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Radiative Heat Loss from Skin to Cold Glass Windows

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Today institutional rooms of many types have single large glass window panes measuring as large as 3.0 meters by 2.5 meters; animal colonies are maintained near these windows in winter, office workers sit by them and thinly clad patients on littercarts are placed beside them. Even though both local air and wall temperature may be 22°C, human subjects beside the windows in winter feel cold because body heat is radiated to the glass which acts as a heat sink. An experiment was conducted during two Iowa winters with measurements of temperatures of outside air, room, wall, undraped glass window, drape-covered window and skin to determine radiated heat loss and to assess the effects of a radiation shield (drape). The glass could be as low as 2°C. Results showed greater protection to the skin by the drape as the weather became colder, although the glass temperature did not change with the weather as much as was expected. Using a standardized room for calculations, we showed that if a person moved from a back wall to a position beside the glass window, he would increase his total heat loss by 32 percent.
INDEX DESCRIPTOR: Temperature Regulation, Skin Heat Loss.

The opinions held by various individuals about body heat loss in a comfortable room (22°C) differ with occupations: the lay person considers the air temperature important; the physiologist tries to partition radiation, conduction, convection and evaporation; the engineer calculates how much furnace heat is lost through glass compared to brick or concrete. In few sources have we found figures referring to the

Figure 1. Many office workers are unaware that warm air called for by the room thermostat will not protect them from radiative heat loss to a cold window.

Figure 2. Hospital personnel are likewise unaware that a lightly-covered patient is not protected against radiative heat loss to a cold window.

body heat loss in a modern room with one or more glass walls. In this paper we have tried to synthesize the views of lay person, physiologist and engineer, and will present some factual data on glass wall temperatures and body heat loss.

This research was prompted by observing office personnel working by large glass windows, who felt they must be ill because an air temperature of 23°C was inadequate (Figure 1); observing patients covered only by sheets, left by attendants beside cold glass windows (air temperature 24°C, Figure 2); and by observing the care of premature babies in plastic thermostatically controlled chambers in which the air temperature was maintained at 31°C but the room temperature was as low as 15°C (found particularly in England and India). This means that the baby radiates to a plastic wall that is relatively cool. When we wished to discuss these cases, we could find no records of the influence of cold winter outdoor temperatures on window glass. *Our hypothesis was that this glass would be cold enough to be of physi-*

ological significance. For two winters we monitored glass temperatures using the following procedure.

METHODS

The study was done in a laboratory containing four north windows made up of eight large single glass panes, each measuring 1.0 by 1.2 meters. For each of two winters, seven thermistors were fixed in position as follows: on the wall, on the furniture, to sample room air, to sample outdoor air, in the center of an exposed pane of glass, in the center of a pane of glass covered by a drape and on the drape covering the glass. An eighth probe recorded daily the temperature of the bare arm of the female observer, seated near the window. The thermistors were calibrated and read to the nearest 0.1°C on a Yellow Springs Telethermometer.

The coldest outdoor temperature observed was -17°C. Graphical analysis was done to correlate indoor cold glass temperatures with those outdoors. The question was whether to extrapolate to colder temperatures than -17°C to represent climatic conditions for Iowa. Let us consider what these winter conditions are. The average minimum temperature over 30 years for Charles City for January was 13°C, and the lowest value recorded was -40°C (Dept. of Commerce, 1956). According to several authors, North America is experiencing a long-range cold cycle (Folk, 1966); for example, the average winter temperature for Iowa in 1940 was -5°C, while for 1964 it was -9°C. In the face of this trend, it appeared reasonable to extrapolate for our calculations to the lowest outdoor figure actually observed, -40°C (Figure 3).
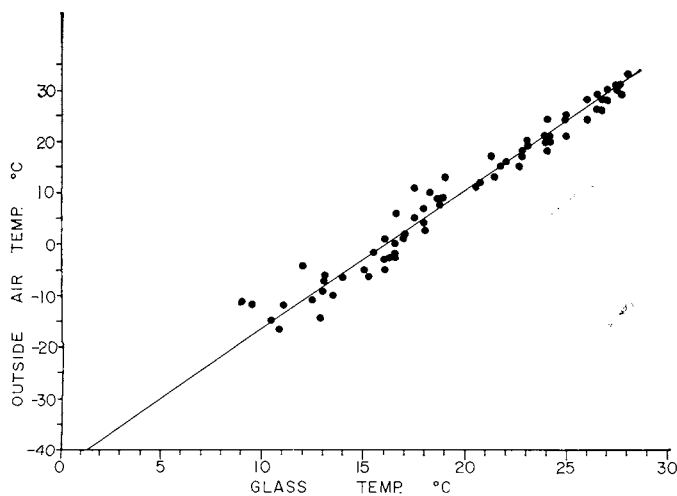
Calculations of heat loss were done using the data obtained from two winters (Appendix A). The simplification of using a vertical cylindrical model to represent a standing person was used throughout the calculations. The cylinders were considered to be blackbodies, and each had the surface area of a typical human subject (1.8 square meters). A standardized room was used to calculate heat loss at each of three positions (1, 2, 3) for several sets of conditions (Figure 4).

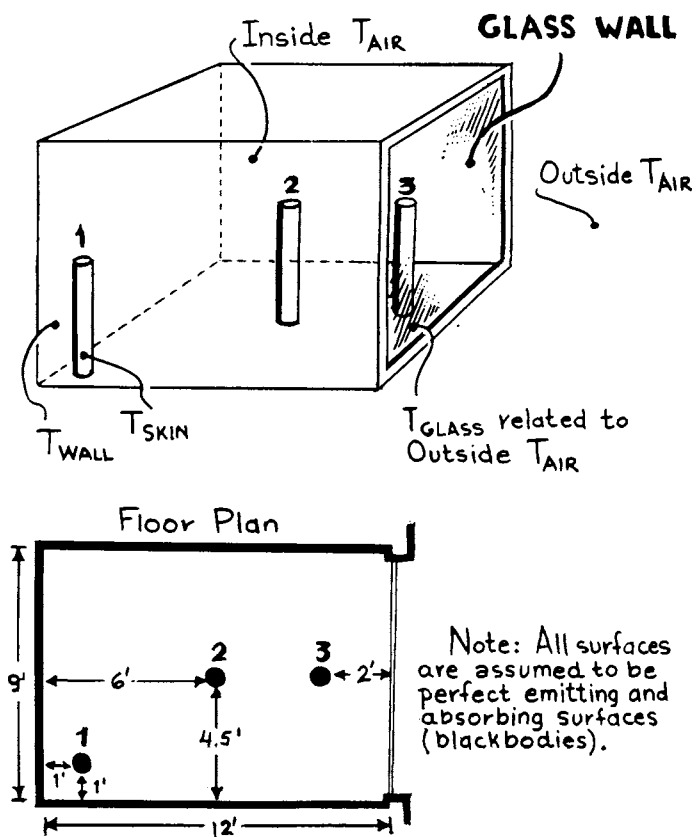## DIMENSIONS AND OTHER FACTORS USED IN ANALYSIS OF HEAT LOSS

Figure 4. Calculations of heat loss were made using a vertical cylindrical model (surface, 1.8 square meters) to represent a person standing in three positions in a standardized room with a glass window at one end.

Figure 3. Measurments to show the influence of outside winter air on window glass temperatures, extrapolated to the lowest recorded reading at Charles City, Iowa.

The glass temperatures did not change with the weather as much as was expected; for a 3°C change in the weather, there was 1°C of change in the north window glass. At -40°C outdoor air, the extrapolated glass temperature was 1.3°C (Figure 3). The colder the weather, the more the drape (radiation shield) protected the skin (Table 1). The glass temperature approximated the room wall temperature more

TABLE 1. THE EFFECT OF A LARGE UNCOVERED WINDOW
COMPARED TO A DRAPE-COVERED WINDOW*

	Jan. 28	Mar. 1	Feb. 24
Outside Air	−17°C	−4°C	−2°C
Glass	11	13	17
Gradient:			
Glass to Outside Air	27	17	19
Skin to Glass	23	21	17
Skin to Drape	15	17	14
Skin to Wall	8	11	9

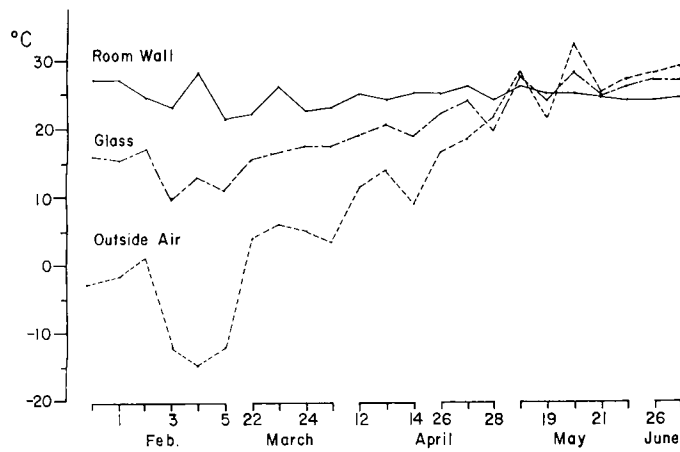* The columns are in ascending temperatures of outside air.

Figure 5. Seasonal changes in temperatures of glass, room wall and outside air. In winter the glass temperature approximated the room wall temperature more closely than it did outside air.

closely than it did outside air (Figure 5). As the weather became warmer, the glass reversed its role and became warmer than the room temperature. Under the conditions of our experiment, one should not expect ice or frost on the inside of the glass window even at Iowa's coldest temperatures. Base-line calculations of the heat loss were begun with the cylinder in the back corner of the room, which was the position of least loss. When the cylinder was moved to the vicinity of the glass, total heat loss increased 32 percent under the coldest conditions (Table 2). The distance to the glass and resulting view factor between the cylinder and the glass were the factors responsible for this increase in heat loss. A comparison was also made at the position in the middle of the room between a window at 12°C and no window at all. A 13 percent increase in total heat loss was calculated when the window was present.

TABLE 2. INCREASE IN RADIATIVE HEAT LOSS RELATIVE TO
PROTECTED CORNER OF ROOM

Glass Temp.	Middle of Room	Beside Glass Window
12°C	16% (11%)*	30% (19%)
2°C	25% (17%)	46% (32%)

* ( ) = increase in total heat loss

DISCUSSION

This study shows that human subjects in buildings of modern architectural design which involve partial glass walls would measurably increase their heat loss. A reasonable estimate for cold winter circumstances would be an increased total loss of about 30 percent; it should be pointed out, however, that this study was done with panes of glass of a single thickness. Presumably, in some modern architecture, thermopane or window heaters will be used even with large expanses of glass. We will probably observe in the future many more work spaces and conference rooms with these large expanses of glass because of the energy crisis in the United States. In new buildings over the past 20 years there has been a trend to place conference rooms in the interior of buildings with total artificial lighting. The energy crisis may result in more meeting rooms and classrooms being designed with natural lighting and with increased expanses of glass walls. The physiologists should take this trend into account. A rule of thumb has been applied for a number of years for rooms without glass walls, as follows: 67 percent of heat loss by radiation to walls, 10 percent by conduction and convection and 23 percent by evaporation for rooms at 23°C (Hardy and DuBois, 1938). Although our figure for an increased total heat loss of about 32 percent due to a glass wall was smaller than predicted, it should be taken into account for the conditions of modern architecture.

APPENDIX A

Radiation Heat Loss

$q = F_{s-w}A_s\sigma(T_s^4-T_w^4) + F_{s-r}A_s\sigma(T_s^4-T_r^4)$ watts
$= A_s\sigma(T_s^4 - F_{s-w}T_w^4 - F_{s-r}T_r^4)$, where
T_s = skin temperature (31°C)
T_w = window temperature (2 or 12°C)
T_r = room temperature (22°C)
σ = Steffan-Boltzman constant
$= 5.668 \times 10^{-8}$ watts $/^2/^0K^4$
A_s = radiating surface area of the body (m²)
F_{s-w} = geometry factor for skin and window
F_{s-r} = geometry factor for skin and room

Radiating Surface Area of Body
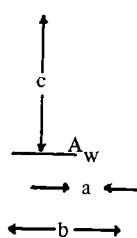Standard Man: $A_s = 1.8$ m²
Area Coefficient = 0.78
From Guibert and Taylor, *Journal of Applied Physiology* 5(1), 1952.
Radiating Surface Area = 1.8(0.78)
$= 1.404$ m²

Radiation Geometry Factors

$$F_{s-w} = \frac{r}{b-a}(\tan^{-1}\frac{b}{c} - \tan^{-1}\frac{a}{c})$$

$$F_{s-r} = 1 - F_{s-w}$$

Convection Heat Loss

$q = hA_s(T_s - T_a)$ watts, where

h = convective heat transfer coefficient
    = 2.72 watts/m²/°C (calculated value)

A_s = surface area of the body

T_s = skin temperature (31°C)

T_a = air temperature (24°C)

Total Heat Loss

$q_{total} = q_{conv} + q_{rad}$

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