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Evaluation of Ventilation Requirements and Energy Consumption in Existing New York City School Buildings

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1. Introduction

Numerous articles and detailed research studies[1, 2, 3/*] indicate that the nation continues to face increasing demands for fuel and electrical energy which in turn impose great pressures on available supplies. This situation, coupled with air and thermal pollution problems of the nation, caused leaders to declare that conservation of energy resources is of paramount importance in government and industry.

Energy used in buildings for space heating and cooling, lighting, hot water heating, and mechanical ventilation constitutes a large portion (32 percent) of energy consumption in the United States, as was recently documented by a Stanford Research Institute report[3/]. It is estimated that at least 10 to 20 percent, and maybe as high as 40 to 50 percent[4/] of energy used in buildings could be saved in the design and construction of new buildings by a comprehensive thermal analysis in the design of the building envelope, by a more careful evaluation of fresh air ventilation requirements and lighting requirements, and by the utilization of efficient energy conversion equipment.

Public school buildings, as a group, constitute a significant portion of the public buildings in the cities of the United States. The Center for Building Technology of the National Bureau of Standards, under the sponsorship of the National Science Foundation, and with the collaboration of the Board of Education of New York City, undertook a study in 1974 on the pattern of energy consumption, and the effect of ventilation on a classroom environment, in a typical urban public school. The purpose was to obtain detailed information on the energy usage of school buildings in order to develop guidelines for energy conservation in the design and construction of future energy-efficient school buildings. This report presents the results of this study.

Work done at NBS on this project consisted of two parts. The first part involved (1) an analysis leading to the selection of a typical existing school in New York City to be used as a norm for comparison with a future new energy-conserving school, and (2) a detailed computer thermal analysis of the selected school using the NBS program called NBSLD[5/] to determine the breakdown of its energy usage with respect to lighting, heating, ventilation, and equipment operation, in order to identify the importance of the major areas of energy consumption in the new school design. The selection of a typical existing school as a norm was based on a study of the fuel-oil and electrical energy consumption data from May 1970 through April 1973, of 19 schools of varying size as supplied by the Board of Education of the City of New York. Field trips to five of the 19 schools were taken jointly with the Board of Education and its principal investigator, Richard Stein and Associates, to obtain a typical school schedule and operating data for various mechanical equipment. These data were then used as input to the NBS computer program for the thermal analysis.

The second part of this report gives the results of a one-week ventilation test conducted in a typical urban classroom in New York City to determine the effect of reduced ventilation on the interior environment, including the concentrations of carbon dioxide and oxygen, the change in dry-bulb temperature, the variation of relative humidity, and the activity and response of the students. These results are expected to provide information on the reduction of the rate of ventilation as a means of reducing the energy consumption.

Details of the above two parts of the project will be discussed in the following sections.

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* See references at end of text.

Table 1 Description of the 19 Schools Included in the Energy Consumption Survey

School No.	Type*	Location	Year Completed	Gross Floor Area 1,000 ft^2	Type of Wall Construction**	No. of Stories	Classroom Ceiling Heights	Ratio of Classroom Window to Exterior Wall Area	Heating System Type
1	H. S.	Brooklyn	1969	404	1	4	10'-0"	0.37	Fin-Tube Steam
2	I. S.	Brooklyn	1963	188	1	3	10'-0"	0.52	Fin-Tube Steam
3	H. S.	Bronx	1969	371	1	3	8'-9"	0.50	Fin-Tube Steam
4	H. S.	Queens	1960	246					
5	H. S.	Queens	1955	311	1	3	10'-8"	0.39	Fin-Tube Steam
6	H. S.	Queens	1965	254	1	3	9'-0"	0.58	Fin-Tube Steam
7	H. S.	Bronx	1959	288	6	4	11'-0"	0.52	Fin-Tube Steam
8	I. S.	Bronx	1970	176					
9	H. S.	Queens	1966	284	1	3	9'-0"	0.29	Fin-Tube Steam
10	I. S.	Brooklyn	1970	169	3	3	10'-0"	0.41	Fin-Tube Steam
11	H. S.	Manhattan	1958	251	5	7	11'-6"	0.25	Fin-Tube Steam
12	H. S.	Brooklyn	1958	300	1	3	8'-0"	0.56	Fin-Tube Steam
13	H. S.	Queens	1964	254	1	3	9'-3"	0.50	Fin-Tube Steam
14	I. S.	Brooklyn	1968	164	2	4	10'-4"	0.05	Fin-Tube Steam
15	I. S.	Manhattan	1958	175					
16	H. S.	Brooklyn	1969	282	4	3	11'-3"	0.49	Fin-Tube Steam
17	H. S.	Brooklyn	1964	248	1	3	8'-5"	0.42	Fin-Tube Steam
18	I. S.	Brooklyn	1966	163					
19	I. S.	Manhattan	1966	170	2	3	8'-0"	0.	Hot Water

* H. S. - High School
I. S. - Intermediate School

** Wall Type 1: 4" face brick, 2" airspace, 6" concrete block
Wall Type 2: 4" face brick, 2" airspace, 4" concrete block
Wall Type 3: 4" face brick, 6" concrete block
Wall Type 4: 10 1/2" masonry, 2" airspace, 3" plaster
Wall Type 5: 4" glass block
Wall Type 6: 10 1/2" masonry

1 ft^2 = 9.29 x 10^{-2} m^2
1 ft = 3.048 x 10^{-1} m
1 in. = 2.54 cm

Table 2 Three-Year Averaged Monthly Electricity Consumption in 19 Schools

School No.	Gross Floor Area 1,000 ft²	Monthly Electricity Consumption in kWh Per 1,000 ft² Floor Area 1	2	3	4	5	6	7	8	9	10	11	12	Yearly Total
1	404	326	332	384	316	362	317	181*	189*	269*	333*	318	306	3,633
2	188	379	378	403	338	386	333	232	214	269	328	354	349	3,963
3	371	416	406	460	340	363	323	178	214	311	355	543		4,307
4	246	443	434	503	358	466	443*	37*	195*	258	320	421	434	4,312
5	311	453	420	487	380	496	386	149	101	309	447	455	429	4,512
6	254	461	444	448	517	504	375	104	110	298	426	474	463	4,624
7	288	424	458	529	440	474	385	135	117*	332*	442	457	482	4,675
8	176	432	430	476	399	477	455	236	2[illegible]9	317	403	434	437	4,745
9	284	487	479	555	444	539	431*	150*	155	365	466	472	487	5,030
10	169	667**/426*	389	518	440	454	372	366*	344*	266*	398	433	639**/419*	5,286/4,825
11	251	551	540	603	492	581	451	261	207	360	521	534	558	5,659
12	300	530	552	641	484	625	524	141	168	368	532	572	555	5,692
13	254	561	540	601	464	570	458	346	373	403	511	535	554	5,916
14	164	553	524	544	485	549	510	417	422	507	532	542	529	6,114
15	175	616	595	631	567	631	534	338	377	406	557	588	580	6,420
16	282	617	576	660*	540*	664	567	393	399	495	583	605	603	6,702
17	248	815	729	815	734	763	685	366	384	574	768	802	766	8,201
18	163	809	784	825	801	786	676	549	633	627	681	765	784	8,722
19	170	1,280	1,129	1,257	1,240	1,306	1,381	1,273	1,296	1,261	1,271	1,212	1,233	15,142

* 2-year average

** Extra large during the opening year operation

1 kWh/1,000 ft^2 = 38,750 J/m^2
1 ft^2 = .093 m^2

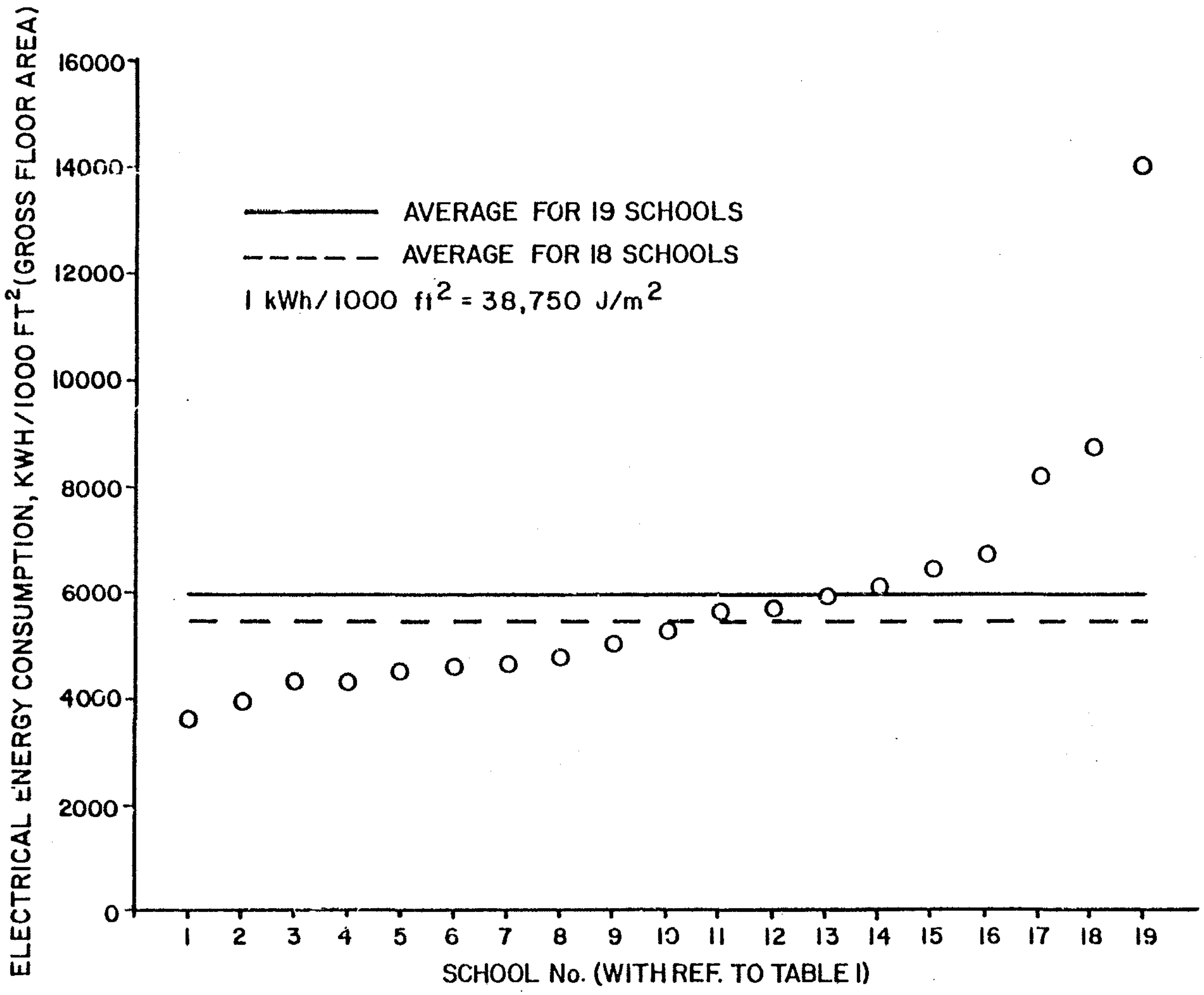

Figure 1 Averaged (3-Year) Y·erly Electrical Energy Consumpticn in 19 Schools

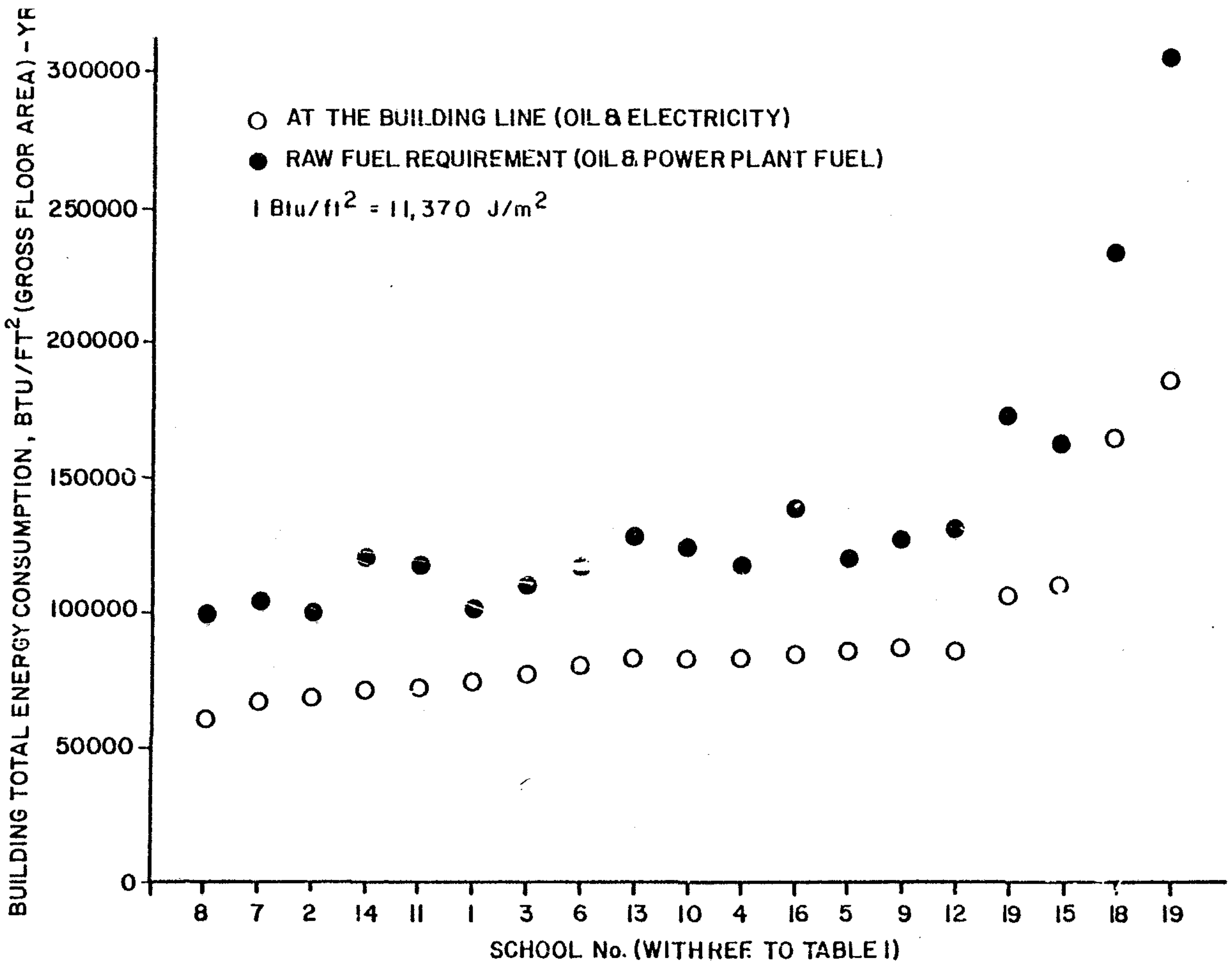

Figure 3 Averaged (3-Year) Yearly Energy Requirement in 19 Schools

Table 4 Operation Schedules of the 5 Schools Visited

School No.	2	6	10	17	19
No. of Day Students	1,720	4,000	1,500	4,000	1,500
School Hours					
Weekdays	8:30 a.m. - 3:00 p.m.	7:00 a.m. - 5:00 p.m.	8:30 a.m. - 3:00 p.m.	7:30 a.m. - 4:30 p.m.	8:30 a.m. - 3:00 p.m.
Week Nights	6:00 p.m. - 10:00 p.m.	7:00 p.m. - 9:30 p.m.	7:00 p.m. - 10:00 p.m., 3/Week	6:00 p.m. - 10:00 p.m.	6:00 p.m. 10:00 p.m., 3/Week
Weekends	Saturday, 9:00 a.m. - 12:00 noon	Saturday, 10:00 a.m. - 5:00 p.m.	Saturday, 9:00 a.m. - 12:00 noon	10:00 a.m. - 3:00 p.m.	10:00 a.m. - 5:00 p.m.
Space Occupied					
Weekdays	All	All	All	All	All
Week Nights	Gymnasium, Auditorium	Gymnasium, 30 Classrooms	Gymnasium, 15% Classrooms	Gymnasium, 12 Classrooms	2nd Floor (25%)
Weekends	Gymnasium, Auditorium	Gymnasium	Gymnasium	Gymnasium	Gymnasium
Lighting					
Weekdays	All	All, 20% Auditorium	All, 25% Auditorium	All	All
Week Nights	Corridor, Gymnasium, Auditorium	Corridor, Gymnasium, 30 Classrooms	Corridor, Gymnasium, 15% Classrooms	Corridor, Gymnasium, 12 Classrooms	Corridor, Cafeteria, Gymnasium, Classrooms
Weekends	Corridor, Gymnasium, Auditorium	Gymnasium	Corridor, Gymnasium	Gymnasium	Corridor, Gymnasium
Thermostat					
Classrooms	72 °F	73 °F	72 °F	72 °F	72 °F
Gymnasium	70 °F	70 °F	70 °F	70 °F	70 °F
Auditorium	70 °F	70 °F	70 °F	70 °F	70 °F
Cafeteria	70 °F	70 °F	70 °F	70 °F	70 °F
Boiler Schedule					
Heating Season	2 Boilers	2 Boilers	2 to 3 Boilers	2 to 3 Boilers	2 Boilers
Other Seasons	1 Boiler	1 Boiler	1 Boiler	1 Boiler	2 Boilers
Boiler Schedule					
Weekdays	7:00 a.m. - 2:30 p.m.	6:00 a.m. - 3:00 p.m.	7:00 a.m. - 2:30 p.m.	5:00 a.m. - 6:00 p.m.	7:00 a.m. - 3:00 p.m.
Week Nights	6:00 p.m. - 8:00 p.m.	7:00 p.m. - 9:00 p.m.	6:00 p.m. - 9:00 p.m.	6:00 p.m. - 9:00 p.m.	6:00 p.m. - 9:00 p.m.
Weekends	Saturday, 8:00 a.m. - 10:00 a.m.	Saturday, 9:00 a.m. - 2:00 p.m.	Saturday, 7:00 a.m. - 10:00 a.m.	9:00 a.m. - 2:00 p.m.	11:00 a.m. - 5:00 p.m.

10. School No. 19 was the only school visited that had air-conditioning. The school was a windowless school with a higher than usual lighting level (5.5 watt/ft^2 (59.2 W/m^2) classroom floor area) and a longer than usual school schedule (open 7 days/week, 52 weeks/year for both teaching and community activities). The boilers supplied steam for space heating during the winter and for the absorption chillers during cooling season. The windowless design and the operating schedule probably caused the high energy consumption rate for this school.

The information gathered during the visit to the schools was used as input to the NBS-developed building thermal load determination program in order to obtain a detailed energy consumption pattern of a typical existing school. The computer analysis is described in the following section.

3. Computerized Analysis of the Energy Consumption Pattern of a Typical Existing School

3.1 Calculation of Indoor Space Conditions by Building Thermal Simulation

Numerous papers have been published and calculation manuals prepared on the subject of heating/cooling load determination. Very few of the computerized models, however, have the capability of handling fluctuations in indoor air temperature as in the case of the schools studied in this report where the boilers are actually shut down during nonoccupied periods of time and the indoor temperature is allowed to drift below the set value of the thermostat.

The heat transfer calculations for room temperature prediction are similar to the heating/cooling load calculations. The former, however, are somewhat more complex than the latter because they require exact heat transfer calculations for heat conduction through exterior surface and infiltration heat exchange. The National Bureau of Standards, over the last several years, has developed a computer program which computes the room heating/cooling load requirement, as well as the temperature fluctuation of a room not heated or air-conditioned, when the building is subjected to hour-by-hour randomly fluctuating outdoor climatic conditions. The program is called "NBSLD" and consists of various subroutines for calculating heat gains and losses, which are similar to those recommended by the ASHRAE Task Group on Energy Requirements[7/]. One major extension of the program beyond the recommended ASHRAE Task Group algorithms is a routine called RMTPK, which solves for the hour-by-hour heating/cooling load requirements or temperature variations, taking into account the transient heat conduction and thermal storage in the building and internal mass, through the use of a series of simultaneous heat balance equations. The details of this routine, and the general description of the overall program, are given in references [5] and [8].

3.2 Construction Data and Operation Schedules of the Selected School

In order to aid in the design of new energy conserving schools and to investigate the application of the NBS computer program NBSLD to school design, one of the schools visited during the field trip was selected for a detailed analysis of its energy consumption pattern with respect to its requirements in heating, ventilation, lighting, and mechanical equipment operation. Once a suitable mode for the energy consumption in an existing typical school is established, areas of major energy consumption can be identified, and new designs can be devised and applied to minimize or reduce the energy requirements in these major areas.

The school selected for this detailed study was school No. 6 because its yearly consumption in fuel oil was approximately the average of the 19 schools studied. Since the computer program "NBSLD" is a thermal energy analysis program and the space heating requirement of a building is intimately associated with the building shell design and ventilation requirement, emphasis was placed on selecting a school which has an average fuel-oil consumption.

The No. 6 school selected for the analysis is a high school facility having an overall floor area of 254,000 sq. ft. (23,600 m^2) and is located in Queens, New York. The facility is composed of 3 buildings: a 3-story classroom and administration building, a gymnasium,

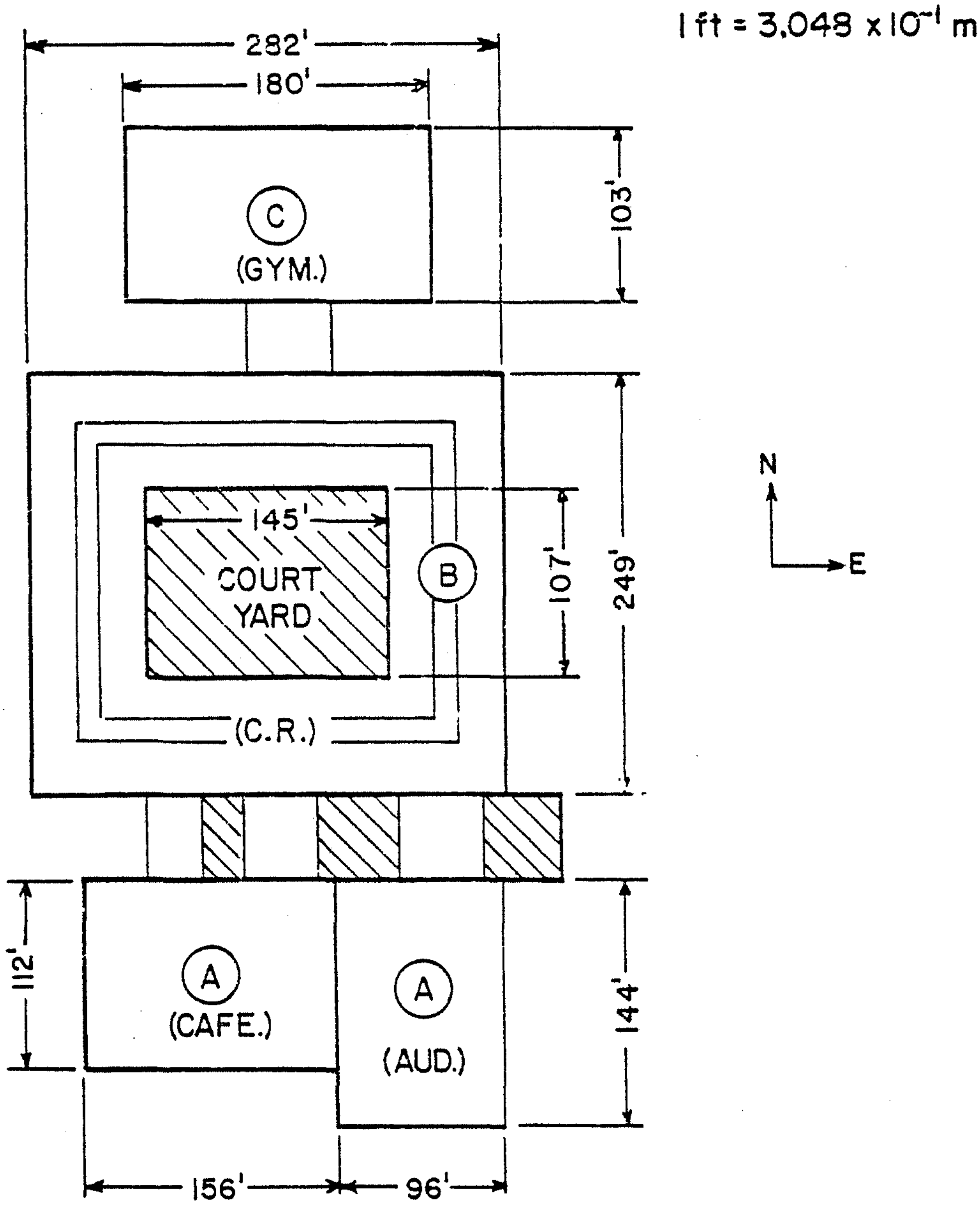

Figure 4 Schematic of School No. 6

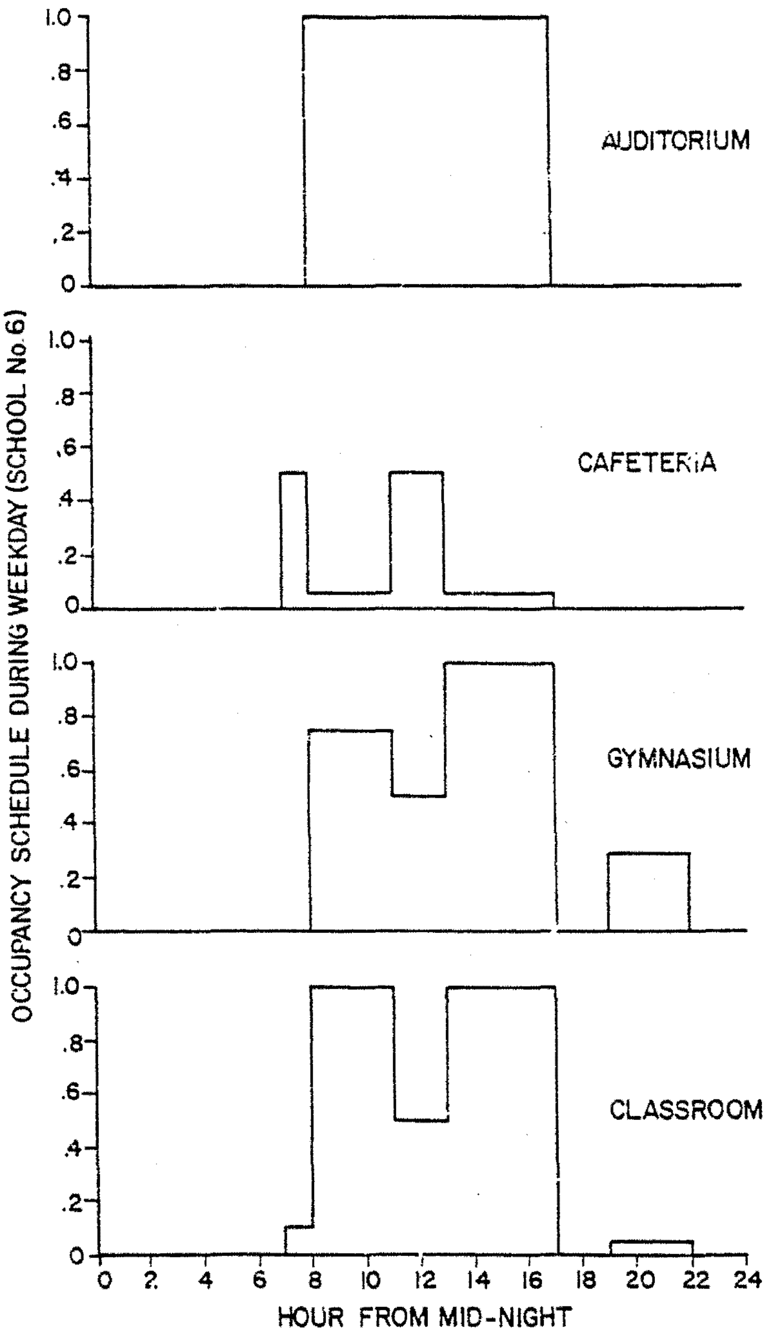

Figure 6 Occupancy Schedules of School No. 6 During a School Day (Heating Season)

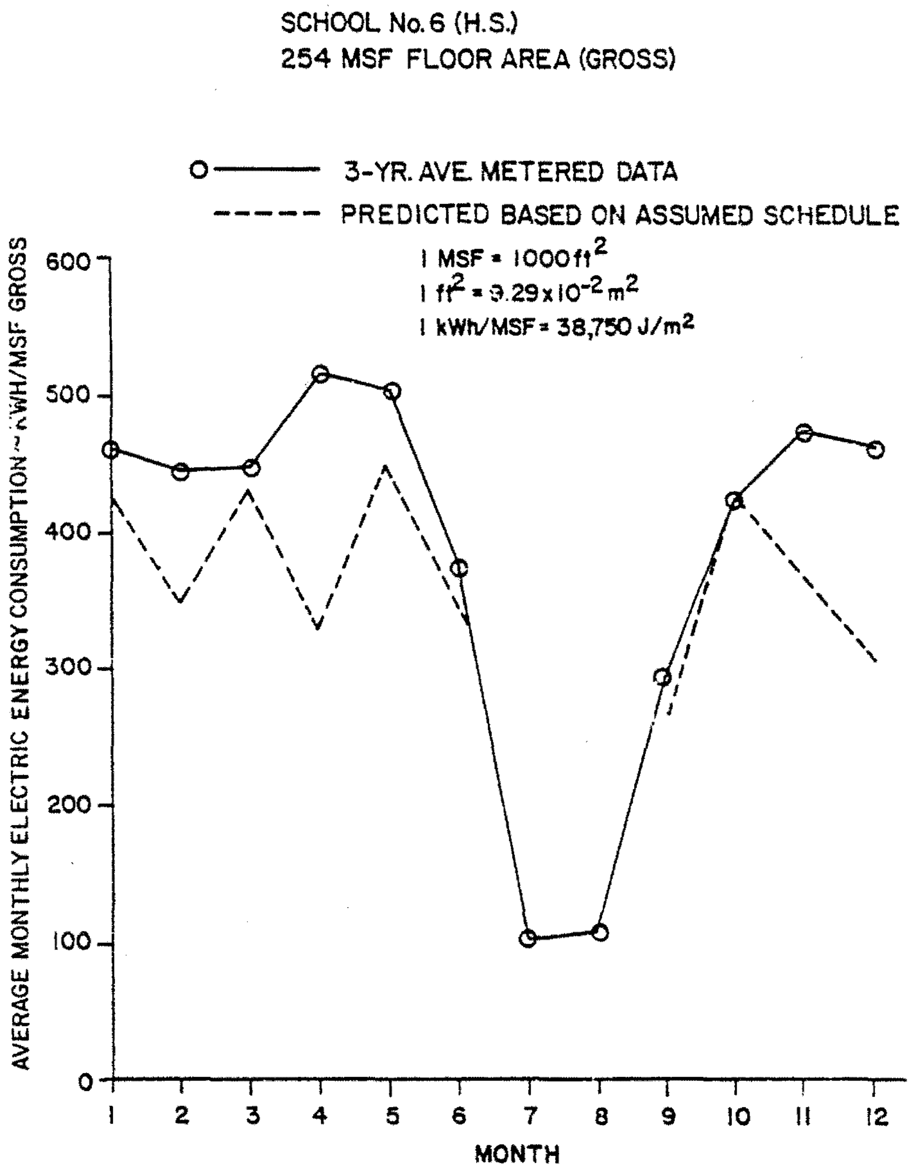

Figure 10 Comparison of Predicted and Actual Measured Monthly Electrical Energy Consumption in School No. 6

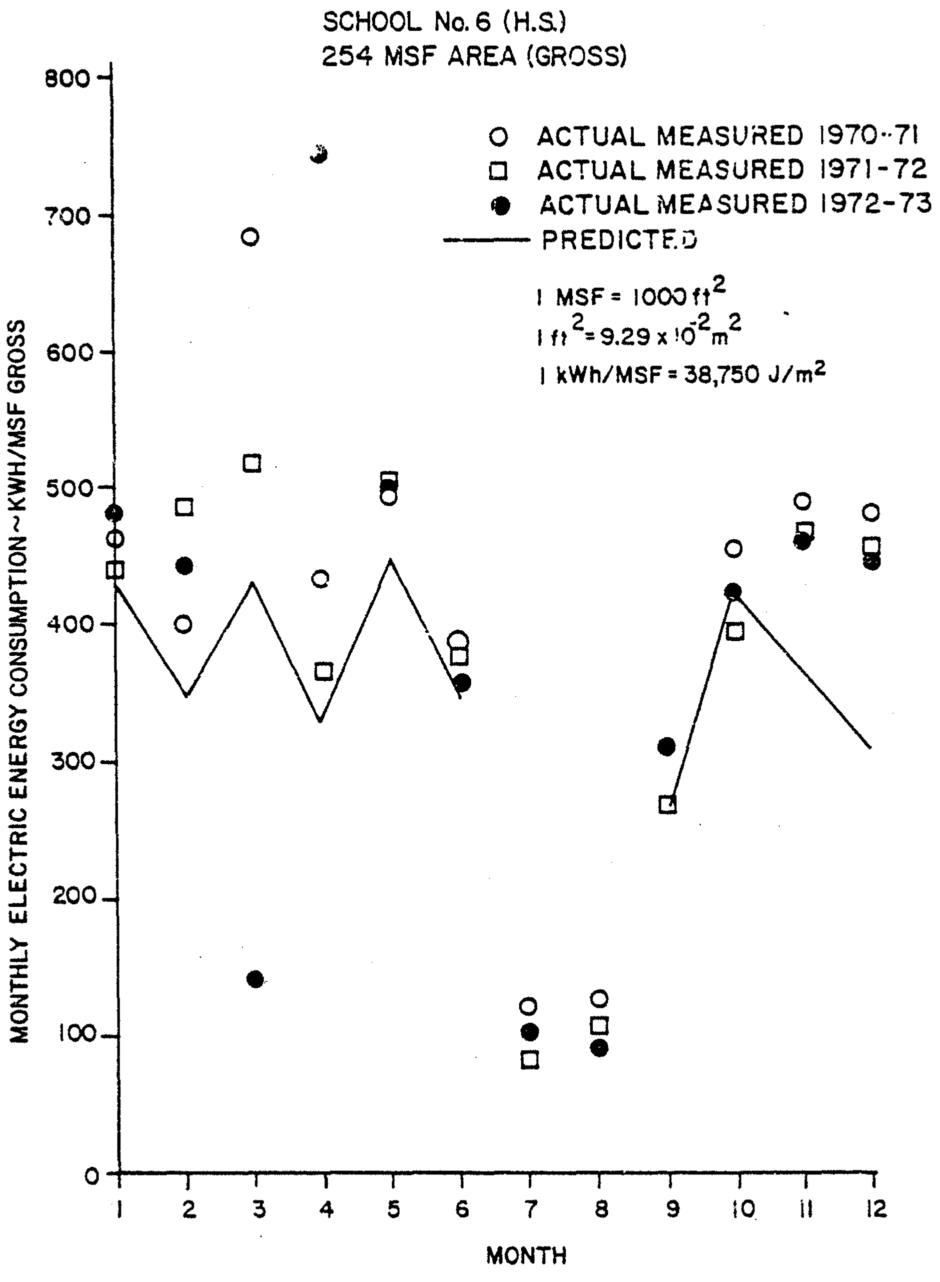

Figure 12 Comparison of Actual Measured Monthly Electrical Energy Consumption With Corresponding Predicted Values

which had the same electricity consumption). With the school officially closed from December 24 to January 1 for the Christmas recess, the December consumption should be much lower than for January if the school was in fact closed entirely during the recess. Also, the schedule for lighting used in the computation was, at best, an estimate of the actual usage pattern which was subjected to much greater variations than space heating or ventilation equipment operations, since those operation schedules were controlled by a single person, the custodian, while the lighting switches were accessible to a large number of people.

Table 6 gives a breakdown of monthly energy usage for ventilation, heat loss through glass, heat loss due to air infiltration and conduction through the building shell, lighting, ventilation fans, and other miscellaneous equipment. Table 7 gives the various types of energy usage in terms of fraction of total energy consumption. It is seen from the two tables that during the heating season (November - February), 76 percent of the heating energy was used to heat ventilation fresh air. The fraction of energy for classroom ventilation was the largest (27 percent), followed by gymnasium (26 percent), auditorium (14 percent), and cafeteria (8.5 percent). These data showed that a significant reduction of heating energy could be obtained by reducing the rate of fresh air intake.

Table 7 shows that the fraction of heating energy used to compensate for heat loss due to fenestration was 2.5 to 2.9 percent, and for heat loss through the solid parts of the building shell and infiltration, was 17 to 19 percent, with a combined total of about 21 percent. However, this relatively small fraction does not mean that there is no need to improve the design of the building shell. The large quantity of heating energy used to heat up the outdoor fresh air for ventilation purpose overshadows the building skin loss. If the fresh air intake is reduced significantly--for example, by a factor of 2--the percent building skin loss will become larger. The heat loss through window glass was the difference between the heat loss by conduction and heat gain due to solar radiation. This loss represents only 2.5 to 2.9 percent of the total building energy usage and 10 to 14 percent of the total heat loss through building shell and by infiltration. This is because even though the amount of glass in the classroom building is large (33 percent, see Table 5), the amounts of glass in the other two buildings are small and the overall ratio of glass to exposed surfaces, including roof and ground floor, amounts to only 7 percent of the total building shell area.

Tables 6 and 7 also give the monthly electrical energy consumption for lighting and equipment operation. It is seen that lighting constituted about 80 percent of the total electrical energy usage and ventilation fans most of the remaining usage. Therefore, any significant reduction in lighting would reduce the overall electricity usage by a large amount. The power requirement for ventilation fans will be reduced if the ventilation rate for classrooms and the air supply rate to the other spaces are reduced.

4. Ventilation Test

4.1 Objective of the Test

As described in the previous section, fresh air ventilation comprises the major heating energy consumption for the existing schools. Any reduction in the ventilation rate will therefore contribute significantly to the effort in reducing fuel-oil consumption.

The purposes in providing ventilation air for a classroom are (1) to prevent the buildup of carbon dioxide gas, and to a lesser extent to prevent the reduction in oxygen supply, to levels considered harmful to the general health of the students; (2) to dilute the intensity of body odors which may be disagreeable and distracting, in a densely occupied space; and (3) to provide air movement in the classroom for the purposes of minimizing the temperature gradient and local pockets of high carbon dioxide or odor concentration.

Chapter 4 of the 1974 Applications Volume of the ASHRAE Guide and Data Book[9] states that, with regard to health consideration, 1 cfm (0.47×10^{-3} m^3/s) of outdoor air per student is required to provide the necessary oxygen content, and 4 cfm (1.89×10^{-3} m^3/s) of outdoor air per student is required to limit the CO_2 concentration to 0.6 percent by volume. These values are applicable to a room with from 110 to 457 ft^3 (3.12 to 12.98 m^3) of airspace per student. In the same reference, the requirement for odor-free air (not necessarily outdoor air) varies from 29 cfm (13.6×10^{-3} m^3/s) per student at 100 ft^3 (2.84 m^3) of airspace per student to

Table 7 Types of Energy Usage as Fractions of Total Calculated Energy Consumption in School No. 6

	Month									
	9	10	11	12	1	2	3	4	5	6
(1) Ventilation Energy Usage (Heating)										
Classroom Ventilation/Total Heating	.125	.225	.276	.272	.275	.272	.274	.237	.194	.068
Gymnasium Ventilation/Total Heating	.170	.273	.263	.268	.259	.264	.269	.237	.248	.078
Cafeteria Ventilation/Total Heating	.000	.033	.058	.070	.085	.080	.060	.063	.020	.000
Auditorium Ventilation/Total Heating	.105	.173	.166	.142	.141	.139	.155	.180	.170	.012
(2) Components of Heating Energy Usage										
Total Ventilation/Total Heating	.400	.704	.763	.752	.760	.755	.758	.717	.632	.158
Glass Loss/Total Heating	.010	.021	.029	.028	.024	.022	.020	.016	.012	.000
Walls, Infiltration Loss/Total Heating	.069	.122	.141	.174	.185	.186	.173	.148	.113	.019
Hot Water/Total Heating	.521	.153	.067	.046	.031	.037	.049	.119	.243	.823
(3) Components of Electrical Energy Usage										
Lighting/Total Electrical	.800	.800	.800	.799	.800	.799	.799	.800	.800	.799
Fans/Total Electrical	.193	.194	.193	.194	.194	.194	.194	.194	.194	.194
Miscellaneous Equipment/Total Electrical	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007
(4) Components of Heat Loss										
Glass Loss/Total Loss	.129	.149	.173	.138	.114	.105	.104	.099	.099	.026
Walls, Infiltration Loss/Total Loss	.871	.851	.827	.862	.886	.895	.896	.901	.901	.974

1 ft = 3.048 x 10^{-1} m

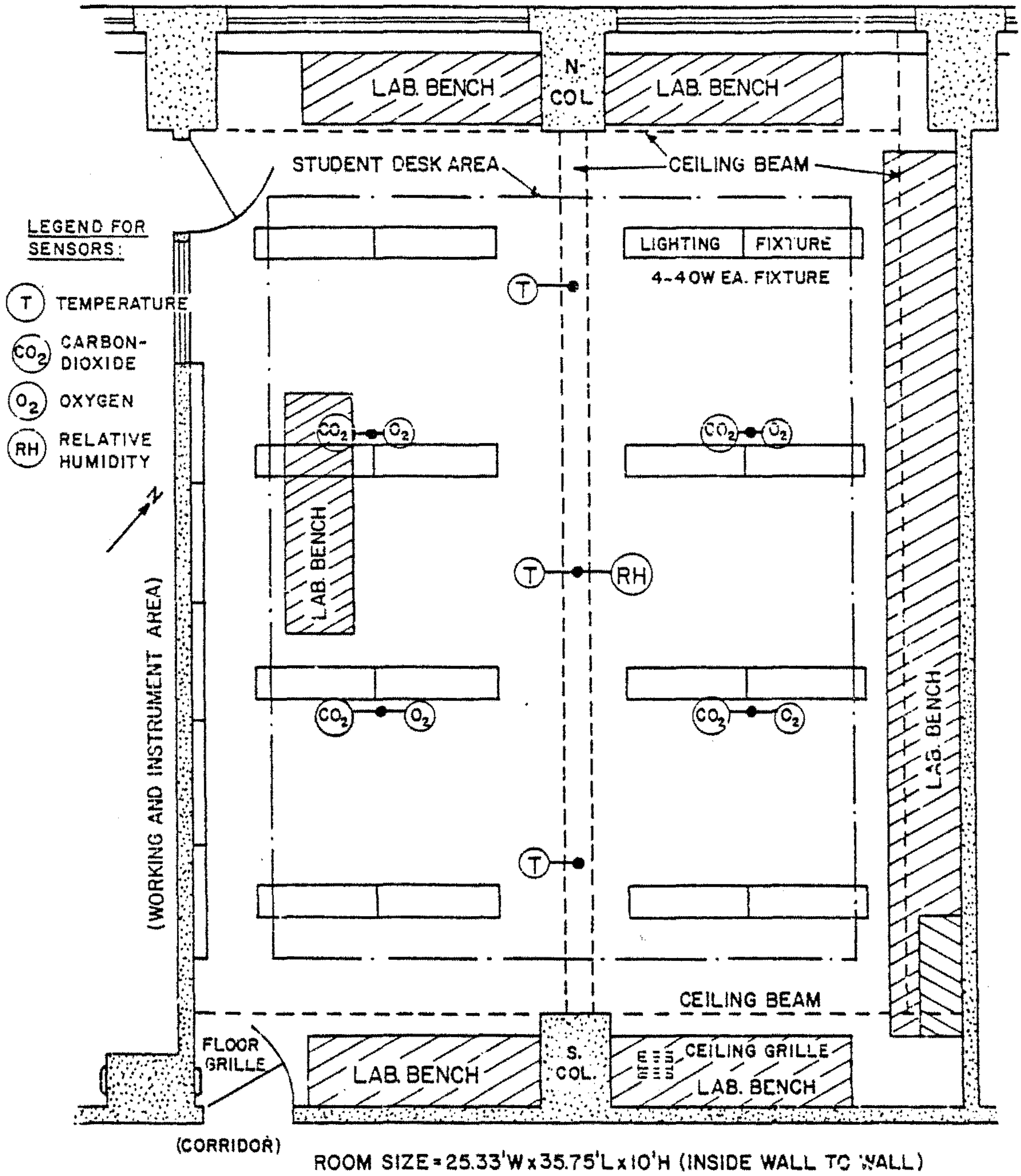

Figure 13 Schematic of the Classroom in School No. 10 Used for the Ventilation Test

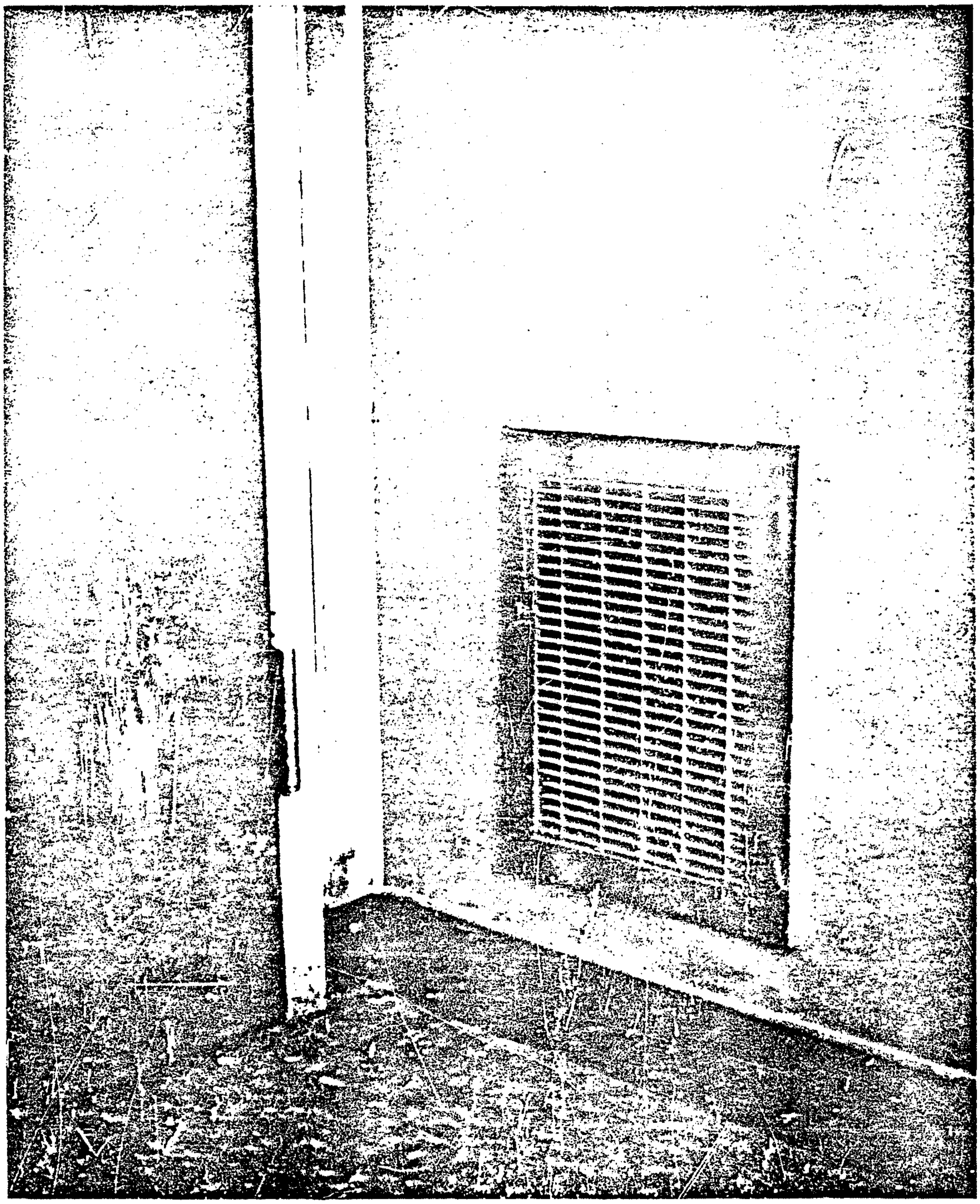

Figure 15 Photograph of the Floor Exhaust Grille in the Test Classroom

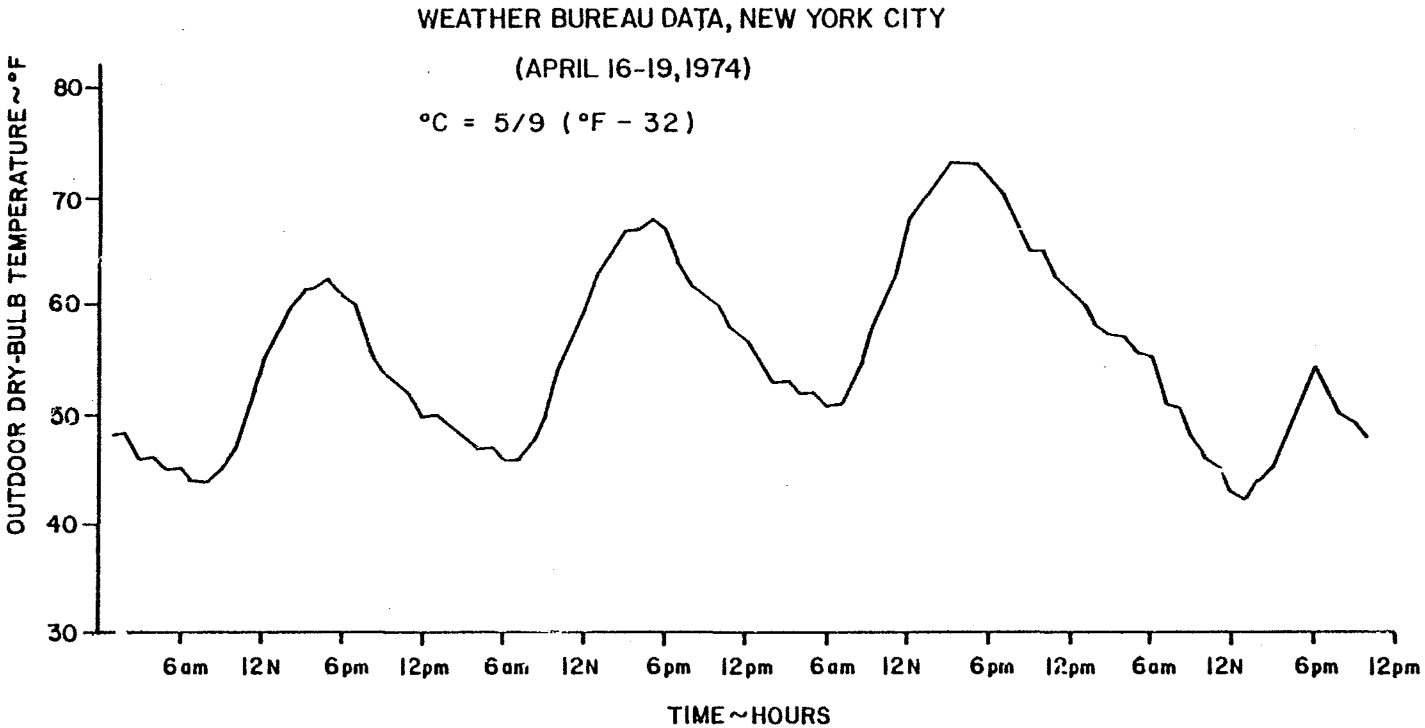

Figure 17 Variation of the Outdoor Dry-Bulb Temperature During the 4-Day Ventilation Test Period

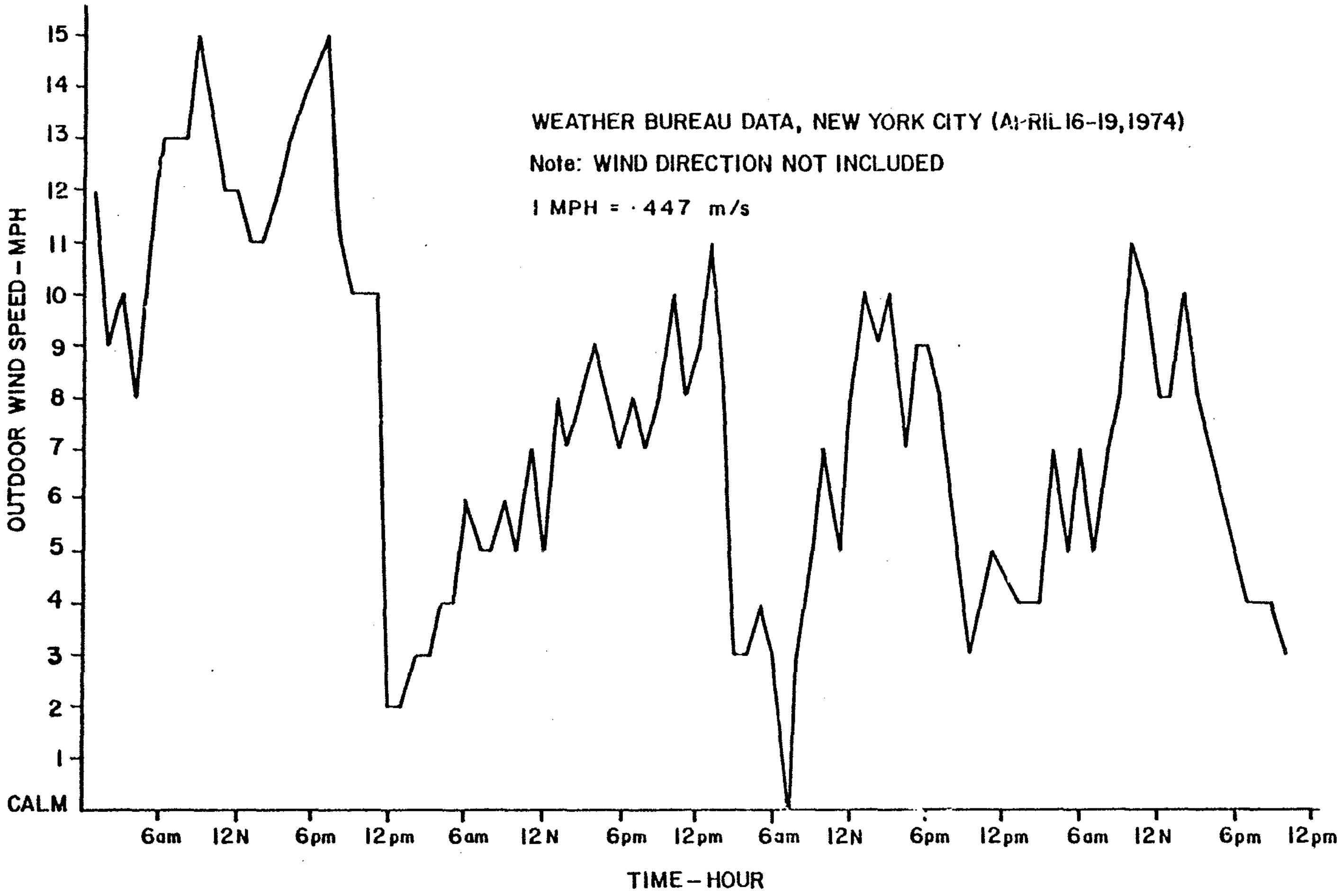

Figure 19 Variation of Outdoor Wind Speed During the 4-Day Ventilation Test Period

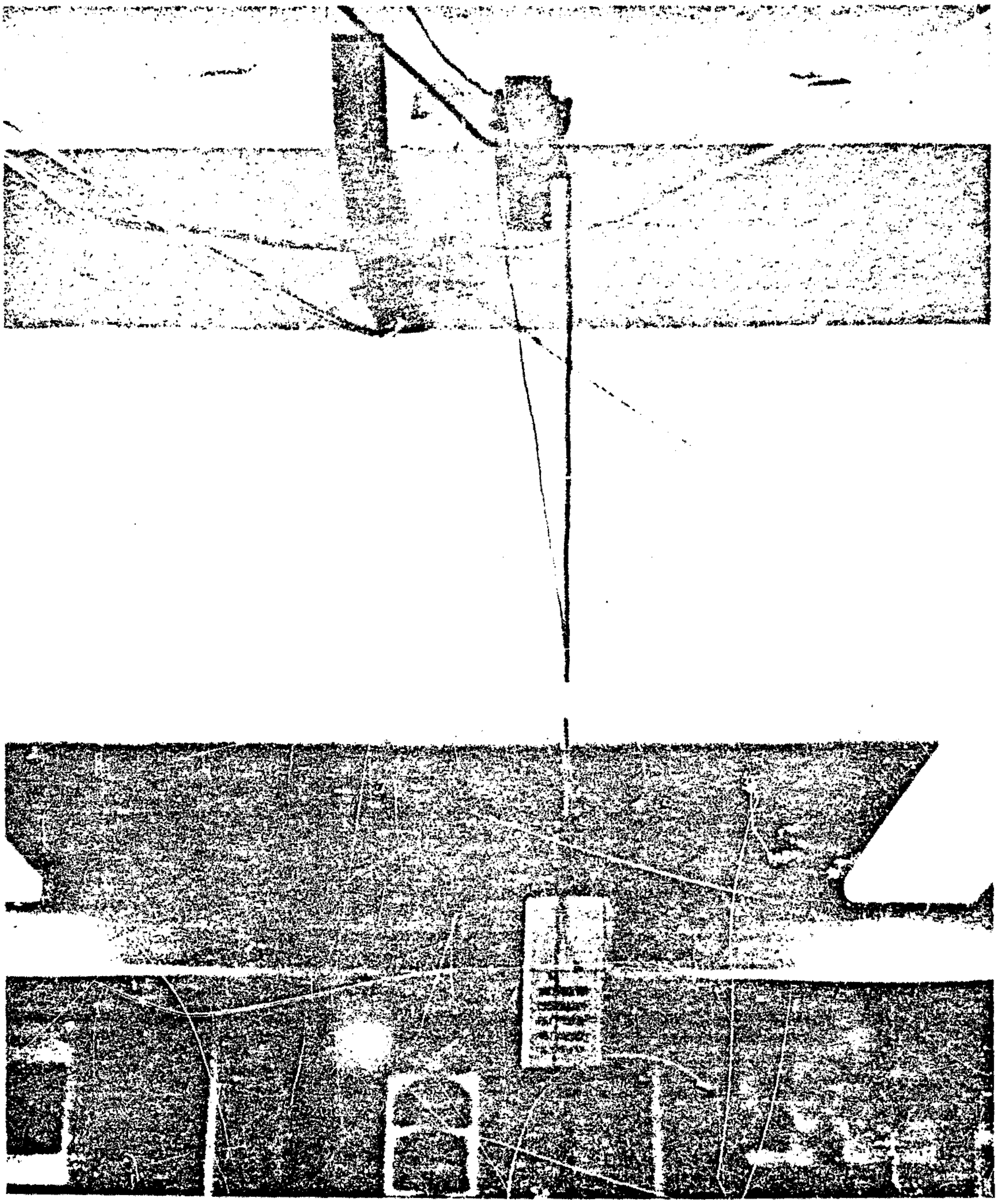

Figure 20 Photograph of the Relative Humidity Sensor and Thermocouple Setup in the Test Classroom

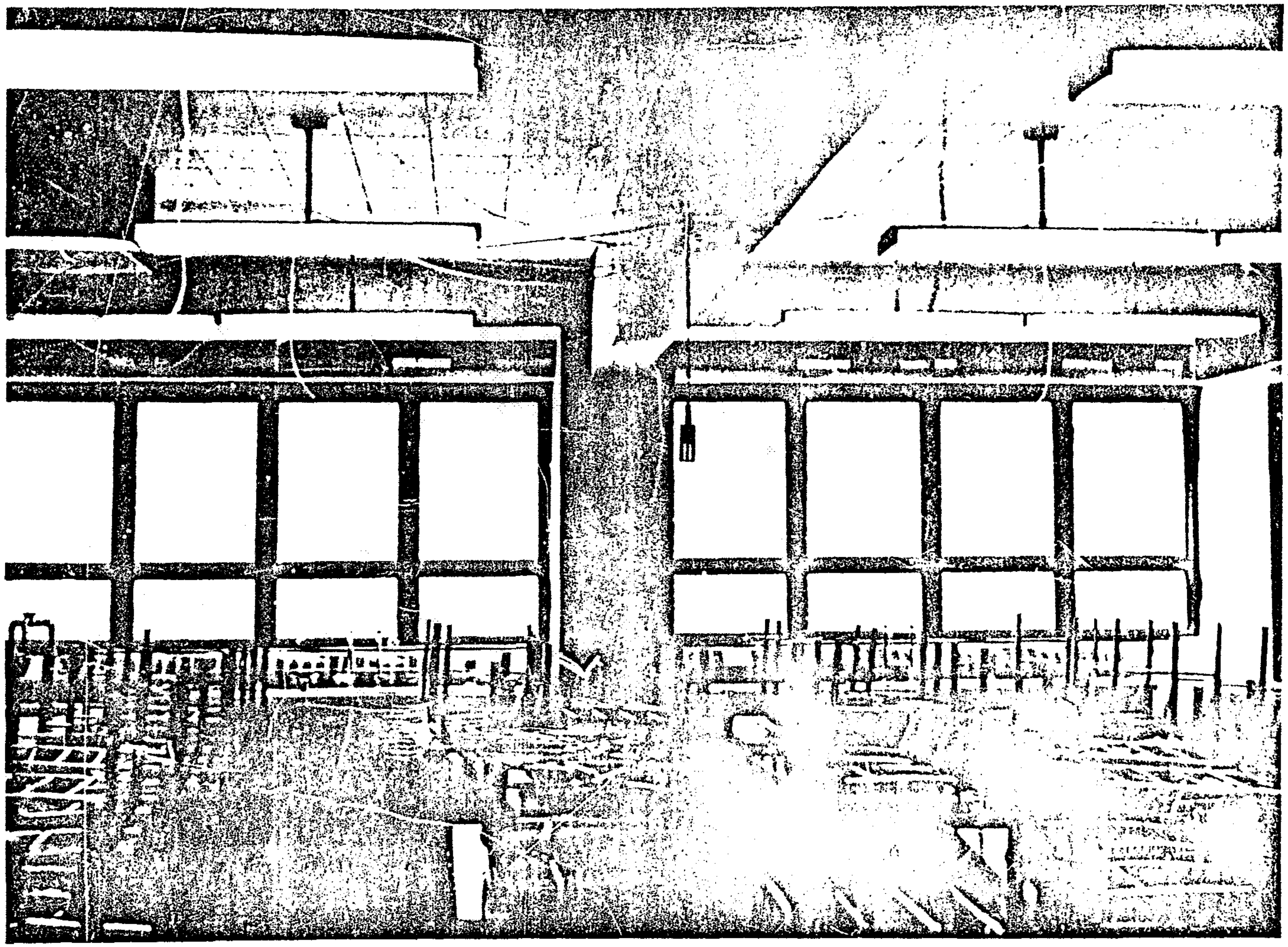

Figure 21 Photograph of the Test Setup in the Classroom for Ventilation Tests

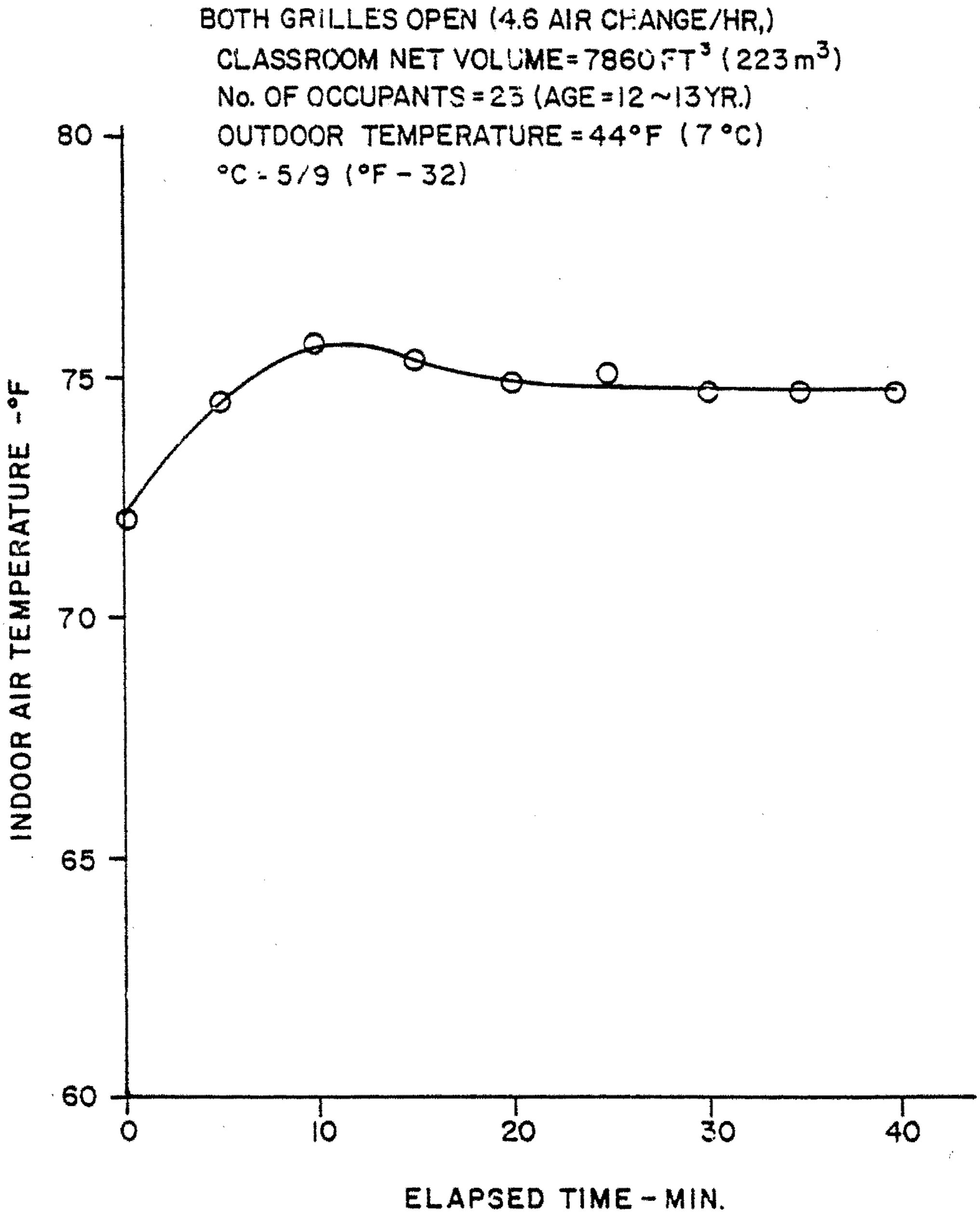

Figure 23 Indoor Air Temperature Variation During One Class Period
(Normal Condition, Both Grilles Open)

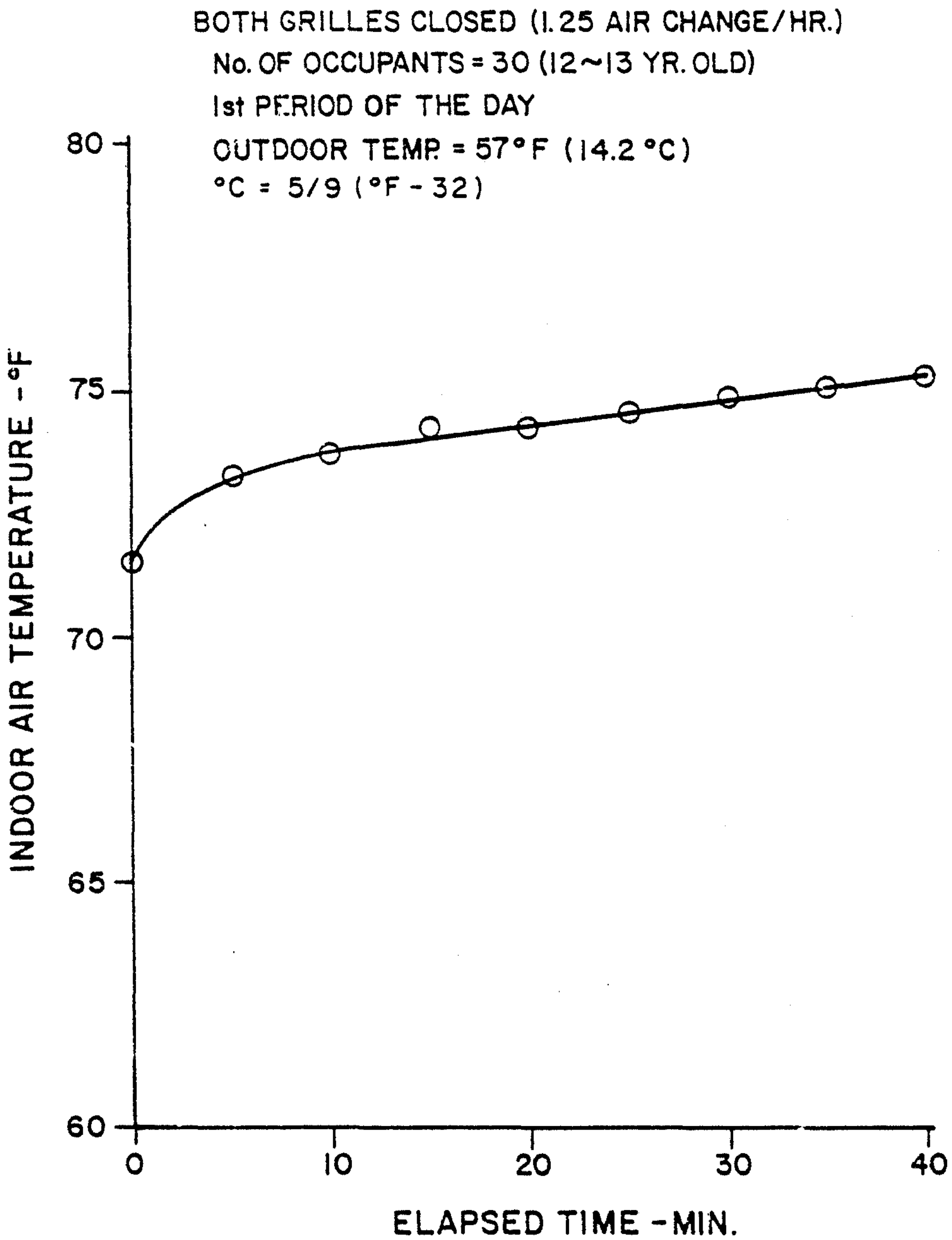

Figure 25 Indoor Air Temperature Variation During One Class Period (Both Grilles Blocked)

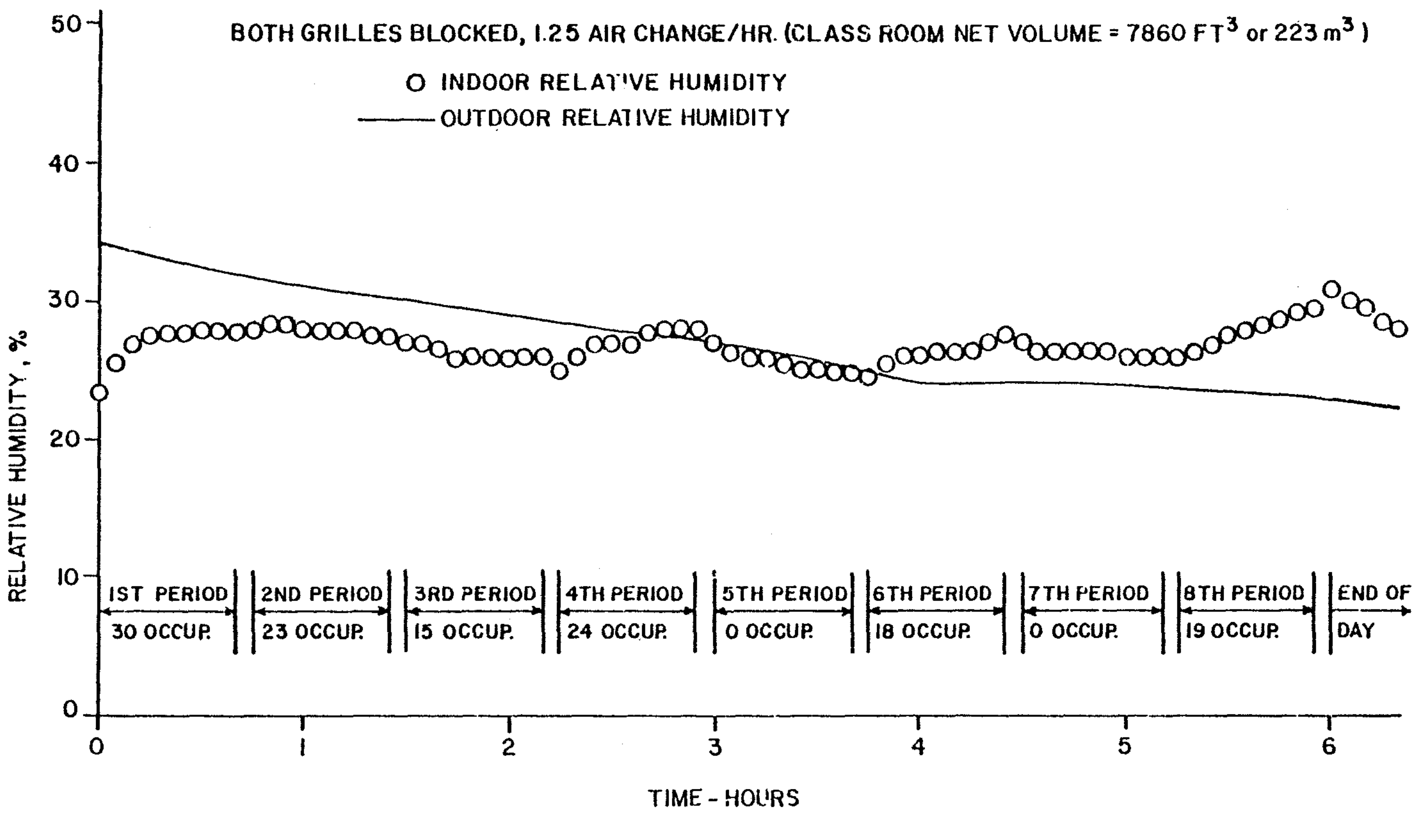

Figure 27 Variation of Indoor Relative Humidity During One School Day (Both Grilles Blocked)

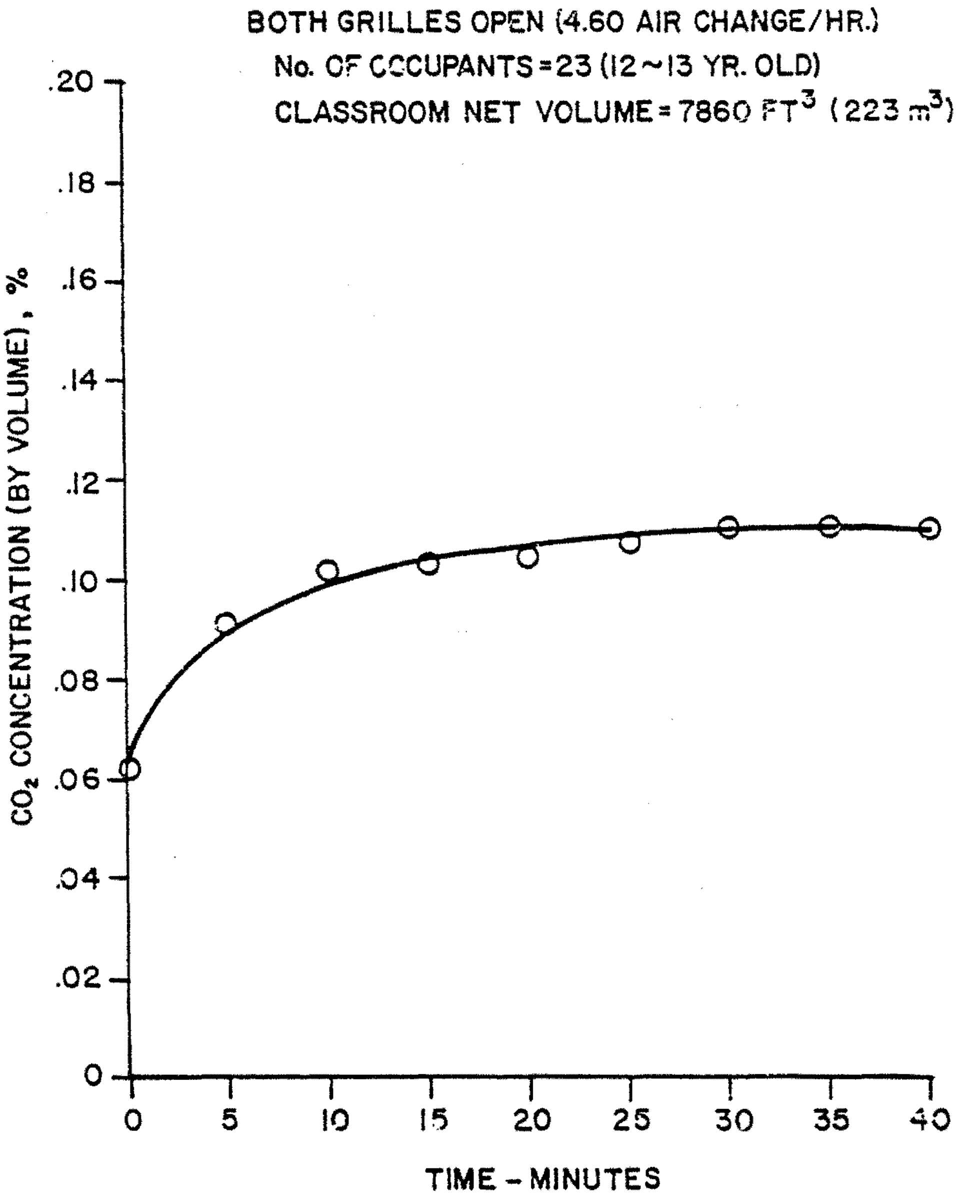

Figure 28 Variation of Indoor CO_2 Concentration During One Class Period (Normal Conditions, Both Grilles Open)

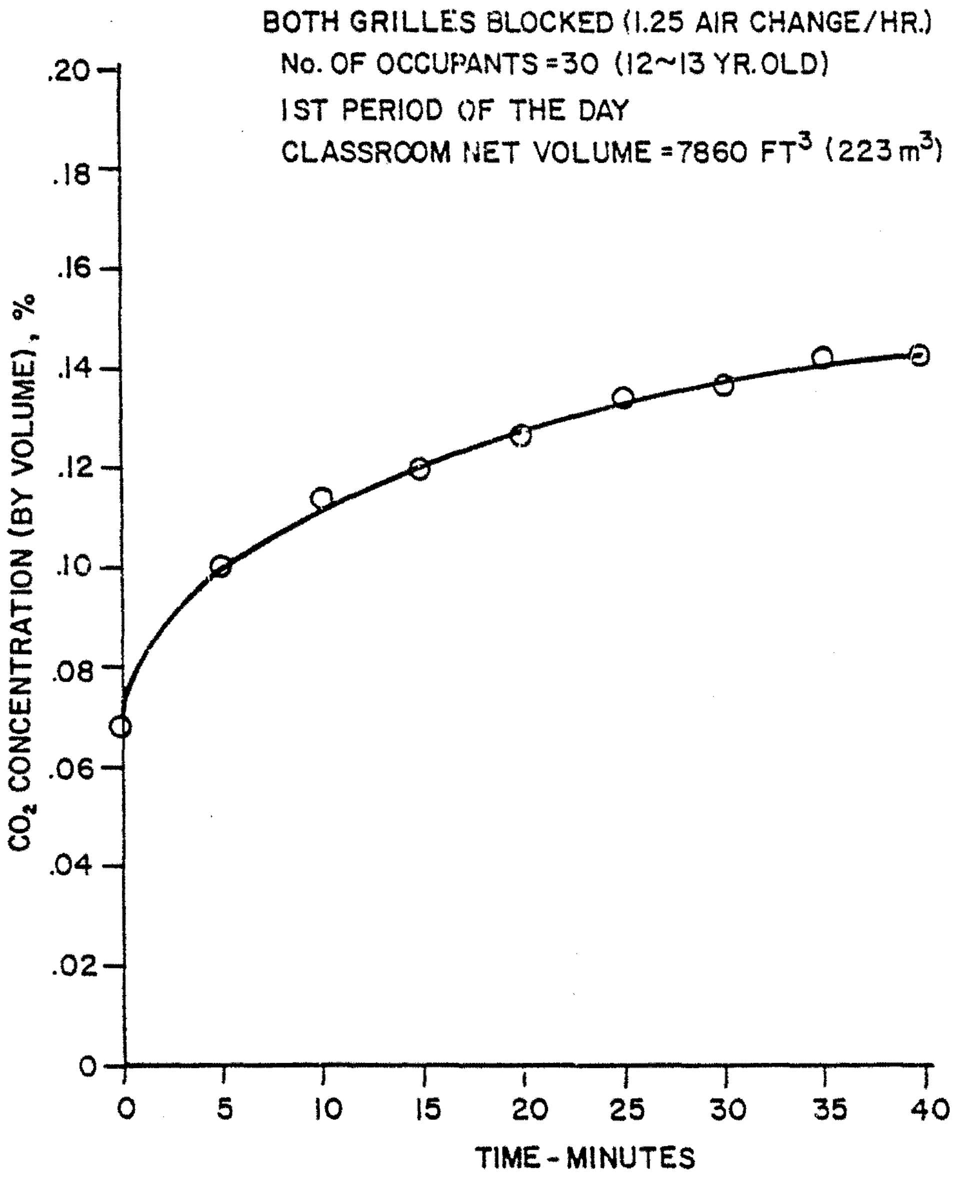

Figure 30 Variation of Indoor CO_2 Concentration During One Class Period (Both Grilles Blocked)

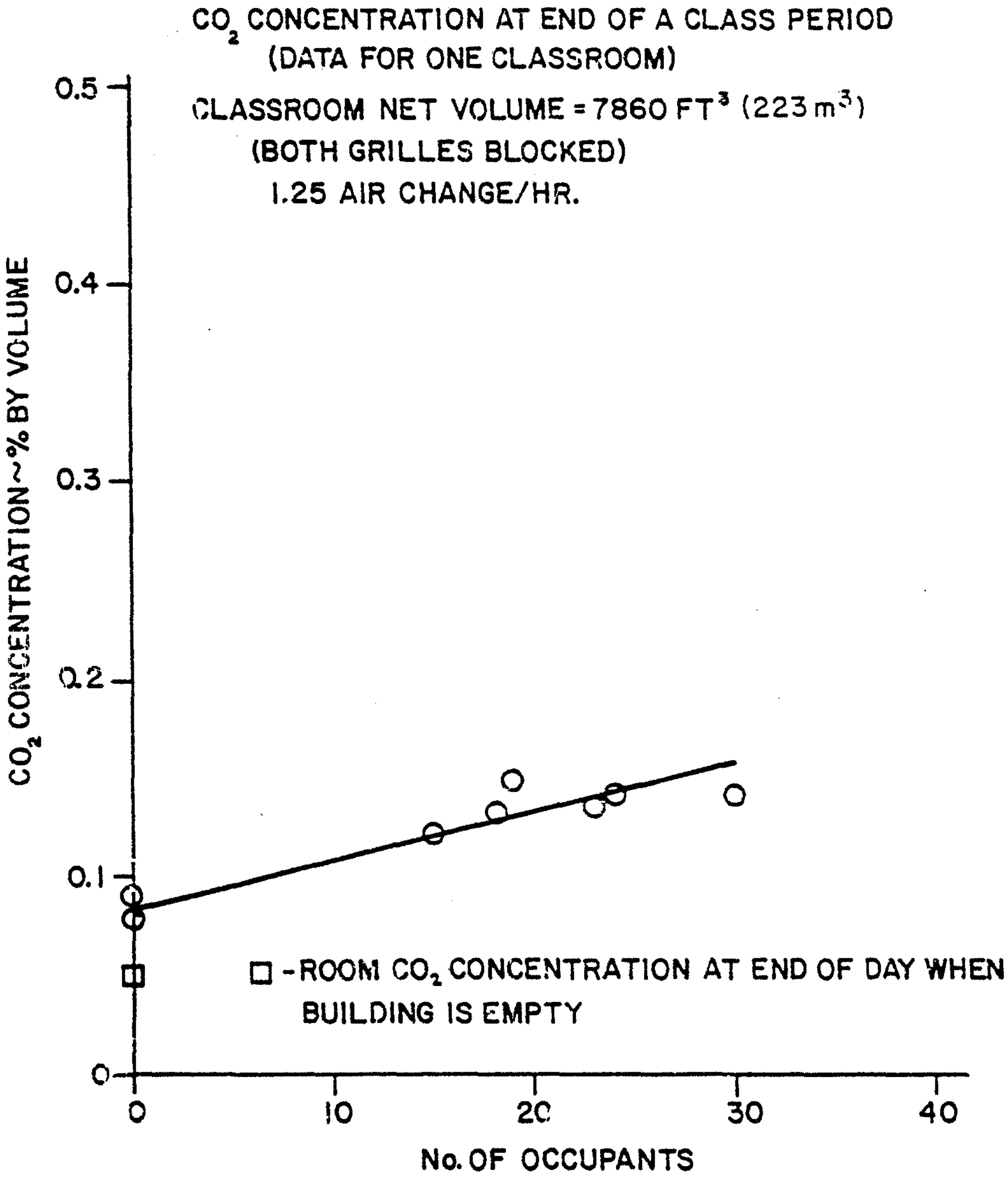

Figure 32 Steady-State Indoor CO_2 Concentration Level Vs. No. of Occupants

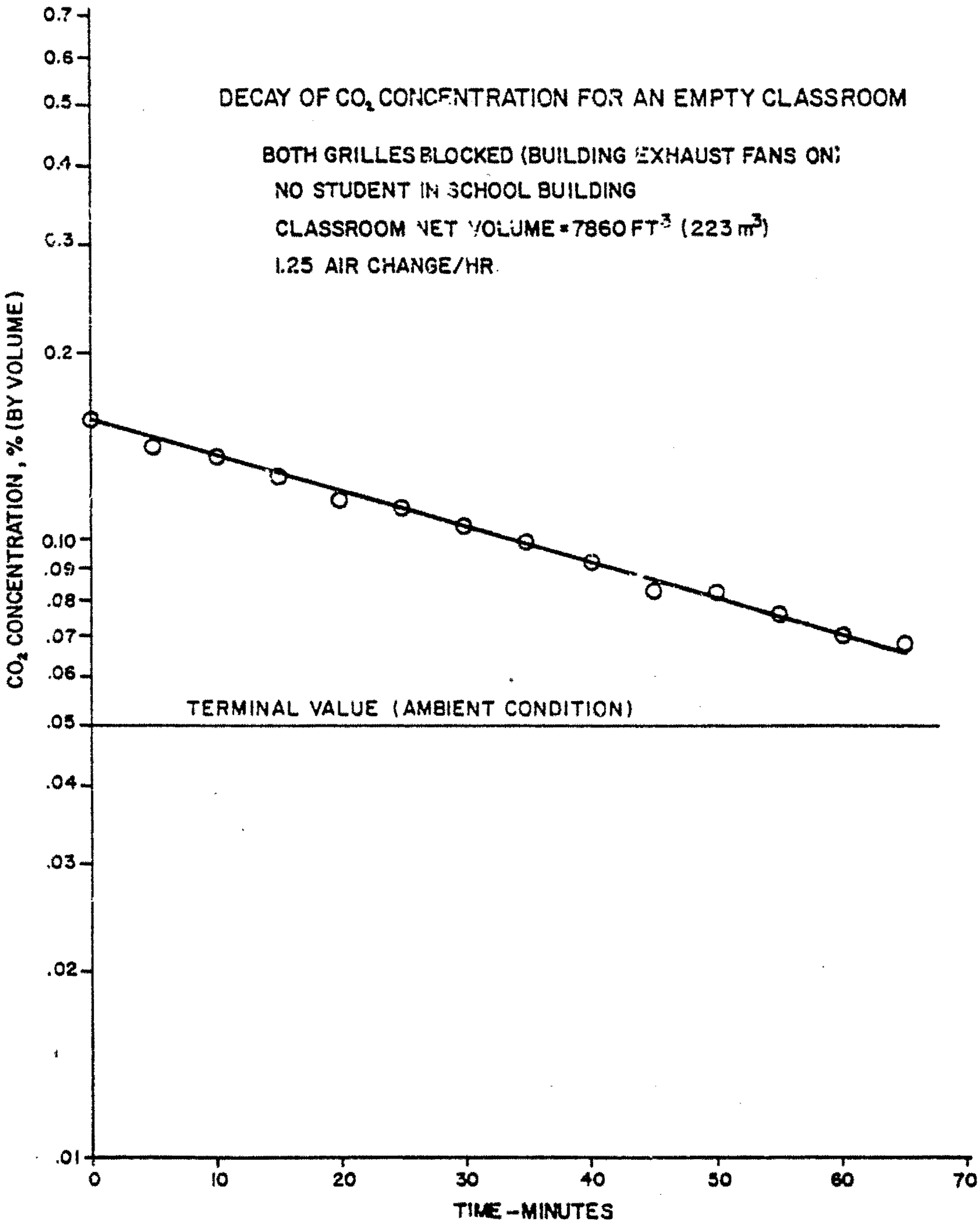

Figure 34 Decay of Indoor CO_2 Concentration in Empty Classroom (Both Grilles Blocked)

C_o = constant outdoor ambient CO_2

N = number of occupants in a room

$\dot{G}$ = average CO_2 volume rate of production/occupant

V = volume of room

A_c = air change rate

t = time

The assumptions for the above equation are:

1. constant outdoor ambient CO_2 concentration level
2. uniform CO_2 concentration throughout the room at any time
3. air change with ambient air at constant CO_2 concentration level only

Equation (1) can be rearranged to solve for $\dot{G}$, giving

$$\dot{G} = \frac{A_c V}{N} \left\{ \frac{Cr - Cr_o}{1 - \exp(-A_c t)} - (Co - Cr_o) \right\} \qquad (2)$$

To obtain an average CO_2 production rate for the students in the test classroom, the test results of Figure 30 were used. From Figure 30, with $A_c = 1.3$, $N = 30$, $C_o = .0005$, $Cr_o = .00068$, $Cr = .00143$ at $t = .667$ hr, and $V = 7{,}860$ ft^3 (223 m^3), the value of $\dot{G}$ is computed by using equation (2). The result is $\dot{G} = 0.44$ ft^3/hr (3.46×10^{-6} m^3/s) per student. This is equivalent to about 540 grams per day which can be compared with 642 grams per day reported by Wang [12] for college students in an auditorium. In reference 9, the production rate of CO_2 for a standard seated adult was given as 0.75 ft^3/hr (5.9×10^{-6} m^3/s). Assuming the production rate of CO_2 for an eighth grader to be 70 percent of that for an adult, the value for $\dot{G}$ will be .525 ft^3/hr (4.13×10^{-6} m^3/s) which is in reasonably good agreement with the computed value based on test results.

Assuming $\dot{G} = .50$ ft^3/hr (3.93×10^{-6} m^3/s) for an average eighth grader, the steady-state concentration of CO_2 in the test classroom with 24 students and an outdoor ambient CO_2 concentration level of .05 percent was computed by equation (1) for various air change rates, and compared with the results obtained from the tests under the three test conditions. The results are shown in Figure 35.

From Figure 35, it is seen that the estimated and the measured results showed excellent agreement. Figure 35 also shows that for an air change rate of 0.25/hr, the CO_2 concentration in the test room with 24 students would reach a steady-state level of 0.65 percent which would be higher than the maximum safety limit of 0.50 percent. (It is therefore concluded that for a building without any mechanical ventilation and with the windows closed, natural air infiltration alone could not be relied upon to prevent the CO_2 concentration level from rising above the maximum safety limit.

5. Conclusions

Under the sponsorship of the National Science Foundation, an analysis on energy consumption and ventilation requirement for an urban school building in New York City was completed. The tasks involved in this project included (1) the selection of a norm in energy consumption for comparison with a future energy-efficient school, based on the actual electrical energy and fuel-oil consumptions of 19 existing schools, (2) a computerized energy analysis of one of the 19 schools that had an energy consumption close to the norm, in order to determine the pattern of energy consumption in the school, and (3) a ventilation test in a classroom to determine the effects of reduced ventilation rate on the general environment of the classroom.

The electrical energy and fuel-oil consumption data of the 19 schools were provided by the Board of Education of New York City. It was found that when two somewhat atypical schools were omitted, the overall energy consumption of the other 17 schools varied by a factor of less than 2. The two atypical schools had a very high consumption rate. Omitting these two schools, the arithmetic values of 5,250 kWh and 417 gallons, both per 1,000 ft^2 gross area (2.03×10^8 J and .017 m^3 per m^2 of gross floor area) were chosen to be the average yearly electrical energy and fuel-oil consumptions of a typical school.

Based on the architectural drawings of the schools provided by the Board of Education, it was found that most of the schools in New York City were of the cavity-wall type construction, 3 stories high, single-pane glass with a window to exterior wall area ratio ranging from 0.3 to 0.6 for a typical classroom. Ventilation was provided for the classrooms by top exhaust fans on the roof, and space heating was provided by fin-tube radiators under window sills using low pressure steam. Except for a few schools, most schools had no space cooling equipment.

The computerized energy analysis was performed on one of the 19 schools. The school had a configuration typical of those described above and had an energy consumption of 4,624 kWh and 428 gallons of fuel oil on a per 1,000 ft^2 gross floor area basis (1.79×10^8 J for electricity and fuel oil of .0174 m^3 per m^2 of gross floor area). Using the operating schedules provided by the school custodian personnel, architectural and mechanical data from the blueprints and the weather data for the year 1962-63 for New York City, a thermal energy simulation was performed using the NBS-developed computer program NBSLD. The monthly electrical energy and fuel-oil consumption agreed well with the actual measured energy consumption data. It was also found that 80 percent of electrical energy was used for the lighting of the school building, and 75 percent of useful thermal energy produced by the fuel oil was used for heating ventilation air. It is therefore concluded that the most effective ways of reducing energy consumption for any new school, and also for the existing schools, are to reduce the lighting levels of the classrooms and the ventilation rates (fresh outdoor air). However, these recommendations need to be tempered with study of illumination needs and change in ventilation required by local building codes. The electrical energy consumed by the ventilation fans which comprised 20 percent of the overall electrical energy consumption would be reduced as a consequence of the reduction in the ventilation rate. Since the conduction through the windows and exterior surfaces and infiltration loss comprised 21 percent of the heating energy, improvements in the construction of the building shell will further reduce the overall energy consumption of a new school.

Ventilation tests were conducted for four days in a classroom used primarily by seventh and eighth graders. The purpose of the test was to determine the effects of reduced ventilation on the environment of the classroom, with special emphasis on the CO_2 concentration and O_2 content. It was found that under three different ventilation rates, ranging from 4.6 to 1.3 air changes per hour, the temperature and relative humidity all stayed within the comfort range of 70 to 76 °F (21.4 to 24.8 °C) and 20 to 30 percent. No change in O_2 content was detected, and the CO_2 concentration at the end of a class period in all cases reached a near steady-state level and did not exceed .16 percent by volume, which was far below the safety limit of 0.5 percent established by the Occupational Safety and Health Administration (OSHA). However, when the school building was not ventilated by any mechanical means, the air change rate in the classroom was reduced to only 0.23 per hour. It was estimated that under this condition, the CO_2 concentration level would reach a steady-state level of 0.7 percent by volume, indicating that mechanical ventilation was required to reduce this value to the acceptable level of 0.5 percent or less. The estimate of 0.7 percent CO_2 concentration was based on students in the 12- to 13-year-old age group. It would be higher if the students were of high school age. However, the ventilation test indicates that reduction of the ventilation level from the present 5 air changes per hour to 1 air change per hour would permit the CO_2 concentration or the O_2 content to stay within the established safety limits. The ventilation test of the present study suggests that significant energy savings in new and existing buildings may be achieved by simply reducing the ventilation rates while still maintaining safe and comfortable indoor conditions. A strong need exists to conduct additional ventilation tests of the type reported in the present study for the purpose of supplying needed information to building code officials so that suitable ventilation rates for an energy conserving building can be established.

Appendix - Calculation of Air Exchange Rates From Tracer Dilution Measurements

Tracer gas is distributed uniformly throughout the ventilated space, and the concentration is measured as a function of time. The rate of decrease of tracer concentration may be represented by the relationship

$$\frac{dc}{dt} = (c_o - c)\frac{v}{V} \qquad (1A)$$

where

c = tracer concentration in the space at time t

c_o = tracer concentration in the outside air entering the ventilated space

v = volume rate at which outside air enters the space

V = volume of the ventilated space

In the case of SF_6 tracer gas c_o is usually o, and equation 1A reduces to

$$\frac{dc}{dt} = - c\frac{v}{V} \qquad (2A)$$

or

$$\ln\frac{c}{c_i} = -\frac{v}{V}t \qquad (3A)$$

where c_i = initial concentration of tracer. If v, V, and t are in consistent units v/V is the infiltration rate in air changes per unit time. Thus, if $\ln(c/c_i)$ is plotted against time, the infiltration rate is obtained from the slope.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Continuation

and measured monthly electricity and fuel-oil consumption data. Detailed analysis of the pattern of energy consumption showed that 75 percent of the thermal energy during the heating season was used for the heating of outdoor air for ventilation purposes, and 30 percent of the electrical energy was used for lighting.

A ventilation test was conducted over a 4-day period in a typical classroom. It was found that a reduction of the air change rate from the normal 4.6 changes per hour to 1.3 changes per hour did not significantly change the indoor environment as expressed in terms of temperature, relative humidity, oxygen content level, and CO_2 concentration level. However, computation indicates that, when no mechanical ventilation was provided, the CO_2 concentration level would exceed the 0.5 percent safety limit, indicating that natural air infiltration alone will not provide adequate ventilation for the general health and safety of the students.

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