings and afternoons between January and April 1967, and October 1967 and March 1968. Thermal conditions were altered occasionally in an attempt to lower excessive temperatures, but otherwise left as found by the investigator. It is believed that the information gained is very representative of classroom conditions of normal occupancy and activity.

RESULTS

The frequency of thermal conditions encountered appears in Table 2 in terms of four thermal measures, and the distribution of thermal sensations appears in Table 3. In general, ventilation rates were very low and on fifty-three sessions the rate of air movement was less than 10 ft./min., while 20 ft./min. was exceeded on only nineteen occasions.

Although the scale of numerical values is quite arbitrary, linear relationships between mean values and thermal conditions have been established by previous investigators. Tables 4 and 5 show the distribution of thermal sensations and corresponding means for intervals of air temperature and T_{eq}.

Graphical representation of the means against equivalent temperature is shown

https://doi.org/10.1017/S0022172400041425 Published online by Cambridge University Press

Table 2. *Distribution of thermal conditions*

Intervals (°F.)	Frequency: Dry bulb	Globe	T_{eq}	C.E.T.
76·5–78·4	2	.	.	.
74·5–76·4	4	7	2	.
72·5–74·4	9	7	5	.
70·5–72·4	11	22	12	3
68·5–70·4	22	20	18	3
66·5–68·4	22	23	18	23
64·5–66·4	14	11	21	26
62·5–64·4	9	10	13	28
60·5–62·4	8	5	9	13
58·5–60·4	5	3	6	9
56·5–58·4	1	1	2	1
54·5–56·4	1	.	2	3
52·5–54·4	1	.	1	.
Total	109	109	109	109

Table 3. *Distribution of thermal sensations*

Sensation	Numerical value	Frequency: Boys	Girls	Total
Much too warm	+3	97	132	229
Too warm	+2	272	304	576
Comfortably warm	+1	308	312	620
Comfortable	0	288	249	537
Comfortably cool	−1	234	214	448
Too cool	−2	77	95	172
Much too cool	−3	21	21	42
Total		1297	1327	2624

Table 4. *Distribution of sensations in relation to dry-bulb temperature*

Dry bulb (°F.)	Frequency: +3	+2	+1	0	−1	−2	−3	Total	Mean sensation
76·5–78·4	19	21	9	4	1	1	.	55	+1·91
74·5–76·4	10	32	51	21	21	5	.	140	+0·81
72·5–74·4	24	72	43	36	15	.	.	190	+1·28
70·5–72·4	66	103	66	42	22	4	1	304	+1·44
68·5–70·4	24	114	155	127	83	20	3	526	+0·61
66·5–68·4	40	107	115	106	78	21	4	471	+0·67
64·5–66·4	35	76	71	64	63	17	8	334	+0·62
62·5–64·4	4	21	39	50	69	38	10	231	−0·35
60·5–62·4	6	15	53	54	51	27	6	212	−0·10
58·5–60·4	1	13	11	22	25	18	5	95	−0·38
56·5–58·4	.	.	1	1	7	8	3	20	−1·55
54·5–56·4	.	2	6	9	4	5	1	27	−0·26
52·5–54·4	.	.	.	1	9	8	1	19	−1·47
Total	229	576	620	537	448	172	42	2624	

in Fig. 1. Inspection reveals linearity, and the abrupt increase of slope at the upper end, as found by Hickish (1955) for adults in summer, is not readily evident. Regression analysis has been applied to individual scores and regression equations

Table 5. *Distribution of sensations in relation to equivalent temperature*

T_{eq} (°F.)	Frequency +3	+2	+1	0	−1	−2	−3	Total	Mean sensation
74·5–76·4	18	19	18	6	2	.	.	63	+1·71
72·5–74·4	19	52	40	24	9	.	.	144	+1·33
70·5–72·4	26	88	66	55	27	6	.	268	+1·05
68·5–70·4	66	114	129	75	48	9	1	442	+1·10
66·5–68·4	20	100	122	105	80	20	3	450	+0·56
64·5–66·4	48	109	105	100	92	27	5	486	+0·63
62·5–64·4	24	48	51	70	69	41	11	314	+0·11
60·5–62·4	2	19	42	46	52	24	9	194	−0·21
58·5–60·4	6	20	36	38	38	18	3	159	+0·07
56·5–58·4	.	5	4	7	11	6	5	38	−0·63
54·5–56·4	.	2	7	10	11	13	4	47	−0·81
52·5–54·4	.	.	.	1	9	8	1	19	−1·47
Total	229	576	620	537	448	172	42	2624	

Table 6. *Regression constants, correlation coefficients and optimum conditions*

Thermal measure (°F.)	r	Constant a	Constant b	Optimum condition
Dry bulb	0·37	0·116	−7·273	62·7
Globe	0·32	0·120	−7·643	63·7
T_{eq}	0·36	0·119	−7·341	61·7
C.E.T.	0·36	0·166	−10·097	60·8

Table 7. *Limits of the comfort zone for children*

Thermal measure (°F.)	Lower limit	Upper limit
Dry bulb	59 (58·5)	70 (70·4)
Globe	61 (60·5)	70 (70·4)
T_{eq}	59 (58·5)	68 (68·4)
C.E.T.	57 (56·5)	66 (66·4)

expressed in the form of $Y = ax+b$, where Y is thermal sensation, a and b constants and x thermal measure. Optimum values of thermal conditions, or those producing a thermal sensation of 0 (or 'comfortable') have been calculated and appear in Table 6, together with the regression constants and the product moment correlation coefficient (r). As pointed out by Hickish (1955), although the mean sensation of a group may be predicted with reasonable accuracy, prediction of an individual's sensation is highly unreliable.

To determine acceptable upper and lower limits for comfort the data have been classified into three categories within which the children may be considered as

https://doi.org/10.1017/S0022172400041425 Published online by Cambridge University Press

feeling comfortable (values +1, 0, −1), too warm (values +3, +2) and too cool (values −2, −3). Percentages were determined for the three categories for each interval of temperature and the percentage comfortable appears in Fig. 2 in relation to T_{eq}.

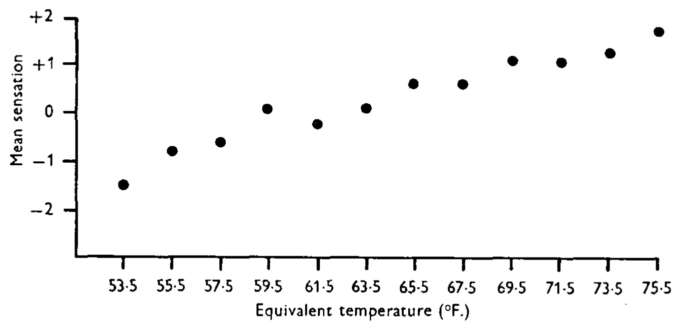

Fig. 1. Mean sensations against equivalent temperature.

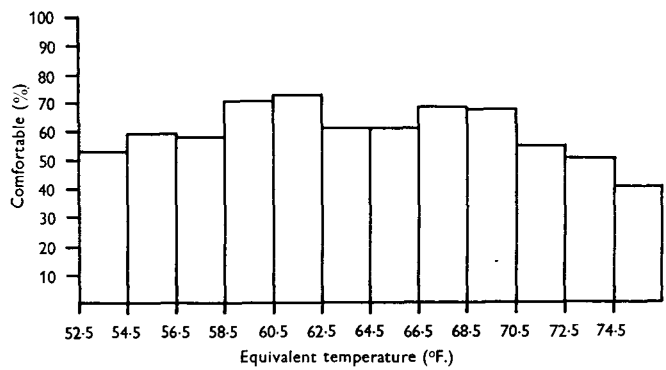

Fig. 2. Percentage of children comfortable in relation to equivalent temperature.

The delineation of the comfort zone is arbitrary and limits have varied greatly with investigators. Hickish (1955) selected a comfort zone on an 80% comfortable basis, Bedford (1936) chose 70% while Partridge & MacLean (1935) and Houghten & Yagloglou (1923) used only 50%. In the present study over 70% comfort conditions occurred very rarely and no comfort zone could be established on this basis. However, a choice of temperatures within which 60% of the children were comfortable seemed satisfactory, and it is this percentage which has been selected. The upper and lower delineation is shown in Table 7.

DISCUSSION

Since conditions of still air were mainly encountered in these tests, the difference in physiologic effect between the optimum air temperature at 62·7° F. and the specified 62° F. (Statutary Instruments, 1954) with its greater air movement becomes appreciably magnified. The latter figure would probably approximate

https://doi.org/10.1017/S0022172400041425 Published online by Cambridge University Press

59° F. T_{eq}, which is nearly three degrees below the optimum found at 61·7° F. T_{eq}. Alternatively, given conditions of approximately equal temperatures of surroundings and air, to produce this optimum T_{eq} with air movement of 30 ft./min., air temperature of approximately 65° F., would be required.

Bedford (1936) found that optimum conditions for adults at sedentary work were at approximately 62° F. T_{eq}, or 65° F. air temperature with average air motion of 30 ft./min. More recently Black (1954) revealed somewhat higher values at 66–67° F. air temperature, but regrettably failed to measure rates of air movement. In comparison, it would seem that if the required rates of ventilation were maintained in schools, the optimum for children in terms of dry-bulb temperature would lie only slightly below those of adults. This finding is supported by the earlier study of Partridge & MacLean (1935), who found that the thermal requirements of children in Canada were almost identical with those of adults. The raised thermal neutrality of children can possibly be explained by acclimatization due to the habitual exposure of children to adult-regulated micro-climates.

The present study indicates that the difficulty in schools is one of overheating rather than that of achieving sufficiently high temperatures. This appears to be associated with the failure to maintain adequate ventilation rates, a problem also observed in classrooms by Weston (1953), and a partial solution may be found by wider window opening.

SUMMARY

Secondary schoolchildren in England were asked to assess thermal conditions in winter according to subjective sensations of warmth. Conditions of normal occupancy and activity were maintained and optimum conditions established in terms of four thermal measures by regression analysis of over 2500 assessments by boys and girls. The comfort zone was delineated as that within which 60 % of the children were comfortable and in terms of the commonly used dry-bulb temperature this zone lay between 59 and 70° F. in still air. The optimum conditions for children were also compared with those recommended for adults.

REFERENCES

ANGUS, T. C. & BROWN, J. R. (1957). Thermal comfort in the lecture room. An experimental study of winter requirements. *J. Instn Heat. Vent. Engrs* **25**, 175.

BEDFORD, T. (1936). The warmth factor in comfort at work. *Rep. ind. Hlth Res. Bd*, no. 76.

BLACK, F. (1954). Desirable temperatures in offices. A study of occupant reaction to heating provided. *J. Instn Heat. Vent. Engrs* **22**, 319.

BUILDING BULLETIN No. 2 (1950). Ministry of Education. H.M.S.O.

CLAY, F. (1929). *Modern School Buildings.* London: Batesford.

HICKISH, D. E. (1955). Thermal sensations of workers in light industry in summer. A field study in Southern England. *J. Hyg., Camb.* **53**, 112.

HOUGHTEN, F. C. & YAGLOGLOU, C. P. (1923). Determination of the comfort zone. *Trans. Am. Soc. Heat. Vent. Engrs* **29**, 361.

MACPHERSON, R. K. (1962). The assessment of the thermal environment. A review. *Br. J. ind. Med.* **19**, 151.

PARTRIDGE, R. C. & MACLEAN, D. L. (1935). Determination of the comfort zone for school children. *J. ind. Hyg.* **17**, 66.

POST WAR BUILDING STUDIES No. 27 (1947). *Heating and Ventilation of Schools.* H.M.S.O.

SEYMOUR, D. W. (1939). *Heating, Ventilation and Lighting of School Buildinas.* Oxford University Press.

STATUTARY INSTRUMENTS NO. 473 (1954). Statutary Publications Office.

THE HEATING AND VENTILATION OF SCHOOLS (1951). *J. Instn Heat. Vent. Engrs* **18**, 466.

VERNON, H. M., BEDFORD, T. & WARNER, C. G. (1930). A study of heating and ventilation in schools. *Rep. ind. Hlth Res. Bd.* no. 58.

WESTON, J. C. (1953). School heating research. *J. Instn Heat. Vent. Engrs* **20**, 459.