Thermal performance of frame walls. Pt 2. Air spaces blocked at mid-height

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CANADA

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PART II

Air Spaces Blocked at Mid-Height

By

G. O. Handegord and N. B. Hutcheon

Reprint of a paper presented at the Semi-Annual Meeting of The American Society of Heating and Ventilating Engineers, June 29-30, July 1, 1953.

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JOURNAL SECTION

Thermal Performance of Frame Walls

Part II — Air Spaces Blocked at Mid-Height

By G. O. Handegord* and N. B. Hutcheon**, Saskatoon, Canada

SUMMARY—Studies of the thermal performance of frame walls previously reported have been extended to include an investigation of the effects produced by inserting horizontal blocking in walls with air spaces. Data are presented which illustrate the vertical variations in temperatures and heat flow rates resulting from convection within frame walls with blocking at mid-height when insulation is ideally applied and when insulation installed to form two air spaces is improperly sealed. Data showing the horizontal variation in surface temperature across walls due to the presence of studding with various forms of insulation are also given.

THE FIRST PAPER[1] presented on this subject dealt with the vertical variations in temperatures and heat flow rates resulting from convection in air spaces in frame walls. Some of the walls tested had insulation ideally applied while others in which insulation was installed to form two air spaces, had gaps left at the top and bottom. The air spaces were continuous over the height of the wall. The present paper deals with walls having horizontal blocking at mid-height, and is concerned, as was the first paper, with the deviations of actual heat flow and temperature patterns from those predicted by simple theory.

Blocking may be installed in frame walls to provide nailing girths and added rigidity. When used for these purposes it need not block off the air space completely. It is frequently required, however, as firestopping and to be effective, must present a barrier to vertical air movement. Walls with complete blocking may be expected to show two convection patterns over their height.

The effect of through framing members on overall wall conductance is usually calculated by one of two methods given in the HEATING, VENTILATING, AIR CONDITIONING GUIDE. In the first of these, the wall is treated as a series of separate parallel heat flow paths only, and in the second as a combination of series and parallel paths. Neither of these methods provides a rational basis for calculation of surface temperature under the actual conditions of heat flow in the wall.

The horizontal surface temperature variation in frame walls will be largely influenced by the type and arrangement of insulation in the wall. For example, consideration may be given to the two walls shown in Fig. 1 in which the same insulation has been installed in two different positions. In the left arrangement 1-a, the outer 1-5/8 in. of the studding is exposed to air at a low temperature while in the right arrangement 1-b, the entire stud is in a region of much higher temperature. It would be expected, therefore, that a greater heat flow would occur laterally from the stud shown in 1-a than that in 1-b, resulting in a lowering of surface temperature in the area over the stud.

When the vertical variations in temperature resulting from convection are also considered, it is seen that the heat flow is three dimensional and that the corresponding surface temperature pattern is complex, particularly in walls with blocking at mid-height. Since these variations are pertinent to any assessment of wall performance, the present study was extended to provide data on the heat flow and surface temperature pattern at points other than at the center of the stud space.

The project reported here was conducted as part of a program of Cold Weather Wall Research being carried on cooperatively by the University of Saskatchewan and the Division of Building Research, National Research Council, at Saskatoon.

Test Apparatus

The basic test apparatus employed has been described previously.[1] Closer regulation of air temperature on both sides of the panel was obtained by the use of resistance-thermometer bridge control systems in place of those originally used. This change involved no alteration in the air heating system on the warm side of the panel, but an intermittent electrical reheat system was substituted for the bypass damper arrangement formerly employed in the cold room.

A second track and carriage was installed on the baffle facing the warm side of the test panel opposite a stud location to permit simultaneous heat meter traverses vertically over a stud as well as between studding. Additional thermocouples were installed to measure wall surface temperatures over the stud and 2 in. from the stud at five different heights, at locations not immediately

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[1]Exponent numerals refer to references.
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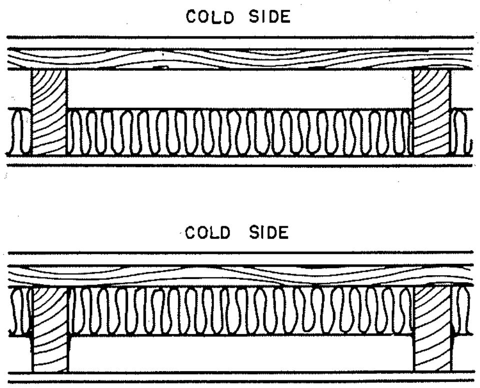

Fig. 1—Two methods of installing batt insulation

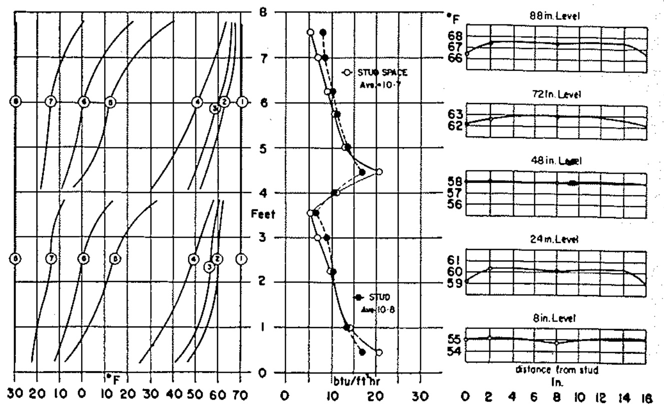

Fig. 2—Temperature and heat flow variation in wall No. 2
Single foil curtain creating two air spaces — Foil sealed to surrounding framing members

adjacent to the metal screws used in construction of the panel.

The heatmeters employed were of the multiple differential thermocouple type, with the sensitive elements mounted between synthetic resin sheets to form a finished meter 4½- by 4½- by 3/64-in. thick. The meter used to traverse the wall at the stud contained two thermopiles, each measuring ⅜- by 1½-in. spaced 1⅜-in. on centers. The meter was oriented with the 1½-in. dimension of the elements horizontal so that no portion of the thermopiles extended beyond the stud. The meter used to traverse the area at the center of the stud space contained four thermopiles each measuring ⅜- by 2-in. equally spaced, within an area 2- by 2⅝-in.

Table 1—Description of Curves

Wall Panel Number	Description of Insulation
1	Aluminum foil cemented to cold surface of plasterboard.
2	Single foil curtain creating two air spaces each faced one side with aluminum foil. Curtain sealed to surrounding framing members.
3	2-in. paper-enclosed mineral wool blanket insulation (actual thickness 1½-in.) creating two air spaces. Blanket sealed to surrounding framing members.
4	2-in. thick mineral wool batt insulation placed next to plasterboard to form one air space on cold side of insulation.
5	Same as 4 except batt placed against sheathing. Paper backing sealed to surrounding framing members.
6	Same as 5 except ⅜- by 14½-in. strips cut from paper backing at bottom and top of each air space.
7	Same as 2 with ⅜- by 14½-in. gap at top and bottom of each air space.
8	Same as 3 except blanket stapled but not sealed to surrounding framing members, staples 6-in. apart.
9	Same as 3 with ⅜- by 14½-in. gap at top and bottom of each air space.

Test Procedure

The same basic wall panel, 8-ft in height by five standard stud spaces in width, was used for all tests. As in the previous study, only the center three stud spaces were actually employed as test area, the outer two spaces being fully insulated with mineral wool insulation.

The test procedure was essentially the same as for the tests reported previously, except that cold room air temperatures were maintained at a more nearly uniform value, and heatmeter indications were recorded for a slightly longer period of time at each location.

Description of Walls Tested

The basic wall panel consisted of ⅜-in. plasterboard, inside on 2- by 4-in. (1½- by 3⅝-in. actual) studding spaced 16-in. on centers and 25/32- by 10-in. spruce shiplap sheathing, building paper and 6- by ½-in. bevel cedar siding on outside. The exterior siding and sheathing, and interior plasterboard were secured with wood screws and the siding was given three coats of oil paint. Joints between framing members and sheathing were sealed with masking tape.

A total of nine different wall constructions was studied, each with blocking at mid-height. Only three different types of insulation were used, but variations were introduced in certain details of application. The various panels tested are described in Table 1.

Walls Nos. 1, 2, 4, 5, 6 and 7 were similar to walls studied in the previous paper, except for the insertion of horizontal blocking at mid-height. The paper-enclosed blanket insulation installed in Walls 3, 8 and 9 was not used in the previous study.

Test Results

Test results are presented graphically in Figs. 2 to 10. The vertical variations in temperature at various locations through the wall at the center line of the stud space have been plotted at the left hand side with the numbering system employed for identification of the curves as shown in Table 2.

Table 2—Identification of Curves on Figs. 2-10

Curved Number	Location
1	Warm side air 1 in. from wall surface.
2	Warm side of plasterboard
3	Cold side of plasterboard
4	Air space ⅜ in. from plasterboard
5	Air space ⅜ in. from sheathing
6	Warm side of sheathing
7	Cold side of sheathing
8	Cold side air 2 in. from wall surface

The vertical variations in heat flow rates into the wall at the centerline of the center stud space and at the stud immediately to the left have also been plotted for each wall. The values shown were the average of at least two runs. The heat flow rates given were obtained from observed heatmeter millivoltages using the conversion data provided by the manufacturer, without further calibration. When the traverse of Wall

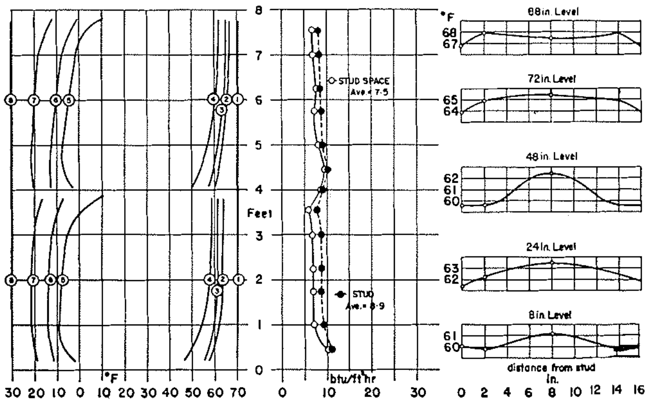

Fig. 3—Temperature and heat flow variation in wall No. 3
Two-inch mineral wool blanket insulation, creating two air spaces, sealed to surrounding framing members

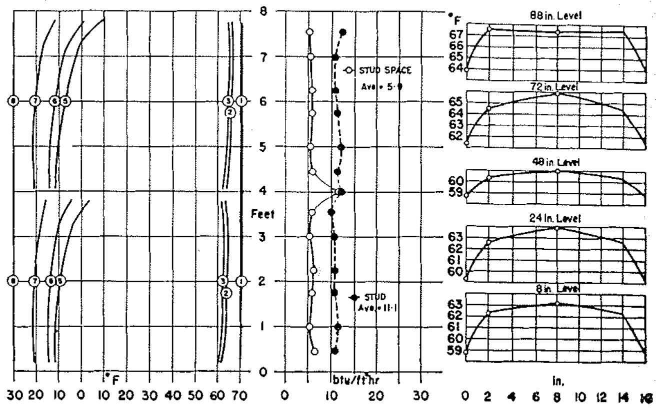

Fig. 4—Temperature and heat flow variation in wall No. 4
Insulated with two-inch mineral wool batt — Air space on cold side of insulation

No. 1 was repeated with the two meters interchanged the average percentage difference between corresponding readings was found to be within 2 percent.

Temperatures of the wall surface at locations over the stud immediately to the right of the center of the wall, 2 in. and 8 in. to the right of this stud are given in Figs. 2 to 10 for five different elevations. These measurements were, therefore, associated with the stud space adjacent to that in which the heatmeter data and additional temperature measurements were made.

Precautions were taken to prevent entry of water vapor into the warm room even though ambient conditions outside in the laboratory were of the order of 15 percent relative humidity or lower for most of the test period. Further protection against condensation was provided by painting the cold side of the plasterboard with two coats of aluminum paint followed with two coats of white oil paint. In spite of these precautions, some frosting occurred on the sheathing in all tests.

Heat Flow into Walls with Air Spaces

The effect produced by inserting horizontal blocking at mid-height was such as to create similar patterns of temperature and heat flow in the sections of the wall above and below the blocking. Each of these patterns was remarkably like those found over the full height of corresponding walls previously tested without blocking. All the walls with air spaces immediately behind the plasterboard showed rates of heat flow into the wall decreasing with height for each air space. This variation was in keeping with the temperature conditions throughout the wall, temperatures generally increasing with height for each space.

Of the walls in which insulation was ideally applied, those containing reflective insulation exhibited the greatest vertical variation in rate of heat flow into the wall. This feature, more fully discussed in the previous paper, can be attributed to the predominance of the effects of convective heat transfer with the reduction in radiant transfer across the space.

The openings left in the reflective curtain at the top and bottom of each air space in Wall No. 7 increased the average heat flow rate into the area between studding by 37 percent over that for Wall No. 2, but the variation with height was not

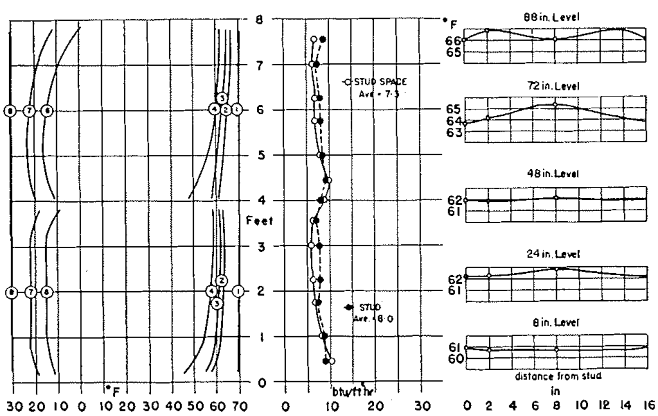

Fig. 5—Temperature and heat flow variation in wall No. 5
Insulated with two-inch mineral wool batt — Air space on warm side of insulation — Batt sealed to surrounding framing members

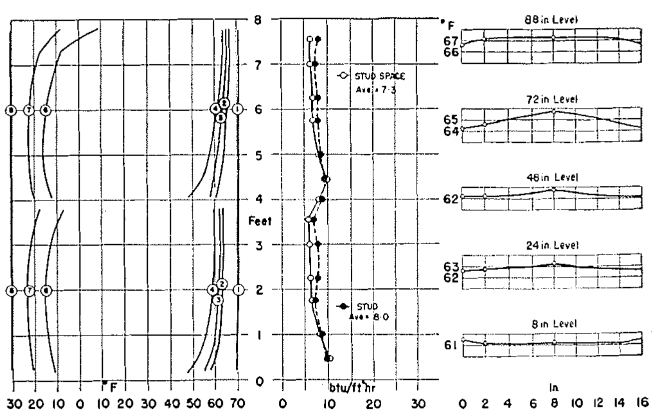

Fig. 6—Temperature and heat flow variation in wall No. 6
Insulated with two-inch mineral wool batt — Air space on warm side of insulation — Gaps of ⅜ in. cut in paper backing at top and bottom of each air space

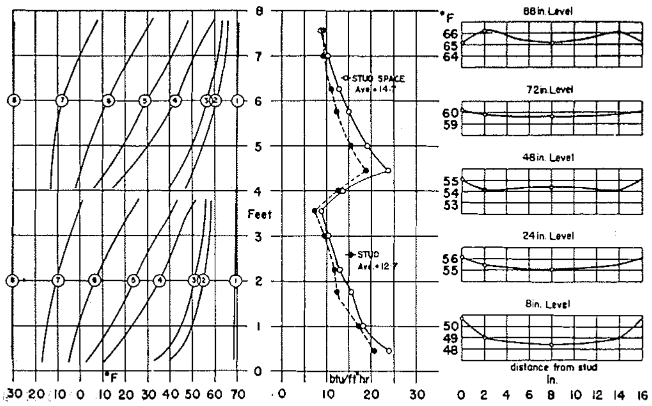

Fig. 7—Temperature and heat flow variation in wall No. 7
Insulated with single foil curtain creating two air spaces — Gap of ⅛ in. at top and bottom of each air space

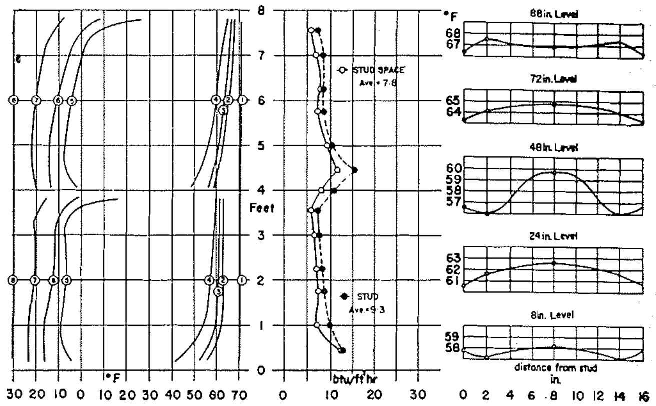

Fig. 8—Temperature and heat flow variation in wall No. 8
Insulated with two-inch blanket creating two air spaces — Blanket stapled but not sealed to surrounding framing members

as extreme. This may partially be accounted for by the fact that condensation had formed on the reflective curtain in Wall No. 2 during test, on an area extending approximately 8 in. from the bottom of each air space. This condensation undoubtedly affected the emissivity of the foil in this region and increased the heat flow into the wall.

The effects of air-space convection are apparent from a comparison of heat flow rates into the center of the stud space for Walls Nos. 3, 8 and 9 in which a mineral wool blanket insulation was installed. Wall No. 9, in which openings existed through the insulation at the bottom and top of each air space, showed the greatest vertical variation in heat flow of all the walls tested, the rate of heat flow into the wall at the 5-in. level being 3 times the average. In addition the average rate of heat flow increased by 21 percent of that for Wall No. 3 in which the insulation was sealed in place. When the insulation was stapled, but not sealed to the surrounding framing members, as in Wall No. 8, only a slight increase in average heat flow over that for Wall No. 3 was observed, with the vertical variation being somewhat greater.

No significant differences in thermal characteristics were found between Walls Nos. 5 and 6 although the insulation was sealed in place in Wall No. 5 and ⅜- by 14 ½-in. openings were cut through the paper backing of the insulation at the top and bottom of each air space in Wall No. 6. This close agreement suggests that little or no air movement occurred through the insulation.

The results shown here, as in the previous paper, indicate that the location of semi-thick batt-type insulation affects both the variation in heat flow with height and the average heat flow rate at the center of the stud space. The greater variation in heat flow vertically in Wall No. 5 can be considered as due to convection in the air space behind the plasterboard.

The presence of this air space makes it possible for heat to enter at one point and leave at some higher point. It is equally possible, however, for heat to enter the convective air stream through the area between studs and be transported laterally to, and leave by, the stud path. This can account for the higher average heat flow between studs for Wall No. 5 and is, in fact, supported by the lower readings of heat flow into the wall opposite studs. When no air space is present on the warm side of the insulation, only relatively high resistance paths to heat flow in the plane of the wall are provided until the air space on the cold side of the insulation is reached. It follows that some of the heat enters the outer air space in Wall No. 4 by way of the stud path and leaves through the sheathing between studs.

In all the walls studied, the vertical variation in the rate of heat flow into the area over studding was very similar to the variation existing in the area between studs. Since such vertical variations can only be attributed to the change in air space temperature with height, it is obvious that the rate of heat flow into studding is influenced to a great extent by the air temperature conditions to which the sides of the stud are exposed. This provides further evidence of the importance of lateral heat exchange between studs and air spaces in determining the overall pattern.

Further consideration might be given to comparison of measured heat flow rates into studding and into the stud space for the walls tested. Some doubt exists, however, as to the calibration corrections to be applied to heatmeter readings when there has been a change in the arrangement of material on which the heatmeter is placed. Such comparison on a strict quantitative basis has, therefore, been reserved until these features of the heatmeter technique have been evaluated, but there seems to be no reason to question the overall pattern of heat flow which the uncorrected values imply.

Surface Temperature Distribution

Inside surface temperatures of exterior walls have a direct bearing on some aspects of indoor comfort conditions, on the performance of panel heating systems, on surface condensation problems and on the formation of dirt patterns on walls. It is of some importance, therefore, to note the very substantial deviations of actual surface temperature patterns from those implied by simple unidirectional heat flow theory.

Nielsen[2] has discussed the problem of dust marking and has shown it to be due to differences in rate of accumulation on adjacent areas at different temperatures. Rogers[3] suggests that a difference of from 3 to 5 F deg in wall surface temperatures may produce noticeable dust patterns. It may be noted that using this criterion, Wall No. 4 may exhibit dust marking over studding, while all the walls except Nos. 4, 5 and 6 may exhibit dust marking just above horizontal blocking. It is not correct, therefore, to assume that the application of insulation will necessarily eliminate the tendency to noticeable dust marking.

Surface condensation will occur whenever the wall surface temperature falls below the dew point temperature of the air. Potential areas for surface condensation will invariably be found at the lower portion of a wall. When the wall construction is such as to produce a high variation in surface temperature vertically over the area between studs the coldest area will tend to be at the bottom of this vertical zone. When, however, the wall arrangement is such as to produce high heat flow into the studs, the convection effects over the center of the space will not be so marked and the coldest area will be opposite the studding. The effect of leakage between air spaces is to exaggerate the vertical variation in surface temperature between studs. All the walls except No. 4 show predominating convective effects and in none of these is the area over studs markedly colder than the area between studs. Wall No. 4, however, has small vertical variations in surface temperature, since the convective effects are restricted to the cold side of the insulation. For the same reason, the heat flow through the studding tends to be high and the coldest area is to be found opposite studding.

Wall No. 4, showing the greatest horizontal variation in surface temperature at the lower portion of the wall does not represent the worst possible case of such variation. In many practical installations, the insulation will not be installed to fit tightly against the studs for its full thickness and relatively lower surface temperatures over studs may be expected as a result of the increased heat flow through studs. The most extreme case known to the authors is for a form of insulation not represented here where leakage existed and the convective effects combined with high heat flow through the studs to produce, not only high variations in temperature vertically, but also extremely low temperatures over studs.

It may be noted that although Wall No. 4 exhibited the greatest horizontal variation in surface temperatures over the lower portion of the wall, Walls Nos. 1, 2, 7 and 9 exhibited much lower surface temperatures in this region. The lowest surface temperature measured at the 3-in. level on Wall No. 9 was 39 F which would permit an inside relative humidity of only 32 percent at 70 F before condensation occurred. This applies to the test conditions of an inside to outside air temperature difference of 100 F deg which although severe for most of the United States, is not unrealistic for the northern part of the continent. All tests, however, were carried out with room air temperatures maintained reasonably constant over the height of the wall. In actual practice some further lowering of surface temperatures at the lower portions of walls may result from reduced room air temperatures at floor level or from contact with cold floors or foundations.

Conclusions

The following conclusions have been drawn from the test results and observations:

1. The heat flow and surface temperature patterns in frame walls are greatly influenced by movement of heat in the plane of the wall.
2. Substantial movement of heat in the plane of a wall occurs largely as a result of convection in air spaces coupled with heat interchange between air spaces and framing members.
3. Vertical variations in both temperature and heat flow are related to the convection in air spaces and can be exaggerated by air leakage into or between air spaces.
4. Horizontal variations in both temperature and heat flow are related not only to the type but also to the arrangement of the material used for insulation, and particularly to the thermal resistance provided over the area between studs before an air space is reached.

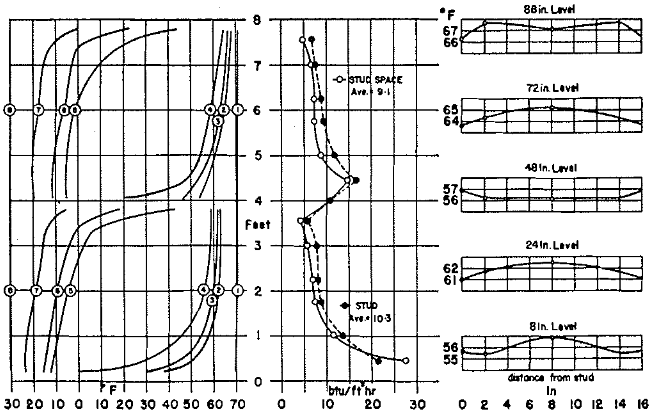

Fig. 9—Temperature and heat flow variation in Wall No. 9
Insulated with two-inch blanket creating two air spaces — Gaps of 3/8 in. at top and bottom of each air space

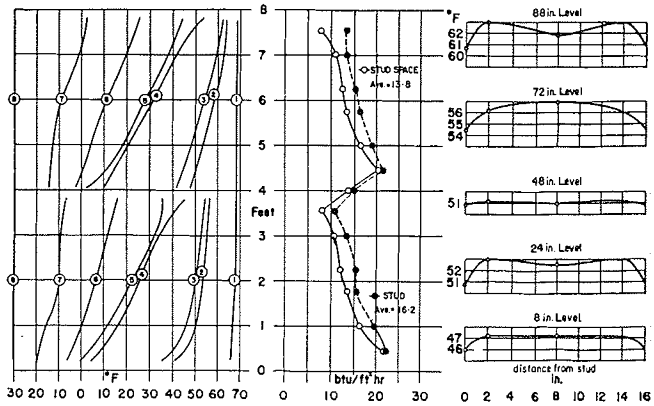

Fig. 10—Temperature and heat flow variation in wall No. 1
Aluminum foil cemented to cold surface of plaster board

5. The characteristic pattern of temperature and heat flow resulting from convective effects is not greatly changed by reducing the free height of the air space from 8 ft to 4 ft and in a wall with horizontal blocking at mid height will be substantially repeated over each blocked-off area.

6. Blocking at mid height may produce potentially serious conditions for dust marking in the area immediately above blocking.

7. The improvement to be obtained through the use of insulation, in tendency toward dust marking and surface condensation depends not only on the insulation but also on the thermal properties of the overall arrangement created.

Acknowledgment

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