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BUILDING RESEARCH TRANSLATION

Thermal Comfort Requirement Adjacent to Cold Walls — Application to Glazed Opening

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Part of the Center for Radiation Research.
[3] Located at Boulder, Colorado 80302.

BUILDING RESEARCH TRANSLATION

Thermal Comfort Requirement Adjacent to Cold Walls— Application to Glazed Opening

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FOREWORD

The United States/French Cooperative Program on Building Technology entails an exchange of personnel between the National Bureau of Standards (Building Research Division) and the Centre Scientifique et Technique du Bâtiment (CSTB) of France. The program also involves the exchange of information between the two research organizations.

It is felt that some of the documented information can be usefully shared with the U.S. building industry; and, therefore, certain papers were selected for reproduction in media on sale to the public by the Government Printing Office. It should be understood that the CSTB documents made public through such media as this TECHNICAL NOTE do not necessarily represent the views of the National Bureau of Standards on either policy or technical levels.

At the same time, building researchers at the National Bureau of Standards consider it a public service to share with the U.S. building industry certain insights into French building technology.

James R. Wright

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THERMAL COMFORT REQUIREMENT ADJACENT TO COLD WALLS-

Application to Glazed Openings

by

J. Anquez and M. Croiset

This paper is translated from the French original and is published under the Building Research Division/ Centre Scientifique et Technique du Bâtiment information exchange program.

The thermal comfort of an individual inside a closed room in winter is essentially a function of the temperature of the air with which the human body transfers heat by convection, and also of the temperature of the room's walls with which the human body transfers heat by radiation. The presence of glazed openings (windows) which in winter are generally the coldest walls in a residence room, can thus be a source of discomfort.

The first part of the paper reports research conducted with a view to determining the thermal comfort requirement near to a cold wall. The research led to the definition of the "air-radiation requirement" for a plane surface element parallel to the wall, the requirement being that, at about 1 m from the wall, this temperature must remain above 16 or 17°C.

The second part of the paper studies ways of satisfying the requirement near to glazed openings in a living room in winter. The solution to the problem will depend on numerous factors: climatic zone, average temperature of the room, position of heat sources, dimensions of the openings, type of glazing (single or double), presence or absence of curtains or screens.

Key words: Curtains, effect of; environmental conditions; glazed openings; human response; thermal comfort requirement.

PART I: DEFINITION OF THE REQUIREMENT

1.1 METHOD EMPLOYED

Method Concept, Test Equipment and Facilities

In order to understand and define the requirement, subjects were placed close to cold walls under known conditions and their responses as to sensations of comfort or discomfort were noted.

The test facility utilized is depicted in Figure 1. It had three rooms:

A. The first room simulated the cold outside atmosphere. An approximate temperature of $0^{\circ}C$ was maintained in this room.

B. The second room simulated a residence room with an outside vertical wall. This wall separated room B from room A. It contained a glazed opening consisting of a single pane of glass covering an area of 2.7 m^2. The remainder of the wall had a K coefficient (coefficient of heat transmission) of 2.6 $kcal/m^2h^{\circ}C$.[1/]

C. The third room simulated a residence room without an outside wall.

Tests were conducted in room B where the subject remained for 10 minutes before being questioned. Room C served as a transition or waiting room in which the subject remained for 30 minutes before entering room B.

[1/] 1 $kcal/m^2h^{\circ}C$ = 0.2048 $Btu/ft^2h^{\circ}F$

Test Environmental Conditions

The environmental conditions maintained in room B for the tests were as follows:

1. Heating was either by radiator or by floor and ceiling (embedded pipe coils).

With floor and ceiling heating, the temperature of the floor was not above 24°C and the ceiling temperature did not exceed 27°C. They were therefore well within comfort limits.

For heating by radiator, the latter was installed in the position indicated by the letter *ℓ* in Figure 1. Screens were arranged in such a way as to virtually eliminate all radiation transfers between radiator and subject, and also between radiator and walls. In this way, heating was almost exclusively by convection.

2. Heating was controlled so as to obtain a temperature measured by "bulb thermometer"[2/] (globe temperature) of approximately 18, 20, or 22°C at a height of one meter in the center of the room.

3. Ventilation air flow was 40 m^3/h.[3/] This means that the air-change rate was essentially equal to one. Air from cold room A was delivered into room B through either a series of openings distributed alongside the ceiling (when heating was by floor and ceiling), or through an elongated, deflector-equipped opening behind the radiator (when a radiator provided the heating). In this way, all likelihood of discomfort due to cold-air drafts was eliminated (see the study on this subject, listed as item *a* in the Bibliography). Air velocity in the zone occupied by the subjects was below 0.15m/s.

[2/] Translation note: bulb thermometer is used for globe thermometer

[3/] 1 m^3/h = 35.3 ft^3/h

4. Humidity of the air was not controlled. But ventilation air came from a cold room in which, therefore, there was little variation in absolute humidity, and furthermore, occupancy conditions were almost always the same. Therefore, relative humidity in room B varied little. It fluctuated between 30 and 45 per cent.

5. The walls, floor and ceiling of the room, other than the exterior wall (between room B and A) and those surfaces possibly used for heating purposes, were either inside walls (between room B and C), or very highly insulated outside walls (K coefficient was of the order of 0.2 kcal/$m^2h°C$). Surface temperatures of all these outside walls thus differed less than half a degree from the normal temperatures of the inside walls.

Temperature, humidity, and average air velocity in room C were identical to those in room B. A radiator provided the heating. In this room also, screens eliminated radiation transfers from the radiator. There was no cold wall nor warm wall. All walls were inside walls or heavily insulated as above for room B.

Test Conditions Relative to the Subjects

As we stated above, the subjects initially stayed in room C for 30 minutes, and then spent 10 minutes in room B. We did verify with 10 subjects during a small number of experiments, that this was sufficient time, since sensations after 10 minutes and after 30 minutes were practically the same. This conclusion is of course valid only within the temperature and humidity range of our experiments. But this range corresponds well enough to average indoor conditions in France during cold-weather periods. The subject was seated when in either room C or B. In room B, the subject sat in the axis of the cold wall and either faced that wall or had his back to it. The distance to the cold wall, measured from the vertical axis of the chair, was 3.30 m, 2.00 m, 1.00 m, or 0.50 m.

Tests were conducted on five subjects, one man and four women, all CSTB staff personnel: a 30-year old male technician (subject A), a 40-year old cafeteria worker (subject B), and three secretaries ranging in age from 20 to 25 years (subjects C, D, and E). Subjects wore their customary indoor clothing.

Recapitulation of Study Parameters and Number of Tests

Study parameters were as follows:

--type of heating: floor and ceiling or by convection.

--average ambient temperatures: 18, 20, or 22°C.

--distance to cold wall: 3.30 m, 2.00 m, 1.00 m or 0.50 m.

--position of subject: facing the cold wall or with back to it.

--subject: A, B, C, D, or E.

If we had used all parameter values we would have had to conduct 2 x 3 x 4 x 2 x 5 = 240 tests. Actually, because subjects were not always readily available, there were some gaps. On the other hand, we often had to start the tests with convection heating over again, We did finally complete a total of 248 tests.

Physical Magnitudes Measured to Characterize the Environment. "Air-Radiation Temperature for a Surface Element."

We did not question the validity of the fact that the sensation of thermal comfort depends exclusively on the dry-bulb temperature of the air and the radiant temperature under the following conditions: a heated room in winter, with still air and an approximately uniform humidity. This principle allows the environment to be characterized by a single temperature generally called "resultant dry temperature" and measured in still air with a "bulb thermometer."

But this procedure appears a priori to be unsatisfactory for our problem. In fact, we observed that the discomfort experienced by the subjects--when there actually was discomfort--resulted from sensations of cold localized on parts of the body (knees, back...) turned toward the cold wall. Consequently, we thought that the globe temperature which uniformly records transfers on all sides of the body, was doubtlessly poorly suited to the problem. We thus devised a method of measurement using a "plane thermometer" to record heat transfers on only one side of the body, the side turned towards the cold wall. This plane thermometer consists of a 20 cm-thick, 0.80 m by 0.40 m block of good thermal insulating material (λ = 0.032 kcal/m.h°C) whose surface temperature is measured by a thermocouple. This block was placed on a chair (see Figure 2) so that it stood vertically on end and was parallel to the cold wall. Temperature was measured in the vertical axis of the block 0.25 m from its top. This was tantamount to a height of 1.00 m above the floor. Measurement was taken without the subject being present, but under the same conditions, and with the chair in the same place.

We shall explain the significance of this measurement in detail by means of a calculation. The heat loss from a surface element of the human body at temperature θ, due to transfers by convection with the air at temperature t_a, and by radiation with the cold walls, with a radiant temperature of θ_r, is represented by the following equation (per surface unit):

$$Q = \alpha_c (\theta - t_a) + \alpha_r (\theta - \theta_r)$$

where α_c and α_r are the coefficients of heat transfer by convection and radiation, respectively. This equation may be written:

$$Q = (\alpha_c + \alpha_r) \left[\theta - \frac{\alpha_c t_a + \alpha_r \theta_r}{\alpha_c + \alpha_r} \right]$$

The ratio $(\alpha_c t_a + \alpha_r \theta_r)/(\alpha_c + \alpha_r)$ is an air-radiation temperature. We shall call it "air-radiation temperature for a surface element" and represent it by the symbol t_{are} (air-radiation temperature of an element).

For the plane thermometer described above, the transfer equation remains the same, but since no heat whatever is produced in the block and that in practice this block is highly insulated on its rear surface (its thermal resistance is of the order of 6.0 $m^2h°C/kcal$), Q is null and θ is equal to t_{are}. Therefore the measurement of θ gives the value of t_{are} This equivalence is approximate, however, for the following reasons:

1. First of all, it assumes that discomfort is due to a cold sensation received on a body surface that is plane and parallel to the cold wall. Of course, it was noted that discomfort originated essentially from the cold sensation felt on the knees when the subject was facing the glazed opening, and on the back in the opposite case. These are indeed sufaces facing the cold wall, but they are neither plane, nor, consequently, parallel to that wall.

2. It then assumes that the body surfaces to be taken into consideration for heat transfers by convection and radiation, are the same. This is almost true where the knees and back are concerned because there

the clothing lies quite flat against the body. But on other parts of the body convection is greater because of the air circulating between the body and the clothing. Moreover, that is probably the reason why discomfort due to the cold wall is experienced to a lesser degree on those parts.

3. It also assumes that the ratio α_c/α_r is the same for the body and the plane thermometer. Since α_r is about constant (of the order of 4.2 kcal/m^{2}h°C), α_c must be held constant. This point--a critical one--is discussed in the appendix to this paper, where it is shown that the result depends particularly on the distance from the measuring point to the top of the block, and that the correct distance is approximately 0.25 m (α is then of the order of 3 kcal/m^{2}h°C). It was this distance that was retained.

4. And it also assumes that replacing the subject by a block does not alter the air-temperature field in the room. It appears that this is actually the case, to at least within half a degree.

5. Lastly, it assumes that there is little variation between the value of the air-radiation temperature in the vertical axis of the chair one meter above the floor, and its value at the exact point where the discomfort is felt. Although such is nearly the case when that point is the subject's back, it is no longer so when the knees or legs are the point of discomfort.

Finally, the measurement made with the plane thermometer can be considered as only the measurement of an index (indication) whose validity can only be allowed or nullified a posteriori. Results--discussed in a subsequent chapter of this paper--proved the retained index's value. In this connection, it should be noted that the problem is the same when an environment is characterized by a temperature measured with a bulb thermometer.

In addition to the plane thermometer measurement (t_{are}), a measurement of the air temperature (t_a) and a bulb-thermometer measurement (t_b) were made for each test at the same point.

Questions Asked the Subjects

At the end of a ten-minute stay in room B the subject was asked the following questions:

--Is the environment thermally comfortable? The subject answered yes or no.

--In the case of a negative response: Is it too cold or too warm for you, and what part of your body feels cold or warm?

Attempts to have the subject specify whether he or she felt slightly cold, cold, or very cold, were abandoned.

1.2 RESULTS

Presentation of Results

A compilation of the results is given in Tables I, II, and III. These tables are for tests conducted at 22°, 20°, and 18°C (average ambient temperatures), respectively.

To facilitate evaluation of the results, they are not presented in the order in which obtained.

Actually, in practice, each subject generally underwent four successive tests with the same type of heating (floor and ceiling or convective), in the same position with respect to the glazed opening (facing it or back to it), and at four distances from that opening (3.30 m, 2.00 m, 1.00 m, and 0.50 m). At times, even eight successive tests were made on the same subject, by varying, first the distance to the glazed opening, then the subject's position (facing the glass or back to it). Of course, as stated above, the subject remained in room C for 30 minutes between two successive tests.

But in order to have the relation between the values of t_b or t_{are} and the comfort reactions of the subjects show up better when tabulated we have grouped when possible (and regardless of the subject), the results obtained at the same distance from the glazed opening, and thus for about the same values of t_b and t_{are}.

Comment on Results

The following comment can be made upon examining Tables I, II, and III:

1. Remarks about the temperatures.

The air temperature (t_a) was almost uniform throughout room B. With floor and ceiling heating, it was below the bulb temperature in the center of the room. With convective heating, it was above that temperature in the center of the room. In both cases the difference was of the order of one degree. The bulb temperature (t_b) decreased in the vicinity of the cold wall. The same was true, but to a greater extent, for the temperature measured with the plane thermometer facing the cold wall (t_{are}).

Variations in these different temperatures as a function of distance to the cold wall are shown in Figures 3a and b for tests conducted at 20°C with floor and panel heating and with heating by convection, respectively.

2. Remarks about comfort responses of the subjects.

As we have already mentioned, whenever the subjects reported feeling cold in one part of the body, it was generally in the knees or legs when in the face-to-the-wall position, and in the back when in the other position. This proves that discomfort sensations do in fact result from the radiation of the cold wall. However in a few tests at 18°C the subject was unable to specify where he felt cold. The discomfort in that instance perhaps resulted from a general impression of cold. In some of the tests conducted at 22°C, one subject declared he experienced a sensation of warmth.

Comparison between Temperatures and Responses of Subjects: Adoption of t_{are} as Criterion of Comfort.

An analysis of the results reveals that there was on the whole little dispersion in the comfort responses of the different subjects and also in the aggregate of the comfort responses when the subject faced the cold wall or turned his or her back to it. This being the case, we then determined the proportion of discomfort responses as a function solely of the following parameters:

--average ambient temperature (22, 20, or 18°C,

--type of heating (floor and ceiling or by convection), and

--distance to the cold wall (3.30 m, 2.00 m, 1.00 m, or 0.50 m).

We therefore did not take the other two parameters into account:

--the subject (A, B, C, D, or E), and

--the position of the subject (facing wall or back to it).

The figures obtained in this manner were grouped in Table IV. Listed opposite the proportions of discomfort cases are the average values of t_b and t_{are} measured during the corresponding tests. The discomfort cases involving a sensation of excessive heat were not retained. Examination of this table reveals that there is a rather good correspondence between the discomfort cases and the values of t_b on the one hand, and those of t_{are} on the other, whatever the average ambient temperature, the type of heating, and the distance to the cold wall. This fact is highlighted by the graphs of Figure 4a and 4b. Study of Figures 4a and 4b shows that the correspondence between the proportion of discomfort cases and temperatures t_b or t_{are} is more precise with t_{are} than with t_b. As a consequence we adopted t_{are} as sole criterion.

<u>Choice of Threshold. Formal Definition of the Requirement</u>.

As often happens in matters of thermal requirement, there is no absolute threshold for the problem considered herein, inasmuch as the choice of threshold is in part a function of economic considerations. Therefore in this instance we do not claim to be setting a definite requirement, we are simply making a proposal.

We consider it reasonable to accept a percentage of discomfort cases of the order of 20 per cent, which is tantamount to fixing 16 to 17°C as the minimum admissible values of t_{are}. To be complete, the formal definition of the requirement must indicate the minimum distance to the cold wall from which comfort is desired. We view it as reasonable to allow a distance of the order of one meter. Since discomfort is experienced only if a person remains at rest (immobile) for a certain time, the adoption of such a distance does not in fact appear restrictive.

PART II: HOW TO SATISFY THE REQUIREMENT IN THE AREA ADJACENT TO GLAZED OPENINGS

With the requirement defined, we now propose to determine what should be done to satisfy that requirement in the vicinity of glazed openings, inside a room in a dwelling.

Problem parameters are as follows:

1. Outside temperature for which it is desired to satisfy the requirement.

2. Inside temperature (more specifically that temperature measured with a bulb thermometer in the center of the room one meter up from the floor) that is accepted as normal.

3. The following construction and equipment characteristics and elements:

--dimensions of the panes of glass,

--insulation of the panes of glass (single or double sheets),

--dimensions and insulation of outside opaque walls,

--presence of curtains,

--type of heating and specific location of heating units in the room.

The effects of most of these parameters can be studied by calculation. The only exceptions are the last two parameters. For them we had to resort to experimentation, and afterwards even to extrapolating by calculation the experimental results obtained. For this last reason we shall begin our account with the experimentation phase and then continue from there with the calculations.

2.1 PRELIMINARY EXPERIMENTAL STUDY OF THE EFFECTS OF THE TYPE OF HEATING AND OF PROTECTIVE CURTAINS OR DRAPES.

Conditions for the Experiment

For this experiment we used the same facility described in Part I and under the same conditions as for the requirement study, with the following differences:

1. When a radiator was used for heating it was employed either with screens, as stated in Part I, or without screens. In the latter case, the radiator was placed either under the glazed opening (position m in Figure 1), or against the opposite wall (position n). In both cases it was parallel to the opening and in its axis.

2. The glass was sometimes protected by curtains or by drapes. Those used were made of cotton cloth of $58 g/m^2$ weight. They were hung 4 cm from the pane of glass.

3. The intended average inside temperature (temperature measured with a bulb thermometer, in the center of the room at a height of one meter) was always 20°C. And the intended outside temperature was always 0°C. As a matter of fact, it was not always possible to obtain exactly 20°C and 0°C. When they could not be obtained, results were corrected to re-establish these conditions, by the method of computation which is described in a subsequent part of this paper.

<u>Effect of the Type of Heating. Improvement Produced by a Radiator Set against the Wall below the Glazed Opening</u>.

Figures 5a to 5d present variations in t_b and t_{are} as a function of the distance to the glazed opening for the following four heating situations:

--Figure 5a: floor and ceiling heating,

--Figure 5b: heating by convection (radiator with screens, in position ℓ),

--Figure 5c: heating by radiator set against the wall below the glazed opening (radiator without screen, in position m)

--Figure 5d: heating by radiator placed against the wall opposite the glazed opening (radiator without screen, position n).

For the moment we will examine only those solid-line curves plotted for the case where the glass was not protected by drapes or curtains.

The four heating modes are classified as follows in order of increasing comfort (increasing values of t_{are} one meter from the opening):

1. Heating by a radiator set against the wall opposite the opening, $t_{are} = 14.3°C$.

2. Heating by floor and ceiling, $t_{are} = 14.9°$.

3. Heating by convection, $t_{are} = 15.9°C$.

4. Heating by radiator set against the wall below the glazed opening, $t_{are} = 17.7°C$.

The results are accounted for as follows:

Heating by a radiator set against the wall below the opening gave decidedly better results than the other heating modes owing to the fact that the warm radiation of the radiator partially compensated for the cold radiation of the window opening. That is the sole reason, for because of the position of the air inlet above the radiator, the glass was not any warmer than with the other heating modes.

Heating by floor and ceiling was less effective than by heating by convection, for the following reason: for a same value of t_b in the center of the room, the air temperature with floor and ceiling heating was approximately two degrees below that with convection heating. Radiant temperature, for the bulb thermometer, was on the other hand approximately two degrees higher in the case of floor and ceiling heating. But for the plane thermometer which measures t_{are} , although there was still two degrees of difference in the air temperature, the same was not true for the two degrees of difference in radiant temperature. Actually the plane thermometer, which is in a vertical position, "sees" the warm floor and ceiling less than the bulb thermometer, especially in the area adjacent to the cold wall.

Heating with the radiator placed against the wall opposite the glazed opening gave the poorest result. This is due in large part to a certain air-temperature gradient in the room and to a lesser temperature of the glass, this second reason being a consequence of the first.

But perhaps we should somewhat qualify what we have just said. We have admitted that the same bulb temperature prevailed in the center of the room, thus that the air temperature was variable, with a variation on the order of two degrees. Yet everyday experience seems to show that such variations are rare: about the same air temperature is required with floor heating as with radiator heating. Perhaps this is due to the fact that the bulb thermometer ignores air movements between skin and clothing. For closer air temperatures, there would practically no longer be any difference between heating by convection and heating by floor and ceiling. On the other hand, heating by a radiator set against the wall below the glazed opening would remain decidedly better (value of t_{are} at one meter from the opening, about two degrees higher), and heating by a radiator set against the wall opposite the glazed opening would become rather sharply, less satisfactory (value of t_{are} one meter from the opening, approximately one degree lower).

We made no measurements for other radiator locations, but an approximate calculation seems to indicate that no distinctly better result can be expected than that obtained with floor and ceiling heating or with convective heating, unless the radiator is positioned against the cold wall or not far from it.

And lastly, we should like to add that the method of room ventilation would have a certain effect and that our results are valid only for the ventilation method we used.

Effect of Curtains and Drapes

The values of t_{are} obtained with drapes or curtains over the glazed opening are depicted by dotted line in Figures 5a, 5c and 5d. This measurement was not made with convection heating. The values of t_b are not shown. In the center of the room these values are the same as without any drapes, within less than half a degree.

The gain in t_{are} at one meter from the opening is nearly the same for the three cases studied. It was approximately one degree. Drapes or curtains are consequently less effective than the radiator set against the wall below the opening for which the gain was close to two degrees.

It was verified that, except for the case of the radiator set against the wall below the opening, this result was practically independent of the interval between the drape and the glass, at least for distances of from 2 to 10 cm. With the radiator set against the wall below the opening, moving the drape away from the pane of glass enhanced the result. The reason for this is that the warm air rising from the radiator more easily enters behind the drape and heats it. Obviously this increases heat losses, but we did not measure to what extent.

2.2 GENERAL STUDY BY CALCULATION. INFLUENCE OF VARIOUS PARAMETERS.

Calculation Principle. Equation for t_{are}.

In Part I we saw that temperature t_{are} was expressed by the equation:

$$t_{are} = \frac{\alpha_c \, t_a + \alpha_r \, \theta_r}{\alpha_c + \alpha_r}$$

where t_a = air temperature

θ = radiant temperature

α_c = coefficient of convection

α_r = coefficient of radiation

The radiant temperature is equal to the average of the temperatures of the walls, floor, and ceiling of the room, with each of these temperatures being "affected" by the "form (geometry) factor" under which it is "seen" by the surface element of the body (or plane thermometer). Calculation of this form factor will be done under the following assumptions:

1. The outside wall(s) include glazed parts and opaque parts, both having uniform temperatures, which we represent by θ_v and θ_o, respectively. This assumption is altogether valid when there is only one outside wall. And we shall see further on that the conclusions reached in this case are generally valid when there are several outside walls.

2. The inside walls, floor and ceiling, have a uniform temperature which we represent by θ_i. Obviously this assumption is false when the room is heated by the ceiling and floor. But at least in the vicinity of the glazed opening--the only point in the room that concerns us--the angle under which the plane thermometer sees the floor and ceiling is so small that the assumption can be allowed with sufficient approximation.

3. The heating units cause no perceptible radiation. This is still true for the plane thermometer near the glazed opening, as long as there is no heating unit against the cold wall. Calculations will be made only in this case.

This being so, let f_i, f_v, and f_o be the form factors for each series of walls defined above: inside walls, glazed outside wall, opaque outside wall. We have

$$\theta_r = f_i \theta_i + f_v \theta_v + f_o \theta_o$$

Furthermore:

$$f_i + f_v + f_o = 1$$

The expression t_{are} may thus be written as:

$$t_{are} = \frac{\alpha_c t_a + \alpha_r [(1 - f_v - f_o) \theta_i + f_v \theta_v + f_o \theta_o]}{\alpha_c + \alpha_r}$$

or again:

$$t_{are} = \frac{\alpha_c t_a + \alpha_r \theta_i}{\alpha_c + \alpha_r} - \frac{\alpha_r}{\alpha_c + \alpha_r} [f_v (\theta_i - \theta_v) + f_o (\theta_i - \theta_v)]$$

The first term of the expression of t_{are} is, approximatively, the resultant dry temperature in the center of the room which we shall henceforth designate by t_i:

The temperature differences $(\theta_i - \theta_v)$ and $(\theta_i - \theta_o)$ are, as a first approximation, proportional to $(t_i - t_e)$, where t_e is the outside temperature; the proportionality coefficients, which we will represent by the letters μ_v and μ_o, are wall characteristics. We thus have

$$t_{are} = t_i - \frac{\alpha_r}{\alpha_c + \alpha_r} (f_v \mu_v + f_o \mu_o)(t_i - t_e)$$

By replacing α_r and α_c with their values 4, 2, and 3 kcal/$m^2 h^\circ C$, we finally obtain

$$\boxed{t_{are} = t_i - 0.6 (f_v \mu_v + f_o \mu_o) (t_i - t_e)}$$

Value of the Parameters.

We shall see what the values of the various parameters of the equation giving t_{are}, may be, and retain a few of these values for a subsequent calculation.

1. Inside temperature t_i

In a dwelling that is heated normally, t_i--approximately the temperature measured with a bulb thermometer in the center of the room at a height of one meter--varies between 19 and 22°C. We shall calculate for 19, 20, 21, and 22°C.

2. Outside temperature t_e

The choice of the outside temperature is first of all a function of the location in which the dwelling is constructed. However, given the rather appreciable relativity of the problem being studied--there is no need to be as rigorous as for computations of heating capacity, for example--we deem it sufficient to limit ourselves to a breakdown of three climatic zones as defined in the CSTB technical report for implementation of the regulation on construction. However we do divide zone A into two parts, one for altitudes of above 800 meters the other part for altitudes of below 800 meters. In selecting the temperature for each of the three zones we will take the following considerations into account:

a. During the coldest hours, generally occurring at night, shutters and/or curtains are closed and the cold-wall effect problem is thereby resolved. Consequently the temperature taken into account should not be the daily minimum, but rather the daily average.

b. In view of the rather large relativity of the problem, a certain number of extreme days may be disregarded. We consider it reasonable to ignore at least five days per year (on an average). Moreover, we feel that it may not be unreasonable to extend this figure to 15 days.

That being so, for a certain number of localities in each zone, we have determined the lowest average daily temperatures observed 5 and 15 days per year on the average. We obtained the following values per zone on an average:

	Lowest average daily temperature observed on an average of:	
	Five Days Per Year	Fifteen Days Per Year
Zone A above 800 m	-12	-8
Zone A under 800 m	-8	-4
Zone B	-4	0
Zone C	0	+4

The above values are those we will use in our calculations.

3. Form factors f_v and f_o.

We should remember that the form factor represents in a sort of way the angle under which the plane thermometer "sees" the wall under consideration.

In a standard residence room, when the opaque walls are correctly insulated, the cold-wall effect arises essentially from the glazed openings, in other words product $f_v \mu_v$ predominates over product $f_o \mu_o$. So factor f_v is the one that mainly interests us. That may not be exact, however, for a room having many outside walls like a gabled room under the roof. This special case will be examined later. For the moment we will consider a room having only one outside wall with only one glazed opening centered on that wall.

We shall calculate for three categories of glazed openings. We shall call these categories "small," "rather large," and "very large." They are illustrated in Figure 6. In each category we have depicted two openings, each with the same form factor, but with windows of different heights. It is noted that the less the height of the windows the less the area of the opening. Those openings in which width exceeds height are more propitious for our problem than those in which height exceeds width.

In the interest of realism, whenever the opening was larger, we sketched the overall wall proportionately larger.

The corresponding values of form factors f_v and f_o (always in the axis of the opening and one meter above the floor), computed by means of the graph at Figure 7 are:

	Small Opening		Rather Large Opening		Very Large Opening	
	f_v	f_o	f_v	f_o	f_v	f_o
at one meter from the opening	0.26	0.40	0.42	0.32	0.60	0.14
at 1.50 meter	0.20	0.38	0.36	0.26	0.50	0.12

In addition to the values at one meter from the opening, we present those at 1.50. We thought it would be interesting to know what the alleviation of the requirement corresponding to this further distance from the opening would entail.

4. The μ_v and μ_o coefficients.

Let us remember that for a wall whose surface temperature is θ,

$$\mu = \frac{t_i - \theta}{t_i - t_e}, \text{ and}$$

that for walls and panes of glass without inside curtains,

$$\mu = \frac{K}{h_i}$$

where K = coefficient of heat transmission of the wall

h_i = coefficient of inside surface heat transfer, equal to approximately 7kcal/m^2h^oC in the case of a vertical wall.

For single-sheet and double-sheet glass, with K coefficients equal to 5 and 3 kcal/m^2h^oC respectively, we obtain

μ_v = 0.71 for single-sheet glass

μ_v = 0.43 for double-sheet glass

The above equation is no longer applicable when the glass is covered by curtains. In such cases μ_v can no longer be determined by calculation. We must resort to other measures. That is what we did by using the results of the experiments described in paragraph 2.1. The procedure followed is outlined in the appendix to this paper. The values obtained for glass-wall areas with the drapes or curtains defined earlier are

μ_v = 0.51 for single-sheet glass

μ_v = 0.31 for double-sheet glass

In our calculations we shall use these values of μ_v, plus those calculated above for glass-wall areas without drapes or curtains.

As for the opaque parts of the outside wall, we shall still consider that coefficient K is equal to 1.2 kcal/m^{2}h$^{\circ}$C, for which the corresponding value of μ_o is 0.16.

Application of the Equation to an Average Case.

In actual conditions, the problem to be resolved is phrased as follows: in a given climatic zone, what size window is admissible for single-sheet glass, for double-sheet glass?

We shall calculate the solution to this problem by using the equation determined earlier, and by restricting ourselves to the case in which that equation is applicable, in other words, specifically by assuming that there is no heating unit set against the wall below the glazed opening. But even when we do this, the solution to the problem is still based on a certain number of conditions that we shall provisionally establish and call "average conditions." They are:

1. Outside temperature is equal to the lowest average daily temperature recorded on an average of five days per year. This temperature is -12° in Zone A at an altitude above 800 meters, -8°C in the rest of Zone A, -4°C in Zone B, and 0°C in Zone C.

2. Inside temperature is 21°C.

3. The glazed opening has drapes or curtains.

4. The distance from the opening at which comfort is desired is one meter.

Table V gives the values obtained under these conditions, for each climatic zone and for each category of opening defined earlier, with single-sheet glass and with double-sheet glass. In this table, and also on those that follow, the cases where t_{are} is below 16°C are highlighted by shading, and where t_{are} is between 16 and 17°C by dotted lines.

If we fix 17°C as the admissible minimum values of t_{are}, we see that single-sheet glass is never satisfactory in Zone A above 800 m altitude, that it is never satisfactory in the rest of Zone A except for small openings, that it is not satisfactory in Zone B for very large openings, and that it is always satisfactory in Zone C.

If we fix the admissible minimum value of t_{are} at 16°C instead of 17°C, single-sheet glass becomes always satisfactory in Zone B, and in Zone A below an altitude of 800 meters, it is insufficient only for very large openings. And we see that in Zone A above 800 meters it becomes satisfactory for the small openings.

Whatever admissible minimum value is established for t_{are}, the double-sheet glass is always satisfactory.

Before concluding, it is convenient to consider what occurs when the adapted conditions are modified.

Effects of a Modification of Conditions.

We shall examine, in turn, the effect of a modification made to each of the conditions defined in the preceding paragraph.

1. Inside temperature.

Table VI gives t_{are} values obtained with t_i of 19, 20, 21, and 22°C and with the other conditions being average conditions.

Since the variations of t_{are} are nearly equal to those of t_i, the effect of a variation in t_i is evidently highly significant.

At 19°C, single-sheet glazing is never completely satisfactory, even in Zone C. And double-sheet glass is frequently insufficient. Conversely at 22°C single-sheet glass is really insufficient only in Zone A above 800 meters with very large glazed openings.

2. Outside temperature.

We stated earlier that it was perhaps not unreasonable to accept that--in the problem being studied herein--the number of discomfort days reached a total of 15 per year.

As seen in Table VII, when instead of 5 discomfort days per year, we use 15 days, which corresponds to an increase of 4°C in t_e, t_{are} is thereby increased by a little more than half a degree. The conclusions are obviously modified thereby, but to a lesser extent than if we increased inside temperature by one degree.

3. Absence of drapes or curtains.

The "average conditions" assume that the glazed openings are protected by drapes or curtains, at least in cold weather. Table VIII shows what would result from an absence of such protection.

With single-sheet glass, t_{are} would be lessened by approximately 2°C, and with double-sheet glass, by a little more than one degree, at least for the most unfavorable cases. This is obviously significant and it would very often be probably preferable to close the drapes or curtains, rather than to raise the heat in the room by an additional one or two degrees.

It should be noted, however, that single-sheet glass with drapes or curtains is less effective than double-sheet glass.

4. Moving comfort "line" away from the opening.

Asking that comfort be provided at a distance of one meter from the glazed opening is perhaps a severe requirement. At a distance of 1.5 meters, the value of t_{are} for single-sheet glazing with drapes/curtains, is approximately one degree higher than that at a distance of one meter, as shown in Table IX, or equal to its value at one meter for an opening twice as small.

Thus by being satisfied with the comfort "line" at 1.50 meters from the opening instead of at one meter, it is possible, for an opening of any given size, to heat the room at one degree less, or for the same room heating to accept an opening that is twice as large.

Special Case of a Radiator Set against the Wall below the Glazed Opening.

The equation for t_{are} determined above is not valid when the radiator is set against the wall below the glazed opening. Moreover, calculation in this case is uncertain and we shall not attempt it. But we can extrapolate experimental results by assuming, as a first approximation, that the difference $t_i - t_{are}$ is, as in the general case, proportional to $t_i - t_e$ and furthermore, that it depends little upon the size of the opening because the size of the radiator is proportioned to the size of the opening.

Under these circumstances, the values of t_{are} for each of the climatic zones under "average" outside-temperature conditions are those given in Table X.

We see that when there are drapes or curtains, there is practically never any likelihood of discomfort, and that even without such protection, there is likelihood of discomfort only when the heating is mediocre (19°C).

Case of Several Glazed Openings or Several Outside Walls

Calculations in the case of several openings or several outside walls present no difficulties. We have calculated for a few such cases. The conclusions reached are approximately as follows, with the reasoning based as always on an equal "resultant dry-bulb temperature" in the center of the room.

1. When there is only one opening but several outside walls, the preceding conclusions remain valid.

2. When there are several openings very close together, the preceding conclusions are still valid, providing the group of openings are considered as a single opening.

3. When there are several openings quite separated from each other, the preceding conclusions are valid on condition that they are applied separately to each one of the openings.

2.3 CONCLUSION

The satisfaction given by an opening of certain dimensions and with certain types of installed glass panes, depends considerably upon the values accepted for the requirement, the outside factors and inside temperature, and whether or not the presence of drapes/curtains are considered.

We consider it reasonable to accept the following:

1. The requirement is that t_{are} must be at least 16/17°C one meter away from the opening.

2. Outside temperature is the average daily temperature recorded on an average of five days per year.

3. Inside temperature is 20-21°C, measured with a bulb thermometer in the center of the room at a height of one meter.

4. The glazed opening is covered by drapes or curtains in cold weather.

Under these conditions, we reach the following conclusions;

1. When there is a radiator of sufficient size set against the wall below the opening, there is no likelihood of discomfort or cold radiation.

2. When there is no radiator set against the wall below the opening or any other heating unit producing an equivalent effect, it seems reasonable to provide double-sheet glass as follows:

--in Zone A above 800 meters, regardless of the size of the opening,

--in the rest of Zone A, whenever the openings are rather large, i.e. of the order of 3 m^2,

--in Zone B, for very large openings, i.e. of the order of 6 m^2.

Whenever these specifications are not followed, it may at times be possible to avoid discomfort by heating better, thus in Zone B if heating is maintained at 22-23°C, there is never any need of double-pane glass.

And lastly, to get back to a point examined in Chapter 2.1, we should like to add that specifications must be made even more severe whenever the heating is particularly nonhomogeneous, for example when radiators are placed against partitions opposite outside walls.

As an overall conclusion it may be said that large glazed openings necessitate good heating, i.e. sufficient temperature, highly uniform temperature throughout the room, and, still better, heating units set against the wall below the glazed openings.

APPENDIX

1. COEFFICIENT OF HEAT TRANSFER BY CONVECTION

The problem is to have coefficient α_c be the same for the human body and for the plane thermometer. To accomplish this it is first of all necessary to know the value of α_c for the human body.

Knowing this value is not a simple matter. The value of α_c is not the same along all the body for various reasons: height above the floor, general geometric shape of the body, geometric shape of each part of the body... But when there is discomfort due to cold walls, it is localized in certain points: back, knees, and legs. This fact seems a priori to simplify the problem. But unfortunately it is practically impossible to determine the value of α_c on these parts of the body. Any measurements require use of a device or apparatus, and that equipment alters the heat transfer conditions.

Several investigators give α_c values. But either because they are for problems that differ from the one we are examining, or because they are rather questionable determinations, no specific value can be drawn from them. The best approach seems to be to refer to those experiments during which it has been possible to compare the relative value of transfers by convection and by radiation (Bibliography). By hypothesizing on the relation of transfer surfaces by convection and by radiation, since the coefficient of transfer by radiation is well known, the value of α_c may be deduced therefrom. In this manner, we find a value of the order of 3 kcal/m^2h^oC.[4/]

But we reiterate, the coefficient of convection α_c has quite different values depending on the various parts of the body. Consequently 3 kcal/m^2h^oC is only an order of magnitude, no more.

How can this value be obtained with the plane thermometer? Here, since the measurement of surface temperature is accurate, and that, moreover, all other elements of the problem can be calculated effectively (particularly the form factors pertaining to the various walls, of the room and to its floor and ceiling), α_c can be accurately determined.

Coefficient α_c is not the same over all the block. It is higher in its upper part than in its lower part, in the case that concerns us, that is to say when the temperature of the block is below that of the air. Coefficient α_c varies also with the temperature of the block; the more

[4/] See footnote 1, page 2.

the latter differs from the air temperature, i.e. the greater the cold radiations, the higher the coefficient α_c.

A few tests showed us that a value of 3 kcal/m^{2}h°C is obtained for a temperature differential between the air and the block, thus approximately between t_i and t_{are}, of the order of 3 to 4 °C, which corresponds to the requirement threshold, when the measurement is made at about 25 cm from the top of the block.

2. VALUES OF COEFFICIENT μ_v WHEN THE GLAZED OPENING HAS A DRAPE OR CURTAIN.

1. With single-sheet glass.

The value of coefficient μ_v is determined experimentally. But instead of directly measuring the temperature of the drape or curtain--a difficult operation for several reasons--we preferred the following procedure:

All things being equal, let t_{are} be the value of the temperature measured with the plane thermometer when the pane of glass has no curtain or drape, and t'_{are} the same temperature when the glass is protected by drapes or curtains. And let μ_v and μ'_v be the ooefficients corresponding to each of these cases. By applying the equation for t_{are} determined in the beginning of Chapter 2.2:

$$t'_{are} - t_{are} = 0.6\ (\mu_v - \mu'_v)\ f_v\ (t_i - t_e)$$

In this equation all terms are known except μ'_v which can therefore be calculated.

2. With double-sheet glass.

We calculated as follows:

Let t_i and t_e' be the outside temperatures leading to the same temperature of glass θ_v for a same inside temperature t_i (therefore also for a same drape/curtain temperature θ_{vo}'), on the one hand, for single-sheet glass with drapes or curtains, and on the other hand, for double-sheet glass also drapes or curtains. The flow leaving the room or area is then the same, i.e. we have

$$\frac{\theta_v - t_e}{1/h_e} = \frac{\theta_v - t_e'}{1/h_e + r}$$

where r = thermal resistance of double-sheet glass (thermal resistance of single-sheet glass is negligible).

Having measured θ_v for a given t_e during tests on single-sheet glass, and with h_e and r being known, we deduce t_e' therefrom.

If μ_V if the value of μ corresponding to single-sheet glass with drapes or curtains, and μ_V' the value for double-sheet glass with drapes or curtains, we have

$$\mu_v = \frac{t_i - \theta_{vo}}{t_i - t_e}$$

$$\text{and } \mu_v' = \frac{t_i - \theta_{vo}}{t_i - t_e'}$$

$$\text{therefore } \mu_v' = \mu_v \frac{t_i - t_e}{t_i - t_e'}$$

μ_v, t_i and t_e are known, t_e' has just been calculated, we thus deduce the value of μ_v' from it.

BIBLIOGRAPHY

a. Croiset, M. and Bizebard, H., Les entrées d'air de ventilation (Ventilation Air-Inlets), Cahier du CSTB Vol. 478, Issue 59.

b. Missenard, A., Mise au point sur les échanges thermiques entre le corps humain et l'ambiance (Restatement of the nature of heat transfers between the human body and its immediate environment), Industries Thermiques, No. 12, 1957.

c. Dupuy, R., Les tâches présentes du conditionnement climatique (Climate Condition's Current Tasks), Chaleur et Climate (Heat and Climate), No. 291.

d. Cours supérieur de chauffage, ventilation et conditionnement de l'air (Advanced Course in Heating, Ventilation, and Air Conditionning Tome 4, Miscellaneous supplementary data by A. Missenard , Tome 4.

e. Yaglou, C.P. and Houghten, F.C., Various articles and papers (see Bibliography, ASHRAE, Guide and Data Book, Section II, Chapter VII).

Conversion Factors

1 ft	= 0.305	m	= 30.48	cm		
1 m	= 39.4	in	= 3.28	ft	= 1. 1	yd
1 cm	= 0.39	in	= 0.033	ft	= 0.011	yd
1 m^2	= 10.8	ft^2	= 1.20	yd^2		
1 ft^2	= 0.09	m^2	= 0.11	yd^2		
1 yd^2	= 0.84	m^2	= 9.0	ft^2		
1 m^3	= 35.3	ft^3	= 1.31	yd^3		
1 yd^3	= 27.0	ft^3	= 0.76	m^3		

Pa	=	Pascal, Newton/m^2
1 Pa	=	0.00401474 in water gauge pressure
°C	=	(F -32)/1.8
1 kcal/m^2h°C	=	0.2048 Btu/ft^2h°F
1 m^3/h	=	35.3 ft^3/h

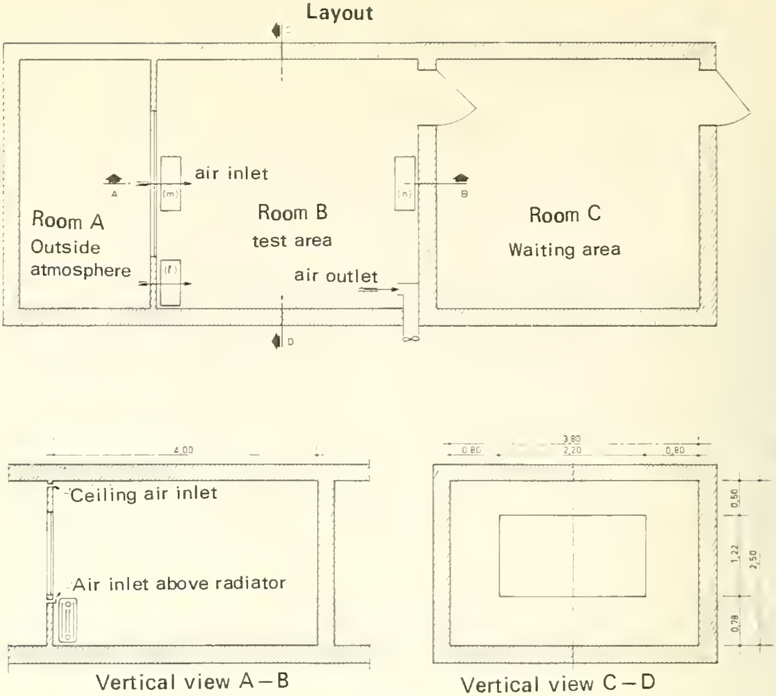


Figure 1. Test facility

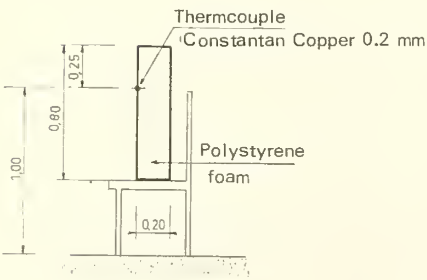
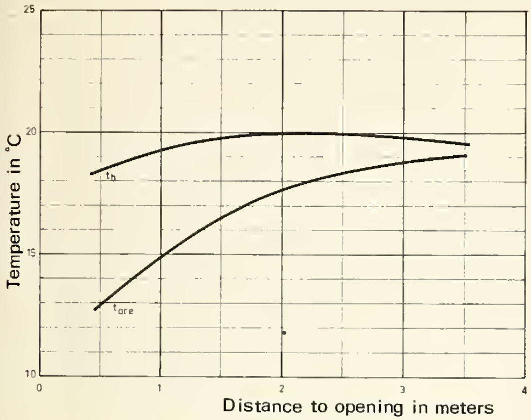


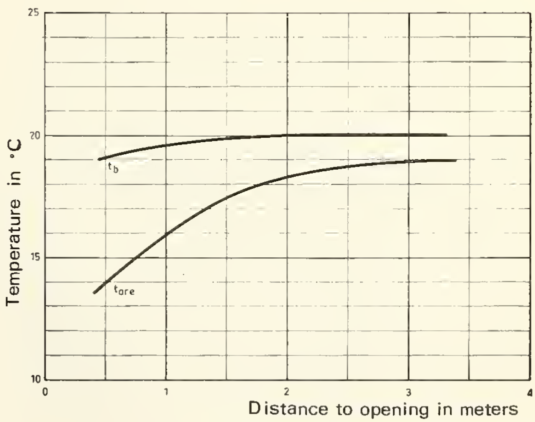
Figure 2.

Device for measuring air radiation temperature of a surface element

Figure 3. Variation of t_b and t_{are} as a function of distance to glazed opening



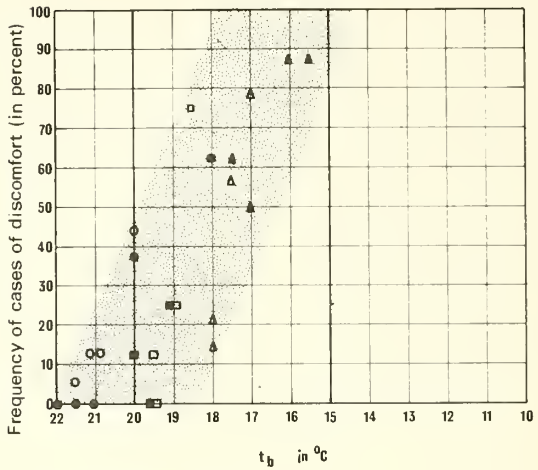
3 *a*) **With floor and ceiling heating**



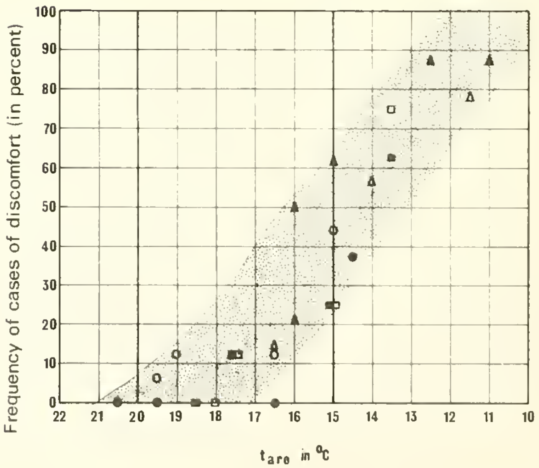
3 *b*) **With heating by convection**

Figure 4. Variation of the percentage of cases of discomfort

Test at :	22 °C	20 °C	18 °C
Floor and ceiling heating	●	■	▲
Heating by convection	○	□	△

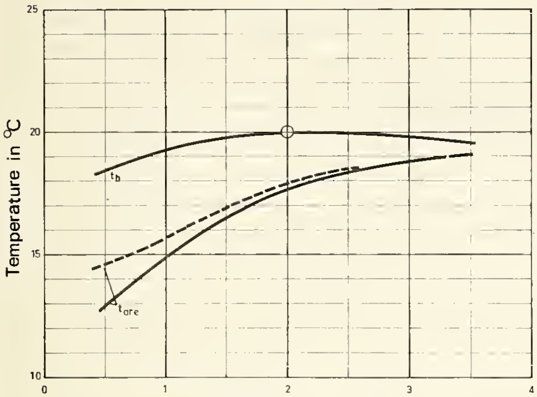


4 *a*) As a function of t_b



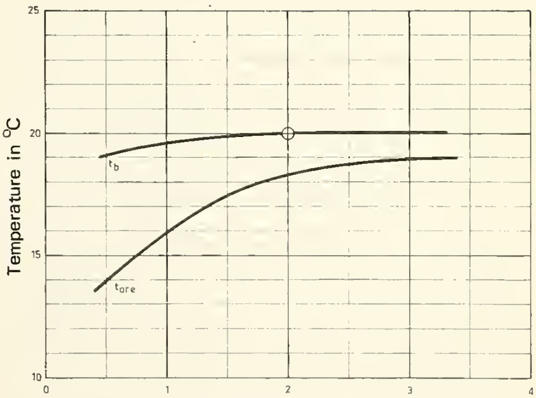
4 *b*) as a function of t,,,

Figure 5. Variation of t_b and t_{are} as a function of distance to glazed opening, with single glass, without drapes (———) and with drapes (– – – – –), for various types of heating



Distance to opening in meters

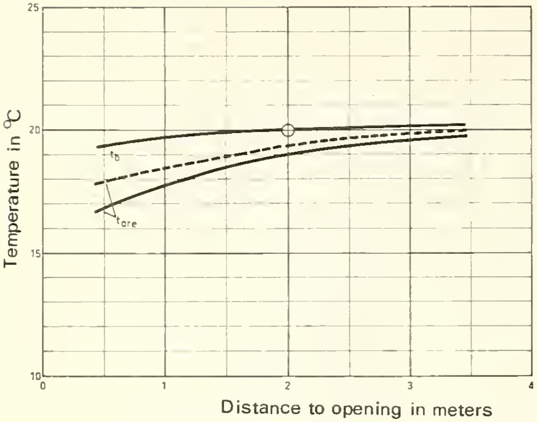
5 a) Floor and ceiling heating



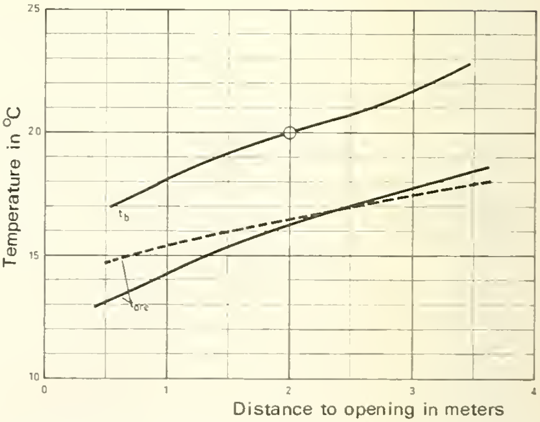
Distance to opening in meters

5 b) Heating by convection

Figure 5. (Cont'd)



5 c) Heating by radiator set against wall below glazed opening



5 d) Heating by radiator set against wall opposite glazed opening

Table I. **Results of tests at 22 °C (average ambient temperature)**

Room B

Type of heating	Distance to glazed opening (in m)	t_a	t_b	$t_{or.}$	Subject	Position of subject	Subject's comfort response
Floor and ceiling	3,30	20,5	21,5	21,0	A	Facing wall	O
		20,5	21,0	20,5	B		Ch
		20,0	21,0	20,0	C		O
		20,5	21,5	20,5	D		Ch
	2,00	21,0	22,0	19,5	A		O
		20,5	21,5	19,0	B		O
		20,0	20,0	19,0	C		O
		21,0	21,0	19,5	D		Ch
	1,00	20,5	21,0	16,5	A		O
		19,5	21,0	16,5	B		O
		19,5	20,5	16,0	C		O
		20,0	21,5	17,0	D		Ch
	0,50	21,0	20,5	15,0	A		O
		19,0	19,5	14,5	B		F
		18,5	19,5	14,0	C		O
		20,5	20,5	15,0	D		O
	3,30	20,5	21,5	20,5	A	back to wall	O
		20,5	21,5	21,0	B		O
		20,0	21,0	20,5	C		Ch
		21,0	22,0	21,0	D		O
	2,00	21,0	22,0	19,5	A		O
		21,0	22,0	19,5	B		O
		20,5	22,0	19,0	C		Ch
		21,5	22,5	19,5	D		O
	1,00	20,5	21,0	16,5	A		O
		20,5	20,5	16,0	B		O
		20,0	20,5	16,0	C		Ch
		21,0	21,5	17,0	D		O
	0,50	21,0	20,0	14,0	A		F
		20,5	19,5	14,0	B		F
		20,0	19,5	14,5	C		Ch
		21,0	20,0	14,5	D		O
Convection (1st series)	3,30	22,5	20,5	18,5	A	Facing wall	O
		22,5	22,5	20,0	B		Ch
		21,5	21,0	18,0	C		F
		24,5	21,5	19,5	D		O
		23,0	21,0	19,0	E		O
	2,00	24,5	20,5	18,0	A		O
		23,5	21,0	19,0	B		Ch
		23,5	20,5	18,5	C		F
		25,0	21,0	19,0	D		O
		24,0	21,0	18,5	E		O
	1,00	22,5	20,0	16,0	A		O
		23,5	21,0	17,0	B		O
		23,0	20,5	16,5	C		F
		24,5	21,0	17,0	D		O
		22,5	20,5	16,5	E		O
	0,50	22,5	19,5	14,5	A		F
		22,5	20,0	15,5	B		O
		23,5	19,5	15,0	C		F
		24,5	21,0	15,0	D		F
		23,5	20,0	15,5	E		O

Table I (conclusion)

Room B							
Type of heating	Distance to glazed opening (in m)	t_a	t_b	t_{are}	Subject	Position of subject	Subject's comfort response
	3,30	24,0	21,5	19,5	A	back to wall	O
		23,0	21,0	18,5	B		O
		23,0	21,0	18,5	C		O
		23,5	21,0	19,0	D		O
		23,5	21,5	19,5	E		O
	2,00	25,0	21,0	19,0	A		O
		24,0	20,5	18,5	B		O
		24,0	20,5	18,5	C		O
		24,5	21,0	18,5	D		F
		25,5	21,0	18,5	E		O
	1,00	23,5	21,0	16,5	A		O
		23,5	20,5	16,0	B		O
		22,5	20,0	16,0	C		O
		22,5	20,0	16,0	D		F
		23,5	21,0	16,5	E		O
	0,50	23,5	19,5	15,0	A		F
		23,5	20,0	14,0	B		F
		23,0	19,5	14,5	C		F
		23,5	20,0	14,5	D		F
		23,5	20,0	15,0	E		O
Convection (2nd series)	3,30	23,0	21,5	20,0	A	Facing wall	Ch
		22,5	21,5	19,5	B		O
		22,5	22,0	21,0	C		Ch
	2,00	23,0	21,5	19,5	A		Ch
		22,5	21,5	19,5	B		O
		23,0	22,0	20,0	C		Ch
	1,00	23,0	21,0	17,0	A		Ch
		22,5	20,5	16,5	B		O
		22,5	21,5	17,5	C		Ch
	0,50	22,5	21,0	15,5	A		O
		22,5	20,5	15,0	B		O
		22,0	21,0	15,5	C		O
	3,30	23,0	22,0	20,5	A	back to wall	O
		24,0	22,5	21,0	B		Ch
		22,0	21,5	20,0	C		O
	2,00	23,5	22,0	20,0	A		O
		24,0	22,5	20,5	B		O
		22,5	21,5	19,5	C		O
	1,00	23,0	21,5	17,0	A		O
		23,5	22,0	17,0	B		O
		22,0	21,5	16,5	C		Ch
	0,50	23,5	21,0	15,0	A		O
		24,0	21,5	15,0	B		O
		22,0	20,5	15,0	C		O

Temperature terms:

t_a : air temperature
t_b : bulb–thermometer temperature
t_{are} : plane–thermometer temperature

Response terms:

O : neither warm nor cold
Ch: sensation of warmth
F : sensation of cold

Table II: Results of tests at 20°C (average ambient temperature)

Room B

Type of Heating	Distance to glazed opening (in m)	t_a	t_b	t_{ars}	Subject	Position of subject	Subject's comfort response
floor and ceiling	3,30	18,0	19,0	18,5	A	facing wall	O
		19,5	20,0	19,0	B		O
		18,5	19,5	18,5	C		O
		19,0	20,0	19,0	D		O
	2,00	18,5	19,5	17,5	A		O
		19,0	20,0	18,0	B		O
		18,5	20,0	17,5	C		O
		19,5	20,5	18,0	D		F
	1,00	18,0	18,5	14,5	A		O
		18,5	19,0	15,5	B		O
		18,0	19,0	15,0	C		O
		19,0	19,5	15,5	D		F
	0,50	18,0	18,0	13,0	A		F
		18,5	18,5	13,5	B		F
		18,5	18,0	13,0	C		O
		19,0	18,5	14,0	D		F
	3,30	19,0	20,5	19,0	A	back to wall	O
		18,5	19,5	18,5	B		O
		18,5	19,5	18,5	C		O
		18,5	19,5	18,5	D		O
	2,00	19,5	20,5	18,0	A		O
		19,0	20,0	17,5	B		O
		18,5	19,5	17,0	C		O
		18,5	19,5	17,5	D		O
	1,00	19,0	19,0	15,0	A		O
		18,5	18,5	14,5	B		F
		18,5	18,5	14,0	C		O
		18,5	18,5	14,5	D		O
	0,50	19,0	18,0	14,5	A		O
		19,0	18,0	13,0	B		F
		18,5	17,5	12,5	C		O
		18,5	17,5	12,5	D		O/F
Convection (2nd series)	3,30	21,0	20,0	19,0	A	Facing wall	O
		20,5	20,0	19,0	B		O
		20,0	19,0	18,0	C		O
	2,00	21,5	20,0	18,5	A		O
		20,5	20,0	18,0	B		O
		20,0	19,0	17,5	C		O
	1,00	21,0	19,5	15,5	A		O
		20,0	19,5	15,5	B		O
		20,0	19,0	15,0	C		O
	0,50	21,0	19,5	14,0	A		F
		20,0	19,0	13,5	B		F
		19,5	18,5	13,5	C		O
	3,30	21,0	20,0	18,5	A	back to wall	O
		19,0	18,5	17,0	B		O
		20,5	19,5	17,5	C		O
	2,00	21,0	20,0	17,5	A		O
		19,5	18,5	16,5	B		F
		21,0	19,0	17,0	C		O
	1,00	20,5	19,5	15,0	A		O
		19,5	18,0	14 0	B		F
		20,5	19,0	15,0	C		O
	0,50	21,0	19,0	13,5	A		F
		19,5	17,5	12,5	B		F
		21,0	19,0	13,0	C		O

Table II (conclusion)

Room B

Type of heating	Distance to glazed opening (in m)	t_a	t_b	t_{are}	Subject	Position of subject	Subject's comfort response
Convection (2nd series)	3.30	21.5	19.5	17.5	A	facing wall	O
	2.00	22.0	19.0	17.5	A		O
	1.00	20.5	19.0	15.5	A		O
	0.50	21·0	18.5	14.0	A		F
	3.30	21.5	19.5	17.5	A	back to wall	O
	2.00	22.0	19.0	17.5	A		O
	1.00	21.0	18.5	15.0	A		F
	0.50	20.5	18.0	13.0	A		F

Temperature terms:
t_a : air temperature
t_b : bulb—thermometer temperature
t_{are} : plane—thermometer temperature

Response terms:
O : neither warm nor cold
Ch: sensation of warmth
F : sensation of cold

Table III Results of tests at 18 C (average ambient temperature)

Room B

Type of heating	Distance to glazed opening (in m)	t_a	t_b	t_{are}	Subject	Position of subject	Subject's comfort response
floor and ceiling	3.30	16.5	17.5	17.0	A	facing wall	O
		16.0	17.0	16.0	B		F
		16.0	16.0	16.0	C		O
		16 5	17.5	16.5	D		F
	2.00	17.0	18.0	16.0	A		F
		16.5	17.5	15.5	B		F
		16.0	17.0	15.0	C		O
		16.5	17.5	15.5	D		F
	1.00	16.5	17.0	13.5	A		F
		16.0	16.5	13.0	B		F
		15.5	16.5	13.0	C		F
		16.0	17.0	13.5	D		F
	0.50	16.5	16.5	12.0	A		F
		16.5	16.0	11.5	B		F
		16.0	15.5	11.5	C		F
		16.5	16.0	11.5	D		F
	3.30	16.5	17.0	16.0	A	back to wall	F
		16.0	17.5	15.5	B		O
		15.5	16.5	15.5	C		O
		16.0	16.5	15.5	D		F
	2.00	16.0	17.0	15.0	A		F
		16.5	17.0	15.0	B		O
		16.0	17.0	14.5	C		O
		16.0	17.0	14.5	D		F
	1.00	16.0	16.0	12.0	A		F
		16.0	16.0	12.5	B		F
		15.5	15.5	12.0	C		O
		15.5	17.5	12.0	D		F
	0.50	16.0	15.5	10.5	A		F
		16.0	15.0	10.5	B		F
		15.5	14.5	10.5	C		O
		15.5	15.0	10.0	D		F

Table III (conclusion)

Room B

Type of heating	Distance to glazed opening (in m)	t_a	t_b	t_{are}	Subject	Position of subject	Subject's comfort response
Convection (1st series)	3,30	19,0	18,0	16,0	B	facing wall	O
		20,0	18,0	16,5	C		F
		20,0	18,0	16,0	D		F
		20,0	18,0	16,5	E		O
	2,00	20,5	17,5	15,5	B		O
		20,5	18,0	16,5	C		F
		20,5	17,5	16,0	D		O
		20,5	18,0	16,0	E		O
	1,00	19,0	17,5	14,0	B		F
		19,5	18,0	14,5	C		F
		19,0	17,5	14,0	D		F
		19,0	17,5	14,5	E		F
	0,50	19,5	16,5	12,5	B		F
		18,5	17,0	13,0	C		F
		20,0	16,5	12,5	D		F
		19,5	17,0	13,0	E		F
	3,30	19,0	17,5	15,0	A	back to wall	O
		19,5	18,0	16,5	C		O
		21,5	18,5	16,5	D		O
		18,0	17,5	16,0	E		O
	2,00	20,5	18,0	16,0	B		O
		20,0	17,5	16,0	C		F
		21,0	18,0	16,0	D		F
		18,5	17,0	15,5	E		F
	1 00	19,5	17,0	15,0	B		O
		18,5	17,5	13,5	C		F
		19,0	17,5	13,5	D		F
		18,0	16,5	13,0	E		F
	0,50	20,0	16,5	12,0	B		F
		19,5	16,5	12,0	C		O
		19,5	16,5	12,0	D		F
		17,5	15,5	11,5	E		F
Convection (2nd series)	3,30	19,0	18,0	16,5	A	facing wall	O
		19,5	19,0	17,5	B		O
		19,5	18,5	17,5	C		O
	2,00	19,0	18,0	16,0	A		O
		20,0	18,5	17,0	B		O
		19,5	18,5	17,0	C		O
	1,00	19,0	17,5	14,0	A		F
		19,5	18,5	15,0	B		O
		19,5	18,0	14,5	C		O
	0,50	19,0	17,0	12,5	A		F
		19,5	18,0	13,5	B		F
		19,0	18,0	13,0	C		O
	3,30	19,0	18,0	16,5	A	back to wall	O
		19,5	18,5	17,5	B		O
		19,0	18,0	16,5	C		O
	2,00	19,5	18,0	16,0	A		O
		19,5	18,5	16,0	B		O
		19,5	18,0	16,0	C		O
	1,00	19,0	17,5	13,5	A		O
		19,0	18,0	13,5	B		O
		19,0	17,5	13,5	C		O
	0,50	19,5	18,0	12,0	A		O
		19,0	17,5	12,0	B		F
		19,0	17,5	12,0	C		F

Temperature terms:

t_a : *air temperature*
t_b : *bulb–thermometer temperature*
t_{are} : *plane–thermometer temperature*

Response terms:

O : neither warm nor cold
F : Sensation of cold

Table IV. **Proportion of Discomfort Cases**
as a function of average ambient temperature, type of heating, and distance to cold wall, and corresponding values of temperatures t_b and t_{are}

Test conditions			Temperatures measured		Proportion of discomfort cases expressed in numbers of cases and, within parentheses, in percentage.	
Temperature (t_b) in center of room	Type of heating	Distance to cold wall (in m)	With bulb–thermometer t_b	With plane thermometer t_{are}		
approximately 22°C	Floor and ceiling	3,00	21,5	20,5	0/8	(0 %)
		2,00	22	19,5	0/8	(0 %)
		1,00	21	16,5	0/8	(0 %)
		0,50	20	14,5	3/8	(37 %)
	By convection	3,30	21,5	19,5	1/16	(6 %)
		2,00	21	19	2/16	(12 %)
		1,00	21	16,5	2/16	(12 %)
		0,50	20	15	7/16	(44 %)
approximately 20°C	Floor and ceiling	3,30	19,5	18,5	0/8	(0 %)
		2,00	20	17,5	1/8	(12 %)
		1,00	19	15	2/8	(25 %)
		0,50	18	13,5	5/8	(62 %)
	By convection	3,30	19,5	18	0/8	(0 %)
		2,00	19,5	17,5	1/8	(12 %)
		1,00	19	15	2/8	(25 %)
		0,50	18,5	13,5	6/8	(75 %)
aoproximately 18°C	Floor and ceiling	3,30	17	16	4/8	(50 %)
		2,00	17,5	15	5/8	(62 %)
		1,00	16	12,5	7/8	(87 %)
		0,50	15,5	11	7/8	(87 %)
	By convection	3,30	18	16,5	2/14	(14 %)
		2,00	18	16	3/14	(21 %)
		1,00	17,5	14	8/14	(57 %)
		0,50	17	12,5	11/14	(59 %)

Figure 6

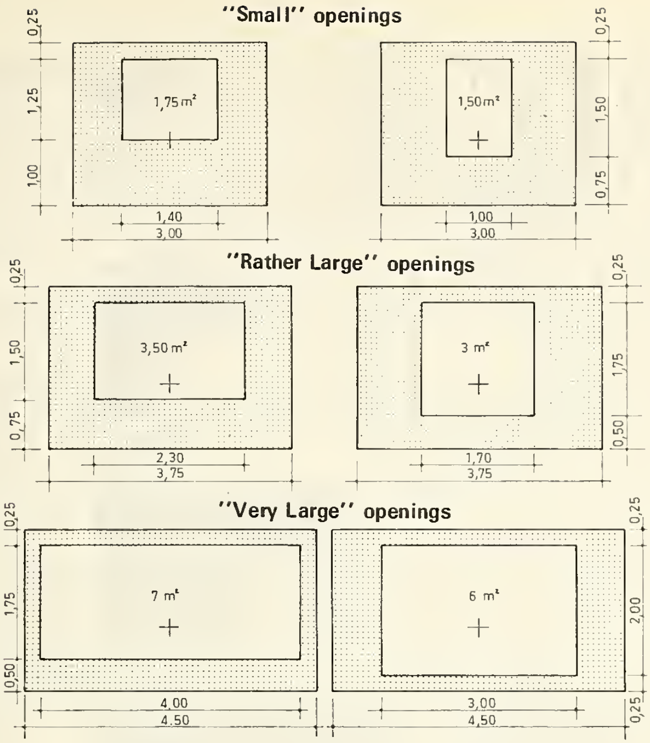


Table V. Values of t_{are} under "average conditions"

	Single–sheet glass			Double–sheet glass		
	Small opening	Rather large opening	Very large opening	Small opening	Rather large opening	Very large opening
Zone A above 800 m	16,9	15,9	14,9	18,1	17,5	17,0
Zone A below 800 m	17,4	16,6	15,6	18,5	17,9	17,5
Zone B	17,9	17,2	16,4	18,8	18,4	18,0
Zone C	18,4	17,8	17,1	19,2	18,8	18,5

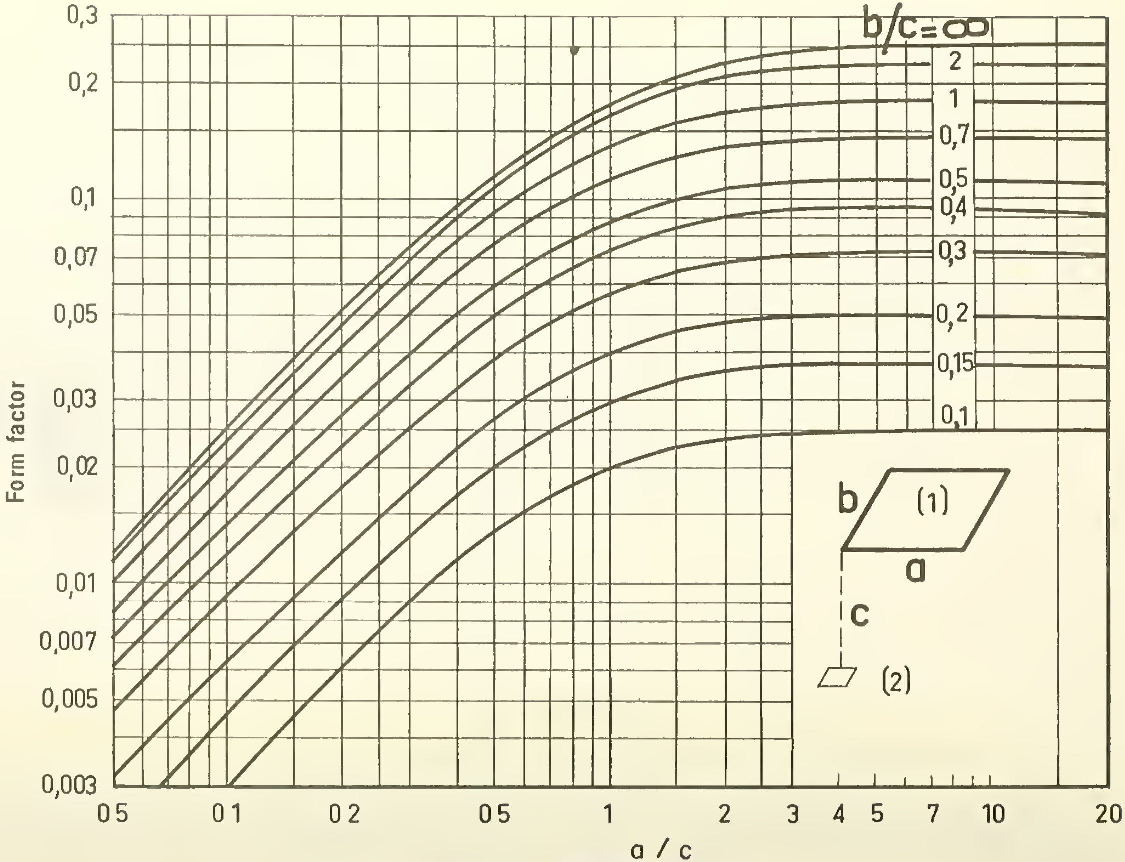


Fig. 7. — Graph for computing form factors

Table VI . Values of ^{t}are for various values of Inside Temperature, under "Average" Conditions

	Inside Temperature : 19 °C			20 °C			21 °C			22 °C		
	Smell opening	Rather large opening	Very large opening	Smell opening	Rather lerge opening	Very lerge opening	Smell opening	Rether lerge opening	Very lerge opening	Small opening	Rether lerge opening	Very lerge opening
Single–sheet glass												
Zone A above 800 m	15,2	14,2	13,2	16,1	15,1	14,0	16,9	15,9	14,9	17,8	16,8	15,8
Zone A below 800 m	15,7	14,9	14,0	16,6	15,7	14,8	17,4	16,6	15,6	18,3	17,4	16,4
Zone B	16,2	15,5	14,7	17,0	16,3	15,5	17,9	17,2	16,4	18,8	18,0	17,9
Zone C	16,7	16,1	15,5	17,5	16,9	16,3	18,4	17,8	17,1	19.3	18,6	17,9
Double–sheet glass												
Zone A above 800 m	16,3	15,7	15,3	17,2	16,6	16,2	18,1	17,5	17,0	19,0	18,4	17,9
Zone A below 800 m	16,6	16,2	15,7	17,6	17,1	16,6	18,5	17,9	17,5	19,4	18,9	18,4
Zone B	17,0	16,6	16,2	17,9	17,5	17,1	18,8	18,4	18,0	19,7	19,3	18,9
Zone C	17,3	17,0	16,7	18,3	17,9	17,6	19,2	18,8	18,5	20,1	19,7	19,4

	5 days of discomfort per year			15 days of discomfort per year		
	Small opaning	Rathar larga opaning	Very large opaning	Small opening	Rather larga opaning	Rathar large opaning
Zone A above 800 m	16,9	15,9	14,9	17,4	16,6	15,6
Zone A below 800 m	17,4	16,6	15,6	17,9	17,2	16,4
Zone B	17,9	17,2	16,4	18,4	17,8	17,2
Zone C	18,4	17,8	17,1	18,9	18,4	18,0

Table VII. Values of t_{are} for various Outside Temperatures (with Single–sheet glass), under "Average" Conditions

- (dark shading) t_{are} below 16°C
- (light shading) t_{are} equal to or about 16°C but below 17°C
- (no shading) t_{are} equal to or about 17°C

Table VIII. Values of t_{are} for opening with or without drapes, under "average" conditions

	With drapes			Without drapes		
	Small opaning	Rathar large opaning	Vary larga opening	Small opaning	larga opaning	Very larga opaning
Single–sheet glass						
Zone A above 800 m	16,9	15,9	14,9	16,1	14,3	12,5
Zone A below 800 m	17,4	16,6	15,6	16,7	15,1	13,5
Zone B	17,9	17,2	16,4	17,3	15,9	14,6
Zone C	18,4	17,8	17,1	17,9	16,7	15,6
Double–sheet glass						
Zone A above 800 m	18,1	17,5	17,0	17,5	16,6	15,7
Zone A below 800 m	18,5	17,9	17,5	18,0	17,1	16,3
Zone B	18,8	18,4	18,0	18,4	17,6	16,9
Zone C	19,2	18,8	18,5	18,8	18,2	17,6

Table IX. Values of t_{are} at 1 m and at 1.50 m from the opening (single-sheet glass), under "average" conditions

	at 1 m from opening			at 1.50 m from opening		
	Small opening	Rather large opening	Very large opening	Small opening	Rather large opening	Very large opening
Zone A above 800 m	16,9	15,9	14,9	18,4	17,2	16,2
Zone A below 800 m	17,4	16,6	15,6	18,7	17,7	16,8
Zone B	17,9	17,2	16,4	19,1	18,1	17,4
Zone C	18,4	17,8	17,1	19,4	18,6	18,0

Table X. Values of t_{are} when there is a radiator set against wall below opening, under "average" outside temperature conditions

	Inside Temperature:			
	19 °C	20 °C	21 °C	22 °C
Single-sheet glass with drapes				
Zone A above 800 m	16,7	17,6	18,5	19,4
Zone A below 800	17,0	17,9	18,8	19,7
Zone B	17,3	18,2	19,1	20,0
Zone C	17,6	18,5	19,4	20,3
Single-sheet glass without drapes				
Zone A above de 800 m	15,4	16,3	17,2	17,1
Zone A below de 800 m	15,9	16,8	17,7	18,6
Zone B	16,4	17,2	18,1	19,0
Zone C	16,8	17,7	18,6	19,5

(shaded) *t_{are} below 16°C*

(blank) *t_{are} equal to or above 16°C but below 17°C*

(blank) *t_{are} equal to or above 17°C*

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

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The thermal comfort of an individual inside a closed room in winter is essentially a function of the temperature of the air with which the human body transfers heat by convection, and also of the temperature of the room's walls with which the human body transfers heat by radiation. The presence of glazed openings (windows) which in winter are generally the coldest walls in a residence room, can thus be a source of discomfort.

The first part of the paper reports research conducted with a view to determining the thermal comfort requirement near to a cold wall. The research led to the definition of the "air-radiation requirement" for a plane surface element parallel to the wall, the requirement being that, at about 1 m from the wall, this temperature must remain above 16 or 17°C.

The second part of the paper studies ways of satisfying the requirement near to glazed openings in a living room in winter. The solution to the problem will depend on numerous factors: climatic zone, average temperature of the room, position of heat sources, dimensions of the openings, type of glazing (single or double), presence or absence of curtains or screens.

17. KEY WORDS (Alphabetical order, separated by semicolons) Curtains, effect of; environmental conditions; glazed openings; human response; thermal comfort requirement.

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