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Energy Budgets for New Construction

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SOMMAIRE

Pour en arriver à déterminer une norme concernant la conservation de l'énergie (Budget consacré à l'énergie), la présente étude donne les résultats obtenus en simulant à l'aide d'ordinateurs les variations de consommation d'énergie dans les écoles, en tenant compte des facteurs suivants: le nombre d'occupants, l'importance du bâtiment et son emplacement. Les résultats des ordinateurs sont alors comparés à la consommation d'énergie réelle. Cette étude présente une méthode pour calculer et détailler les budgets consacrés à l'énergie et traite aussi de l'utilisation de ces budgets pour en arriver à des normes sur la conservation de l'énergie. La présente étude, bien que se rapportant surtout aux écoles, peut s'appliquer, en général, à d'autres genres de bâtiments.

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Energy Budgets for New Construction

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In support of a performance (energy budget) energy conservation standard, this paper explores by means of computer simulation, the variation of energy consumption in schools, with such factors as occupancy, size and location. Computed results are compared with recorded consumptions. A method of calculating and specifying energy budgets is presented. The use of energy budgets for energy conservation standards is discussed.

The work described, though relating specifically to schools, has general relevance to other building types.

INTRODUCTION

This paper summarizes work undertaken at the National Research Council of Canada, in support of a 'performance' type of energy conservation standard. The intent of the standard is to control energy use in buildings by establishing an 'energy budget', i.e., a maximum allowable annual energy use. The building owner or his agent would decide how best to meet this budget. While the standard is ultimately to cover a wide range of building types, two groups of buildings (schools and offices), were selected for initial consideration.

The work described in this paper relates specifically to schools although the recommendations and discussion presented have relevance to other building types.

The variation of energy consumption with such factors as occupancy, size and location is explored by means of computer models; the computer results are compared with actual recorded consumptions. A method for calculating and specifying energy budgets for new construction is suggested and the use of energy budgets for code purposes is discussed.

METHOD OF DETERMINATION OF ENERGY BUDGETS

A review of fuel consumption figures obtained from school boards suggested that such data alone would not provide a suitable basis for determining energy budgets because:

(1) large variations in consumption make trends difficult to identify and practically impossible to quantify (see Figs. 1 and 2); and

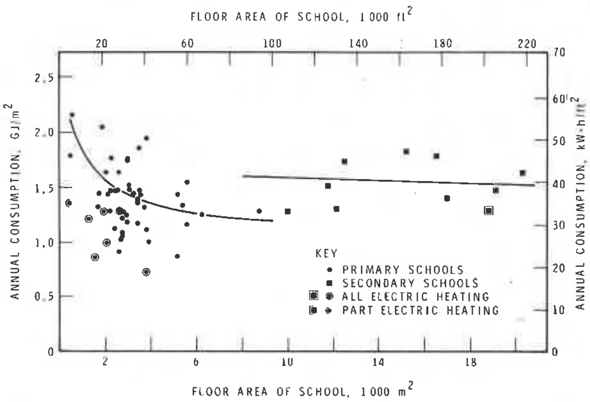

Fig. 1. Variation in annual energy consumption for Ottawa schools, 1974, as a function of size and type of school.

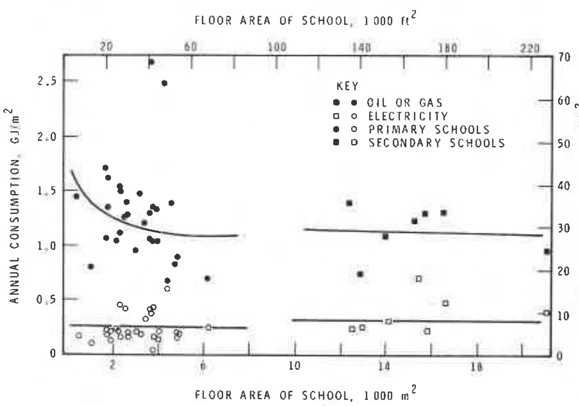

Fig. 2. Variation in annual heating and electricity consumption for Winnipeg schools, 1973, as a function of size and type of school.

(2) the data reflect 'pre-energy-conscious' design and construction.

A more suitable approach would be to calculate annual energy consumption for prototypical school buildings. Preliminary investigations suggested that the following aspects would need to be considered:

(1) the 'scaling effect' which results in less exposed surface area per unit of floor area as the building size increases;
(2) differing uses and environmental requirements in elementary and secondary schools;
(3) variation in hours of use when schools are used for community activities. Local Ottawa school board records for 1974 show that use of school facilities for community activities varied between 0 and 4700 hours, with an average of 879 hours in elementary schools and 2307 hours in secondary. (These are the sum totals of hours of use by community groups; because of simultaneous usage they are *not* the additional hours of operation of the school.)
(4) variation of energy consumption with location.

CALCULATIONS OF ANNUAL ENERGY CONSUMPTION OF PROTOTYPICAL SCHOOLS

A series of models representing prototypical schools were defined. To aid in the formulation of physical layout of the models, a brief study of school type, planning, and use was carried out, based on architectural layouts and other relevant information provided by a local school board [1]. A layout was adopted which was considered to be consistent with typical schooling requirements and cognizant of the need to limit exposed surface without placing undue restraints on building shape.

Environmental conditions were set with due consideration of existing standards [3 - 6] and of the need to minimize energy consumption. In sympathy with this last requirement two alternative models were considered, the first with lighting levels as recommended by the Illuminating Engineering Society of America [5] and referred to in the test as the 'High Illuminance Model,' the second with levels typical of European practice [6] and referred to as the 'Low Illuminance Model.'

Exterior envelope requirements and environmental systems were generally in accordance with ASHRAE Standard 90-75 'Energy Conservation in New Building Design' [7].

A summary of the parameters used to define these prototypical school models is given in the Appendix. Calculations of net annual energy requirements were made using the Meriwether Energy Systems Analysis ERE computer program [8].

SUITABILITY OF SCHOOL MODELS

Comparisons of calculated and recorded consumptions [1, 2] were made for schools at two locations, Ottawa and Winnipeg. The results of the analyses are shown in Figs. 3 and 4. For this comparison gross consumption figures were arrived at by assuming seasonal boiler efficiency of 70%, seasonal refrigeration plant 'coefficient of performance' (COP) of 2.7, and a miscellaneous electrical equipment use of 20% of the calculated lighting and fan consumption.

Comparison of measured and calculated annual energy consumption generally confirms the aptness of the school model. There is, however, sufficient divergence of results for secondary schools to warrant comment. This difference could be the result of any

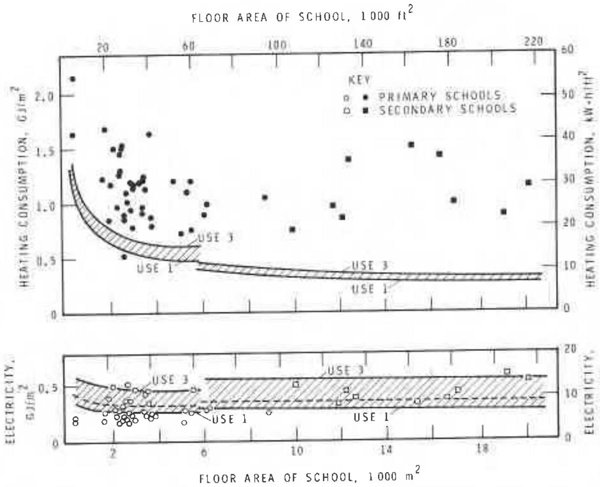

Fig. 3. Comparison of recorded consumptions and calculated 'energy budgets' for Ottawa schools in 1974 (8,615 F degree-days; 4,700 C degree-days). Calculated budgets, based on 'High Illuminance Model', show variation of consumption with use.

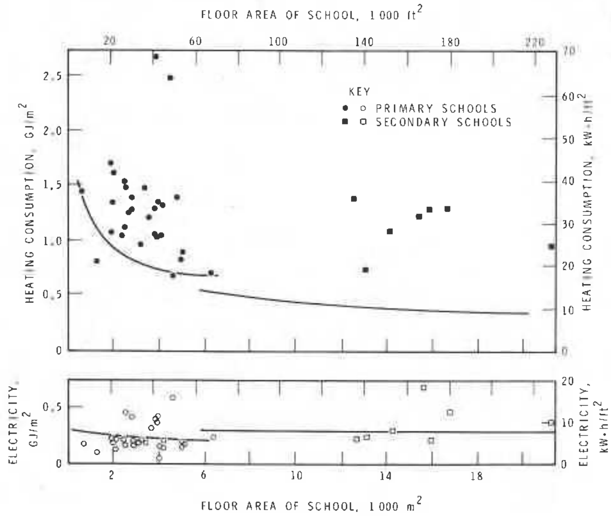

Fig. 4. Comparison of recorded consumptions and calculated 'energy budgets' for Winnipeg schools in 1973 (10,135 F degree-days; 5,532 C degree-days). Calculations based on the 'Low Illuminance Model', 'Use 2'.

one or combination of the following factors:
(1) longer hours of use in secondary schools with frequent after-school activity;
(2) higher environmental standards in secondary schools, reflected typically in higher lighting levels, high ventilation rates and frequently, mechanical cooling. Generally the potential for waste in these 'highly serviced' schools is much greater than in those schools with simple systems.

Although the calculated energy consumptions for the two locations are generally much lower than those of the existing facilities, it should be remembered that these schools were built at a time when energy conservation was not a prime consideration and that their operation during the years of recording (1973 and 1974) preceded any major attempts at energy conservation. It is interesting to note that as a result of an active energy conservation program the overall consumptions of the Ottawa area schools [1] have been brought nearer to, and in a few cases lower than, these calculated 'budget figures' (see Fig. 3).

While there are certain aspects of the model which need refining, particularly in relation to occupant interaction with energy consuming systems, it was considered a suitable vehicle with which to explore some of the basic problems associated with a performance type of standard. Such problems are addressed in the following sections.

VARIATION OF ENERGY CONSUMPTION WITH SCHOOL SIZE

Size had a pronounced effect on the variation of energy consumption (see Figs. 1 to 5), particularly in schools with an area of up to 6,000 m^2 (60,000 ft^2*). Therefore it is suggested that the energy budget, particularly in relation to the heating component, should vary with floor size and be specified as a function of gross floor area, i.e., as kilowatt-hour per square metre or megajoule per square metre.

As an additional study, the implications of an energy budget independent of area were pursued; such an approach would result in an obvious and desirable simplification. Since it was considered to be inappropriate to raise the budgets of larger buildings, such a simplification would need to be achieved by greatly improving the thermal performance of the smaller buildings. The measures involved to achieve such a uniform consumption were viewed to be impractical. For instance, to reduce the per unit floor area consumption of a school 460 m^2 (5,000 ft^2) to that of a school 5,500 m^2 (60,000 ft^2) would entail doubling insulation of walls and roof, triple glazing or reducing fenestration from 25% to 14.5% (as viewed from inside), adoption of a

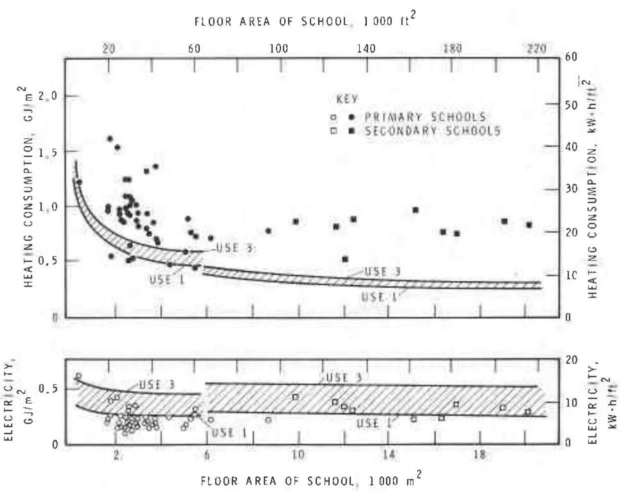

Fig. 5. Comparison of recorded consumption for Ottawa schools for the 12-month period June 1976 to June 1977 (8,795 F degree-days; 4,800 C degree-days) with the calculated budgets as presented in Fig. 3 (8,615 F degree-days; 4,700 C degree-days).

*All calculations reported in this paper were carried out in Imperial units; all SI units are 'rounded off'.

single square plan configuration and reducing infiltration rate by 30%. There is, however, some justification in improving the thermal characteristics of the small school since the financial benefit of additional insulation is highest in those buildings with low values of internal heat gain per unit area of envelope. It is proposed that, as an additional constraint on any final model, the transmittances should vary not only with severity of climate but also with building size.

Although considered reasonable for schools, energy budgets expressed as a unit of gross floor area may not necessarily be suitable for all types of buildings. For instance, consideration of the effects of building height (number of storeys) may be necessary in those classes of occupancy where building height is a major variable, e.g., downtown offices. The prototypical schools are considered single storey below 1,860 m^2 (20,000 ft^2) and two storey above 1,860 m^2 (20,000 ft^2) gross floor area. This configuration is considered representative of contemporary school constuction.

VARIATION OF ENERGY CONSUMPTION WITH LOCATION

The original concept was to develop energy budgets on a regional basis. To this end, Canada was subdivided into nine climatic zones; for each zone a representative location (city) and weather year (RY - 'reference year') was selected. See Fig. 6.

For a selection of school sizes ERE runs were made using these 'reference year' weather tapes. Additional runs were made for three major cities in Zone 6 to check the variations in consumption across a climatic zone and to check the year-to-year variations in consumption at any one location.

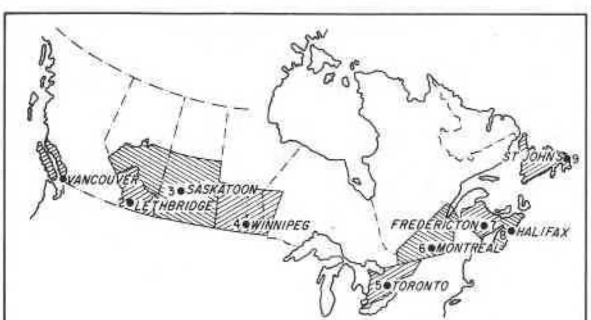

Fig. 6. Map of Canada showing extent of 'climatic zones' and 'reference city' locations.

It was apparent that the regional approach would need much modification to make it a workable concept, especially if some form of post-construction monitoring check would be made on the building, as was proposed. A basis for setting and applying budgets which would be closely in tune with the actual weather at the site is required.

To achieve this it is suggested that budgets can be developed from the addition of the following components of energy use:

1 heating
2 cooling
3 heating and air conditioning system fans
4 heating peripherals
5 cooling peripherals
6 lighting
7 domestic hot water
8 miscellaneous electrical equipment.

The last three items can be considered dependent only on use and nominally independent of climate. For the purposes of this study it is also assumed that lighting use is *not* affected by climate although it might well be in certain instances, i.e., where people respond to the available daylight by switching off unnecessary lights or where control systems are installed to switch off automatically or dim lighting in sympathy with the availability of natural light.

For such an approach to be satisfactory, consideration would need to be given to the significance of any inconsistencies in allotted energy budgets, resulting from the summing of the components without rigorous regard for their combined effects. (The addition of the components is strictly valid only at the reference cities).

For building code purposes it may be desirable to group some of these components together for administrative ease.

Heating consumption

Consideration of the graph in Fig. 7, which summarizes annual energy consumption calculations at the reference cities, suggests that it would be quite reasonable to set the heating component by the normal degree-days heating at the location. Further it would seem logical to choose 'normal' heating-degree days, i.e., degree days below 18 °C (65 °F), since these are

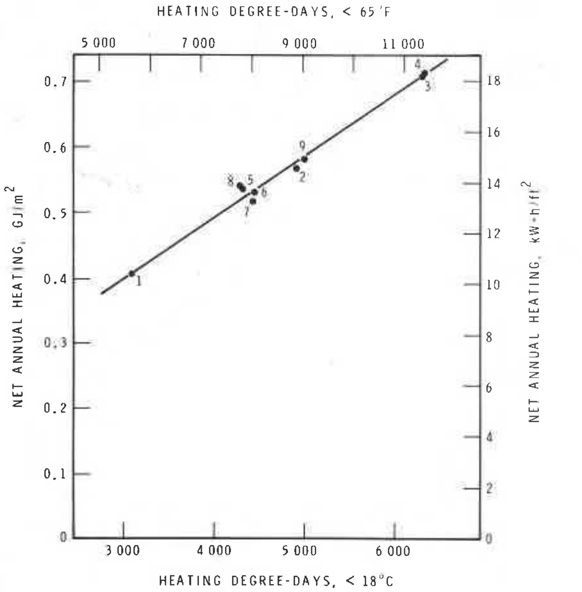

Fig. 7. Variation of net heating consumption with degree days for a primary school 1,860 m^2 (20,000 ft^2) in area. Calculations for the 'Low Illuminance Model', 'Use 2'.

readily available for most locations throughout Canada [9, 10].

It should be noted that both the hours of use and the size and type of school affect the slope of the graph and its intercept on the axes. The graph will only pass through the origin if:

(1) The hypothetical balance temperature (t_f) for the building coincides with the base temperature used in the computation of degree days; t_f can be considered as t_i—d where t_i is the average inside temperature, and d the average temperature rise maintained by internal and solar gains.

(2) The heating and ventilating system, excluding central plant, is 100% efficient, i.e., there is no simultaneous heating and cooling. This precludes all heating and air conditioning systems utilising any form of terminal re-heat.

Cooling consumption

The only readily available comprehensive information that might serve as a useful parameter for defining cooling budgets are summer design dry-bulb and wet-bulb temperatures. Neither of these give satisfactory correlation with calculated net cooling consumptions.

The best correlation was found to be with cooling degree-hours; a base of 13 °C (55 °F) looked most favourable for the two school sizes considered. Since cooling is assumed in secondary schools only, which are generally of this size range, and therefore relatively insensitive to external factors, it is considered that 13 °C (55 °F) will be a suitable base from which to calculate cooling degree-hours. Figure 8 shows the variation of cooling with cooling degree-hours at the nine reference city locations.

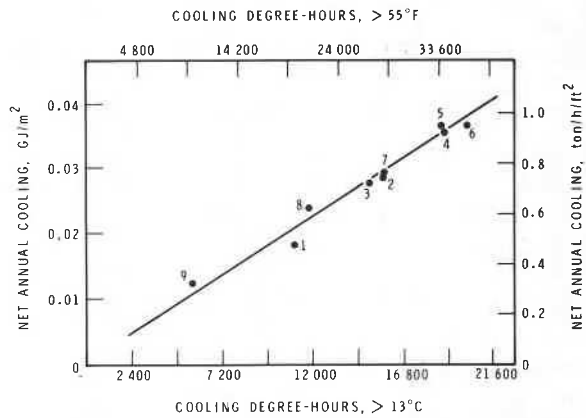

Fig. 8. Variation of net cooling consumption with cooling degree-hours for a secondary school 6,500 m^2 (70,000 ft^2) in area. Calculations for the 'Low Illuminance Model', 'Use 3'.

Heating and air conditioning system fans (HVAC)

For constant volume systems, the fan consumption can be considered as a function of design conditions, e.g., for heating, ambient design dry bulb, and for cooling, some function of ambient design dry-bulb, wet-bulb and a 'solar factor'.

For variable-air-volume (VAV) systems, seasonal climatic variation will affect the consumption; cooling degree-days might provide a suitable modifier.

From calculations of annual energy requirements, fan consumption is seen to be a weak function of climate in the larger schools. For example, the regional variation for a primary school 1,820 m^2 (20,000 ft^2), which is not air-conditioned, is between 62 and 93 MJ/m^2 per annum (1.6 and 2.4 kW·h/ft^2) while for an air-conditioned secondary school of 6,500 m^2 (70,000 ft^2), it is only between 186 and 209 MJ/m^2 per annum (4.8 and 5.4 kW·h/ft^2).

This result can be attributed to the fact that, although lower volumes could meet the load, higher volumes are necessary to satisfy the minimum air supply rates set at 2.5 $dm^3/s \cdot m^2$ (0.5 cfm/ft^2). It is questionable whether 'minimum rates' of this magnitude, although common, are appropriate in the light of their effect on fan energy consumption.

Heating and cooling peripherals

This group would include such equipment as pumps, boiler and chiller auxiliaries and cooling tower fans. It is probable that some method based on design conditions and weather variation could be used for determining the contribution of these components to the budget. No attempt to develop such a method has yet been made.

VARIATION OF ENERGY CONSUMPTION WITH USE

Figures 9, 10 and 11 show the variation of heating, electricity (fans and lights) and cooling with use, based on three defined periods of operation and corresponding profiles (occupancy, lights, etc), viz,

Use 1, normal academic year;
Use 2, school partially occupied during school day and evenings;
Use 3, as in Use 2 plus summer school.

Assuming these profiles to be representative of school use, there is a clear need to relate energy budgets to periods and patterns of use.

The variation of energy consumption with use is perhaps the most troublesome aspect of a performance standard, especially since information relating to the continuous (non-peak) requirements and use of buildings is extremely limited. This lack of information becomes a major limitation since to calculate energy budgets it is first necessary to define usage patterns (profiles of use) for incorporation into the computer model. The wider implications of the problem, however, are somewhat dependent on the method by which compliance with the standard is to be determined.

If compliance with the standard is to be determined by a pre-construction calculation of the annual energy consumption, then for consistency this analysis should assume the same profiles of use as are used to generate the budgets. These profiles should be *representative* of actual use.

If compliance with the standard is to be determined by post-construction monitoring of energy use, the profiles used to generate the budgets must model a building's actual use very closely. A major problem exists in trying to establish a system of energy budgets

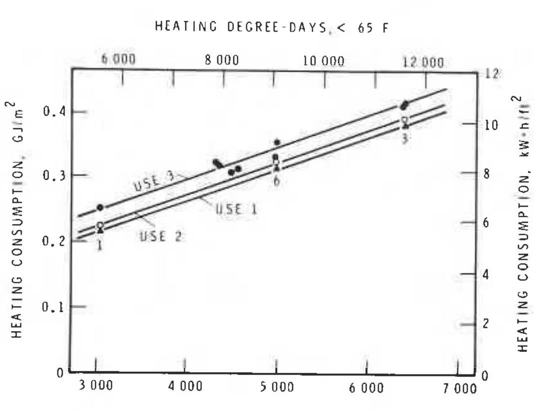

Fig. 9. Variation of heating consumption with heating degree-days and use for a secondary school 6,500 m^2 (70,000 ft^2) in area. Calculations for the 'Low Illuminance Model.

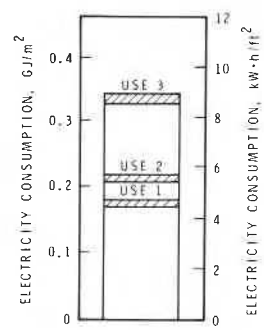

Fig. 10. Variation of electricity consumption (fans and lights only) with use (showing regional variation) for a secondary school 6,500 m^2 (70,000 ft^2) in area. Calculations for the 'Low Illuminance Model'.

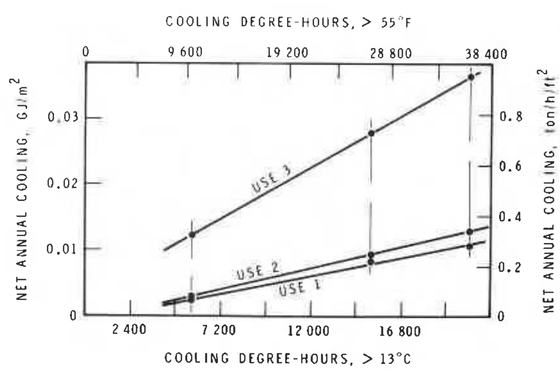

Fig. 11. Variation of cooling consumption with cooling degree-hours for a secondary school 6,500 m^2 (70,000 ft^2) in area. Calculations for the 'Low Illuminance Model'.

that can be related in some way with actual building use because, for some classes of occupancy, usage may vary considerably between apparently similar buildings, as is the case with schools. It is unlikely, for instance, that a simple correlation of energy consumption with hours of use is feasible since the degree of occupancy and time of occupancy (e.g., day, night, winter, summer), will also influence the energy consumption.

It is appreciated that the adoption of post-construction monitoring introduces additional complexities into a building code. It is nevertheless viewed as desirable since only by monitoring the building's energy use can one be quite sure that the building is being operated in a way that takes full advantage of its energy saving features.

CONCLUSIONS

It is recommended that energy budgets be set by the analysis of prototypical buildings, the consistency of the calculations being verified by comparing results from the models with measured consumptions for actual buildings. The major problems in so doing lie with establishing a suitable model (particularly in defining the interaction of occupants with energy-consuming systems), and with the collection of energy-consumption data for low-energy buildings to justify or refute the calculated budgets.

For schools it is suggested that budgets be specified as an allowance per unit of gross floor area and that they vary with school size, type, location and degree of use. Budgets for a given location should be specified in terms of local climatic factors, such as heating and cooling degree-days.

The large variation in use of school facilities and consequent variation in energy consumption is viewed to be a major problem if compliance with an energy conservation code is to be achieved through post-construction monitoring.

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APPENDIX

SUMMARY OF DEFINITION OF SCHOOL MODEL

Size
Size is variable from 460 m^2 to 20,500 m^2 (5,000 ft^2 to 220,000 ft^2).

Shape
Compound — two rectangular-shaped sections joined at one corner.
(i) Hall/Gymnasium — occupying 10% of the area in primary school and 14% in secondary school. Width-to-length ratio of 1.5 to 1; height 7.9 m (26 ft).
(ii) Classroom block — single storey if gross floor area $\leq$ 1,860 m^2 (20,000 ft^2); two storey > 1,860 m^2 (20,000 ft^2). Width-to-length ratio 2 to 1; height 3.8 m (12.5 ft) per level.

Orientation
The major axis runs SW to NE.

Construction
U values adjusted for climate as in ASHRAE 90-75; 25% glazing (as viewed from inside); inside floor to ceiling height, 2.74 m (9 ft). Glazing shading coefficient = 0.57. 'Medium weight' construction.

Environmental criteria

Over-all ventilation:	2.36 dm^3/s per person (5 cfm/person);
— primary school	— 0.0072 $dm^3/(s \cdot m^2)$ (0.085 cfm/ft^2);
— secondary school	— 0.0038 $dm^3/(s \cdot m^2)$ (0.045 cfm/ft^2).

Temperatures:
— classroom block 22.2 °C (72 °F)
— general purpose hall 20.0 °C (68 °F)
— gymnasium 18.3 °C (65 °F)
Lighting Levels:
'High Illuminance Model'
(i) Hall — 750 lx (70 Fc);
electrical load 31.21 W/m^2 (2.9 W/ft^2).
(ii) Gymnasium — 320 lx (30 Fc);
electrical load 11.84 W/m^2 (1.1 W/ft^2).
(iii) Classroom Block — 160 to 750 lx (15 to 70 Fc) depending on use;
overall electrical load 24.76 W/m^2 (2.3 W/ft^2).
'Low Illuminance Model'
(i) Hall — 300 lx (28 Fc);
electrical load 19 W/m^2 (1.77 W/ft^2).
(ii) Gymnasium — as in (i).
(iii) Classroom Block
— primary school, 100 to 300 lx (9 to 28 Fc); overall electrical load 12 W/m^2 (1.12 W/ft^2);
— secondary school, 100 to 500 lx (9 to 47 Fc); overall electrical load 17.1 W/m^2 (1.59 W/ft^2).
Domestic hot water (maximum demands):
(i) Gymnasium — 5.0 W/m^2 (1.6 $Btu/(h\cdot ft^2)$);
(ii) Classroom Block
— primary school, 7.9 W/m^2 (2.5 $Btu/(h\cdot ft^2)$);
— secondary school, 4.1 W/m^2 (1.3 $Btu/(h\cdot ft^2)$);

Infiltration
Climatic zones 1 to 6:
(i) Hall/Gymnasium 0.0139 $dm^3/(s\cdot m^2)$ (0.15 cfm/ft^2);
(ii) Classroom Block 0.0279 $dm^3/(s\cdot m^2)$ (0.3 cfm/ft^2) of wall.
Values increased for eastern seaboard locations. Assumed that wind acts on the long wall.

HVAC systems
(i) Hall and Gymnasium
— single duct constant volume; variable temperature system.
(ii) Classroom Block
— primary school: terminal re-heat with scheduled supply air temperature; no mechanical cooling.
— secondary school: VAV with re-heat and scheduled supply air temperature during heating duty. Minimum volume - 50% of full volume or 0.0423 $dm^3/(s\cdot m^2)$ (0.5 cfm/ft^2 whichever is greater. Mechanically cooled.

All systems are set back 5.5 °C (10 °F) during unoccupied periods.

Fans:
all air supply rates based on 16.6 °C (30 °F) supply temperature differential for heating and 8.3 °C (15 °F) for cooling; subject to minimum supply of 0.0423 $dm^3/(s\cdot m^2)$ (0.5 cfm/ft^2).

Fan static pressures:
VAV — 1000 Pa (4 in.) supply,
370 Pa ($1\frac{1}{2}$ in.) return.
All other fans — 500 Pa (2 in.) supply,
250 Pa (1 in.) return.

Efficiency:
fan — 70%
drive — 95%
motor — 65 to 90% depending on size. Assumed that VAV fans have inlet guide valves (with performance as in Key 5 Meriwether).

Use
Three periods of use are considered.
Use 1: typical school day operation; normal plant operation 6 a.m. to 6 p.m.
Use 2: school is assumed to be used during the evenings of school-days. Plant operation 6 a.m. to 10 p.m. on school-days; 50% occupancy and reduced lighting use in evenings.
Use 3: school used throughout year, i.e., evenings, as above, plus summer school.