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# BUILDING RESEARCH NOTE



## RELATION BETWEEN THERMAL RESISTANCE AND HEAT STORAGE IN BUILDING ENCLOSURES



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The annual building heating energy requirement is a function of the thermal resistance of the building enclosure and, to a lesser extent, of the mass of the building envelope. In this Note relations that can be used to estimate the "trade-off" between the mass and the thermal resistance of the building enclosure* are presented in graphical form. These relations define the permitted allowances for mass in terms of reduction in thermal resistance as given in "Measures for Energy Conservation in New Buildings 1978".**

The changes in the annual energy requirement for heating of buildings due to changes in thermal storage of building enclosures were determined by computer simulation.[1,2] From the results of these calculations it was possible to derive a simple relation between changes in the mass of building enclosure and corresponding changes in thermal resistance of building enclosure based on the condition that the annual building heating energy requirement remained constant. For example, as the mass of an exterior wall is increased, it is possible to decrease the wall thermal resistance without changing the building annual heating energy requirement.

The computer simulation considered the following factors.

1. Type of building
   a) Single-family residence. (According to "Measures for Energy Conservation in New Buildings 1978", this type is classified as "Enclosures for buildings with low energy requirements for lighting, fans and pumps.")
   b) Large office building. (Classified as "Enclosures for buildings with high energy requirements for lighting, fans and pumps.")

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* The "thermal resistance of building enclosure" is the over-all thermal resistance between inside and outside air.

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2. Climate

Hourly weather data for Winnipeg, Ottawa and Vancouver for 1970 were used for the calculations.

3. Mass of interior construction

Light, medium and heavy interior constructions were considered:

a) Light ≈ 150 kg/m$^2$ of floor surface area

b) Medium ≈ 350 kg/m$^2$ of floor surface area

c) Heavy ≈ 600 kg/m$^2$ of floor surface

4. Mass of exterior wall

a) Light, e.g., frame wall

b) Medium, e.g., layer of concrete about 15 cm thick plus insulating layer

c) Heavy, e.g., layer of concrete about 30 cm thick plus insulating layer

5. Relative position of mass layer with respect to insulating layer

a) mass layer on the indoor side of insulating layer

b) mass layer on the outdoor side of the insulating layer

6. Thermostat set-point schedules

a) Single-family residence:

Schedule (i) Constant at 22°C

Schedule (ii) Daytime at 22°C
Nighttime at 18°C

b) Large Office building:

| | Occupied Period | Unoccupied Period |
|---|---|---|
| Schedule (i) | 20.0°C | 18.3°C |
| Schedule (ii) | 21.7°C | 20.0°C |
| Schedule (iii) | 20.0°C | 15.6°C |
| Schedule (iv) | 22.2°C | 22.2°C |

Throttling range in all cases was assumed to be 1.7K degrees.

7. Orientation

   a) Single-family residence: three orientations used, major glazed facade facing south, west or north.

   b) Large office building was oriented with its sides facing the cardinal directions.

8. Zoning

   a) Single-family residence was considered as a single zone.

   b) Large office building was simulated assuming that each storey of the building is made up of nine zones. Four of the zones are the four corners; the other four are the sides and the ninth is the interior zone. The depth of the exterior zones was taken as 1.6 times the height of one storey.

The results of the computer simulations indicated that in the relation between thermal resistance and mass for building enclosures, the following are significant factors:

1. Type of building.*

2. Position of mass layer with respect to the insulating layer.

3. Mass of interior.

4. Mass of mass layer of the building enclosure.

5. Thermostat set-point schedule (in the case of large office buildings).

The thermostat set-point schedule is not treated separately as a distinct variable in the presentation of the relation between thermal resistance and mass, since the operation of the building is not controlled by the designer. The average of the results for all the thermostat set-point schedules is taken as the representative value. Also, in a similar way, the average of the results was taken for the other weaker variables, such as orientation and climate. Consequently, the thermal resistance/mass relations presented in Figs. 1 to 4 are for:

a) Building types*

b) Position of the mass in the building enclosure relative to insulating layer.

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* Single-family residence or large office building.

In "Measures for Energy Conservation in New Buildings 1978" designations, such as single-family residences and large office buildings, are not used; buildings are classified according to the rate of heat loss relative to internal heat gain. Usually, a single-family residence has a high rate of heat loss relative to internal heat gain. Results for such residences can be used, therefore, as examples of the class defined as "enclosures for buildings with low energy requirements for lighting, fans and pumps." The thermal resistance/mass relations for these types of enclosures are given in Figs. 1 and 3. Examples of the other group of enclosures, i.e., "enclosures for buildings with high energy requirements for lighting, fans and pumps," are given by the thermal resistance/mass relations of large office buildings (Figs. 2 and 4).

Figures 1 and 2 define the thermal resistance/mass relation for the mass layer on the outside of the insulating layer of the building enclosure. Experience indicates that the effectiveness of the mass layer depends on the thermal resistance between room air and the mass layer. Any resistance in addition to that of the air film reduces the effectiveness of the mass layer as an interior heat storage component. In this Note anything other than direct contact between mass layer and space air (where direct contact means a thermal resistance equal or less than 0.2 $m^2 \cdot K/W$) is considered as an insulating layer. Examples of this layer are false ceilings, sprayed asbestos fire protection, as well as the main insulating layer in the building enclosure.

Figures 3 and 4 define the thermal resistance/mass relation for the mass layer on the inside and in direct contact with controlled space air. The use of Figures 3 and 4 is not straightforward because the addition of a mass layer augments the interior mass and the annual heating requirement of the building depends on the combined effect of all the interior mass. In addition, the mass effect is not linear since the increase of mass beyond approximately 500 $kg/m^2$ of floor surface area has little effect on the annual building heating requirement. This can be seen in Figs. 3 and 4 where the extensions of the "R" curves are parallel to the mass axes beyond 500 $kg/m^2$ of floor surface area.

## Example Problems to Determine the Allowance in Terms of Thermal Resistance for the Mass Layer in a Building Enclosure

### Using Figures 1 and 2

Figures 1 and 2 can be used to estimate the change in thermal resistance of the building enclosure which is equivalent to the layer of mass for the condition where the mass layer does not contribute to the interior mass, i.e., a mass layer that is not in direct contact with temperature controlled space air.

### Example Problem 1

Determine the allowable reduction of exterior wall thermal resistance, $\Delta R$, due to the mass layer in the exterior wall. The mass layer is not in direct contact with interior space air.

Given Data

Type of Building: Buildings with low energy requirements for lighting, fans and pumps (single-family residence).

Exterior wall thermal resistance: $R = 3.6\ m^2 \cdot K/W$

Mass of the exterior wall layer: $D = 200\ kg/m^2$ of wall surface area

Solution

Use Fig. 1 because building has low energy requirements for lighting, fans and pumps and mass layer is not in direct contact with interior space air.

From curves R = 3 and R = 4 for d = 200 $kg/m^2$ of wall surface area, read

$$\Delta R_3 = 0.010 \text{ (from curve R = 3)}$$

$$\Delta R_4 = 0.018 \text{ (from curve R = 4)}$$

Then, by linear interpolation,

$\Delta R$ for $R = 3.6\ m^2 \cdot K/W$ is

$$\Delta R_{3.6} = 0.01 + 0.6 \times (0.018 - 0.010) \approx 0.015\ m^2 \cdot K/W$$

Thus an exterior wall with over-all thermal resistance of $R = 3.6\ m^2 \cdot K/W$ and no mass is considered equivalent to an exterior wall with over-all thermal resistance $R = 3.6 - 0.015 = 3.585\ m^2 \cdot K/W \approx 3.59\ m^2 \cdot K/W$ and mass layer of 200 $kg/m^2$ of wall surface area. The equivalence is on the basis of the building annual heating requirement (all other factors being equal).

Example Problem 2

Determine the allowable reduction of thermal resistance, $\Delta R$, of a roof-ceiling system due to the mass layer in this system. Mass layer is not in direct contact with interior space air.

Given Data

Type of Building: Building with high energy requirements of lighting, fans and pumps (large office building)

Thermal resistance of roof-ceiling system: $R = 4.0\ m^2 \cdot K/W$

Mass of the layer: $d = 300\ kg/m^2$ of roof surface area

Solution

Use Fig. 2 because building has high energy requirements for lighting, fans and pumps and mass layer is not in direct contact with interior space air.

Using curve R = 4 for d = 300 $kg/m^2$ of roof surface area, read

$\Delta R_4 = 0.12\ m^2 \cdot K/W$

Thus the use of a mass layer of 300 $kg/m^2$ of roof surface area allows a reduction of over-all roof-ceiling thermal resistance of $R = 4.0\ m^2 \cdot K/W$ by $\Delta R = 0.12\ m^2 \cdot K/W$.

Using Figures 3 and 4

Figures 3 and 4 are used to estimate the allowable reduction in thermal resistance of a building enclosure component, i.e., exterior wall or roof-ceiling system, when the mass layer in this component is in direct contact with the interior space air. The use of these figures is more complicated than the use of Figs. 1 and 2 therefore the following procedure is recommended.

1) Using given data calculate the contribution to the interior mass by the mass layer of the building enclosure, $M_E$.

a) Roof-ceiling system:

$$M_E = (A_L \times M_L)/A_F$$

where

$A_L$ = Surface (plan) area of mass layer that is in direct contact with interior space air, $m^2$

$M_L$ = Mass of layer, $kg/m^2$ of surface area

$A_F$ = Floor area, $m^2$

When computing contribution to the interior mass by the mass of roof-ceiling system or floor, allowances should be made for shaft areas or other discontinuities, i.e., $A_L$ should be the net area of mass layer. In the case of slab-on-grade floor, the mass of the concrete floor should be included in the calculations of $M_E$ unless it is not in direct contact with room air (e.g., if floor is covered by heavy carpet).

b) Exterior wall:

$$M_E = (A_W \times M_L)/A_Z$$

where

$A_W$ = Surface (elevation) area of the mass layer in exterior wall

$A_Z$ = Area of the floor where the interior mass is considered to be affected by the mass layer in an exterior wall. In this Note it is assumed that

$$A_Z = 1.5\ A_T$$

where

$A_T$ = total exterior wall area of the storey in question.

Similarly, large concrete columns, beams and fixed partitions that are in direct contact with room air and are located within the area $A_Z$ should be included in the calculation:

$M_C$ = (Total mass of beams, columns and partitions)/$A_Z$.

2) Using given data, calculate total interior mass $M_T$, of the space with floor area $A_Z$. The $M_T$ value should include the mass of furnishings, partitions and floor slab as well as the mass of the layer in question. As this information is not usually available, because the position and type of partitions as well as the type and amount of furnishings are usually not fixed at the time the outside envelope is designed, it is recommended that a fixed value of 100 kg/m$^2$ of floor area be used as the mass of furniture and movable partitions. Thus

$$M_T = 100 + M_F + M_C + M_E \text{ kg/m}^2 \text{ of floor area}$$

where

$M_F$ = mass of floor, kg/m$^2$ of floor surface area.

3) Read $\Delta R_1$ and $\Delta R_2$ values against $M_T$ and ($M_T$ - $M_E$) values respectively using appropriate "R" curves. Use linear interpolation as shown in Example Problem 1 in case the thermal resistance of the building enclosure component is not an integer.

4) The difference $\Delta R = \Delta R_1 - \Delta R_2$ is the allowable reduction of the thermal resistance of the building enclosure component due to the mass layer in this component when this mass layer is in direct contact with interior space air.

The use of this procedure is illustrated by Example Problem 3.

Example Problem 3

Determine the allowable reduction of exterior wall thermal resistance, $\Delta R$, based on the mass layer of an exterior wall that is in direct contact with interior space air.

Given data:

| | |
|---|---|
| Type of building: | Building with high energy requirements for lighting, fans and pumps (large office building) |
| Exterior wall thermal resistance: | $R = 3.0\ m^2 \cdot K/W$ |
| Mass of exterior wall mass layer: | $M_L = 250\ kg/m^2$ of wall surface area |
| Mass of floor slab: | $M_F = 300\ kg/m^2$ of floor surface area |
| Surface area of mass layer in exterior wall: | $A_W = 200\ m^2$ |
| Surface area of exterior wall: | $A_T = 300\ m^2$ |

Solution

Use Fig. 4 because building has high energy requirements for lighting, fans and pumps and the mass layer is in direct contact with the interior space air.

Contribution of mass layer to interior mass:

$$M_E = (A_W \times M_L)/A_Z$$

$$= (200 \times 2500)/(1.5 \times 300)$$

$$= 111\ kg/m^2 \text{ of floor area}$$

Total interior mass:

$$M_T = 100 + M_F + M_E$$

$$= 100 + 300 + 111 = 511\ kg/m^2 \text{ of floor surface area}$$

Using curve R = 3 (Fig. 4), for $M_T = 511$ and for $(M_T - M_E) = 400\ kg/m^2$ of floor surface area read, respectively,

$$\Delta R_1 = 0.82 \ m^2 \cdot K/W$$

$$\Delta R_2 = 0.69 \ m^2 \cdot K/W$$

then the reduction is

$$\Delta R = 0.82 = 0.69 \approx 0.13 \ m^2 \cdot K/W$$

Additional Notes

1) Consider an exterior wall or roof which is made up of three layers such that the insulation layer is placed between two mass layers and the interior mass layer is in direct contact with room air. In this case the allowable reduction of exterior wall thermal resistance, ΔR, is the sum of two allowable reductions: a) one determined using Figs. 1 or 2 and b) one determined using Figs. 3 or 4.

2) Consider an enclosure which is made up of exterior wall and roof such that the mass layers of both are in direct contact with room air. In this case the total contribution to the interior mass is the sum of the masses of the roof-ceiling system and exterior wall, i.e., $M_E = (A_L \times M_L)/A_F + (A_W + M_L)/A_Z$. Using Figs. 3 or 4 and the above value of $M_E$ the allowable reduction of the thermal resistance for exterior wall or roof-ceiling system can be determined. Note that only one allowable reduction can be used because both are based on the total mass of the room, i.e., ΔR calculated for exterior wall or ΔR calculated for roof-ceiling system.

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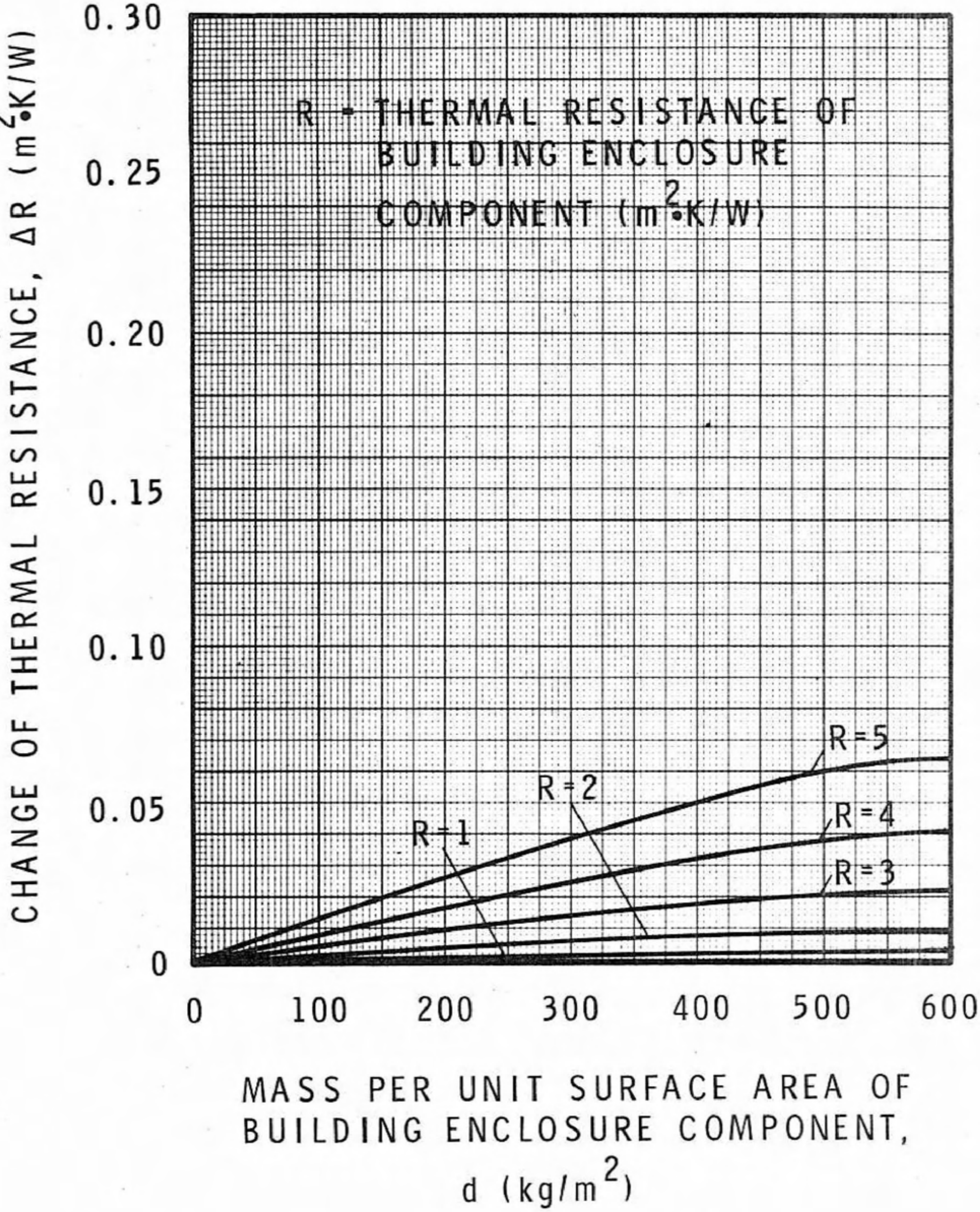


FIGURE 1

RELATION BETWEEN THERMAL RESISTANCE AND MASS OF BUILDING ENCLOSURE COMPONENT

MASS LAYER ON THE OUTSIDE OF INSULATING LAYER

TYPE OF ENCLOSURE: ENCLOSURE FOR BUILDINGS WITH LOW ENERGY REQUIREMENTS FOR LIGHTING, FANS AND PUMPS

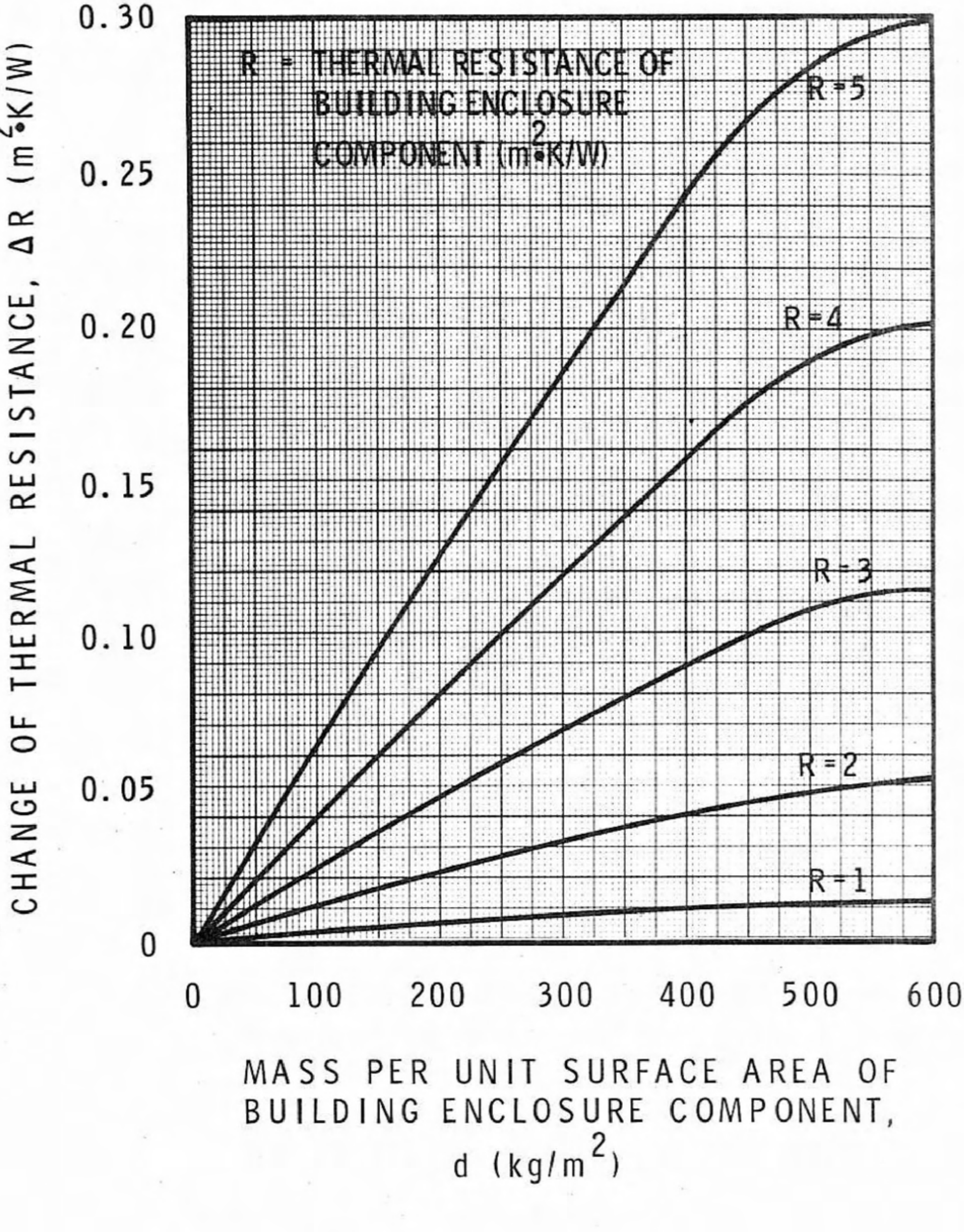


FIGURE 2

RELATION BETWEEN THERMAL RESISTANCE AND MASS OF BUILDING ENCLOSURE COMPONENT

MASS LAYER ON THE OUTSIDE OF INSULATING LAYER

TYPE OF ENCLOSURE: ENCLOSURE FOR BUILDINGS WITH HIGH ENERGY REQUIREMENTS FOR LIGHTING, FANS AND PUMPS

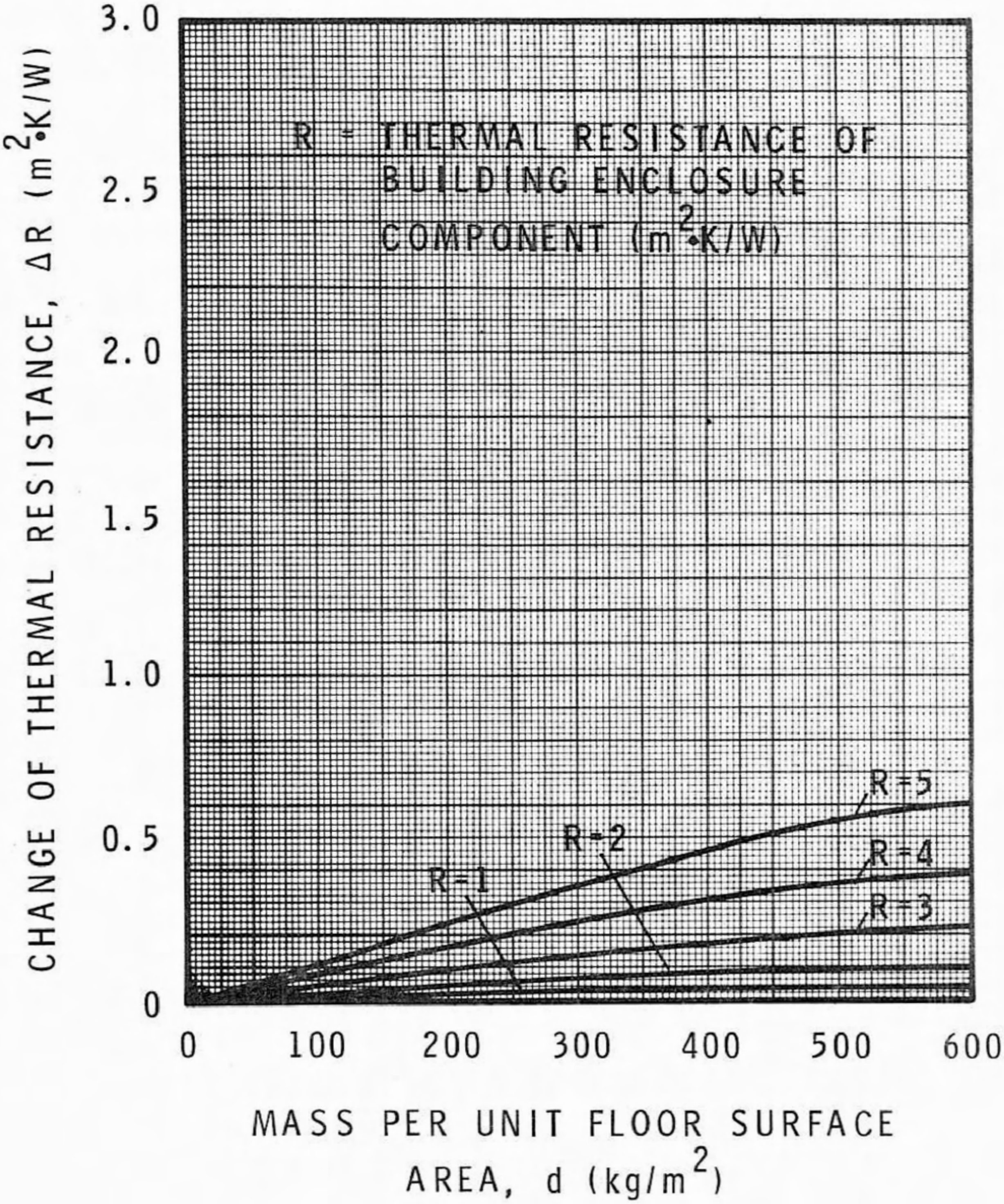


FIGURE 3

RELATION BETWEEN THERMAL RESISTANCE AND MASS OF BUILDING ENCLOSURE COMPONENT

MASS LAYER IN DIRECT CONTACT WITH INTERIOR SPACE AIR

TYPE OF ENCLOSURE: ENCLOSURE FOR BUILDINGS WITH LOW ENERGY REQUIREMENTS FOR LIGHTING, FANS AND PUMPS (SINGLE FAMILY RESIDENCE)

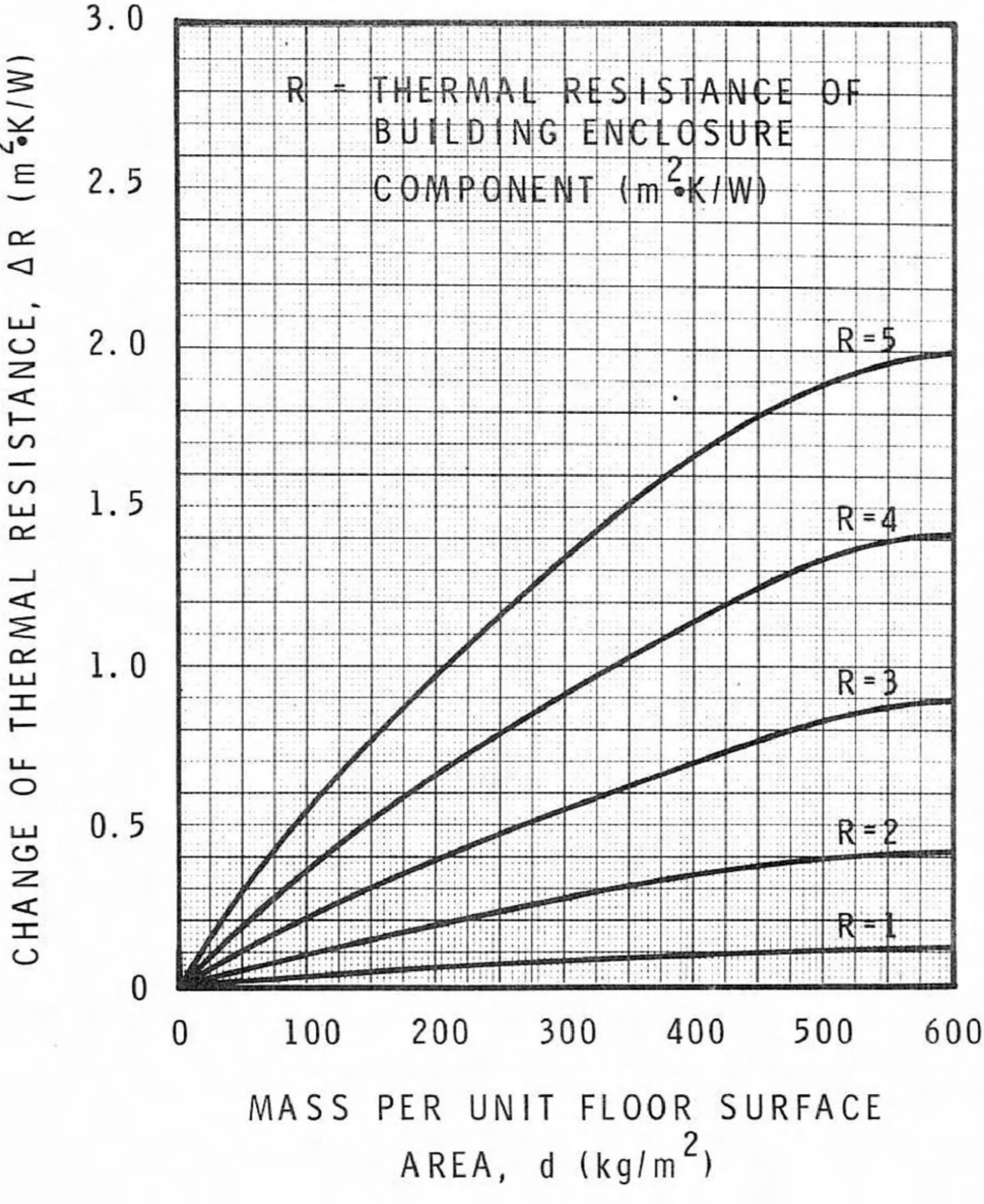


FIGURE 4

RELATION BETWEEN THERMAL RESISTANCE AND MASS OF BUILDING ENCLOSURE COMPONENT

MASS LAYER IN DIRECT CONTACT WITH INTERIOR SPACE AIR

TYPE OF ENCLOSURE: ENCLOSURE FOR BUILDINGS WITH HIGH ENERGY REQUIREMENTS FOR LIGHTING, FANS AND PUMPS (LARGE OFFICE BUILDING)