TOWARD ZERO ENERGY USE IN CANADIAN NON-RESIDENTIAL BUILDINGS

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ABSTRACT

Canadians have responded to the urgent need for energy conservation by reducing the energy required for typical new commercial buildings to about 600 MJ/m^2/year, compared with typical energy intensities in the 1975 building stock of about 1,500 MJ/m^2/year. This paper outlines the most important building design and operational measures responsible for this reduction and suggests how additional savings in post-1981 buildings could meet an energy intensity target of about 300 MJ/m^2/year.

INTRODUCTION

Energy Use in Residential vs. Non-residential Buildings

Although the total floor area of residential construction in Canada exceeds non-residential floorspace by almost 2 to 1, the energy used by non-residential buildings is almost as large (see Figure 1).

There are other comparisons. Residential space requires about two-thirds of its energy for heating, while non-residential buildings may use less than a third for this purpose, input because non-residential buildings are typically larger and have a lower envelope-to-volume ratio.

FIGURE 1

ENERGY USE IN CANADIAN BUILDINGS

Type of Building	Floor Area	Typical Energy Intensity in 1975	Overall Energy Requirements	Future energy** Objective
	$M^2 \times 10^8$	MJ/²/Year	$J \times 10^{18*}$	MJ/²/Year
Residential	8	1,000	0.8	400 - 750
Non-residential	5	1,500***	0.75	300 - 600

* Approximately 1 quad or 10^{15}

** Cost-effective based on current energy cost projections.

*** Some buildings are now modified to use less than 50% of the energy used in 1975. However, the average improvement seems to be less than 15%.

A second difference exists in the potential for energy savings. Residential buildings must improve their envelope thermal integrity for any major conservation effect. But, at present, energy costs often will not justify envelope improvements beyond those indicated in Figure 1. Non-residential buildings, on the other hand, are known to waste substantial amounts of energy in their space conditioning and lighting systems. With reasonable attention to energy in design and operation, new non-residential buildings can be made to use only 20-40% of past levels. Even existing non-residential buildings have the potential to reduce energy use up to 50%. It is this possibility, and the economy with which the changes can be made, that makes the study of non-residential building energy so interesting.

After the first stirrings of energy concern in 1973, designers of non-residential buildings began to specify structures and equipment requiring as little as 600 MJ/m²/year. This compares favorably with surveys* in 1975 which found that existing office, retail, and educational buildings averaged approximately 1,500 MJ/m²/year and residences about 1,000 MJ/m²/year.

In the remainder of this article, we will illustrate both the energy savings that have already been accomplished by better design of typical new non-residential buildings, and those that remain to be achieved but appear cost-effective and likely, in post-1981 construction. In both cases, we summarize the energy-saving elements of a typical building in the form of a "staircase of energy savings" (see Figures 2 and 3). The discussion in the text follows the same order shown in the two Figures.

Typical Reduction in Non-Residential Building Energy

Figure 2 illustrates some of the most important energy conservation modifications which have been built into the design of new non-residential buildings in Canada in the period 1973-81.

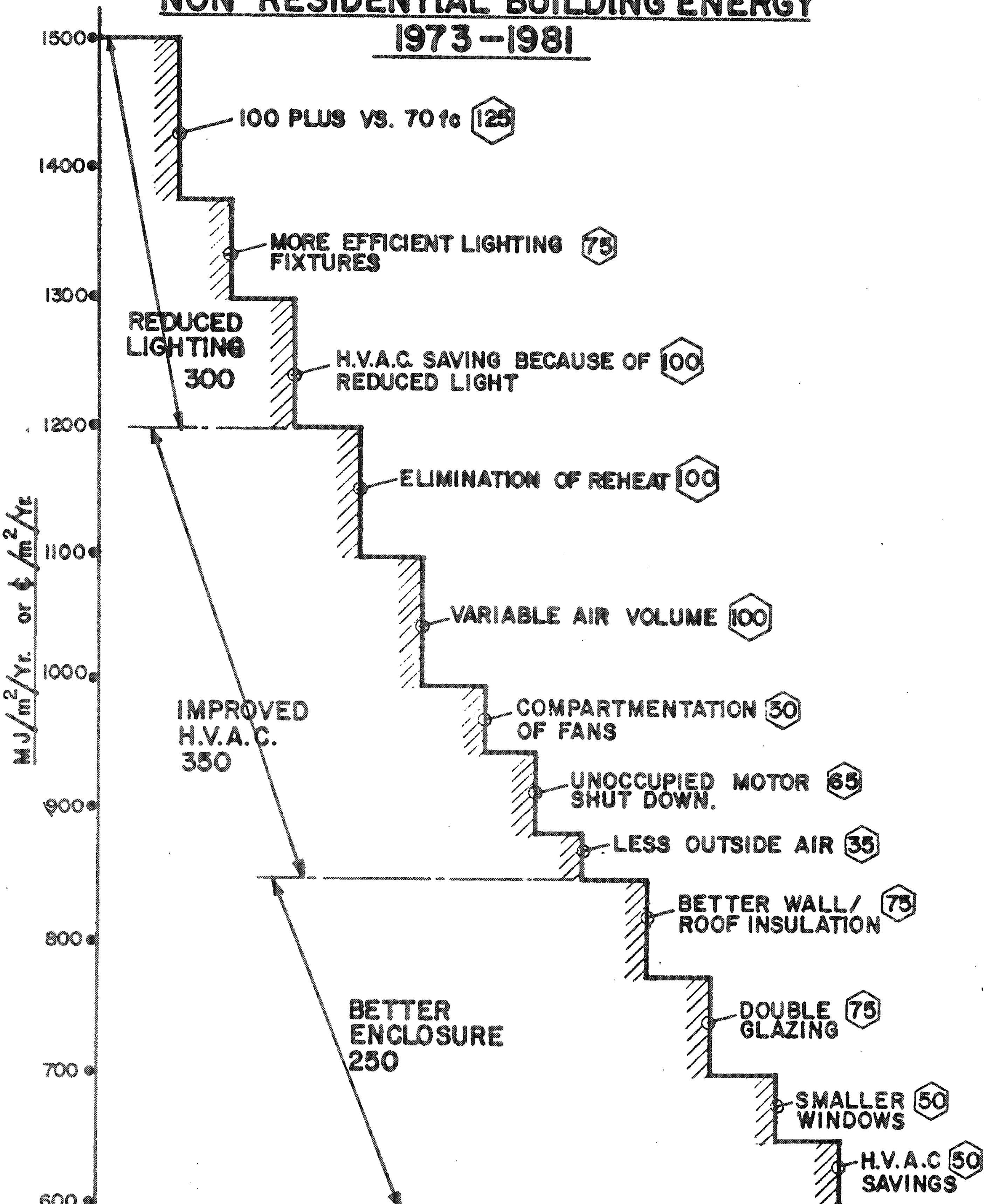
Note all of the conservation measures now in use have been included, and those that are could be quantified differently. Even the order in which they are considered would vary their individual contributions. However, it is a fact that most new construction in 1981 will have a design energy intensity in the vicinity of 600 MJ/m^2/year.*

The improvements shown in Figure 2 are grouped in three categories - electrical (lighting), mechanical (HVAC), and architectural (improved building shell), corresponding to the designer who controls the result. Note how equally the three disciplines are involved in achieving low energy usage.

Equivalent annual savings in energy costs are shown alongside each energy-saving measure, based upon assumptions which are felt to be representative of Canadian buildings at this time. For example, electricity costs 3.4¢/kWh; natural gas costs $4.25/MCF and has an average seasonal use efficiency of 65%; and two-thirds of the total energy for non-residential buildings will be supplied by electricity. Escalating these current costs slightly to account for rising real energy prices, we can read the savings on the vertical scale of Figure 2 (and also Figure 3) not only in energy units (MJ/m^2/year) but also as approximate dollar savings on annual fuel and electric bills (¢/m^2/year) for non-residential buildings.

FIGURE-2

TYPICAL REDUCTION IN NEW NON RESIDENTIAL BUILDING ENERGY 1973–1981



TYPICAL ENERGY-SAVING MEASURES - 1973-81 (SEE FIGURE 2)

Electrical Systems

100 plus vs. 70 Footcandles Although no change occured from 1958 to 1978 in the lighting levels recommended by the Illuminating Engineering Society of North America (IES), and although no significant increase in productivity could be assured, commercial lighting practice yielded to the thrust of manufacturers and utilities for higher levels. But in 1973, the argument for 100 footcandles of uniform illumination was re-examined in the light of logic and economics. As a result, design practice began to return to the original IES standard of 70 footcandles for office work. This, in turn, is now being threatened by Europeans' long-term satisfaction with 50 footcandles, and by the IES standard calling for a "range of levels," from 50 to 100 footcandles for office work, based on the task and the occupant's age. It is common for the developers of space to provide ambient lighting at the lower end of this recommended range, leaving the option (and cost) of increased lighting to the tenant.

The result of these lower ambient lighting levels in new buildings is an energy saving, based on 4,000 operating hours per year, of approximately 125 MJ/m^2/year.

More efficient lighting fixtures. Closer re-examination of lighting levels revealed other ways of reducing first-cost as well as saving energy, mainly by buying fewer fixtures for the same effect. Enlarging the box in which the lamps are placed, for instance, was found to increase light output by up to 15%, at a fraction of the cost of fixtures thus eliminated. Designers are now showing great care in examining the many more efficient lighting fixtures and light-ceiling configurations which have become available.

This trend is responsible for further energy savings in commercial space of about 75 MJ/m^2/year.

HVAC savings because of reduced lighting. New lighting arrangements are able to maintain 70 footcandles with inputs of 2 watts/sq.ft. or less. This contrasts with earlier systems which typical generated 100 footcandles using 4 watts/sq.ft.

Savings of each watt of input for lighting have resulted in reductions in HVAC energy for cooling, fans, and pumps of up to 1/2 watt, yielding further reductions of, perhaps, 100 MJ/m^2/year.

Recent lighting changes have therefore resulted in direct or indirect savings of 300 MJ/m^2/year, fully half of all the energy previously expended on this component.

Mechanical Systems

Elimination of reheat. In many non-residential air conditioning systems it was common practice to supply the cooling medium at some base temperature and then reheat it locally to suit thermostat settings. The waste involved in overcooling and reheating can take place in so many ways that a major revision in design practice and strongly held beliefs has been necessary to remove this energy parasite. In some existing buildings, reheat for temperature control has been found to be the largest element in space conditioning energy use, exceeding the amount of heat required for ventilation and losses through the building shell.

Despite the difficulty of reversing well-established design practices, the typical reduction in reheat requirements is expected to save 100 MJ/m^2/year over 1975 practice.

Variable air volume. Another important design improvement is a concept which meters the amount of coolant required rather than constantly cooling and then reheating the maximum volume. Beyond the cost of reheat, this idea can save fan energy and reduce the amount of overcooling.

Although slow to reach acceptance in the 1960's, VAV systems made large gains in the 1970's, and now form the basis of temperature control in most new non-residential HVAC systems.

This approach may save another 100 MJ/m^2/year in addition to the reheat savings noted above.

Fan compartmentation. Formerly, most air movement capacity in non-residential buildings was centralized in large fan rooms. The length of air travel and the entrance and exit losses in the plenums required pusher and puller fan assemblies that consumed major amounts of energy.

The use of local fans has been found to cut this overall resistance in half, saving enough to offset the loss of the "free cooling" effects available from central fan rooms. Local air handling also provides the option of local after-hours use of space without turning on the entire system.

Fan compartmentation is a concept which is now widely used and which provides savings of up to 50 MJ/m^2/year over former practice.

Unoccupied motor shut-down. HVAC motors for fans, pumps, and refrigeration are now generally connected to time clocks set to operate only when the building is occupied. This saves electrical energy, although the electric demand component of the utility bill is seldom saved. The largest savings, up to 65 MJ/m^2/year, derive from the energy required to heat and cool air which characterically leaks through closed outside air dampers behind fans operated during the unoccupied period.

Less outside air. Careful evaluation of ventilation requirements has led to a reduced use of outside air, although additional ventilation is still used to save energy in the cooling process ("economizer" cycles).

The revised ASHRAE Standard 55-73 recommends energy savings through reductions in the use of outside air, amounting to about 35 MJ/m^2/year.

Altogether, then, there has been a reduction in HVAC design energy requirements of 350 $MJ/m^2/year$ between 1973 and 1981.

Better Enclosure

Better wall/roof insulation. Non-residential buildings used little insulation prior to 1973. More recently, studies of cost-effectiveness have shown the economic value of using prescribed amounts of insulation.

The savings resulting from the values recommended by the National Research Council may be 75 $MJ/m^2/year$.

Double-glazing. Except in western Provinces, it was uncommon to specify double glazing in non-residential buildings. This product has now become fashionable as well as economically justifiable, however, and may save another 75 $MJ/m^2/year$ in typical cases.

Smaller windows. Driven by aesthetics and style, building designers began to use more window glass than could be justified for the visual needs of the occupants.

As the energy cost of large glass areas became better understood, less of it has been specified, resulting in typical energy savings of 50 $MJ/m^2/year$ over previous design.

Other HVAC savings. The result of better building configurations has been a further saving in HVAC requirements. This may amount to as much as 50 $MJ/m^2/year$.

In all, there may be savings of 250 $MJ/m^2/year$ for building enclosures, proving that the architect is a vital partner in low-energy design.

The gross savings of 900 $MJ/m^2/year$ from all three design disciplines is remarkable not only for its size, 60% of former use, but because the savings in lighting fixtures alone have more than paid for the first-cost of better insulation. An obvious question is "Why wasn't the logic of low-energy design perceived much earlier?"

POTENTIAL ENERGY USE REDUCTIONS - 1981-1990 (See Figure 3)

Electrical Systems

Abandon uniform lighting for "task ambient." The new IES lighting standard is concerned mainly with the task, suggesting that ambient lighting levels in other areas can be reduced to one-third of that recommended for the work station.

This will lead inevitably to increased use of desk lamps, although such devices require additional 110-volt wiring and shed little light beyond the task area. More acceptable solutions, insofar as the developers of space are concerned, involve ceiling-mounted fluorescent fixtures, which can be fed economically with 347 volts. If fixtures are arranged to be moved into various ceiling positions in order to provide the highest quality light for each occupant, good lighting conditions can be provided with as little as one watt/sq.ft. This, in turn, could reduce lighting energy by at least 40 MJ/m^2/year.

Switching/dimming. For some time it has been conventional to ignore the daylighting effects in areas alongside windows, and compensate only for the heating consequences of solar gain. In many buildings the water chiller must labor against the combined heat gains from the sun and artificial lighting in perimeter zones, even when the daylight alone exceeds 250 footcandles.

An expensive way of overcoming this has been to block both the solar gain and the daylighting benefits with reflective window glass. Another concept is to provide manual light switches for perimeter zones. The problem here is that it would be optimistic to assume that 50% of the switches would ever be used.

The newest concept, costing less than the premium for reflective glass, is automatic (photometric) dimming of perimeter lights. The advantage with automatic dimming is that commensurate savings in HVAC capacity may be confidently assumed at the design stage, just as they can for reflective glass.

POTENTIAL FOR FURTHER REDUCTION IN NEW NON RESIDENTIAL BUILDING ENERGY 1981-1990

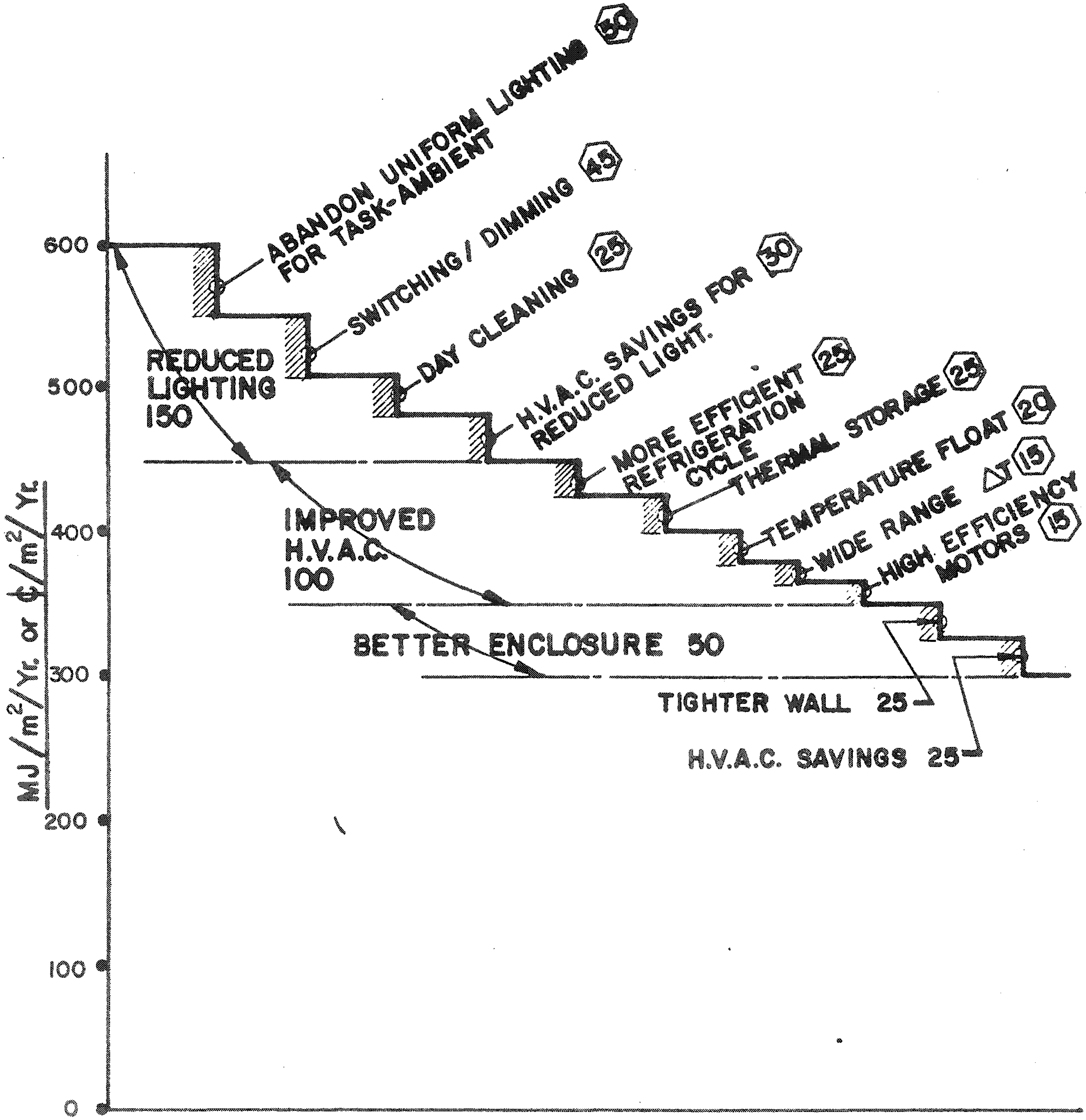


FIGURE-3

In future buildings a certain minimum glass area will be specified to permit daylighting, and the reflectivity of windows will be limited to ensure adequate light transmission. Cities such as Vancouver and St. John's, with cloudy climates, are especially benefitted by daylighting systems, because on cloudy days the daylight gains on the three non-sunlit walls can be double what they are on clear days.

Savings with well-designed dimming systems can be as much as 45 MJ/m^2/year, and pay for themselves within five years. (The cost of manual switching may be only half as great, but so are the savings--and the latter are far less certain.)

Daytime cleaning. A significant share of lighting energy is used for nighttime cleaning of space. While efforts have been made to reduce this usage by circuiting fewer lamps for nighttime cleaning (and security), the best chance of reducing lighting from 4,000 hours/year to 2,800 will depend upon the adoption of daytime cleaning programs. Already, most government offices have instituted 2:00 p.m. to 9:00 p.m. cleaning, which partially overlaps with office use, while owners of some private space are experimenting with a 7:00 a.m. to 3:00 p.m. program, obviating any extension of lighting operating hours for cleaning.

The potential for further savings with daytime cleaning may be about 25 MJ/m^2/year.

HVAC savings for reduced lighting. As before, there will be savings in HVAC energy commensurate with savings in lighting loads. This may amount to 30 MJ/m^2/year, bringing the overall potential savings from lighting to 150 MJ/m^2/year.

Improved HVAC Systems

More efficient refrigeration cycle. Energy for mechanical cooling of non-residential buildings in Canada has usually been less than 10% of the total. Yet, in the 1980's, this component will be examined more carefully for savings.

Chillers will have larger heat-exchange surfaces. Refrigerant temperature will be varied to suit the maximum load. Water towers will be designed for minimum fan energy by using enlarged surface areas and wider condensing temperature ranges.

The effect of these measures may aggregate to savings of 25 MJ/m^2/year.

Thermal storage. The major cost savings from thermal energy storage may relate to reduced electric peak demand charges for cooling in summer. Nevertheless, there is an opportunity for using storage to recycle waste heat from occupied periods to cold nights and weekends, when some non-residential buildings still need to maintain minimum temperatures.

The first-cost of thermal storage may make it less feasible for smaller buildings, but the concept may reduce heating energy by up to 25 MJ/m^2/year when the economics are favorable.

Temperature float. In the past, it has been conventional to maintain the temperature in non-residential space as close to 23°C as possible.

If occupants can be persuaded to accept a larger range of temperatures, between 20°C and 24°C, there may be further savings of 20 MJ/m^2/year.

Wide-range ΔT. Temperature ranges for air and water in commercial HVAC systems have been a matter of rote. More careful examination of initial and energy operating costs would seem to justify different temperature choices (and allowing temperatures to float within a defined range) depending on the circumstances. Chiller energy, pumping energy, the added cost of larger-diameter pipes (with less pumping resistance but increased conductive losses), and increased heat-exchanger surfaces are all factors to be considered in the trade-offs.

Rethinking the temperature ranges on circulating air and water may save up to 20 MJ/m^2/year.

High-efficiency drives. Motors consumes 75% or more of the electricity used in North America. In HVAC systems, the use of high-efficiency motors would seem economically tenuous because of the short periods of operation. Yet, the major saving in energy and power factor for high-efficiency motors is during part-load operation. With variable fan and pump operation, the high-efficiency product may thus offer a 5-year pay-out or better. The savings for high-efficiency motors in future HVAC systems may be as much as 15 MJ/m^2/year.

The overall potential for future HVAC savings may therefore be as much as 100 MJ/m^2/year.

Better Enclosure

Tighter walls. The advent of larger and taller non-residential buildings has raised concern for the added infiltration caused by the chimney effect. In buildings over 10 stories, this problem may exceed infiltration caused by wind loads by as much as 4 to 1. Pretesting of building wall panels to ensure reasonable airtightness will become standard in the 1980's. As a recheck on construction, it will become normal practice to test completed buildings, as well, to ensure that overall air leakage values have been achieved.

The air leakage criterion which may be expected for a building with average tightness will be 4 m^3/m^2/hour, with the standing pressure of a 40 Km/hour wind. If achieved, this will save 25 MJ/m^2/year over typical construction with twice that leakage rate.

HVAC savings. Tight walls save heating energy. In addition, they reduce the energy required to operate systems needed to maintain temperature during unoccupied periods. The savings in fan and pump energy may equal the reduction in heating, for a further savings of 25 MJ/m^2/year.

In conclusion, the potential for saving another 50%, or 300 MJ/m^2/year, still appears to exist for post-1981 non-residential buildings. The majority of this will require some further investment but, once again, the savings in lighting first-cost may pay for the balance of the energy improvements.

Where energy is concerned, if building designers don't learn to balance the budget, we to budget the balance.