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BUILDING RESEARCH TRANSLATION

Ventilation Air Inlets For Dwellings

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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.
[4] Part of the Center for Building Technology.

BUILDING RESEARCH TRANSLATION

Ventilation Air Inlets for Dwellings

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Paris, France

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U.S. DEPARTMENT OF COMMERCE, Peter G. Peterson, *Secretary*
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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 (Center for Building Technology) 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

James R. Wright, Director
Center for Building Technology
Institute for Applied Technology
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VENTILATION AIR INLETS FOR DWELLINGS

Recommendations for the Elimination of Discomforting Drafts in the Case of Outside-Wall Air Inlets Designed for Dwelling Ventilation[1]

by

M. Croiset and H. Bizebard

Preliminary tests have shown the existence of a "discomfort index", a function firstly of the difference between the temperature in the room and the temperature of the air current and, secondly of the speed of the air stream. The permissible limit for this index has been fixed at two degrees C.[2], at least in that part of the room situated more than 20 cm. from the outside walls and less than two meters in height.

Systematic artificial tests have resulted in satisfactory solutions being found for the air inlets into the outside walls.

--An elongated aperture placed above a radiator and fitted with a deflector so that cold air entering the room mingles with the ascending warm air current.

--An aperture located behind a convector heater so that the same result is achieved as in the case of the radiator.

--A row of apertures located along the heated ceiling placed so that entering air is diffueed into the warm air before reaching the occupied zone.

Some calculations aimed at determining the orders of magnitude of the necessary sections and the possible force of the air current in a high wind, have revealed the need for a manual or an automatic regulator where a wall is exposed to wind.

Key words: Air inlet; discomfort index; draft; outside wall; ventilation; wind.

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[1] 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.

[2] Centigrade thermometer readings will be used in temperature measurements unless otherwise stated.

1. GENERAL

Statutory requirements for air inlets or intakes supplying ventilation in dwellings are contained in the 14 November 1958 governmental decree on ventilation of residences and in the memorandum of the same date prescribing Sanitary Regulations for Lavatories, Bathrooms, and Toilets in Central Position (i.e. not along outside walls). Among the measures commonly adopted in compliance with this decree and its associated regulations is the provision of air-inlet openings in external walls. Generally these air inlets are simple 150 cm^2 rectangular holes covered with protective grilles.

Following our research--a report of which is contained in the enclosed supporting study--we are now in a position to make recommendations on air inlets in external walls. These recommendations do conflict with the regulations on some points. But the CSTB will shortly submit proposals for the amendments needed to obtain maximum benefit from the findings of its research.

The subject recommendations concern solely direct air-inlet openings in external walls. They do not cover any other air-inlet principles, such as horizontal air ducts, vertical air ducts, etc., a fact which does not per se constitute disapproval of these other principles or systems.

1.1 Guidelines

The guidelines from which these recommendations stem, are as follows:

First, relate the cross section of air inlets, or more correctly, their pressure-loss characteristics, to the desired air changes within the different rooms of the dwelling. This relationship is expressed by the concept of "basic air flow".

Second, establish cross-section limits not only with a view to obtaining a minimum degree of ventilation, but also to precluding excessive flow of air under high wind conditions. Authorize, as and if required, air inlet devices with adjustable openings.

Third, provide a means for numerically expressing the degree of protection against cold air drafts by employing the concept of a discomfort index.

Fourth, distribute air inlets as much as possible throughout the dwelling by authorizing indirect ventilation in kitchens, bathrooms, and toilets, whether these rooms be in a central position (i.e. along an outside wall) or not. Air would enter into living rooms and bedrooms and leave from service rooms, (i.e. kitchens, bathrooms, toilets) where the air is most polluted. Such an arrangement allows the air flow from the air inlets to be more widely distributed and consequently facilitates efforts to control drafts. In addition, it provides better ventilation for the dwelling unit as a whole.

1.2 Basic Air Flow

The basic air flow of an air inlet is defined as that amount of air that must be delivered by the inlet to provide the desired air change throughout the various rooms in a dwelling. No regulations presently prescribes the desired air change. We recommend the following values:

Bedrooms and living rooms:

less than 15 m^2. . . . . 30 m^3/h

more than 15 m^2. . . . . 45 m^3/h

Service rooms:

kitchens for dwellings of less than three rooms . . . . 45 m^3/h

kitchens for dwellings of three or more rooms. . . . . 60 m^3/h

bathrooms. 30 m^3/h

toilets. . . . . 30 m^3/h

combined bathroom-toilet . . . . 30 m^3/h

When each room is ventilated independently of the others, the basic air flow of each air inlet must be equal to the desired air change in the room serviced by that inlet. If we adopt the principle of placing air inlets in living areas (bedrooms, living rooms) and air outlets (or exhausts) in service rooms, the basic air flow of each inlet must be at least equal to the desired air change in the room in which that inlet is located, and also be such that the outlet air flow in the service rooms is at least equal to the desired air changes for those rooms.

First example: air inlets are located in two bedrooms of less than 15 m^2 and the outlet is in a combined bathroom-toilet. The basic air flow of each air inlet will be 30 m^3/h.

Second example: the air inlet is located in a living room, the outlet in a kitchen. The basic air flow will be 45 m^3/h in small dwellings and 60 m^3/h in the others. Air inlets may also be divided between the kitchen and living room, thus limiting the basic air flow for each room to 30 m^3/h.

Provision should therefore be made for air inlets with basic air flows equal to 30 m^3/h, 45 m^3/h, or 60 m^3/h, depending on the case involved. But an efficient distribution of the inlets among the various rooms will often permit limiting needs to basic air flows of 30 m^3/h.

1.3 Practical Air-Flow Limit

As we said above, the cross sections of air inlets must be such as to meet two contradictory requirements. The first is to obtain approximately the basic air flow under average thermal draft conditions, the second is not to have excessive air flow under high wind conditions. The compromise which can be made thus leads to "a practical limit" to air flow, a limit corresponding to wind pressures that are rarely exceeded. Shielding or protection against cold air drafts must be provided up to this air flow limit.

1. In natural ventilation conditions, the practical limit can be set at a value equal to the basic air flow or four times as great. On those outside walls that are particularly exposed, because of the site of the dwelling, its orientation, or height, this requires using air inlets with openings that are manually or automically adjustable. Obviously these openings cannot be completely closed. When shut and under average thermal draft conditions, air flow should be equal to at least half of the basic flow.

In certain cases of exceptionally unfavorable exposure to wind where we would be required to set a higher practical limit, it appears advisable to consider solutions other than direct inlets in outside walls, for example, vertical or horizontal ducts that are not covered by the recommendations herein.

The practical limit indicated above can be reduced in the following two special cases:

--when through automatic control and adjustment the air-inlet air flow remains clearly below the quadruple of the basic air flow. In such cases the practical limit employed will be the flow actually obtained under the limiting wind-pressure conditions employed in the general case;

--in the case of exceptionally sheltered situations.

However, in no case will the practical limit ever drop below double the basic air flow.

2. In mechanical ventilation conditions it is generally possible to provide air inlets having a smaller cross section than those used with natural ventilation, and thus reduce wind effect. Consequently the practical limit will generally be less than the quadruple of the basic air flow. The flow actually obtained under the limiting wind-pressure conditions of the general case will be used.

When the present regulation is amended it will be possible to define more exactly therein the rules on the pressure-loss characteristics of air inlets. However, as of now, we consider that the orders of magnitude of the values that it would be advisable to adopt for natural ventilation are as follows:

--0.3 to 0.8 mm of water for pressure loss corresponding to basic air flow;

--4 to 16mm--depending upon exposure conditions and exclusive of of exceptional situations--for the pressure corresponding to the practical limit of air flow.

Air inlet cross sections with which these two specifications can be met, are of the order of 30 to 70 cm^2 for fixed inlet devices. Cross sections of adjustable devices would be the same in the open position but could be reduced by one-half in the closed position.

1.4 Definition of the Discomfort Index

The discomfort which a cold draft of air produces at a particular point inside a room is expressed numerically by the value of the "discomfort index" equal to the sum of the difference between the mean air temperature of the room at the same level and the temperature of the air stream at that point, affected by the drop in temperature equivalent to the velocity of the air stream at that point given by the graph in figure 1, p. 9.

2. RULE

The value of the discomfort index determined for an outside temperature of 0° , an inside temperature of 20° , and an air-inlet air flow equal to the practical limit defined in paragraph 1.3, must not exceed two degrees throughout the entire zone situated at a height of less than two meters and at a distance of more than 20 cm from the outside walls.

When the air inlet is combined with the heating system, the above rule must be complied with under normal heating conditions. Furthermore, in the absence of any heating and with outside and inside air temperatures equal to 20°, the rule must also be followed.

When the air inlet has a manually adjustable aperture, the recommendation should be followed with the aperture in its minimum open position.

3. PRINCIPLES OF VARIOUS SOLUTIONS

The air inlets whose principles are described below permit carrying out the recommendation pertaining to the discomfort caused by drafts in the general case of an air flow which is four times greater than the basic air flow. Only the principles are outlined below. Working details for implementing the recommendation on pressure losses, plus the customary rules for safeguards against intruding animals, rain and snow, can be presented in detail within subsequent documents (agreements or standards).

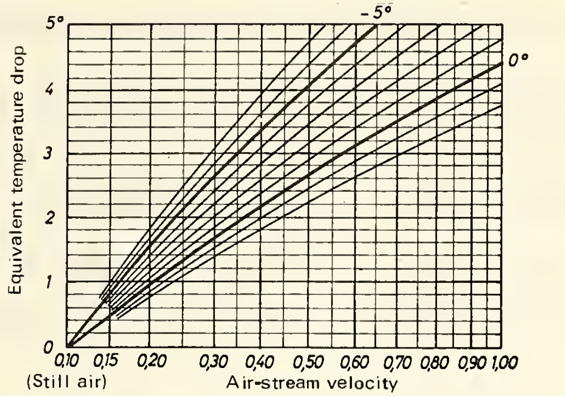
These solutions do not exclude other solutions, especially if the control and adjustment provisions, or use in sheltered situations, allow the requirement for protection against cold air drafts to be limited to double the basic air flow.

The air inlets of standard design recommended below all require combination with a heating system.

3.1 Air Inlet Combined with Radiator Heating (Figure 2a, p. 9)

The principle of this device calls for an elongated opening in the wall behind or above a radiator. The opening has a deflector which directs the air upward in such a way that the supply cold air mixes with the ascending warm air current produced by the radiator. The elongated opening must not extend more than 10 cm beyond each side of the radiator.

Fig. 1. Drop in temperature equivalent to the velocity of the air stream.



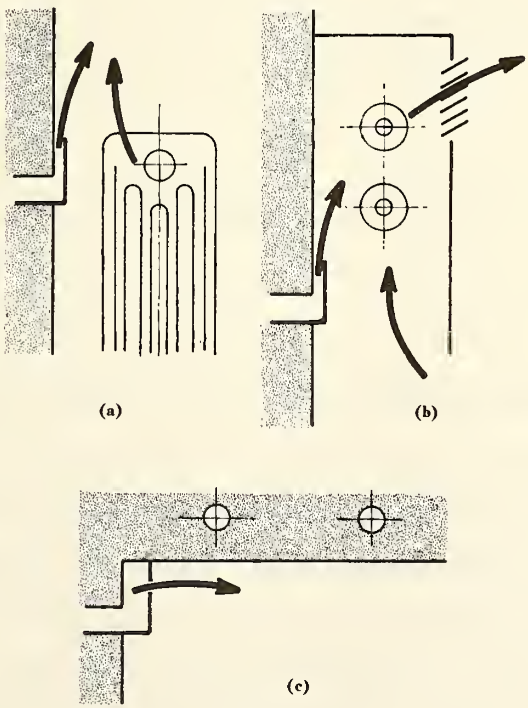


Fig. 2.

3.2 Air Inlet Combined with Shielded-Convector Heating (Figure 2b, p. 9)

The principle here calls for positioning the opening behind the heater section with the supply cold air being directed so that it mixes with the naturally recirculating air in passing over the heating tubes.

3.3 Air Inlet Combined with Ceiling Radiant (Panel) Heating (Fig. 2c, p. 9)

The principle involved here calls for a series of point openings distributed alongside the ceiling over the maximum possible length of the outside wall in such a manner as to diffuse the supply cold air within the layer of warm air lying under the ceiling above the occupied zone.

3.4 In the case of warm-air heating, there is no need to conduct research for adequate air inlets in the outside wall since the warm-air registers or grilles constitute such air inlets.

SUPPORTING STUDY

Introduction

In France at the present time ventilation design almost generally calls for 150 cm^2 air inlet openings in the lower part of walls within kitchens and bathrooms along outside walls. During the cold season the drafts created by these inlets become intolerable. Occupants unable to stand the strong cold blast of air usually aimed at their ankles or feet, block the air inlets. We decided to study ways and means capable of eliminating or reducing the discomfort caused by such drafts so as to make air inlets on outside walls acceptable.

The study was conducted in two phases:

- --preliminary natural tests that led to the definition of a numerically expressed "discomfort index," and also to the selection of classification criteria for air inlets;
- --systematic artificial tests of the various possible types of air inlets combined or not combined with the heating system.

A survey made in occupied dwellings partially confirmed the results obtained.

PART 1: DEFINITION OF A QUALITY CRITERION AND DETERMINATION OF ADMISSIBLE LIMITS

1. TESTS COMPLETED AND DEFINITION OF A DISCOMFORT INDEX

Tests were undertaken with a view to relating the sensation of discomfort experienced upon contact with a draft to the latter's velocity and temperature characteristics, and to deduce therefrom admissible limiting values for these drafts.

These tests were conducted in situ within a bathroom located on the second floor of a seven-story building. The bathroom had a conventional air inlet on the outside wall and a vertical duct that provided rather good ventilation in the wintertime since the air flow (measured by the "tracer-gas" method) varied from 45 to 60 m^3/h. To obtain various combinations of draft velocity and temperature, a deflector was mounted on the opening in some cases, in other cases the entering air was more or less heated by a portable radiator.

Air temperature and velocity were measured at points located at varying distances from the inlet opening along the air stream direction of flow, by means of an electrical anemometer or a resistance thermometer. By means of these two characteristics and by making use of the concept of "resulting" temperature it is possible to compute a single index which we have called the "discomfort index." It is computed in the following manner:

The discomfort caused by a draft results from the local cooling of the human body. This cooling is due simultaneously to the temperature differential of the draft and the air, and to the velocity of the draft, phenomena that cumulatively produce an overall drop in the resulting temperature. An equal drop in temperature, that is to say, an equal sensation of cold, could be brought about by a greater drop in air temperature without velocity. Consequently it can be stated that the velocity is equivalent to an additional deviation in temperature. The latter is given by the chart in Figure 1 , p. 33. These curves were deduced from curves plotted by the American Society of Heating and Air Conditioning Engineers, and by A. Missenard (Bibliograph 1) for the case of an undressed person at rest. In fact, drafts are most disagreeable to those parts of a person at rest (immobile) that are covered by little or no clothing, such as the ankles, and the nape of the neck.

If $\Delta\theta$ is the true air temperature deviation and $\Delta\theta'$ the temperature equivalent to the increase in velocity, then the discomfort index is equal to their sum. This index is thus expressed in degrees and is represented by the letter g.

The accompanying table presents an example of the values obtained in the case of a 150 cm^2 inlet opening with and without a deflector, for an air flow of 60 m^3/h, an outside temperature of +1°, and an inside temperature of +18°.

Distance to opening (cm)	Air-stream temperature (°)	Δθ (°)	Air-stream velocity (m/s)	Δθ′ (°)	g (°)
Opening without deflector					
10 cm	2	16	1 / 1,40	> 10	> 26
30	4,5	13,5	0,80 / 0,90	11	24,5
60	9,5	8,5	0,30 / 0,50	5,5	14
100	12	6	0,30 / 0,45	4	10
150	13,5	4,5	0,30	3	7,5
Opening with deflector					
10	13	5	0,20 / 0,30	3,5	8,5
30	14,5	3,5	0,25	2,5	6
60	15,5	2,5	0,15	0,5	3
100	17	1	0,10	0	1

Sensations experienced by the human subjects in the various experiments were classified as follows:

--"unbearable" if the immediate sensation was extremely disagreeable;

--"very disagreeable" if the sensation was immediately disagreeable;

--"disagreeable" if the sensation was disagreeable after being at rest ("stationary") for a certain time;

--"slightly disagreeable" if the cool-air movement was felt without being disagreeable after being at rest for an extended period;

--"bearable" if no disagreeable sensation was experienced even after an extended period at rest.

2. TEST RESULTS. VALUE OF DISCOMFORT INDEX

Test results grouped on the accompanying table proved that there was satisfactory agreement between the values of the discomfort index and the sensations experienced.

Temperature (°)		Δθ	Velocity of air-stream	Δθ′	g = Δθ + Δθ′
of still air	of air stream	(°)	(m/s)	(°)	(°)
Measurements corresponding to an intolerable sensation.					
21,5	16	5,5	0,60	4,3	9,8
23,5	17	6,5	0,40	2,8	9,3
22	14,5	7,5	0,70	5,5	13
22	14,5	7,5	0,80	6	13,5
21	13,5	7,5	0,50	4,8	12,3
22	15	7	0,40	3,5	10,2
Measurements corresponding to a very disagreeable sensation					
20	16,5	3,5	0,40	3	6,5
22	16,5	5,5	0,25	1,8	7,3
21	15	6	0,25	2	8
21,2	17,5	4	0,50	3	7
20	16,5	3,5	0,40 0,50	3,3	6,8
Measurements corresponding to a disagreeable sensation.					
22	20,5	1,5	0,8	3,8	5,3
21	17,5	3,5	0,30	2	5,5
21	16,5	4,5	0,20	1,3	5,8
21,5	18,5	3	0,40	2,5	5,5
21,2	17,5	3,7	0,20	1,1	4,5
21	17,5	3,5	0,30	2	5,5
21,5	18,5	3	0,25	1,3	4,2
21	16,5	4,5	0,20	1,3	5,8
Measurements corresponding to a slightly disagreeable sensation.					
20	18	2	0,35	2	4
20	17,3	2,7	0,15	0,5	3,2
23,5	22	1,5	0,20	0,7	2,2
21,5	18,5	3	0,20	0,8	3,8

For those discomfort index values under two degrees, the sensation was bearable. We do not give the corresponding values for temperature and velocity deviations, because their measurement thus becomes quite inaccurate and does not have much significance. The correspondence is as follows:

Discomfort under value	Sensation experienced
Above 10°	Intolerable
From 6 to 10	Very disagreeable
From 4 to 6	Disagreeable
From 2 to 4	Slightly disagreeable
Below 2°	Bearable

The limiting value of two degrees may seem to be quite low. However, that same value is also found in the conclusions of studies made in allied subject areas.

Figure 2, p. 33, gives curves established by Houghten (Bibliography 2) for air-conditioning problems. On the same graph we have plotted those curves of equal value for the discomfort index. It is noted that:

--for low values of g--the most important--the paths of the two curves are about parallel;

--considering the divergence between the two definitions of still air (0 m/s on the one hand, and 0.10 m/s on the other), the value g = 2° corresponds to a percentage of "dissatisfied or discontented individuals" of the order of 10 per cent.

Recommendations submitted by COSTIC [Comite Scientifique et Technique de l'Industrie du Chauffage, de la Ventilation et du Conditionnement d'Air;

Scientific and Technical Committee of the Heating, Ventilation and Air-Conditioning Industry] (Bibliography 3) are based on the Houghten curve for 10 per cent "dissatisfied individuals."

COSTIC bases its recommendations for floor or ceiling heating (Bibliography 4) on the need not to exceed a 2° radiant temperature differential between head and feet. With respect to floor heating this rule would correspond to only 5 per cent "dissatisfied persons."

3. OCCUPIED ZONE AND CLASSIFICATION CRITERIA FOR AN AIR INLET

There is no need to consider any discomfort caused by cold drafts in the zone adjacent to the ceiling, a zone that is inaccessible unless a person raises his arms. The same may be admitted for the zone close to walls and mainly to outside walls which, colder than the other walls, are in any event a cooling sources.

We will allow that an air inlet, under given temperature and air flow conditions, is acceptable if the discomfort index is below 2° throughout the zone located at a height of less than 2 meters and at a distance of more than 20 cm from the outside walls. We will call this the "occupied zone."

In a more qualified manner, and for the purpose of making some system of classification possible, we will adopt the following criteria:

--g below 2° throughout the occupied zone . . . . GOOD.

--g below 4° in the occupied zone and below 2° in the zone limited to a height of 2 meters and a distance of 40 cm from outside walls (zone where individuals remain for a prolonged period of time) . . . . UNSATISFACTORY.

--other cases . . . . POOR.

It may also be necessary to give consideration to relative position with respect to "hot spots" in the zone (e.g. proximity of a radiator), since the contrast in such cases accentuates the cold sensation from a draft.

PART 2: SYSTEMATIC ARTIFICIAL TESTS

1. EXPERIMENTAL METHOD

1.1. Apparatus and Facilities

The experimental facilities and apparatus are illustrated in Figure 3, p. 34. The specific air inlet unit to be examined and tested was set within the wall separating the two rooms. One of these rooms represents a room in a house, the other the outside ambient medium. Air was exhausted by means of a duct with its outlet generally in the ceiling. However, this outlet could be moved if desired, for example to cause the air to leave from a low part of the room. This duct was equipped with a controlled (variable) blow fan.

The inside room was heated by radiator, ceiling or floor panel heating, which made various heating and ventilation combinations possible.

1.2 Test Conditions

Inside temperature was maintained at 20°C, outside temperature at 0°C. When this was not strictly possible, the two temperatures were simultaneously raised or lowered so that their differential would remain equal to 20°.

In an initial test series the air flow used was uniformly equal to 60 m^3/h. As indicated in the recommendations outlined in the beginning of this "Cahier", this air flow is, for an air inlet situated in a standard size room in a dwelling, that minimum flow for which the requirement for protection against cold drafts must be met.

Those air inlets having given satisfactory results during the initial test series were subjected to an additional test with an air flow of 120 m^3/h. The latter is the maximum flow called for by the Recommendations for air inlets with a basic flow equal to 30 m^3/h.

After calculating the values of index g the following were plotted:

--the curve of maximum discomfort as a function of the distance to the wall, obtained by determining the point where g is maximum in each vertical plane considered;

--the vertical projection of the volume in which g is equal to or greater than 2°, called the discomfort zone. We generally prefer the second of the above representations. With it the draft can be located and pinpointed in relation to the room's hot spots.

This testing facility can also be used, if desired, to measure the air inlet's pressure loss.

1.3 Conduct of a Test

By means of a preliminary test in which smoke was used, the air stream's trajectory could be located and the zone in which measurements were to be made could thus be limited. Then air-stream velocity and temperature were measured successively at different points located at an increasing distance from the air inlet, generally at 10, 30, 60 and 100 cm. The drop in air temperature was thus measured by taking the temperature gradient within the room into account.

The resistance temperature detectors were not shielded from cold or hot radiations.

1.4 Accuracy

There were two kinds of error sources.

1. Errors in Test Conditions

Inside temperatures (Ti) and outside temperatures (Te) were not always 20° and 0°. They were frequently several degrees higher than that but the Ti - Te temperature differential remained equal to 20° $\pm$1°. This resulted in a relative error of 5 per cent in the $\Delta\theta$, which in the zone of interest to us ($\Delta\theta$ # 2°) amounted to an absolute error of one-tenth of a degree.

The air flow had to be corrected to take account of air leakage from the room. This correction was made by adding the leakage flow corresponding to air-inlet pressure loss to the desired flow through the air inlet (60 or 120 m^3/h). This implied a prior calibration with the air inlet absent, but unfortunately it was a rather rough measurement for the leaks were not uniform, especially those at right angles to the door. The higher the air inlet's pressure loss, the higher the correction required.

Numerous tests were performed on inlet openings of the order of 200 cm^2; this is always the case with floor heating. Pressure losses remained low and the correction made to the air flow scarcely exceeded five per cent. This correction was not always made. If it is deemed that there was the same resultant relative error in air stream velocity, the absolute error in that velocity was at the most equal to 0.015 m/s for the velocities of interest to us (0.30 m/s). This corresponds to an equivalent temperature drop of one-tenth of a degree.

With smaller cross sections of the inlet opening, the correction increased rapidly. For 50 cm^2 it was of the order of 30 per cent. Some tests were made without this correction having been rigorously estimated, and it now seems that it would have been clearly underestimated. The error by default in the air flows amounted to 20 per cent. There was a resulting error of one-half of a degree in the equivalent drop in temperature. The corresponding tests will be conducted anew. As we shall see in paragraph 3, these tests are part of the supplementary research program aimed at obtaining more specific and detailed information on the ejection velocity of the air. The fact that the first tests at high velocity were carried out under favorable conditions (air flow was too weak) foreshadows less favorable new results.

2. Errors in Measurements.

Temperatures were continuously recorded. The magnitude of the cyclic variation due to automatic regulation and control was of the order of a degree. But owing to the lengthy period of this variation, the error in the difference of the two temperatures of the air stream and the still air was reduced by making both readings at two equivalent instants of the cycle. The error under these conditions could be estimated to be less than three-tenths of a degree.

Velocity was measured within 5 cm/s. The resultant error in the equivalent drop in temperature in the zone of interest (30 cm/s) was of the order of four-tenths of a degree.

In conclusion, except for the case of the inlet openings with small cross sections, the two errors in tests conditions were of the order of one-tenth of a degree. The errors in measurements were larger. We feel, however, that we did considerably reduce the overall error by multiplying the number of tests. Only the average results obtained are given herein, since the deviations between various results were clearly below the sum of the errors evaluated above.

2. RESULTS OF A SYSTEMATIC TESTS WITH A 60 m^3/h AIR FLOW

Results presented in the form of a vertical projection of the discomfort zone are grouped within Figure 4, p. 35. Also shown in that figure are the points of maximum discomfort at fixed distances from the outside wall, i.e. at 10, 30, 60 and 100 cm. The values of g, $\Delta\theta$, and $\Delta\theta'$ at each of these points is also indicated. The limit of the occupied zone is marked on each diagram. We will first comment on the results in the order presented in Figure 4, p. 35, then we will synthesize them.

2.1 Compact Opening in the Lower Part of Wall

2.11 Without Deflector (Figure 4A, p. 35)

This was a 150 cm^2 opening installed 20 cm from the floor. It is the most common type of air inlet in current use (Figure 5, p. 34). The result obtained was very poor. As it left the opening, the cold, and thus heavy, air stream dropped toward the floor and travelled along it for a distance of more than two meters from the wall, without spreading out. At 1.50 meters the sensation was still uncomfortable and g was above 6°.

2.12 With Deflector (Figures 4B, 4C, and 4D, p. 35)

The opening was left unchanged and three deflectors were tried. The first deflector was a single plain plate set 3 cm out from the opening and projecting beyond it for 5 cm on all four sides. The draft was divided, checked, and perceptible only as far as 0.80 meters from the wall. However, the result was still poor.

A better result was obtained by closing off the bottom and one side of the deflector. This arrangement prevented the air stream from being forced down to the floor where it could be deflected and then spread throughout the room. Although the result was unsatisfactory, this arrangement may at times prove worthwhile in cases where the use of a room is such that there is little probability that occupants will remain on the open side of the deflector for any length of time.

The same deflector with only its upper part left open produced slightly better but still unsatisfactory results.

The curves of maximum discomfort as a function of distance from the air inlet (Figure 6, p. 36), highlight the various successive improvements.

2.2 Elongated Opening at Window Sill Height (Figures 4E, 4F, and 4G, p. 35, and Figure 7, p. 36)

In comparison with the preceding arrangement, an attempt was made in this case to spread out the air stream by increasing the width of the opening from 15 to 100 cm, and also to move the air stream away from the floor where it can only penetrate into the occupied zone.

We will only describe the results obtained with a deflector, since results without a deflector remained poor and are of little value. With the length of the inlet opening fixed and equal to 1 meter, we studied the effect of its aperture (dimension "e" on Figure 8, p. 37). The smaller that aperture, the better the result obtained. The explanation for this most probably lies in the fact that the velocity of the air as it leaves the opening facilitates the diffusion of the air against or close to the wall, outside of the occupied zone. We further ascertained that a reduction of one-half in the length through modification of the aperture led to about the same result, since the increase in velocity compensated for the decrease in spread. None of the results obtained were, however, completely satisfactory.

For the present, no study has been made with inlet openings of greater length, at least in the case of openings with deflectors. One test was made with a 1.50 m by 1.50 m window whose joints (cracks) had a total crack length of 7.50 m (Figure 4H, p. 35). But the disparities in the thickness of these joints caused the air to enter essentially via the horizontal joints and mainly in the lower part of the window. The result was unsatisfactory. The cold air stream dropped rapidly toward the floor near which it penetrated into the occupied zone.

2.3 Air Inlet Combined with Radiator Heating

Tests proved that to have an efficient combination of air inlet and radiator:

- the air must be delivered into the top part of the radiator or above the radiator in order to take advantage of the ascending warm air;

--a deflector must be provided to direct the air upward so as to preclude having the velocity of the cold air stream drive the stream through the ascending warm current without having time to become sufficiently heated. This is true even if the air is delivered behind the radiator.

In figure 4 I-4L, p. 35, we show results obtained with an elongated opening set above the radiator. This is the most practical solution (Figure 9, p. 37).

Without a deflector (Figure 4I, p. 35)--length of radiator and inlet opening = 1 meter--the cold air stream was still discomforting 30 cm from the wall, although it was being carried upward by the current of warm air. This discomfort was accentuated by the contrast with the radiator's warm radiation.

With a deflector (Figure 4J, 4K, and 4L, p. 35), and with the length of the radiator and inlet opening still at one meter, good results were obtained. The discomfort zone was extremely limited. However, it is important to insure that the air inlet does not extend up beyond the top level of the radiator. On the other hand, the inlet opening can be extended laterally to each side of the radiator providing this lateral extension is for no more than 20 centimeters. Good results obtained with a 10 cm extension were still observed at possibly 30 cm but with definitely no more than that. Results became clearly unsatisfactory with a 50 cm extension.

2.4 <u>Air Inlet Combined with Floor Panel Heating</u> (Figures 4M and 4N, p. 35)

The same one-meter long opening with a deflector that had proved satisfactory with radiator heating, was no longer so with floor heating.

Results were even very poor. The floor temperature (26°) is obviously much lower than that of the radiator and there is no ascending warm air current of the same large volume as that produced by the radiator.

Spreading the delivery of air over a length of 4 meters by means of a row of 4 cm^2 openings 8 cm apart scarcely improved results.

Additional improvement might perhaps be obtained by reducing the total cross section of the inlet in order to increase the ascending velocity. In that case the favorable elements would undoubtedly be the velocity and distribution of air more than the presence of a heated floor. The proximity of the floor may even be a disadvantage.

2.5 <u>Air Inlet at the Ceiling. Combined with Ceiling Panel Heating</u>.

2.51 Without Ceiling Heating (Figures 40 and 4P, p. 35)

Two arrangements were tested. The first consisted of a two-meter long and two-centimeter wide opening. The second was a row of 4 cm^2 openings, with an opening every 8 cm over a distance of 4 meters (Figure 10, p. 37). First result was poor, the second unsatisfactory. In the second instance, as the air streams spread out, they lost their velocity more quickly and the mass of cold air dropped down closer to the wall. In both cases the air stream accelerated the convection current flowing down along the outside wall. Heating was provided from the floor.

No study was made of the effect of an increase in the ejection velocity obtained by reducing the cross section of the air inlet.

2.52 With Ceiling Heating

The two preceding tests were repeated with ceiling heating and a ceiling surface temperature of close to 30°. With the one-meter long opening, the heated air stream dropped down less rapidly than previously and penetrated into the occupied zone only 80 cm from the wall. The result was unsatisfactory. The draft was discomforting up to 1.50 cm above the floor.

With the openings spread out, the cold air was able to become widely diffused in the warm air and also became quickly heated. On the other hand, its velocity decreased rapidly and was only 0.25 m/s at 10 cm from the wall whereas with the one-meter long inlet opening and the same cross section, the velocity was still 0.30 m/s at 60 cm from the wall. The discomfort zone was localized within the 20 cm surrounding the air inlet. The result was excellent.

2.6 Summary Analysis of Results

Those arrangements and devices (designed to protect occupants against cold drafts) that have just been tested and examined are based on two principles.

When the air inlet is located in the upper part of the occupied zone, that is to say less than two meters high, the objective is to reduce the velocity of the air and to heat it within the 20 cm-thick layer alongside the wall.

When the air inlet is located above the occupied zone, the objective is to obtain similar results, but in this case within the 50 cm layer under the ceiling.

2.61 Air Inlets in the Upper Part of the Occupied Zone

When the inlet is not combined with a heating system, a deflector directing the air upwards constitutes the first and most effective means of protection. The purpose of the deflector is to halt the air stream and above all to prevent the cold, and thus heavy, air from falling too rapidly to the floor where it cannot help from penetrating into the occupied zone. A table placed against the wall produces the same result with respect to the floor; and, in particular, it should change the unsatisfactory results obtained with a window into poor results.

The efficiency of an opening with a deflector appears to depend on two elements capable of accelerating diffusion of the cold air within the warm air before penetration into the occupied zone. These elements are the ejection velocity of the air and its spreading. Tests in this subject area have not yet been completed. But the only air-inlet devices which could most likely produce satisfactory results (opening of great length or divided opening spread over a great length, and a small cross section) present practical development problems of a probably critical nature, such as homogeneous distribution of the opening over a distance of several meters, and constriction on the order of a millimeter.

The combination of inlet and radiator heating gives satisfactory results provided certain rules are followed relative to the level and extension of the opening with respect to the radiator.

Floor heating produced only poor results. It does not seem apt to lead to a satisfactory solution, at least in the case of direct air inlets in outside walls. In this report, we do not take up the problem of ducts laid within the floor or in contact with it.

2.62 Air Inlets at the Ceiling

To take maximum advantage of the free 50 centimeters below the ceiling, the air must penetrate or at least be directed as close as possible to the ceiling. Distribution of the air over a great length is of prime importance, at least with cross sections of the order of 200 cm^2. Small cross sections producing great ejection velocity were not studied.

As our tests now stand, only the combination of air inlet and ceiling heating is conducive to satisfactory results.

3. RESULTS OF A FEW TESTS WITH AN AIR FLOW OF 120 m^3/h.

These tests were limited to the two arrangements that had produced satisfactory results with a 60 m^3/h air flow--opening with deflectors above a radiator, and divided opening spread alongside a ceiling with panel heating--and to the "traditional" air inlet constituted by the window already tested at 60 m^3/h.

Results are assembled in Figure 11, p. 38.

Opening with deflector above a radiator

The results were still good. The test was made with the opening extending laterally 10 cm beyond each side of the radiator.

Opening spread alongside a ceiling with panel heating

Here also results remained good. The air became heated more slowly but the discomfort area did not extend down more than 40 cm from the ceiling.

Window

The previous unsatisfactory results became poor in this case. The air stream emanating from the top joint of the window penetrated slightly into the occupied zone. The much larger air stream entering from the bottom joint was still discomforting 60 cm from the wall.

SURVEY IN OCCUPIED DWELLINGS

PARTIAL CONFIRMATION OF RESULTS

A short survey was conducted in occupied dwellings equipped with the only type of air inlet in current use, namely the 150 cm^2 inlet set in the lower part of the wall. This device had been improved by the installation of deflectors.

The survey was made in the kitchens of HLM [Habitations a Layer Moderee; Low-Cost Housing Program) apartment buildings within the Paris area. The following deflectors were installed in various floors and at different exposures:

--a single plate or panel set 3 cm away from the opening;

--the same arrangement, but with the bottom and one side closed; the closed side faced the most utilized part of the kitchen;

--the same arrangement with only the top open.

The deflectors were installed during February 1960. Occupants were questioned in March and April, 1960, and at the end of the winter of 1960-1961. A summary of answers obtained follows:

1. Deflector open on all four sides.

The occupants acknowledged that this was an improvement over the opening without a deflector. But they complained of gusts of wind. They thought that the current of cold air passing under the deflector was especially disagreeable. Replacement of this deflector by another type closed at the bottom was appreciated.

2. Deflector with bottom and one side closed.

Ten deflectors were installed on the first five floors of the building. A pronounced improvement was noticed and occupants on the whole appeared satisfied. Some, however, did complain of gusts of wind. It would seem that the small size of the kitchen renders the cold current that rises along the wall, discomforting.

3. Deflector with only the top open.

Nine deflectors were installed. We then received additional requests for these from other tenants. Yet several persons did object to the gusts of wind and the very swift current of cold air along the wall.

In our opinion, these results demonstrate:

--the substantial improvement brought about by a deflector;

--the need to eliminate, however, all air currents directed toward the floor;

--the satisfaction, although not total, resulting from the third arrangement or device;

--the need to reduce the discomfort zone to an extemely limited layer of air along the wall.

CONCLUSION

The recommendations presented at the beginning of this "Cahier" constitute this study's conclusions. We shall add but a brief comment.

Our standards for satisfactory air inlets, namely, a discomfort index value limited to two degrees, and a maximum distance of 20 cm from the wall, may appear severe. With respect to the first standard, we have seen, however, that we also find similar values for problems in allied fields. As for the second criterion, the results of the survey outlined above seem to confirm the need to be rather strict.

Up to now tests have been conducted with only a 20° temperature differential, one that is often exceeded in cold regions. Tests will be undertaken with greater differentials which can but lead to stricter conclusions.

Certain tests are not yet finished, particularly those in connection with the combined effect of air inlet velocity (openings with small cross sections) and distribution (openings of great length). Even though we can, if necessary, hope to obtain worthwhile results for an air flow of 60 m^3/h without combing the air inlet with the heating system, it does not seem that such would be possible for double that flow. Yet only adjustable openings--for which there is no guaranty of success--in relatively unexposed sites, permit obtaining valid protection with an air flow of 60 m^3/h.

For all these reasons, we have presently defined as standard air inlets only those devices combined with a heating system, devices whose effectiveness with a strong air flow is certain.

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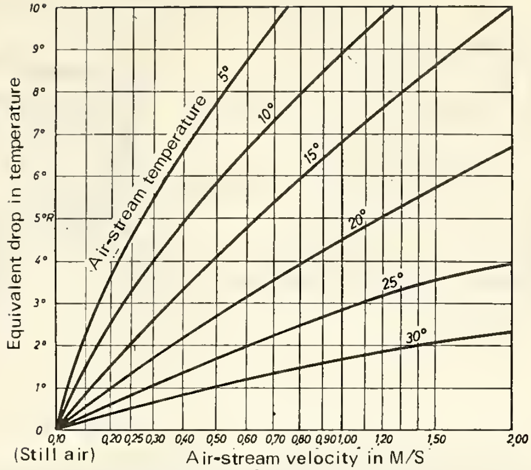


Drop in temperature equivalent to an increase in the volocity of the air for different air-stream temperatures.

Figure 1.

Figure 2.

——— HOUGHTEN: percentage of "dissatisfied persons" in air conditioning as a function of velocity and temperature differential with comfort conditions.

- - - - Line of equal value of discomfort index.

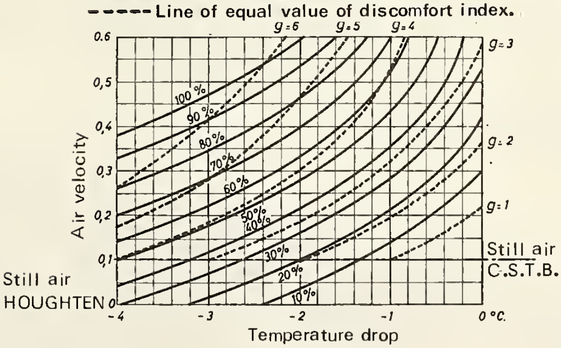
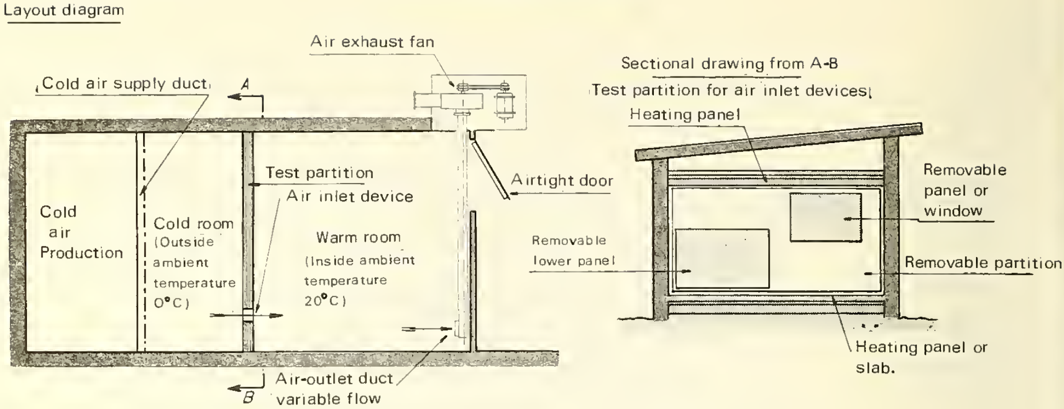


Fig. 3. Experimental apparatus



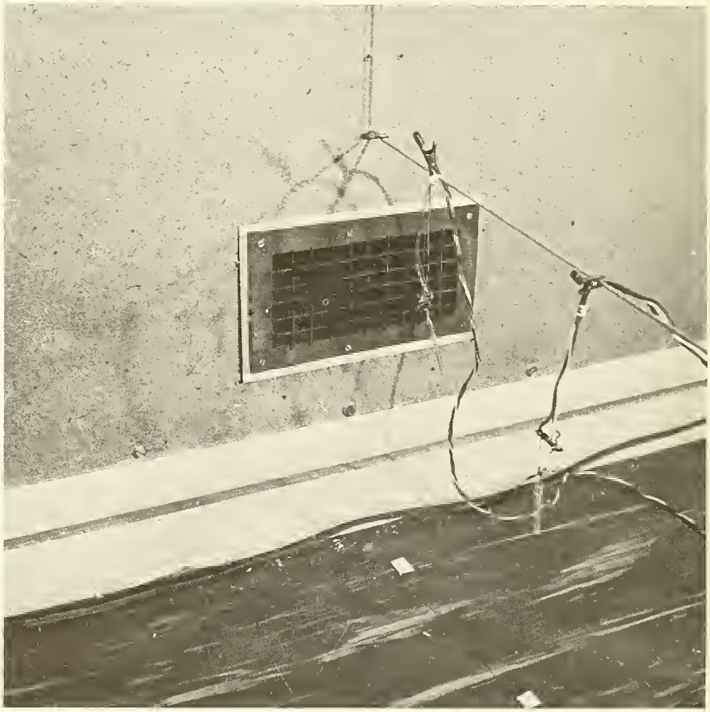
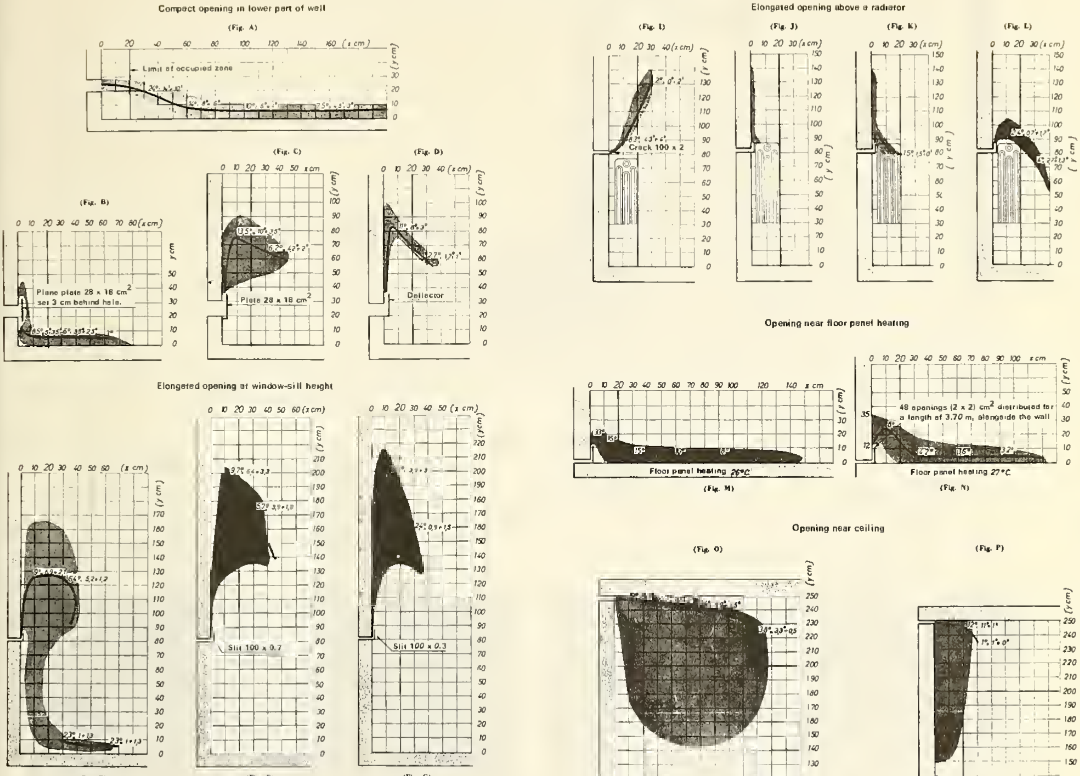
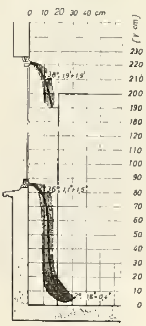


Fig. 5. The 150 cm^2 opening installed 20 cm from the floor (shown are resistance temperature detectors for measuring air-stream temperatures)

Fig. 4 Test Results with an Air Flow of 60 Cubic Meters Per Hour

Vertical project of discomfort zone and indication of maximum values of g, Δθ et Δθ along the air stream.





(Fig. H)

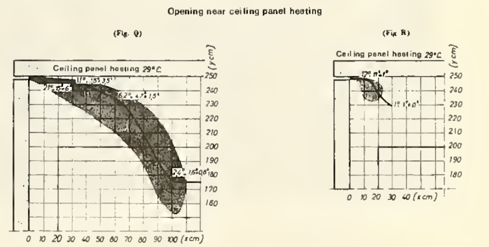


Fig. A. 150 cm^2 opening with deflector

Fig. B. Same opening with deflector open on 4 sides

Fig. C. Deflector open on 2 sides (top and 1 side)

Fig. D. Deflector open on 1 side (top)

Fig. E. Opening 1 meter long with deflector aperture 2 cm

Fig. F. 0.5 cm opening

Fig. G. 0.2 cm opening

Fig. H. Window cracks or joints

Fig. I. Orifice 1m long without deflector

Fig. J. With deflector, no extension beyond radiator

Fig. K. With 19 cm lateral extension beyond radiator

Fig. L. With 59 cm lateral extension beyond radiator

Fig. M. Continuous opening 1 meter long with deflector

Fig. N. Divided opening spread along 3.70 meters with deflector

Fig. O. Continuous opening 1 meter long

Fig. P. Divided opening spread along 4 meters

Fig. Q. Continuous opening 1 meter long

Fig. R. Divided opening spread along 4 meters

Figure 6.

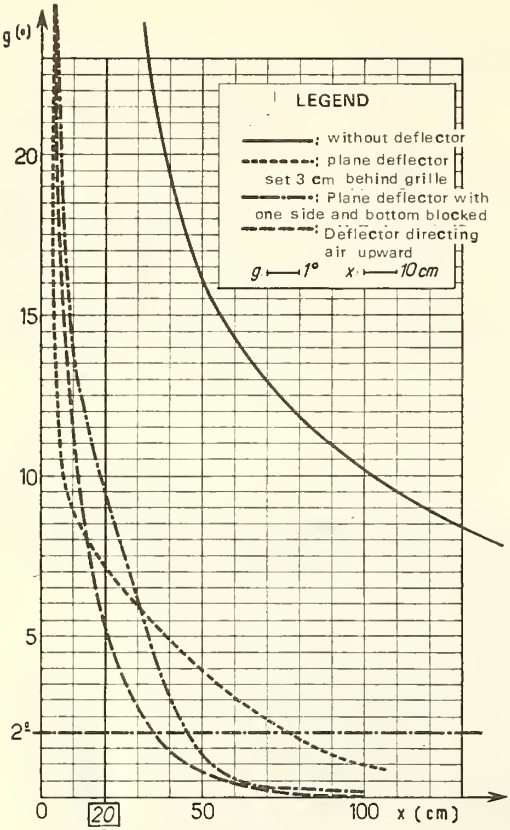
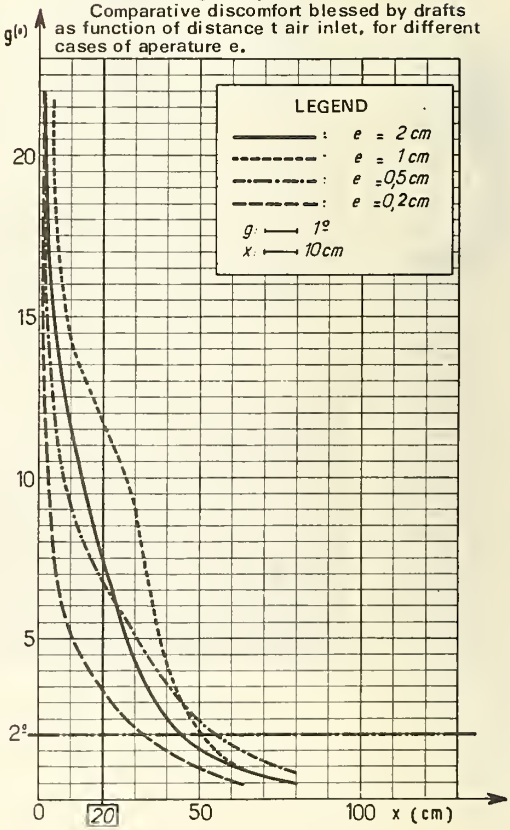


Fig. 7. Elongated opening with deflector directing air upward.
Comparative discomfort blessed by drafts as function of distance t air inlet, for different cases of aperature e.



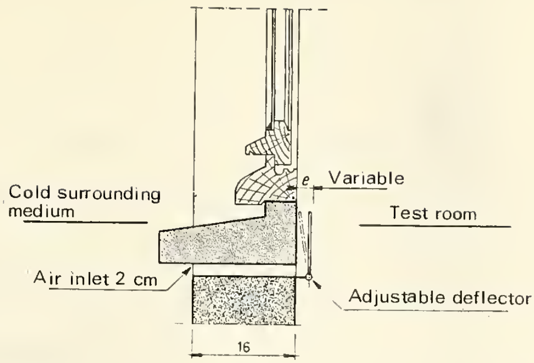


Figure 8.

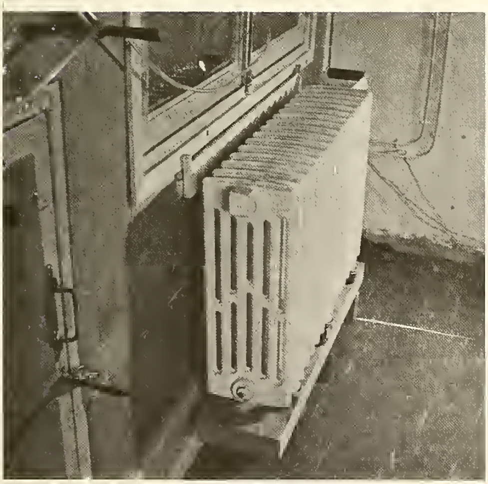


Fig. 9. Opening with deflector above a radiator.

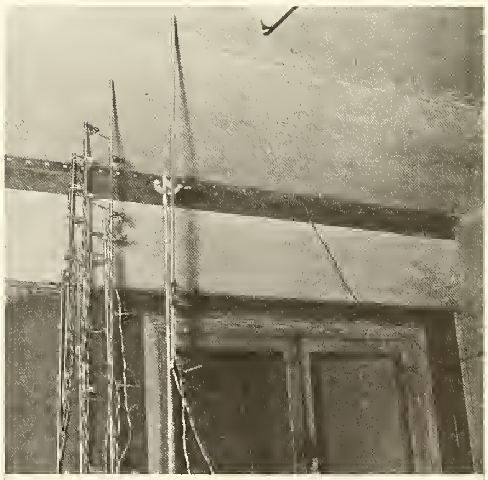
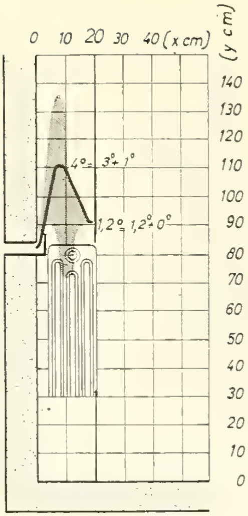
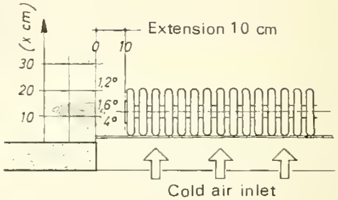


Fig. 10. Orifice spread alongside ceiling.

Fig. 11. Test results with a 120 m^3/h air flow

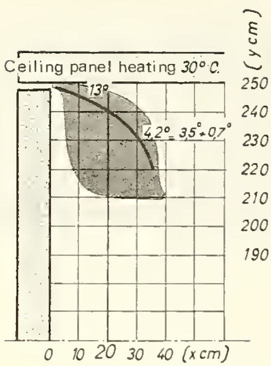


Verticle projection

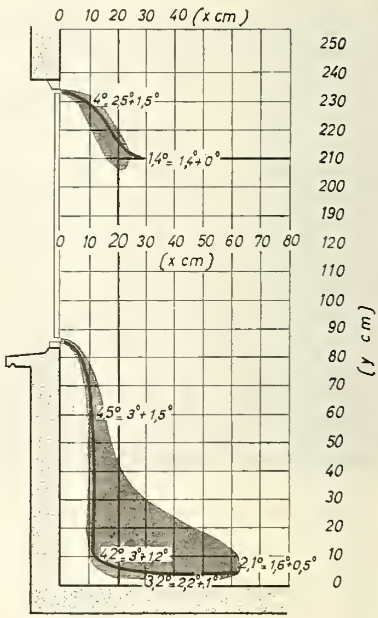


Horizontal projection

Small slit with deflector and inlet above top of a radiator



Elongated divided opening close to ceiling with panel heating



Horizontal joints (slits) in a window

A N N E X

DETERMINATION OF THE PRACTICAL AIR FLOW LIMIT

1. INTRODUCTION

Air inlets must be neither too closed nor too open. Not too closed, so as to preclude their blocking ventilation under the most frequent draft (draw) conditions (average thermal draft, light winds). Not too open, in order to avoid excessive air flow during a strong draft, in other words, during high winds. This is the old argument as to whether windows should or should not be airtight.

Even if those measures outlined in the preceding study are taken to control discomfort resulting from cold air drafts, the drawbacks of strong air flows continue to exist. First of all the latter needlessly increases heat losses. Then they can also cause discomfort outside the normal heating period since most facilities used to eliminate discomfort caused by cold air drafts involve combining the heating and ventilation systems. And lastly, even during a heating period, a strong air flow reduces the effectiveness of these facilities.

The calculations which follow are designed to determine the order of magnitude of pressure losses reconciling at best the contradictory requirements we have just mentioned. Rigorous calculations should take a very large number of variables into consideration, inter alia, those pertaining to exposure to winds, construction of air-outlet ducts, part played by static exhaust fans, etc. The CSTB is currently studying these complex problems. These studies have not been completed. To obtain some orders of magnitude and grasp the meaning of the phenomena involved, we shall limit ourselves in this report to simple values, but, in our view, these values are sufficient.

2. FACTS SURROUNDING THE PROBLEM. THERMAL DRAFT AND FORCE OF WIND

We have chosen to study the following ventilation plan in which air inlets placed along outside walls are fully brought into play. The air inlets are located in the "non-service" rooms of the dwelling, such as the living room and bedrooms, and the air exhaust outlets consisting of vertical ducts are in the service rooms, i.e. kitchen, bathroom and toilet. To be more specific we shall limit our study to an apartment depicted in Figure 1, p. 51. It comprises two non-service rooms along the west outside wall and two along the east outside wall. One exhaust duct outlet is in the kitchen, the other in the combination bathroom-toilet. If we assume that the windows in the service rooms are airtight, then it makes little difference ventilation-wise whether these rooms are along outside walls or in the central part of the dwelling, that is not along an outside wall.

During the winter, in the absence of any wind, solely thermal draft (chimney effect) is active. The air enters almost uniformly through the four non-service rooms and leaves by the service rooms where it is the most polluted. When there is a light wind, the ventilation flow diagram remains unchanged, however, the rooms on the west are more ventilated than those on the east.

Under strong-wind conditions, ventilation through the ducts is supplemented by cross-ventilation, with a great volume of air entering by the west rooms and leaving partially through the ducts and partially through the east rooms. Outside of the heating season, cross-ventilation is dominant and vertical ventilation is almost nonexistent.

What is the relative importance of the forces involved?

Thermal draft is proportional to height of the duct and temperature differential Δt between the outside and inside temperatures. Its value, in millimeters of water, is:

$$0.0045h\Delta t$$

where h is expressed in meters, and Δt in degrees centigrade.

The influence of the duct's height is obviously important. However, for our purposes we shall limit ourselves to the average height of ducts in five-story buildings, that is 8.50 meters, and defer until later any study of the influence of the height.

For Δt, we shall use as average value, the average value for six winter months in Paris, that is the inside temperature of 22° (temperature in the ducts is always slightly higher than the average temperature of the rooms) minus the outside temperature of 6°, consequently a Δt of 17°. Under severe weather conditions (-15°), thermal draft is double. In mild weather (+15°), it is reduced by one half. Since air flow varies almost like the square root of the draft, the result is that air-flow variations are only around the average value of approximately $\pm$ 40 per cent. Moreover, the importance attached to natural ventilation by thermal draft lies in this phenomenon.

When the wind is perpendicular to the building, it creates pressure on one façade and reduces pressure on the other.

The relation linking pressure and reduced pressure to wind velocity is a function of many factors: height and shape of the building, neighboring obstacles . . . . With V as the wind velocity in an open site at a given height, it is assumed that pressure and reduced pressure on a building at that height and in the absence of obstacles, are equal respectively to:

$$+0.8 \frac{V^2}{16} \text{ and } -0.5 \frac{V^2}{16}$$

where $\frac{V^2}{16}$ = dynamic pressure of the wind in millimeters of water, with V expressed in meters per second.

Wind-velocity rates vary considerably with site, exposure and height. We consider as:

--light, a 2 m/s wind with dynamic pressure equal to 0.25 mm of water;

--moderate, a 4 m/s wind ($V^2/16$ = 1 mm);

--strong, an 8 m/s wind ($V^2/16$ = 4 mm);

--very strong, a 16 m/s wind ($V^2/16$ = 16 mm).

On the average site, 2 m/s represents the most frequent velocity. Hence it can be seen that in a very strong wind, pressures and reduced pressures will be 64 times what they are on the average, and air flow will be 8 times the average air flow.

In concluding, under average winter conditions, thermal draft is approximately three times greater than the force of the wind. On the other hand, in exceptional conditions, thermal draft can increase air flow by merely 40 per cent, whereas the wind can multiply it by eight. The solution to the problem is to facilitate vertical ventilation to the maximum by employing large ducts, and, contrariwise, to reduce cross-ventilation by using rather constricted air inlets.

3. CALCULATION OF AIR FLOW IN THE CASE OF AN AIR INLET CONSISTING OF MORE OR LESS AIRTIGHT WINDOWS OR 150 cm^2 OPENINGS.

To simplify computations we can assume--with little error-that all air leaving via the kitchen duct comes from the living room and first bedroom, and that all air exhausted through the bathroom duct comes from the other two bedrooms. Both halves of the dwelling may then be considered separately. By deeming both halves to be identical from our point of view, we may even make our computations for only one half.

We shall make those computations with three types of air inlets characterized by pressure-loss curves E_1, E_2, and E_3 plotted in Figure 2, p. 51. Curve E_1 is for a highly airtight window, one that frankly is not very common in France. Curve E_2 is for a very ordinary wooden window. Curve E_3 is for a 150 cm^2 opening covered with a fine-mesh grille.

We chose pressure losses in the ducts that are clearly below the losses experienced in ducts generally constructed. As we indicated above, we did this in order to favor vertical ventilation as much as possible. Such a pressure-loss curve can be realized providing the cross section of the ducts is increased, and, above all providing any constriction at the inlet grille duct fittings, and exhaust fan, is avoided. But that is not the purpose of this study.

In our computations all the dwelling's inside doors were assumed open and then closed. Rather airtight doors were chosen (curve P_1, Figure 2, p. 51) in order to better highlight their effect.

Compiled results are given in Table 1, p. 53. To simplify matters, it was assumed that there was no air flow within the vertical duct in the absence of any thermal draft. In using a desired hourly air change equal to one, or a total air flow by duct of the order of 60 m^3/h, it was ascertained that, in the absence of wind and with average thermal draft, only the combination of 150 cm^2 openings and open doors was satisfactory. Unfortunately, with a very strong wind this leads to an air flow five times greater than the one desired. Furthermore, with all air entering the west bedroom in this case, the flow in that bedroom is ten times greater than desired. It seems, therefore, that it is difficult to find a compromise. But very strong winds only occur frequently in exposed sites. If we disregard them it would be possible perhaps to arrive at an acceptable solution by using pressure losses ranging from those experienced with ordinary windows to those with 150 cm^2 openings. Such pressure losses can be obtained for example, with elongated and thin openings (of the order of one-meter long and 5 mm thick) which correspond to those measures advocated for control of cold air drafts in the case of radiator heating.

Closing the doors reduced air flow in a strong wind to a rather appreciable extent. Such closing also reduces air flow under thermal draft conditions. A good solution is to reduce pressure losses in the air entering the bathroom (or kitchen). As a matter of fact, under thermal draft conditions the air flow there is double the flow passing by the bedroom doors, and consequently pressure loss is approximately four times as great. Pressure losses can be rather easily reduced, and moreover with little inconvenience, by, for example, providing a permanent staggered air passage, approximately one-centimeter wide, above the door (Figure 3, p. 52).

We shall resume our computations in more detail with this new data.

4. COMPUTATION OF AIR FLOW IN THE CASE OF CONSTRICTED OPENINGS AND PERMANENT AIR PASSAGES INTO SERVICE ROOMS.

Computations were made as before by using as pressure-loss curves:

--curve E_4, for air inlets;

--curve P_1, for bedroom doors,

--curve P_2, for kitchen and bathroom doors.

Results are compiled in Table II.

With doors open, the values are between those in the second and third columns of Table I, and there is nothing special to report.

With the doors closed, and with only thermal draft, air flow is reduced by merely 15 per cent, whereas without air passages at the entrance to service rooms it would be reduced by 25 per cent. With wind only, the reduction is of the order of 20 per cent.

Computations were carried further than previously with a view to determining the combined action of wind and thermal draft, at least under average thermal draft conditions. The effect of wind on the static exhaust fan, pressure loss included, was assimilated to a reduced pressure equal to $0.25 \frac{V^2}{16}$.

Overall results are in Table III, p. 54. Following are the results expressed as ratios of the desired values (air change of 60 m^3/h for half of the dwelling, entering air flow of 30 m^3/h per room):

	Dwelling air changes	Entering air flow West facade
No wind	0.8 — 0.7	1.1 — 0.9
Light wind	0.85 — 0.75	1.1 — 0.9
Moderate wind	0.9 — 0.8	1.8 — 1.4
Strong wind	1.7 — 1.4	3.5 — 2.8
Very strong wind	3.7 — 2.9	7.4 — 5.8

For no wind, light wind, or moderate wind, air change in the dwelling almost reaches the desired value without the entering air flow on the west facade attaining more than twice the desired value.

For a strong wind, air change in the dwelling exceed the desired value by fifty per cent, and entering air flow on the west facade is triple the desired value. Given the rather infrequent occurrence of such winds, whose velocity is exceeded not anymore than one to five times out of a hundred on the average site, the excess in air change is acceptable. As for the discomfort caused by drafts, we have seen in the preceding study that certain steps can be taken to alleviate that discomfort in situations where air flows are equal to four times the desired value.

For a very strong wind, the overall air change is more than triple the desired value, and the air-inlet air flow on the west facade can be seven times greater than the desired value. These values are unacceptable.

But there is no fear of encountering such winds with appreciable frequency except on an exposed site. In such instances, special precautions are necessary. Two such precautionary measures were studied.

Dyssymmetrical Openings

With a profile such as the one depicted in Figure 4, p. 52, it is possible to obtain an outlet pressure loss triple that of the inlet loss.

With average thermal draft and a very strong wind, air change in a dwelling and air-inlet air flows on a west façade decrease very little: 210 m^3/h instead of 220 m^3/h, with doors open, or a reduction of only five per cent.

This solution consequently seems to be of little value.

Adjustable Openings

If the inlet opening has a hand-lever with which the aperture can be adjusted at will, all settings are possible. However, we believe it desirable to limit the possibility of closing the opening, in such a way that the air flow for a given pressure loss does not decrease more than one-half.

Under these conditions and with average thermal draft, the following results are obtained:

	Air change in half of dwelling	Air inlet air flow per room on west facade
No wind	32 m^3/h instead of 44, or 27 percent reduction	16 instead of 32
Light wind	34 m^3/h instead of 51, or 33 percent reduction	20 instead of 32
Moderate wind	38 m^3/h instead of 53, or 30 percent reduction	28 instead of 53
Strong wind	55 m^3/h instead of 104, or 47 percent reduction	55 m^3/h instead of 104, or 47 percent reduction
Very strong wind	115 m^3/h instead of 220, or 48 percent reduction	115 m^3/h instead of 220, or 48 percent reduction

With no wind, light wind, or moderate wind, air change in the dwelling is reduced only approximately 30 per cent. On the other hand, with a strong or very strong wind, air change, like the air flow from the air inlet on the west facade, is cut nearly in half.

It appears, therefore, that this solution should be retained. Automatically adjustable openings can also be devised.

5. INFLUENCE OF HEIGHT

All preceding computations were made in the case of a uniform height of 8.50 meters.

With greater heights, thermal draft increases. To retain the same air flows, pressure losses should be increased, and preferably air-inlet losses rather than duct losses. Wind effect can be reduced by such action.

An approximate calculation shows that for a draft height, double the height previously used of 8.50 m, the same air flow can be obtained, with no wind, by multiplying air-inlet pressure losses by 2.5 and duct pressure losses by 1.5. With a strong wind, there will be a resultant decrease in air flow, on the west façade, of the order of 35 per cent compared with previous computations.

For lesser heights, pressure losses should contrariwise be decreased and preferably those within the ducts.

For a draft height that is one-half of the 8.50 m height previously used, the same air flow can be obtained, with no wind, by reducing the pressure losses of the duct by two-thirds and those of the air inlets by one-third. With a strong wind, there will be a resultant increase in air flow of the order of 30 per cent.

The most difficult case to resolve is that of the last few floors of high buildings subjected to the most violent winds, and having only a limited thermal draft height. Perhaps some common or collective duct arrangements would allow equilibration of thermal drafts at the different floors of buildings. And lastly, air inlets in outside walls are not the only possible inlets. In extreme cases, air inlets by means of ducts are perhaps desirable.

6. CONCLUSION

The Recommendations given in the first few pages of this "Cahier" contain the conclusions of this report. These conclusions amount to distinguishing four natural ventilation situations with respect to exposure to wind.

1. Minimum exposure situation, that is to say a situation in which velocities greater than 8 m/s can be disregarded from our viewpoint. Inlet openings with fixed apertures seem suitable. The exact value of pressure loss characteristics cannot be given, since, strictly speaking, that value is a function of the other parameters upon which ventilation depends (cross section and height of ducts...). These characteristics must be such, however, that for a 4 mm pressure loss--corresponding to the pressure difference obtained on a west facade with a "strong" wind--air flow must not be more than four times the basic air flow. Protection against cold air drafts will be provided for this air flow.

2. In an exposed situation, adjustable inlet openings are practically necessary. We recommend that they be accepted on condition that the air flow in closed position remain equal to half of the air flow in open

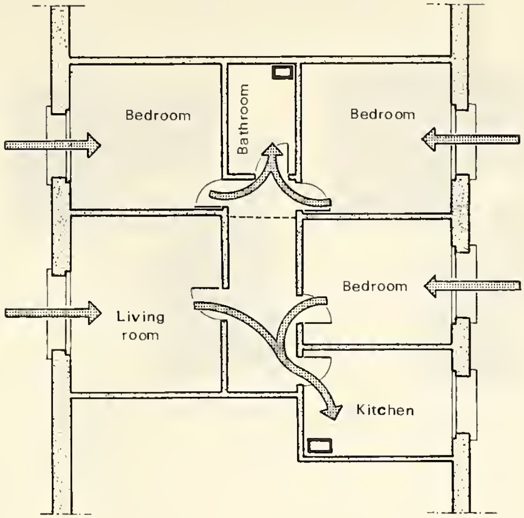
position. Pressure-loss characteristics will be such that air flow does not exceed the quadruple of the basic air flow in closed position and for a 16 mm pressure loss corresponding to the pressure difference obtained on the west facade under a "very strong" wind.

3. In an exceptionally exposed situation, which can be the case of a very high building or one situated on an extremely open site, it will be difficult to obtain satisfactory results with air inlets in outside walls, except perhaps when automatically adjustable or controlled devices permit limiting the air flow regardless of the wind pressure.

4. In an exceptionally sheltered situation, which can be the case inside a city, we could tolerate having protection against cold air drafts provided only for double the basic air flow.

In artificial ventilation, the problem is different. A permanent draft of several millimeters is actually available and it is much superior to thermal draft. Consequently, air-inlet pressure losses can be increased and wind effect decreased. This can be a worthwhile solution for high buildings exposed to wind.

Fig. 1. Ventilation flow diagram for an apartment with two exposed walls



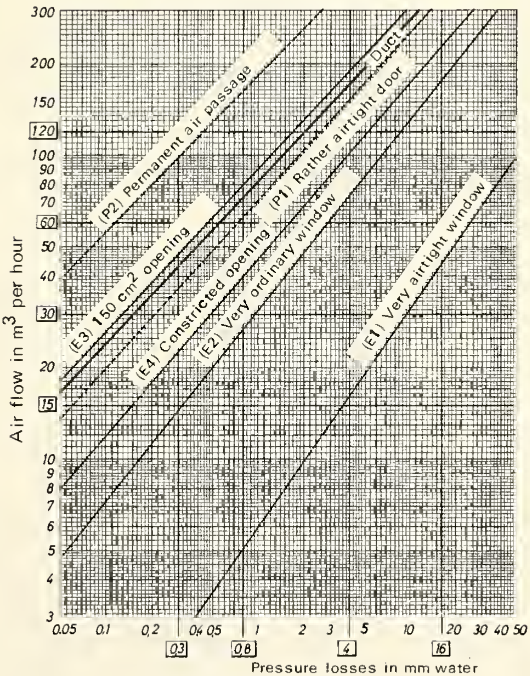


Fig. 2. Pressure-loss graph

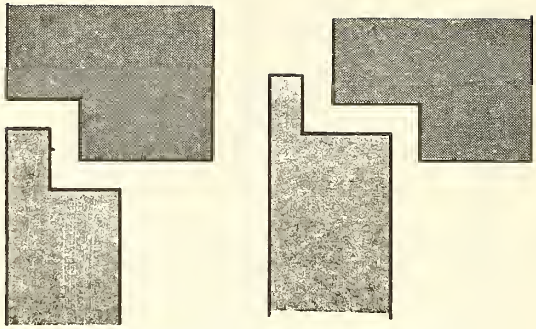


Fig. 3 Permanent air passages at top of floor

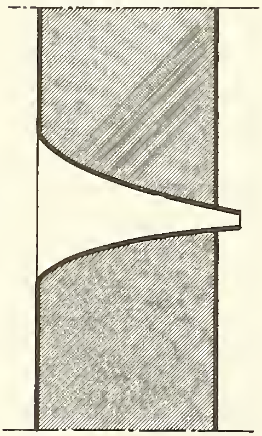


Fig. 4. Dyssymmetrical opening

Table I

Air Inlets in More or Less Airtight Windows or in 150 cm^2 Openings
All Doors are Rather Airtight

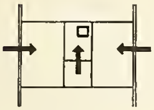
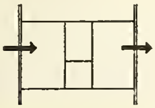
		Ventilation air flow for half of dwelling, doors open and doors closed.		
		Rather airtight windows	Very ordinary windows	150 cm^2 openings
a) Thermal draft only				
	Mild weather	6 — 6	25 — 19	40 — 25
	Winter average	9 — 9	37 — 28	59 — 37
	Exceptional cold	15 — 14	55 — 42	88 — 54
b) Wind only				
	Light	2 — 2	10 — 9	34 — 20
	Moderate	4 — 4	23 — 20	71 — 43
	Strong	12 — 11	55 — 48	238 — 90
	Very strong	32 — 31	132 — 112	310 — 190

Table II

Entering air through constricted openings, rather airtight bedroom doors, permanent air passages into kitchen and bathrooms

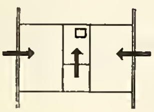
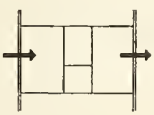
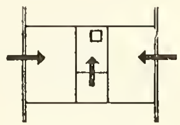
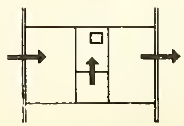
		Ventilation air flow for half of dwelling, doors open and doors closed
a) Thermal draft only		In parentheses the air flow that would be obtained if all doors were sufficiently airtight
	Mild weather	32 — 28
	Winter average	47 — 41 (35)
	Exceptional cold	69 — 60
b) Wind only		
	Light	15 — 12
	Moderate	35 — 28
	Strong	78 — 63
	Very strong	178 — 137

Table III

Same conditions as indicated for Table II

Average thermal draw and variable wind		Air changes for half of dwelling	Air inlet air flow on west facade
		First value is for open doors second is for closed doors.	
	No wind	47 — 41	24 — 22
	Light wind, most frequent case	51 — 44	32 — 27
	Moderate wind	53 — 47	53 — 43
	Strong wind	104 — 85	104 — 85
	Very strong wind	220 — 176	220 — 176

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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.)

Preliminary tests have shown the existence of a "discomfort index", a function firstly of the difference between the temperature in the room and the temperature of the air current and, secondly of the speed of the air stream. The permissible limit for this index has been fixed at two degrees C., at least in that part of the room situated more than 20 cm. from the outside walls and less than two meters in height.

Systematic artificial tests have resulted in satisfactory solutions being found for the air inlets into the outside walls.

--An elongated aperture placed above a radiator and fitted with a deflector so that cold air entering the room mingles with the ascending warm air current.

--An aperture located behind a convector heater so that the same result is achieved as in the case of the radiator.

--A row of apertures located along the heated ceiling placed so that entering air is diffused into the warm air before reaching the occupied zone.

Some calculations aimed at determining the orders of magnitude of the necessary sections and the possible force of the air current in a high wind, have revealed the need for a manual or an automatic regulator where a wall is exposed to wind.

17. KEY WORDS (Alphabetical order, separated by semicolons)

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