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November 7-12, 1982

TECHNOLOGY FOR ENERGY-EFFICIENT BUILDINGS

Arthur H. Rosenfeld

November 1982

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This is the first of two papers presented by
A. H. Rosenfeld at the First U.S.-China
Conference on Energy, Resources and Environment,
Beijing, China, November 7-12, 1982.
Paper II: "Energy Efficiency in Chinese
Apartment Buildings: Parametric Runs with the
DOE.2 Computer Program," LBL 15183, EEB 82-3.

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TECHNOLOGY FOR ENERGY-EFFICIENT BUILDINGS

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ABSTRACT

New Western buildings use little energy for heating, even compared to current Chinese usage. Research and progress in energy efficiency are summarized and applications to China pointed out, especially in regard to insulation, thermal mass, and improved daylighting.

Note added October, 1982: This paper has been slightly shortened and has become one of two papers.

In the original version, written in July and submitted to the Conference Proceedings, our recommendations for more insulation were based on hand calculations and on U.S. prices. The results looked so interesting that I have collaborated with four colleagues to run our DOE.2 computer program (for building energy analysis), make a series of parametric runs, and gather Chinese prices. The results confirm the July estimates, but are more precise and are presented in Paper II [Huang, 1982].

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I. INTRODUCTION

Because buildings in the U.S. and Western Europe use huge amounts of energy by Chinese standards, my Chinese readers may find it surprising that I can make any useful comments about Chinese buildings. However, in Section II of this paper I will show, using Figures 1 through 3, that our new buildings are much more efficient than our stock, and are already down to Chinese levels of energy use (and may soon dive below). So, I can usefully outline some of the ways we are using energy better, with no significant reduction in comfort.

Why has the U.S., in the nine years since the 1973 Oil Embargo, changed from a country that knew and cared little about end-uses of energy, to one that now has a Federal Conservation Budget of 340 million dollars? (We even offer a 15% tax credit to homeowners who "retrofit" their homes to make them more energy efficient, and in California the credit is 55%.) The answer is that the price of energy has risen, and now it pays us to use it more wisely. A more detailed answer is that in 1982 the U.S. will spend one billion dollars/day to purchase energy for buildings, industry, and transportation. We are beginning to realize that we could save about half of this huge expense if we switched half of our 67 billion dollars annual capital investments in energy into improving our buildings, industry, and transportation--instead of concentrating on building power plants and transmission facilities and seeking and developing new supplies of fuel.

In conclusion, the U.S. now has a very active buildings research program, and, as a buildings scientist, I would like to present some results that might be useful to you.

II. TRENDS IN U.S. AND EUROPEAN AUTOS AND BUILDINGS

Figures 1, 2, and 3 show that Europe has responded promptly and dramatically to the rise in energy prices that started about 1970. The U.S. is trailing by only about 10 years for autos and office buildings, but by 20-30 years for homes.

It is interesting to compare Fig. 1 (Autos) and Fig. 2 (Office Buildings) because they both show the same dramatic drop in end-use of energy and both represent comparable amounts of resource energy, 10 x 10^{18}J (= 10 EJ or 10 quadrillion Btu).

I shall not discuss autos here, since other papers on transportation are being contributed to this conference.

- Office buildings became much more energy-intensive between World War II and the 1973 Oil Embargo, for three reasons: (1) the popularity of glass facades (mainly single-glazed); (2) intensive area lighting (up to $60W/m^2$); (3) large and inefficient "HVAC" systems (for Heating, Ventilating, and Air-Conditioning). This all changed by 1975, when ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) passed its now-famous voluntary Standard 90-'75, which recommended a factor 2 reduction in annual resource energy use, down to 250 $kBtu/ft^2$, as shown in Fig. 2. This was accomplished cheaply by decreasing glass area and light levels, and introducing well-insulated walls, small windows (double-glazed), and smaller HVAC systems. Savings on HVAC, glazing area, and lighting fixtures then paid for increased insulation and double-glazing.

Standard 90-'75 was so successful that it was voluntarily revised about 1980 (as shown in Fig. 2). Here, recommended lighting power was reduced to no more than 20W/m^2, supplemented with task lighting, mainly from desk lamps.

The point marked "1985," at 110 kBtu/ft^2, was originally proposed by the U.S. Carter Administration as a mandatory Building Energy Performance Standard but was recast as a voluntary guideline by the Reagan Administration. It will probably be adopted by ASHRAE as voluntary Standard 90-'85.

The point marked "Optimum" at 70 kBtu/ft^2 is the life-cycle cost minimum using 1980 technology, with considerable attention to daylighting and thermal storage. Its first cost is \$10-20/m^2 more than today's typical costs (i.e., only a few percent). The buildings need almost no space heat--the 70 kBtu/ft^2 of resource energy is almost all specific electricity for lighting, ventilation, and equipment. And it is reassuring to note that the Swedes have followed a similar path, but earlier, and with smaller fluctuations. New Swedish office buildings, of which the first of its class was the one labeled Farsta Folksam (plotted at 90 kBtu/ft^2), have enough thermal storage to get through a long Stockholm winter with only 120 kWh/m^2 of electricity, of which 80 kWh/m^2 is for routine lighting and equipment, and only 40 kWh/m^2 for electric resistance heat--less space heat than is required by a Beijing office.

I shall return to these points later, but recognizing the importance of life-cycle costing has clearly made an historic change in building design, and is producing low-energy buildings even by Chinese standards.

• Residences are summarized in Fig. 3, which shows the growing efficiency of space heating for single-family homes in the U.S., which are usually stand-alone structures with four exterior walls and a roof (as opposed to an apartment that may have only one exterior surface). New U.S. homes typically have 150 m^2 of floor area, but the average of existing homes and apartments is about 100 m^2.

Before discussing the U.S. progress in Fig. 3, we want to relate it to current Chinese building practice. The Beijing apartment discussed in Section III and Paper II, with no insulation, kept at 18°C, uses 34 GJ/100m^2, which appears to be comparable with U.S. practice. But the Beijing "middle" unit loses heat through only two walls (north & south), no roof, and no ceiling. To compare it with Fig. 3, which represents distinct (detached) dwellings, with floor areas of 120-150 m^2, we should add losses through two more walls and a roof, which we assume is a typical Beijing roof of 17 cm of aerated concrete. If we assume a thermostat setting of 20°C, as is typical in the U.S., then the fuel intensity will be about 100 GJ/100 m^2 or well off-scale for Fig. 3; in fact, 2-3 times as bad as current U.B. building practice. So we should call for progress in China, too, and shall do so in Paper II.

We return to our discussion of the U.S. Although less dramatic than those shown in Figs. 1 and 2, the progress in Fig. 3 is notable. With adequate insulation (i.e., 15 cm of fiberglass in the walls and 30 cm in the roof) and double- or triple-glazing, but no real innovation, the cost-effective fuel intensity today is about 20 GJ/100 m^2 of floor area. By reducing the natural infiltration from 0.7 air changes per hour (ach) to 0.3, and then supplying 0.4 ach mechanically through a heat exchanger, the cost-effective optimum drops to about 10 GJ/100 m^2.

A number of U.S. homebuilders now offer homes that use only 10-20 GJ/100 m^2, but today they still represent only a few percent of all new homes. California has just updated its mandatory standards to approach the cost-effective limit at about 0.5 ach. The extra cost is estimated at only 2-4%, i.e., \$1500-\$3000 on a \$70,000 home (2-4%).

The most interesting development is the superinsulated house, using about 5 GJ/m^2. It uses all the features mentioned so far, plus even more insulation (typically 25 cm in the walls), has its windows concentrated to the south, and usually has insulating window shades for use at night. Even in Canada, where superinsulated houses are popular, they do not need a conventional central heating system. Instead they use small baseboard electric heaters or tiny radiators that use hot water from the domestic water heater.

Figure 4 summarizes the economics of superinsulated ("I"), passive solar ("P"), and active solar ("A") homes. It is taken from LBL's annual publication BECA-A (Building Energy Compilation and Analysis, Part A--New Residences, LBL 14576). We see that the typical "I" and "P" home costs only a few thousand dollars more than current practice. The economic analysis is explained in the figure caption. To be competitive, at today's gas prices, the square representing a home must lie well below the line labeled "oil at \$10/MBtu." We note that most of the "I" and "P" homes are economically very attractive, but that most of the active solar "A"'s don't compete successfully even with electric resistance space heat (i.e., they lie above the line labeled "Electricity at 6.2¢/kWh"). But please do not confuse uneconomic active solar space heat with economic solar domestic hot water. In the U.S., and certainly in Israel, solar hot water competes with electric hot water, and is beginning to compete with gas.

III. A FIRST SUGGESTION--INSULATION

NOTE, October, 1982. As mentioned on page 1, this section has been expanded into a complete separate paper [Huang '82], whose abstract reads as follows:

> Using a typical-design uninsulated Beijing apartment building as a base case, we have used the DOE.2 energy analysis program to study the cost-effectiveness of more energy-efficient building design. Two measures have attractive simple payback times: insulation of the north wall (seven years payback) and reduced infiltration (? years). The cost of conserved coal for the insulation measure is 1.3 Yuan/GJ, which is only about half the price of coal. This insulation adds only 0.6% to the first cost of the building, yet, combined with more attention to infiltration, it reduces annual heat load from 230 MJ/m^2 to 130. The first cost of these two measures is probably offset by downsizing the heating plant. In Shanghai, reduced infiltration and insulation are justified not on the basis of saving fuel, but because they make the dwellings much more comfortable.

IV. A SECOND SUGGESTION--THERMAL MASS AND THERMODECK

I have just said that exterior walls should have cavities filled with insulation. Now I want to point out that Chinese construction already frequently employs concrete floor-ceiling slabs having hollow cores; you could improve the comfort level of your buildings by circulating indoor air through these cores. This technique is now popular in Sweden, and is called Thermodeck (Andersson et al., 1979); it adds little or nothing to the first cost of the building.

A concrete floor-ceiling slab represents a convenient and large amount of thermal mass (about 100 Watt-hours/m^2 K). The trouble is that if it is isolated from the room or office space by acoustical tile on the ceiling and rugs on the floor, then it is not in good thermal contact with the occupied space.

Now, in the West, manufacturers want to make prestressed, reinforced concrete floor-ceiling slabs that are thick (20-30 cm) for the sake of rigidity, but light for the sake of economy--so the slabs are usually extruded with long hollow cores. (Even if the slabs are poured in place, the same considerations apply, and it is easy to pour the concrete around a serpentine duct.) In Sweden, Andersson and Isfalt (1979) have shown that by blowing room air through these ducts, using only tiny amounts of fan power (0.3 W/m^2 as compared to 15 W/m^2 for lighting), they can control the flow of heat to and from the slab.

A computer simulation of four typical designs is shown in Fig. 5. Curve (a) represents a rug and acoustical tile in a well-insulated room, or any room on a mild day. Lights and people heat up the air rapidly, and after an hour occupants will open the windows or turn on air conditioning. Thus they store no heat for the next chilly morning. Curve (b) shows the ceiling tile and rugs still in place, but air circulated through the hollow cores, as in the Thermodeck system. Curve (c), which is indistinguishable from (b), shows the ceiling tile and rug removed, but no Thermodeck. Curve (d), which may be "overkill," shows no ceiling tile and rugs, plus Thermodeck.

The Swedes have very well-insulated buildings, so they use this technique routinely to store heat (in the winter) over nights and weekends, and to store summer nighttime "coolth" to keep the building comfortable the following afternoon. The first of these buildings, the Folksam building in Farsta, was represented by the lowest Swedish point in Fig. 2.

In Beijing, with less well-insulated buildings, you probably will not save much heat in January, but you can halve the length of your heating season and make your buildings more comfortable the rest of the year. At least you should try it--it's free, and I think you'll like it.

V. A THIRD SUGGESTION--BETTER DAYLIGHTING

My last suggestion, like my first two, costs almost nothing, and will improve daylighting, thus saving power in the winter, and power and undesirable heat in the summer. The reason you save heat in the summer is that daylight is cooler than artificial light: Daylight provides 100-120 lumens/watt, fluorescent lamps provide about 70, and a 50-W incandescent lamp provides only 15.

My suggestion is to separate the daylighting part of the window (top 60 cm, extending up to the ceiling) from the view part, as shown in Fig. 6. The top part should be clear glass, and provided with a white or silvered Venetian blind to bounce light off the white ceiling. The top of the overhang should be painted white. All this permits optimum daylighting under all weather conditions.

The view part of the window should be treated separately, and in warm climates should use solar-control (reflective) glass. Its shade should be separately operated, so that is can be shaded on hot sunny days, without interfering with the daylight coming in above.

Again, my advice is, "Try it on a few buildings--and see if you like it."

I hope some of these suggestions will accelerate the trend towards comfortable, efficient Chinese buildings.

VI. ACKNOWLEDGEMENTS

I want to thank Metin Lokmanhekim, Joe Huang, and John Ingersoll for their suggestions.

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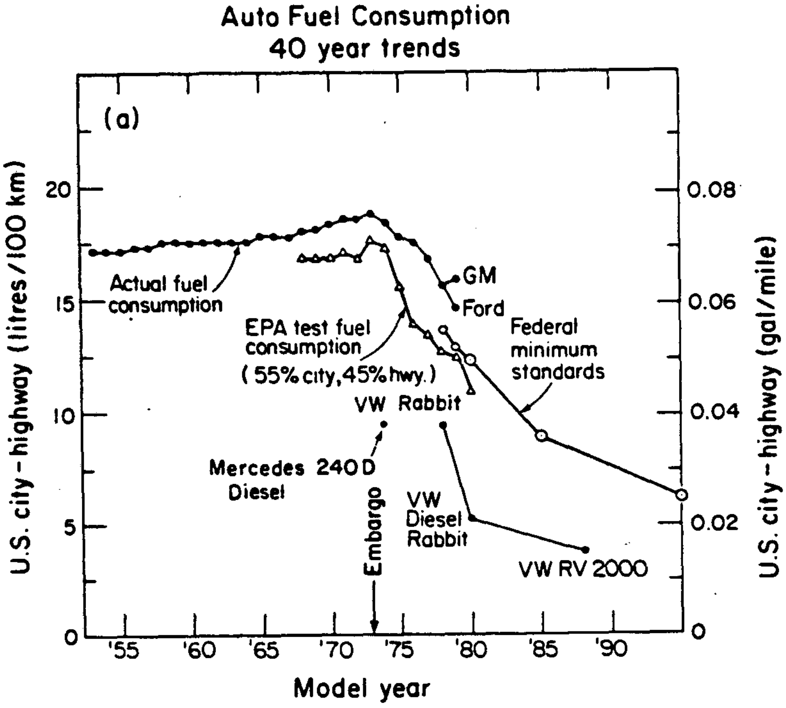

Fig. 1. Forty-year trend in fuel consumption of new U.S. auto fleet and some foreign competition. Source: Cray and Von Hippel, Scientific American, 244, 36 (May, 1981).

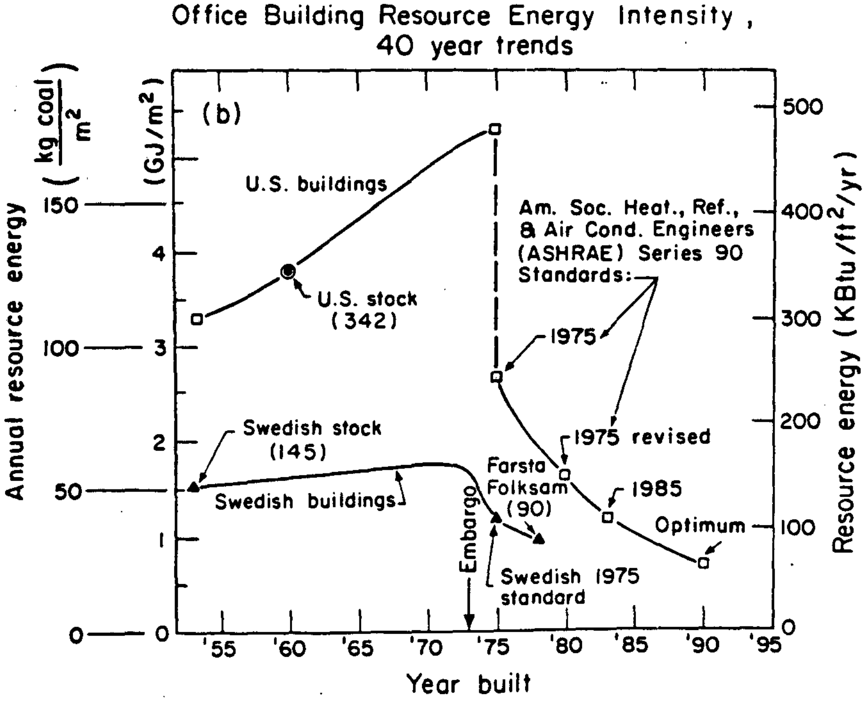

Fig. 2. Forty-year trend in annual energy use per unit floor area of new U.S. and Swedish fuel-heated office buildings. Electricity for lighting, cooling, etc., is counted in resource energy units of 11,500 Btu (12 MJ) burned at the power plant per kWh sold. Source: A New Prosperity--SERI Solar/Conservation Study, Brick House Publishing Co. (1981).

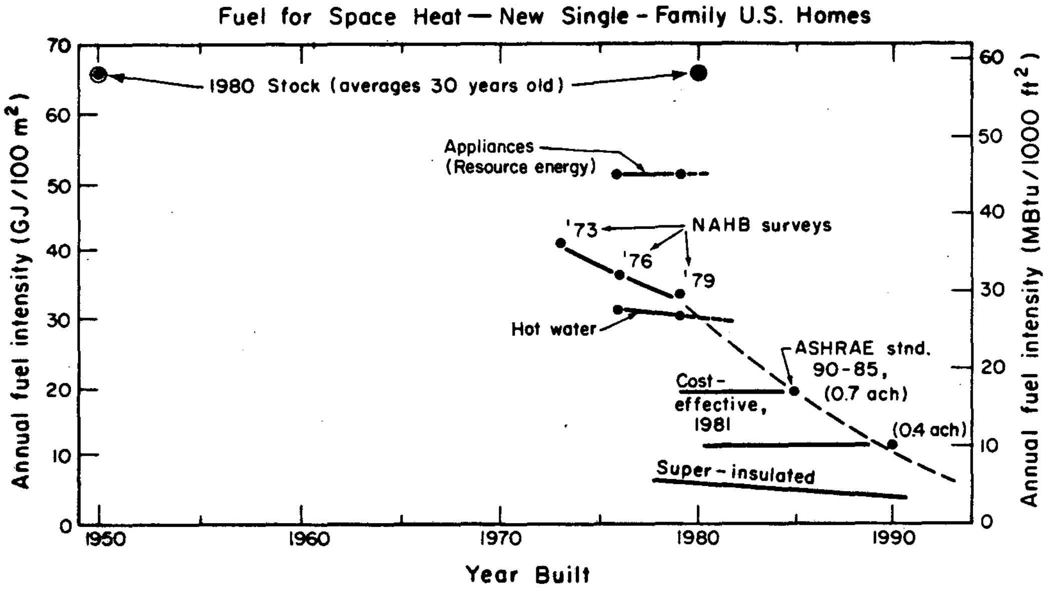

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Fig. 3. Forty-year trend in fuel intensity for space heat in new fuel-heated U.S. single-family homes. The vertical scale is fuel use per 100 m^2 of floor area (not facade area), because the 100 m^2 is roughly the average area of a U.S. or European dwelling. Source: J. Ribot et al., "Building Energy Use Compilation and Analysis, BECA-A: New Residences," LBL 14576 (1982), to be published in Energy and Buildings, 1983.

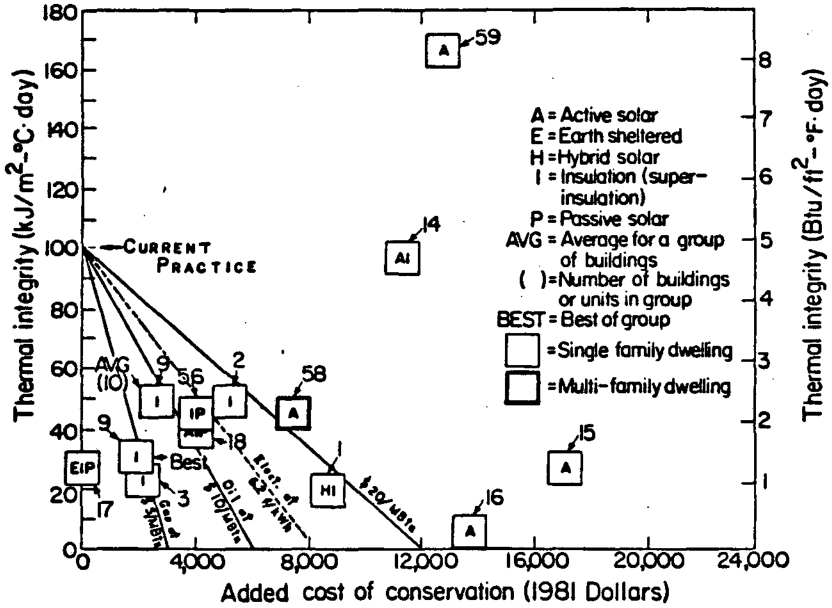

Fig. 4. Twenty-one-home scatter plot of thermal integrity vs. added first cost of conservation-and-solar features. Heating loads have been divided by floor area and heating degree days. The point on the y-axis at 100 kJ/m^2-°C-day) represents average U.S. current practice; the sloping lines descending from it are boundaries of cost effectiveness for typical residential energy prices assuming 70% efficient furnaces for gas and oil, or electric resistance heating. Since conservation investments are typically "one-time," the future stream of energy savings for 30 years are converted to a single present value, assuming a 6% real discount rate (yielding a capital recovery rate of 7.25% per year). The home is cost effective if its point lies <u>below</u> the fuel line in question. Superinsulated homes fall mainly in the fuel price range of $4-to-10 per MBtu for gas, and are excellent compared to 6.2¢/kWh for electricity. Active solar homes are far worse. ($5 per MBtu equals 50¢ a therm for gas and $10 per MBtu equals $1.30 for oil.) The number related to each square by an arrow is the ID number in the BECA-A Database [LBL-14576 (1982)].

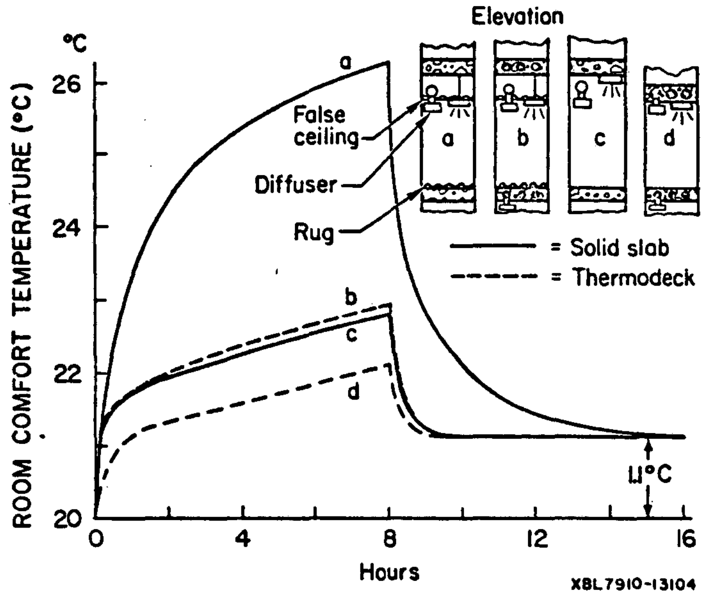

Fig. 5. Response/relaxation curves calculated by the BRIS-program for equal rooms with two different slabs, each with a heat capacity of 100 Wh/m^{2}K. The surroundings are assumed symmetric on all sides (as in an office in the core of a building). 15 W/m^2 of lighting (50% radiation) is turned on for the first 8 hours of each run. The cases are as follows:

a. 20-cm thick solid concrete slab, with rug, insulated, suspended ceiling, and plenum. Resistances assumed were: rug -- 0.1 (W/m^{2}K)$^{-1}$; insulated false ceiling -- o.5; plenum -- 0.17.

b. Same as a., but slab is 30 cm. thick Thermodeck.

c. 20 cm. thick concrete slab, but bare -- no rugs, suspended ceilings, plenum.

d. Same as c., but slab is 30 cm. thick Thermodeck
Source: Andersson et al. (1979),

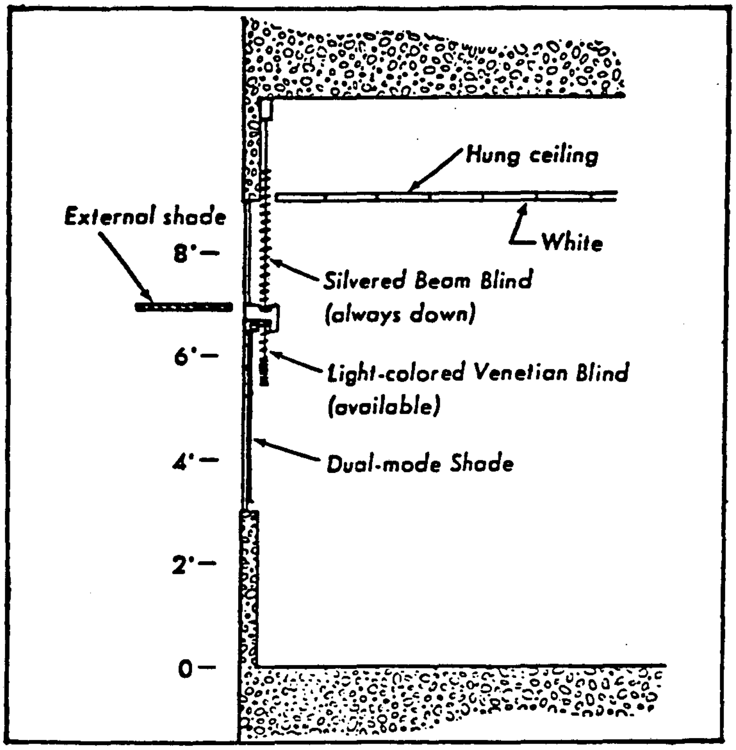

Fig. 6. Separation of daylighting window above an overhang from view window below. On South windows there should be an overhang painted white on top to act as a light shelf. Source: Rosenfeld and Selkowitz (1977).

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